IMPACT OF EMPLOYMENT DECENTRALIZATION

ON

METROPOLITAN ROAD NETWORKS

By

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ENGLISH ABSTRACT

Socio-economic changes and employment decentralization in North America have transformed the traditional centrally-oriented travel pattern into a more complex many-to-many type, resulting in increased traffic congestion.

This research quantifies the impact of activity decentralization on road infrastructure requirements by super district and facility type.

The Supply Demand Linkage Model or 'SDLM', for a case study, relates the independent variable demand in passenger trips to the dependent variable the mean of traffic density in vehicles per kilometre. It is an aggregate travel demand model developed using a quasi experimental approach. This is accomplished through:

- Extensive cross sectional analyses.
- Calibration and validation of a travel demand model (EMME/2) requiring a large data base.
- Variations in trip demand are implemented, using EMME/2, and the corresponding traffic densities are computed by super district and facility type.
- Multivariate analyses relating supply-demand measures were implemented and produced the SDLM models which replace the trip assignment stage of travel demand models and compliments UTMS models at the sketch planning level.
- Sensitivity analysis testing SDLM reliability against the EMME/2.
- Application of the SDLM models through forecasting scenarios of employment and population to obtain the "Impact of employment decentralization in metropolitan road networks".

The multivariate analyses showed that variations in demand could explain 99.61% of the variations in traffic density at a 95% confidence level. And the sensitivity analyses demonstrated that the SDLM results are within 5% of actual values. The SDLM models may not be transportable but the established procedure is expected to be transportable.

The impact analyses has quantified the changes in travel pattern resulting from activity dispersion. This simplified procedure, transforms the SDLM models into a powerful tool.

FRENCH ABSTRACT

Les transformations socio-économique et la décentralisation de l'emploi en Amérique du Nord ont transformé le déplacement traditionnelle vers les centre-villes en forme plus complexe 'many-to-many' résultant en congestion du trafic.
Cette recherche quantifie l'impact de la décentralisation des activités sur l'infrastructure des routes et leur type par super district pour une métropole.

Le SDLM, Supply-Demand Linkage Model, est un modèle qui lie l'offre et la demande de transport pour une métropole, établi un lien entre la demande de transport en "passenger-trips", variable indépendante et la moyenne de la densité du trafic en véhicule par km, variable dépendante. Le SDLM est un modèle intégré développé dans cette recherche en utilisant une approche quasi-experimentale. Les étapes suivantes de la recherche ont été réalisées:

- De vastes analyses a travers la métropole.
- La calibration et la validation d'un modèle de déplacement spatial des demandes de transport (EMME/2).
- L'application des variations des demandes de transport en utilisant l'EMME/2 et le calcul des densités du trafic correspondantes par type de route et par super district.
- Des analyses a variables multiples reliant des mesures d'offre et de demande exécutées pour développer le SDLM qui remplace la quatrième étape du modèle spatial de la demande de transport pour 'sketch planning'.
- Une analyse de sensitivité testant la fiabilité de SDLM comparée a L'EMME/2.
- L'application de SDLM a travers des scénarios de projection de l'emploi et de la population pour obtenir le "Impact of employment décentralisation in metropolitan road networks".

Les analyses multivariées ont démontré que les variations des demandes de transport peuvent expliquer a 99.61% les variations des densités du trafic avec un niveau de confiance de 95%.

Les analyses de sensitivité ont démontré que les résultats du SDLM sont a 5% près des valeurs réelles. Le modèle SDLM n'est probablement pas transférable mais la transferabilité de la procédure établie est prévue.

Les analyses d'impact ont quantifié les transformations des formes de déplacement résultant de la dispersion des activités en centre-ville. Cette procédure simplifiée fait du SDLM un outil puissant.

OUTLINE FOR

GENERAL TABLE OF CONTENTS

LIST OF ABBREVIATIONS

A = Arterials or Auto person-trips
ABS = Absolute growth
AHS = American Housing Survey
At = Trip attractions
BSQ = Bureau de la statistique du Quebec
CAR = Car ownership
CBD = Commercial business district
CEN = Central agglomeration (not SD1)
CEN. = City Centre (not SD1)
CMA = Census Metropolitan Area for MTL
Constr.= Construction
CT = Census Tracts
D = District or districts
DCTZN= Decentralization
DEM = Demand
dDEM = Difference in DEM
DEN = Mean of traffic density in EPC/km
dDEN = Difference in DEN
DENA = Traffic density in EPC/km, arterials
DENF = Traffic density in EPC/km, freeways & expressways
dEPC = Difference in EPC
DU = Household/s, dwelling units
dZLL = Difference in ZLL in lane-km
dZLLA= Difference in ZLLA in lane-km
dZLLF= Difference in ZLLF in lane-km.
ELF = Employed labour force
EMP = Employment
EPC = Equivalent passenger car trips
FAR = Floor area ratio
FHA = Federal Highway Administration
FIRE = Finance, insurance, and real estate
Fn = Finance
GMA = Greater Montreal Area
GRTH = Growth
H = High growth scenario
HBW = Home-based work trips
HCM = Highway Capacity Manual
HED = High EMP DCTZN scenario
HHLD = Household or household size
HOV = High Occupancy Vehicles
HPG = High POP growth scenario
km = Kilometre

L = Blue collar labour or Low growth scenario
LA = Arterial links
LAN = Directional lanes
Lav = Laval or Jesus Island
LEN = link-length in km
LF = freeway links
LOS = Level-of-service
M = Most expected scenario or manufacturing ind.
M'Y = estimated migratory balance, regional, and provincial
MOTQ = Ministry of Transport of Quebec in Montreal
MTL = Montreal Island or Montreal Is.
N'L = Estimated natural population growth, (birth-death)
NA = Data not available
NCHRP= National Cooperative Highway Research Program
NPTS = Nationwide Personal Transportation Study
NS = North Shore
NTL = national effect
OD = Origin-destination
P = Pivot scenario
PCT = percentage total growth relative to 1986
PER = peripheral agglomeration
PHF = Peak hour factor
PHW = Peak hour work trips
POP = Population
POR = Place-of-residence
POW = Place-of-work
PPM = pivot point demand
Pr = Production trips
Prod.= Production industry
Prof.= Professionals (by occupation)
Pub ser = public service industry
QRS = Quick response system
Ret = Retail industry
RGNL = Regional effect on growth
S/Ser= service industry EMP
Sc = scenario
SD/SDs= Super district/districts
SD1 = Montreal City Centre
SDLM = Supply Demand Linkage Model
SEC = Suburban Employment Centres
SPD = mean link speed in km/hr
SS = South Shore
STCUM= Societe de transport de la Communaute urbaine de MTL
STL = structural effect

T = Transit person-trips
TAU = mean link travel time in minutes
Transp. = transportation
TSM = Transportation System Management
TW = Zonal work trips
UBM = Upper bound demand matrix
UTMS = Urban Transportation Modelling System
VAU = mean link traffic volumes in EPC
VDF = Volume delay functions
WW2 = World War Two
Z/Zs = Traffic zones, zone number, or centroid number
ZLL = mean lane-links length in km
ZLLA = ZLL for arterial streets
ZLLF = ZLL for freeway and expressway streets

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CHAPTER 1

INTRODUCTION: RESEARCH SCOPE

1. INTRODUCTION

In the last four decades, major socio-economic changes have dramatically transformed urban growth patterns in North America, resulting in increased traffic congestion and dramatically-altered travel patterns. This congestion has, in turn, contributed to further employment decentralization and the shift of the place-of-work to the suburbs. This has, in some cases, brought about the creation of large suburban activity centres in the vicinity of large cities.

Increasing employment decentralization has essentially transformed the commuter trip from a many-to-one to a many-to-many pattern, thus decreasing public transit effectiveness and ridership, and increasing suburban road traffic congestion. This is due to the increasing predominance of the auto mode of transport. Furthermore, decentralization has brought about an increase in housing demand for most income groups in the suburbs, so that the suburbs are no longer the exclusive habitat of white collar workers.

This phenomenon of decentralization and altered travel patterns is fuelled as well by the decrease in household size and the increase in female labour force participation.

This trend of activity decentralization provides the primary focus for this research, which investigates the impact of the decentralization of employment on urban travel mobility.

There are no ready-made solutions to the urban-suburban mobility problem. A broad range of supply-demand simplified responses are needed to assist governments to respond quickly, effectively and creatively to the imbalance between supply and demand for transport facilities. This is the challenge that this research addresses.

2. EMERGENCE OF NEW URBAN FORMS IN CANADA

The empirical results obtained by Bourne (1989), from the testing of five separate but related hypotheses concerning the outcome of the process of emerging new urban forms in Canada, confirm the hypotheses of a continuous decentralization of population and employment, and the changing form and structure of Canadian metropolises.

The resultant impact is further urban dispersion through suburbanization and inner city decline. The inner city 'reverse trend' or 'gentrification', though in progress in Canadian cities, is of minor impact.

However, the results of Bourne's empirical analyses of distance-density relationships confirmed that the "traditional core dominated relationships still hold" in urban Canada.

So, despite extensive decentralization, urban areas in Canada are still spatially organized with respect to a strong central nucleus, the commercial business district (CBD).

3. COMMUTING STATISTICS IN NORTH AMERICA

The predominant commuter flow is now the suburb-to-suburb trip, which in the U.S. represents one-third of all metropolitan commuting. The traditional commuting between suburb and city centre, although still growing, is no longer the dominant pattern.

The auto mode of transportation outweighs all other modes combined and is the main cause of traffic congestion. The rising predominance of the private vehicle as a commuting mode of transportation and the decline of public transit is a major cause of road congestion. This is further accentuated by the increase in the availability of vehicles per household, and the decrease in household size.

A comparison between metropolitan areas in Canada and USA shows several areas of similarity and a few areas showing differences. Census surveys of metropolitan journey-to-work trips in both countries provide clear evidence that work trip distances are consistently shorter in Canada; while there appears to be little difference in work trip travel time.

On the supply or infrastructure side, in 1980, there were more than four times as many lanes of freeway available to the average American metropolitan resident compared with analogous Canadian situations. Also, Americans owned and operated 50% more automobiles per capita in the early eighties. Furthermore, patronage of public transit facilities is, on a per capita basis, two-and-a-half times higher in Canada's urban regions than in the U.S.

4. SUPPLY-DEMAND RELATIONSHIPS

The demand for travel may be defined very simply as a 'derived demand': people travel out of necessity, to partake in opportunities at the destination. It is a function of the trip origin and destination and transportation service characteristics between the origin and destination.

Travel demand may be considered as the volume of vehicle-travel on a road network over a time interval, while the supply is the capacity for vehicle-travel in passenger car equivalents that the physical system can accommodate at a selected level-of-service (LOS).

Capacity is defined in the Highway Capacity Manual (HCM) 1985, "as the maximum hourly rate at which persons or vehicles can reasonably be expected to traverse a point or a uniform section of a lane or roadway during a given time period under prevailing roadway, traffic, and control conditions" (p1-3).

Capacity refers to the 'maximum hourly rate' of vehicular traffic traversing 'a point or a uniform section of a lane or roadway'. Thus, highway sections having different prevailing roadway conditions will have different capacities i.e., capacity varies by facility type and roadway conditions.

Table 1.1 gives the LOS for a basic freeway section as a traffic density range, where LOS (E) represents capacity and LOS (F) represent gridlock conditions (traffic mobility loss). LOS is a measure of equilibrium between the demand, in passenger car equivalents, for the use of the facility and the provided facility supply i.e., the number of vehicles per lane per unit length. It is computed for a roadway segment, an at-grade intersection, and the like.

LOS	A	B	C	D	E	F
Traffic density (EPC/km)*	<=7.42	>7.42 <=12.36	>12.36 <=18.54	>18.54 <=25.96	>25.96 <=41.41	>41.41

TABLE 1.1 LEVELS OF SERVICE
For a basic freeway section.

*** EPC/km: equivalent passengers car per kilometre per lane.**
Source: HCM 1985, Table 3.1

LOS is "a qualitative measure describing operational conditions within a traffic stream and their perception by motorists and/or passengers" [HCM, p1-3]. Thus, LOS is a qualitative measure defined in terms that are perceived by motorists; these terms are basically the three operational parameters: (1) speed and its inverse, travel time; (2) traffic density; and (3) traffic flow [McShane et al. 1990].

LOS is quantified for a basic freeway section in Table 1.1, by the traffic density parameter. It is the parameter mostly perceived by the motorists besides travel time. It is adopted in capacity analyses in general and in this research.

The LOS at the sketch planning or aggregate level, is indicative of an overall status of a zone (further defined by the mobility concept, Chapter 5) and the traffic density parameter, in itself a supply-demand measure, becomes the central focus of the research. The assessment of the LOS is very complex, even for an intersection at grade, at the aggregate level; the LOS estimation is dependent on sound engineering judgment based on HCM criteria.

Fig. 1.1 presents the relationships between flow and density, and the LOS for a multilane facility with uninterrupted flow [McShane et al, 1990, Fig. 10.1]; where flow is given in vehicles per hour per lane (vphpl) and density in vehicle per mile per lane (vpmpl). The dashed line presents unstable flow, or forced flow.

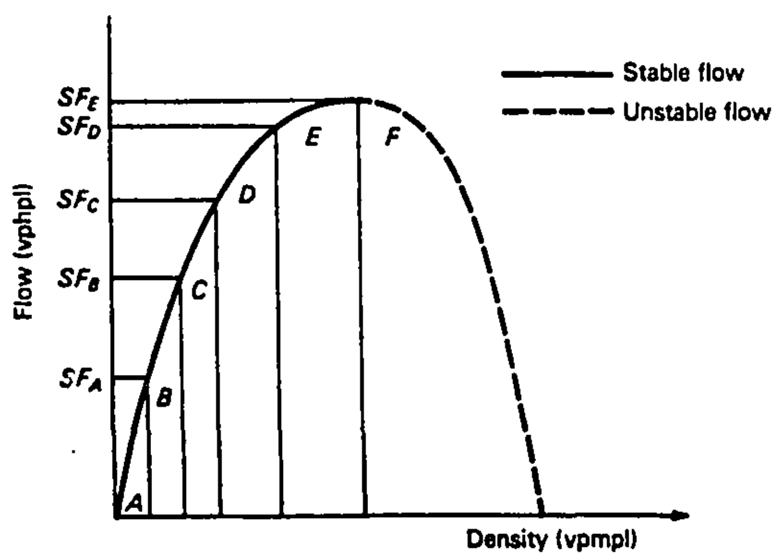


FIG. 1.1: LOS FOR UNINTERRUPTED FLOW
For multilane facilities.

Fig. 1.2 presents the relationships among speed, density, and rate of flow on uninterrupted flow facilities [HCM 1985, Fig. 1.1].

The dashed part in the graphs represent 'unstable flows' i.e., 'traffic jam' as their extreme value (at zero flow and speed, and maximum density) or gridlock. It is of interest to note that V1, the volume flow in equivalent passenger cars per hour is shown as point A for 'stable flow' and point B for 'unstable flow'.

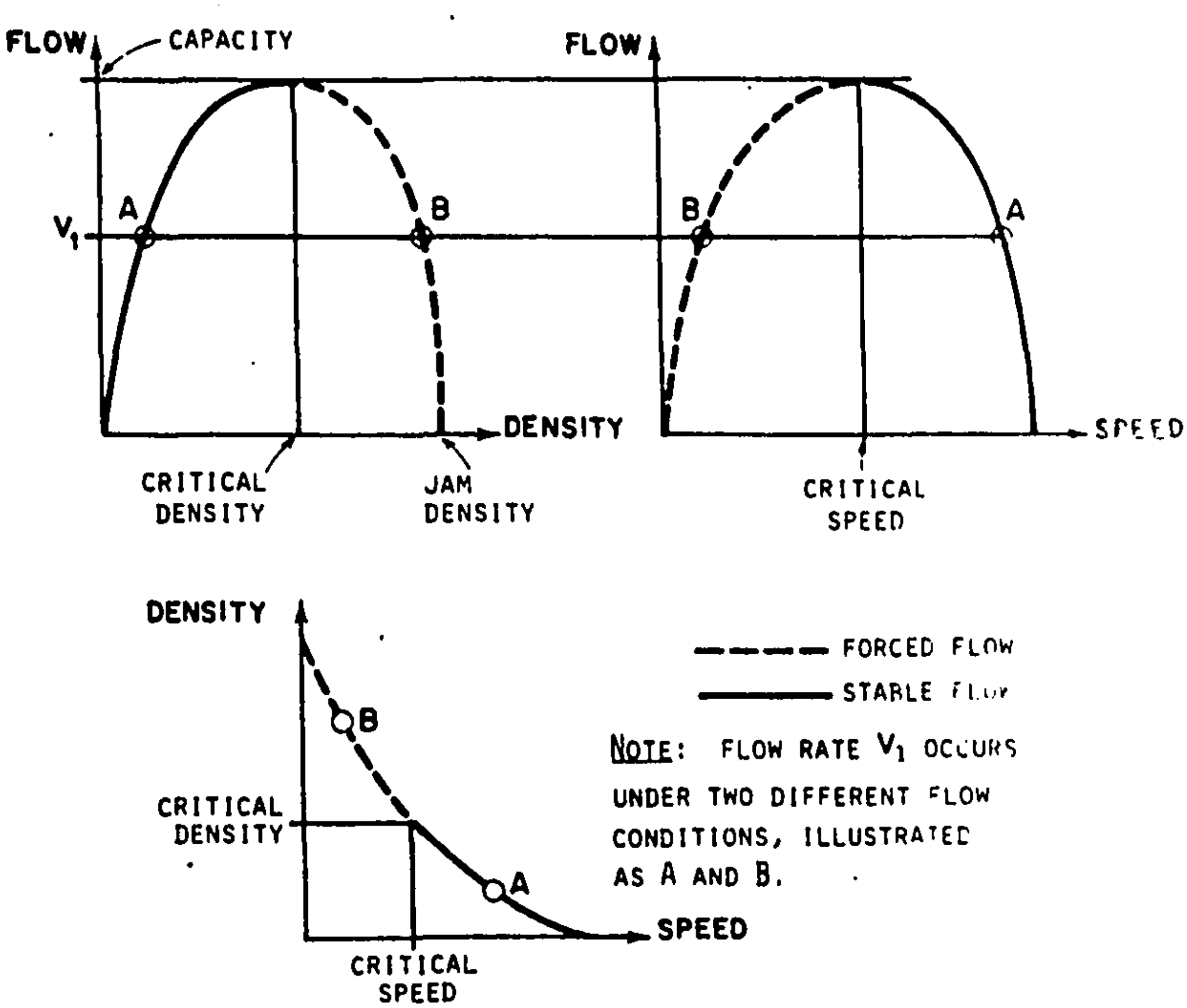


FIG. 1.2: SPEED, DENSITY AND RATE OF FLOW For uninterrupted flow.

5. IDENTIFICATION OF RESEARCH NEEDS

Research is needed to expand and extend the work done by Pisarski (1987), Bourne (1989), Cervero (1989), and others through "**case studies** of selected cities (that) are needed to provide detailed trip pattern data to corroborate and extend the present understanding of commuting trends... Facility-based analyses are required... Traffic operations studies are needed to examine opportunities for enhanced use of available facility capacity responsive to changed patterns of demand... New data research is needed to overcome present weaknesses and gaps in our knowledge" [Pisarski 1987, p65].

5.1 Research Objectives

Urban transportation planning has evolved since World War Two, into a very sophisticated set of procedures, incorporating comprehensive computerized models that permit the analysis of future transport system requirements in response to changing travel demand patterns.

The complexity and time-consuming calibration and implementation of such models, coupled with the ever-shrinking availability of funds to engineers and analysts, provides the basic rationale for this research. To date efforts at simplifying the standard modelling process have been dependent upon the use of more aggregate zone-systems and transport networks.

One area where there has been far less research and where a considerable knowledge gap remains is the area where simple linkages between transport supply and demand measures are modelled without network representation. This might possibly be achieved through careful calibration and validation of a comprehensive computer model, and the repetitive application of the model under controlled 'quasi-experimental' conditions.

This research will develop relationships between the demand for travel on the road system and traffic lane requirements. This is done to simplify or by-pass the complex assignment stage of UTMS models, and to compliment such models at the sketch planning level of analysis. This would permit, for example, the assessment of the impact of changing work patterns. Such complex changes in travel demand patterns are transforming the commuting trip into the more complex many-to-many type.

Thus, the main research objective is to develop a simplified model relating supply and demand measures at the sketch planning level, for the case study situation of Montreal. This will allow for the assessment of the significance of the

implication of employment decentralization on road network requirements.

<u>In simple terms</u>; the research answers the question of the number and location of additional lane kilometres, by facility type, needed to balance future possible variations in travel demand.

Furthermore, the matching between the place where we live and the place where we work is an important component in the traffic congestion process. This research analyzes and presents a new "zonal efficiency" concept, and a new "zonal mobility" concept that relates to the aggregate Level-Of-Service of the road network. Such complex concepts become minor research contributions and future research topics.

5.2 Research Program

The research program is presented in Fig. 1.3 and is made up of two main components; a descriptive component [Phase I] and an analytic component [Phase II]. These are described briefly in section 6, on Methodology. The program is presented in the following two pages.

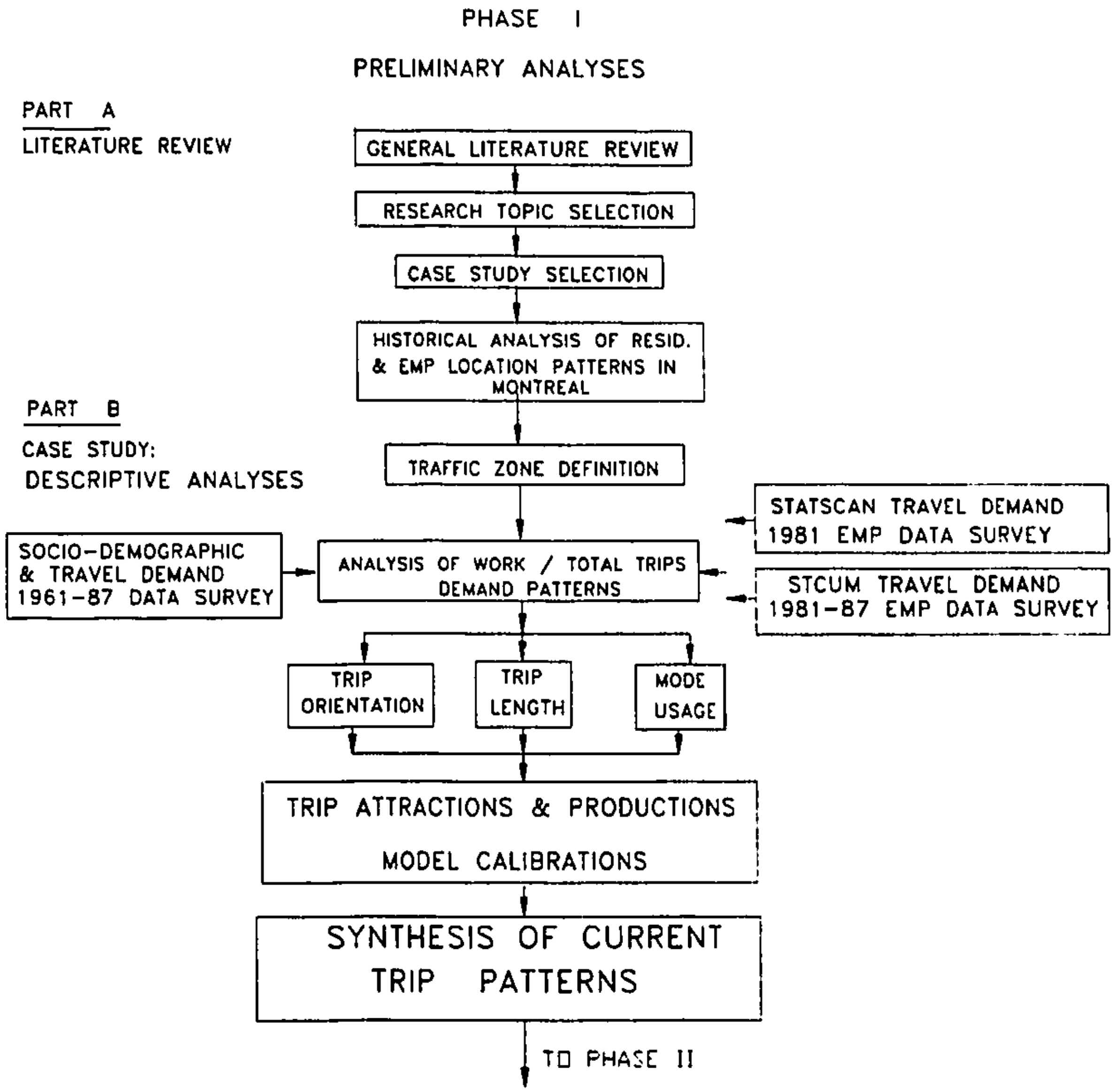


FIG. 1.3: RESEARCH PROGRAM

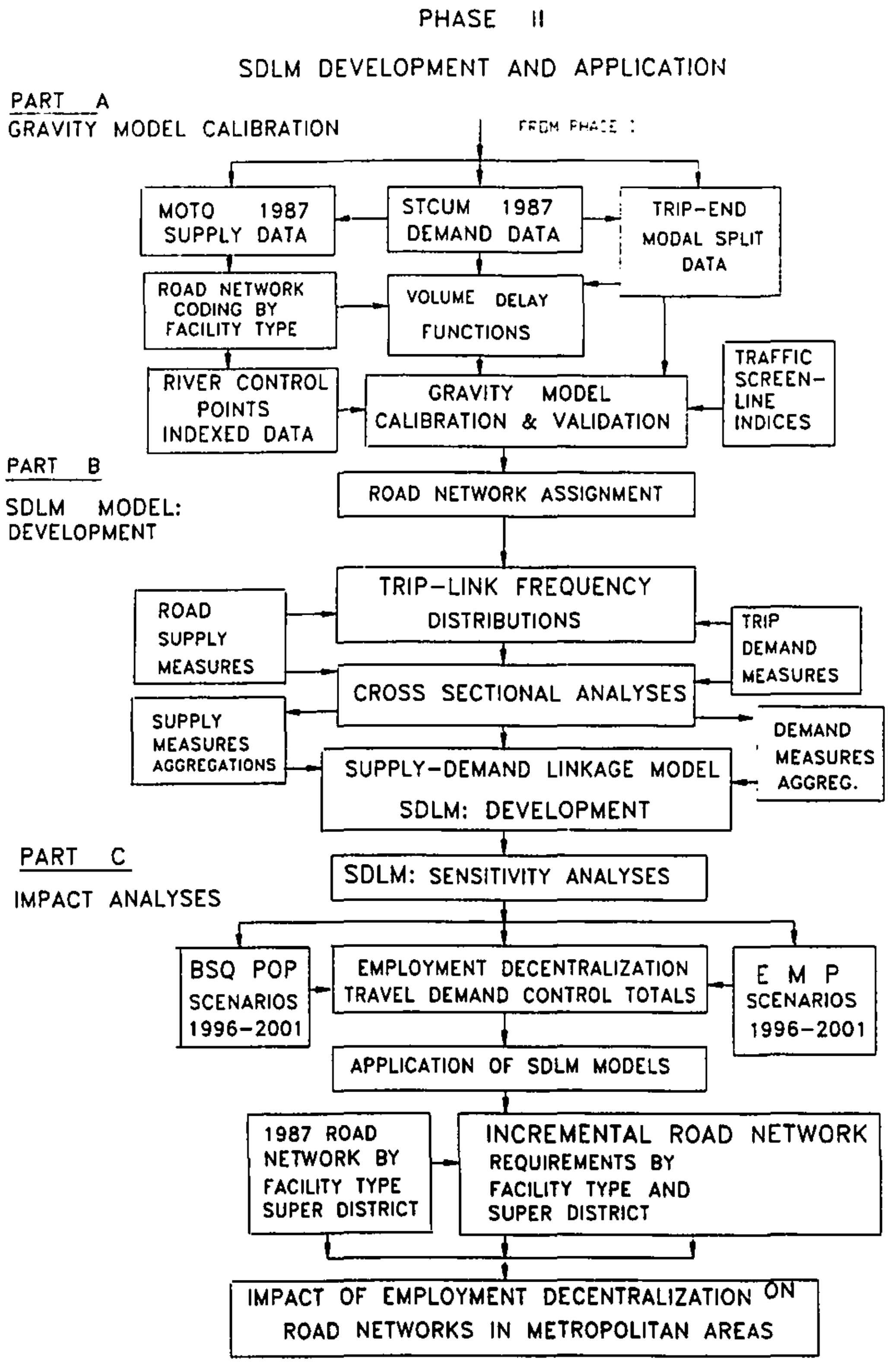


FIG. 1.3: RESEARCH PROGRAM (continued)

6. METHODOLOGY

The research methodology is described in this section conforming to the program presented in Fig. 1.3 on the previous two pages. This is preferred to the chapter by chapter approach due to the interaction between complex activities. Yet, cross referencing with chapter numbers is continuously presented.

6.1 Research Phase I

Phase I of the research, as outlined in Fig. 1.3, includes the descriptive analysis of the case study and the main component of the preparatory works, the demand matrices, needed to carry out the research; it is comprised of two parts.

6.1.1 Part A: Literature review

Part A, presented in Chapter 2, includes the literature review and the historical analysis leading to the refinement of the research scope.

6.1.2 Part B: Case study

Part B is presented in Chapter 3, the descriptive analysis of the case study and includes:

1. Selection of the case study for empirical analyses: the

Greater Montreal Area.

2. Definition of traffic zones: the Census Metropolitan Area (CMA) Census Tracts (CT) were aggregated into 38 large traffic zones (Z), grouped into 12 districts (D) and 6 super districts (SD). An elaborate set of criteria was used to achieve these aggregations.

3. Survey of available local data for population (POP) and employment (EMP).

4. Descriptive analysis utilizing the 1981 StatsCar. ome-based work trips (HBW), place-of-work survey data, classifying EMP, by occupation and industry, and by CT. Ten matrices were retrieved from special magnetic tapes utilizing the main frame computer at McGill University. EMP is also cross-classified by place-of-work (POW) and place-of-residence (POR).

5. Model calibration of production and attraction measures at the zonal level and descriptive analysis utilizing the "Societe de transport de la Communaute urbaine de Montreal" (STCUM) data matrices (about a hundred matrices were retrieved from magnetic tapes utilizing the main frame computer).

6.2 Research Phase II

Phase II of the research, as outlined in Fig. 1.3, is comprised of three main parts, forming the main body of the thesis.

6.2.1 Part A: Model calibration

The Urban Transportation Modelling System (UTMS), presented in Chapter 4, is a sophisticated and elaborate, state-of-the-art, four-stage aggregate sequential model relating supply and demand measures as point estimates, using coded network nodes and links and elaborate volume delay functions, in a complex multi-modal network. The four stages of the UTMS model are shown in Fig. 1.3 and are briefly described below:

1. Trip generation

The trip generation stage relates trip production to population (land-use characteristics), and is usually formulated as a regression model. The required zonal data was retrieved from STCUM and the Ministry of Transport of Quebec in Montreal (MOTQ).

Zonal regression models, trip productions and trip attractions, were calibrated for the case study, and are described in Chapter 3. Regression models, aggregated by SD, were calibrated for the case study and are presented in Chapter 6.

2. Modal split

The modal split component is classified as either a trip-end or trip-interchange model, i.e. a pre- or post-distribution stage component. It is dependent on socio-economic factors, like household income, age and sex, and number of cars per household in addition to transport service variables such as transit fares, transit availability, parking and gasoline costs. It varies by time of day, and by trip purpose.

In this research, due to the sketch planning approach being taken, trip-end modal split is used. Equivalent passenger cars are distributed instead of person trips.

This is of minor importance to the research, as approximately 70% of transit riders are captive riders [Canadian Transit Handbook, 1985]. Thus, mode split behaviour is assumed constant over time, and modal split variations have marginal impact at the sketch planning level of analysis as demonstrated in Chapter 3.

3. <u>Trip distribution</u>

The gravity model, being the most prominent distribution model for decades, is based on Newton's Gravitational Law, and it distributes the aggregate trip productions to their destination zones on pairwise impedances or the inter-zonal travel time matrix.

The calibration process, the main activity of Part A is presented in Chapter 4. It is a complex, and sophisticated state-of-the-art process and is case dependant and must be calibrated for any particular use. The calibration process requires a large database and re-calibration is necessary over time to truly validate the process.

In this research, a UTMS model, EMME/2, is calibrated to satisfy GMA multiple constraints which are presented in Chapter 4. A preliminary investigation showed that the EMME/2 model, used by the MOTQ, is needed to retrieve the supply road network data, and it is one of the most complete state-of-the-art models.

A comparison between the three available models at McGill University: EMME/2, TMODEL/2 and QRS II, is presented in Chapter 4; while the development of the UTMS models and their availability are presented in Chapter 2.

4. <u>Trip assignment</u>

In the trip assignment stage, interzonal origin-destination (OD) trips are assigned to particular routes in a way to minimize the user's disutility in terms of time, distance and cost. More than 8000 links and 3000 nodes were used to represent the GMA road network.

It may be concluded that the UTMS is both an expensive and time consuming modelling process; in this research, aggregate relationships between supply and demand measures, are constructed to replace the last, trip assignment stage of the UTMS model. This is achieved through the development of a **"Supply-Demand Linkage Model"**.

6.2.2 Part B: Supply-demand linkage model

The development and calibration of the supply-demand linkage model (SDLM) is the main contribution of the research; it is presented in Chapter 5. The basic task is to model the supply-demand variables, traffic density and vehicle trips, as obtained from the calibrated gravity model, described briefly in 6.2.1 above. Furthermore, the SDLM models sensitivity is tested using hypothetical forecasting scenarios and comparing results between EMME/2 and the SDLM Base model and Sub-model.

<u>The resulting SDLM models, similar to the regression models and empirical factors developed in the NCHRP special report No. 187 (1978) in USA, replaces the UTMS trip assignment stage at the sketch planning level.</u>

The main task, then, was to model supply-demand measures, using the EMME/2 calibrated model in Chapter 4. This is done in six discrete steps (Chapter 5), as follows:

<u>Step 1.</u>

To do cross sectional analyses, using EMME/2 1987 base year results, and to estimate 'trip-link' frequency distributions by zone and by zonal aggregations, and by facility type (freeways and expressways or arterials).

The 'trip-link' is defined as the directional number of trips per link, per lane-kilometre i.e., the traffic density (DEN). This is a supply-demand measure reflecting the infrastructure supply. It is directly related to the LOS in Table 1.1.

Step 2.

To compute the 'total trip-demand', using EMME/2 base year results, by SD. The 'total trip-demand' is defined as the sum total of trips produced and attracted per SD excluding the 'intra super district' trips. This is the demand (DEM).

Step 3.

To implement over time, cross sectional demand variation increments, and to repeat Steps (1) and (2) per increment by super district i.e., repeat EMME/2 assignment and the trip link frequency distributions per increment and retrieve results by SD, the most meaningful aggregation obtained from the cross sectional analyses. A total of six increments to obtain six observations.

Step 4.

To do multivariate analyses, using the mean of the 'trip-link' frequency distribution (DEN) as dependant variable, and the 'total trip-demand' (DEM) as independent variable which are

confirmed to be the most representative supply-demand measures by the cross sectional analysis.
This is the supply-demand linkage model or SDLM, for the GMA; the first-main objective of the research.

Step 5.

Repeat steps (3) and (4) and implement over time, cross sectional demand differential increments between the GMA and the City Centre i.e., repeat EMME/2 assignment and the trip link frequency distributions per differential increment and retrieve results by SD. A total of six differential increments are implemented to obtain six observations.
This is the SDLM Sub-model for the City Centre.

Step 6

To do a sensitivity analysis and to test the SDLM models through a forecasting exercise in which differential demand variations, between the City Centre and the GMA, are applied to both; the EMME/2 model and to the SDLM Base model and Sub-model and to super-impose their results.

The above six steps outlined the methodology to achieve the research main objective; the development of the SDLM models. The research second main objective the 'Impact of Employment Decentralization on Metropolitan Road Network' is achieved through the implementation of an impact analysis.

6.2.3 Part C: Forecasting scenarios: Impact analysis

The impact analysis is presented in Chapter 6. Ten and fifteen years forecasting periods were adopted (1996 and 2001) to restrict the analysis to relatively short forecasting periods, in order to be able to assume constancy of some variables over time. This decision is enhanced by the availability of forecasting scenarios for POP and EMP dispersion. The research work was accomplished in four steps, summarized as follows:

1. To do necessary preliminary work to obtain demand variables by SD to be used in the SDLM models.
2. To translate POP and EMP scenarios into their equivalent DEM scenario, using the results of Step (1) above.
3. To use the SDLM models to compute the change in DEN due to a change in DEM per scenario, by SD, and by facility type.
4. To compute the differential infrastructure requirements in lane kilometres (ZLL) by facility type and by super district.

This is the "Impact of Employment Decentralization on Metropolitan Road Networks", the second-main objective of the research.

A zonal efficiency concept is quantified using the SDLM models and a zonal mobility concept is tentatively defined. These concepts are minor contributions and are starters for new research.

7. RESEARCH CONTRIBUTION

The research improves the understanding of changing travel patterns from a many-to-one (traditional trip pattern) to the more complex many-to-many type and quantifies the requirements for roads, by facility type, resulting from EMP decentralization.

The resultant supply-demand linkage model (SDLM) relating transport supply-demand measures at the sketch planning level replaces the complex and time consuming assignment stage of the UTMS model. This is the first-main objective of the research.

The SDLM may not be transportable to other Canadian CMAs, but it is expected that the established procedure is transportable, since the structural relationships established are strong and reasonable ones.

The impact analyses, the second-main contribution of the research, has quantified the changes in travel patterns resulting from EMP dispersion using the SDLM models. This simplified procedure, transforms the SDLM models into a powerful tool.

CHAPTER 2

LITERATURE REVIEW:
EMPLOYMENT DECENTRALIZATION IN NORTH AMERICA

1. INTRODUCTION

Major socio-economic changes in North America in the last four decades have dramatically transformed the urban growth pattern and consequently the travel demand pattern from the simple traditional hub and spoke or many-to-one pattern to the more complex and convoluted many-to-many type. This has resulted from the dispersion of the place-of-work i.e., the decentralization of employment (EMP).

The decentralization of EMP, in turn, has created large activity centres or 'super suburbs' in the vicinity of large cities, and resulted in traffic congestion. The existing infrastructure, of grid type or street blocks, in most metropolitan areas, is ill-prepared to cope with the circumferential new traffic pattern.

This phenomenon has essentially decreased public transit ridership, resulting from lower suburban population (POP) densities, and increased urban and suburban traffic congestion. Furthermore, this brought about an increase in housing demand for most income groups in suburbia, thus the suburbs are no more the exclusive habitat of the white collar workers.

The EMP decentralization has received a great boom from the changing household structure and increasing female working force and their availability in the suburbs near the newly-formed office clusters.

The emphasis in this chapter is on U.S. data in general, due to its higher availability, while Canadian and U.S. data relating to the case study are presented in Chapter 3.

2. THE NORTH AMERICAN METROPOLISES: CANADIAN Vs. U.S. CITIES

The relationships and contrast between Canadian and U.S. metropolitan areas are assessed in this section in ordre to establish possible links between them.

The boundary between Canada and the United States is a function of history; it is physically invisible, and geographically illogical [Goldberg et al 1986, p1, from Hugh Keenleyside].

"So blurred is the border between Canada and the United States and so great is the ignorance about Canada by Americans that one almost wonders why we should even consider critiquing the notion of North American city or North American anything for that matter." [Goldberg et al. 1986, p2].

The above statements, apparently contradictory, they share the fact that while Canadian metropolises and their U.S. counterparts do differ, they also have many outstanding similarities.

In prefacing a recent comparative analysis in the field of urban planning, Masser (Goldberg et al 1986, p10) succinctly sums up the benefits of the approach: "Over the last few years, the idea of cross-national comparative research has become increasingly attractive because of the opportunities that it provides for analysts to test emerging theories under new circumstances and for practitioners to consider the lessons from other people's experience." In his view, cross-national comparative analyses also have the potential to stimulate the development of new and better theories.

The American geographer Brian Berry (1981) is insensitive to important Canadian-American urban differences. He continues to hold on to the concept of the North American city, allowing that such differences that do arise, are attributable to the deep-seated racism in American culture.

Comparative analyses challenge his over-generalization that the public sector performed as poorly in urban Canada as it has in the United States. To argue that economic and political power, vested in the claims of ownership and property, is widely dispersed and competitively exercised (Berry 1981) is exaggerating in the case of Canada, where economic and political power is highly concentrated.

Although British colonial settlements and British liberalism were common antecedents to the formation of culture in Canada and the United States, yet different political cultures and social histories have resulted in contrasting urban experiences. "In short, different outcomes can and did derive from similar antecedents." [Goldberg et al. 1986, p11].

Only through a natural increase, fuelled by the highest fertility of any region in Canada, has the francophone population sustained itself. But in a forty-year period, and particularly during the last two decades, Quebec went from being the province with the highest reproduction rate to the province of the lowest growth.

The Canadian Charter of Rights and Freedoms, enacted in 1982, explicitly excluded property rights from among the enumerated and protected rights. The collectivism incorporated in the conservative tradition and in successful movements can perhaps be understood in terms of the organic society notion. The political philosophy stands in marked contrast to individualist philosophy popular in the United States [Goldberg et al.].

Goldberg et al. pointed out that Canadian cities are more livable due to greater emphasis being placed in Canada on 'collective' action and 'multiculturalism' associated with lower urban crime rate. Thus, U.S. metropolitan areas are expected to be more decentralized spatially and economically in view of "the strong desire expressed by the Americans for suburban and quasi-rural living, combined with an affection for small, responsive local governments, associated with a geographically different structure of local government" (p174), and having different urban fiscal revenues. If the preceding is true then "Canadian cities constitute a distinctive group having more in common with each other than they do with cities in the U.S." (p174).

Furthermore, the Canadian urban areas are more compact in form with greater reliance upon public mass modes of travel, and are "experiencing a greater degree of suburbanization and higher level of foreign immigration... and as having lower status differences between the inner and the outer cities with the former retaining the traditional family-oriented households" (p174).

Both countries have witnessed a sharp drop in fertility, to the degree that their populations are incapable of reproducing themselves without immigration. Families have declined in importance, and there has been a significant increase in non-family households. It is evident that both economies, economic elites and economic establishments are closely linked.

Public transit in Canada did experience lower ridership declines than those registered in the U.S. in the heyday of freeway and suburban developments, in part because of the much less extensive freeway programs in Canada and higher per capita transit subsides [Cervero, 1986c]

Census surveys of metropolitan journey-to-work trips in both countries provide clear evidence that work trip distances are consistently shorter in Canada. Interestingly, there appears to be little difference in work trip travel time so that it may be concluded that Canadians drive at lower speeds.
The Canadian central city has NOT experienced the flight of middle-income families to the suburbs to the extent that American cities have [Goldberg et al].

The hypothesis examined by Goldberg et al. that Canadian metropolitan areas are distinct is consistent with the fundamental argument that Canadian metropolitan areas, while having certain features and characteristics in common with their American counterparts, yet are sufficiently distinctive to require a separate theoretical treatment.

The multivariate analyses utilized [Goldberg et al. 1986] for selected variables in the comparison between Canadian and U.S. cities concluded that Canadian cities are distinct and the concept of a North American city is a myth, yet "the conclusion concerning contextual differences and their implications for urban development reflect both caution and boldness; caution because of the limited nature of some evidence,...and boldness because of the importance of the differences which have come to light in each of the four major macro-systems explored... These differences... are intimately related to the urban differences between Canada and U.S..." [Goldberg et al. p144].

It may be concluded that Canadian and U.S. cities may be distinct, but there is limited evidence to fully support such a claim and consequently although Canadian cities may have more in common among themselves, yet their differences with U.S. cities are not basic. This permits cautious cross-referencing between Canadian and U.S. cities.

3. THE DECENTRALIZATION PROCESS IN NORTH AMERICA

The decentralization of employment in the North American context, started after World War Two (WW2) and has become highly problematic during the last two decades.

Statistics for the U.S. show that office space use outside CBDs has increased from 25% in 1970 to 43% in 1980 and up to 57% in 1984 [Lindsey, 1985]. This shift is more dramatic in some areas like Houston and Denver, where it grew from less than 20% in 1970 to more than 75% in 1980. Furthermore, more than 40% of all interzonal trips in 1980 were between suburbs as compared to only 20% between suburbs and CBDs.

The business park regulations are changing, allowing higher development densities. For instance, the floor area ratio (FAR) has increased steadily from 0.20 to 1.00 and even to 2.00 in some cases as reported by Galehouse (1984). In spite of this, the site lay out design is centred on the auto mode of transport to the detriment of all other passenger transportation modes.

The distinction between what is 'suburban' and what is 'urban' has blurred in recent years. In many cases, political boundaries are used to distinguish suburbs from central cities, even though activities on both sides of the boundary may be virtually identical. Partly for convenience, the term 'suburban' is used in this research to suggest the location of land activities outside of a city centre, generally more than ten radial kilometres away. Another distinguishing characteristic of suburban agglomerations is whether they are nodal clusters of development or centres; or linear strips or corridors [Baerwald, 1982].

3.1 Historic Review

Over the last three decades, office-based occupations have been the fastest growing employment sectors in the United States. The share of jobs in the manufacturing sector has fallen from 32% right after World War Two to 24% in the early 1980s. The service sector, including jobs in office, retail, government, education, and entertainment, grew from 49% to 66% of total employment during this same period.

While in the industrial era there was a logic to separating homes from smokestacks, slaughterhouses, rendering plants, and their nuisances; in today's work environment of supposedly pollution-free work spaces, the rationale for separating homes and workplaces by ribbons of freeways has become a matter of choice rather than a necessity.

Historically, land use and transportation have been closely related to one another. The reason why most European cities are so compact, with many residents living near their workplaces, is that they evolved in an era when walking was the primary mode of travel.

Early residential suburbs grew up around street car lines. The frequent stops of a streetcar encouraged solid development along the route. According to Jonathan Barnett (1989), the strip development persisted after the streetcars were superseded by buses and automobiles, and was then replicated in many zoning regulations. Furthermore, much of the suburban traffic problem is traceable to the development of offices and shopping centres along corridors.

In America, beltways were originally intended to allow interstate traffic to by-pass city centres and to allow regional traffic to move swiftly around a city through less congested streets. Baerwald (1982), states that, "... circumferential freeways offer greater access to larger parts of the metropolis than do radial freeways, clusters and corridors usually are more intensively developed along beltways." (p11).

The transportation system, and the attractions offered by land use regulations, is altered over time because of the change in demand which affects the accessibility of new locations and their use. The characteristics of an area's land use and the transportation system are continuously influencing each other until theoretically a dynamic 'equilibrium' is reached.

Yet, as it is rightly pointed out, it will take more than numerical balancing of jobs and housing to reduce suburban commuting; far more important will be the matching of residences with the income and taste preferences of the labour force in suburbia Cervero (1986, 1988). This is investigated further in Chapter 3 and Chapter 6 as a 'zonal efficiency' concept.

Suburban residents would not allow their neighbourhoods to become more densely populated because this is detrimental to what they conceive as their quality of life in the suburbs. The suburbs grew up as an alternative to the higher density living that characterizes downtowns, thus it is unrealistic to expect people to prefer to live in suburban cities with high densities. The preferences of suburban residents must be addressed effectively because only then can alternatives be found which will retain the qualities that make suburban areas livable [Appleyard, 1980].

Main streets were built after WW2 along ecologically sensitive areas like stream beds. Malls have 'flattened' the countryside. If zoning had included environmental protection measures this would be drastically reduced and natural areas would be preserved, leading to higher densities in lesser environmental sensitive areas, thus favouring public transit.

High-density suburban development has a weak political constituency; "in the minds of suburban residents, high densities do not reduce automobile dependency; instead they breed traffic." [Orski 1989, p32].

In his recent book Cervero (1989), proposes that housing and jobs be balanced within a five miles radius; bonuses could be given in the form of lower impact fees or greater allowed density if housing is part of an office development. In San Francisco new offices pay impact fees which reflect the number of new residents they will introduce into the area.

To change land use patterns, a long term process needs to be consistently and continuously implemented. Land use policies may be able to balance the effects of high rates of job turnover [Cervero 1984-1986]. Thus, there is a need for tools to quickly assess changes in demand, due to land use variations, at the sketch planning level. Such tools, like the SDLM models, are developed in this research.

It has been the "white-collarization" of America's employment sector that has prompted many businesses to relocate their offices in suburbia. No longer are most firms today tied to rail spurs and waterports. Rather, they have become, "footloose" i.e., able to make locational decisions on the basis of factors other than proximity to raw materials and goods [Cervero 1986].

Some suburban municipalities have evolved into major work centres while others have become mainly bedroom communities. In many regions in North America, the jobs-housing imbalance is at the root cause of the large increase in intersuburban commuting. Presently, few suburban work centres in the United States have on-site housing; from the national survey, only 15% of suburban complexes with predominantly office functions had residential units for sale or lease on their premises [Cervero 1986].

3.2 Socio-Demographique Trends

There is more behind traffic congestion than just the arrival of office jobs from CBDs. Notably, a number of demographic and life style 'megatrends' are continually altering commuting habits in North America. Perhaps most telling have been the changes in family composition.

Today's households are smaller and more diverse. Since 1950, the average U.S. family has shrunk from 3.4 to 2.7 persons. No longer does the two-parent, two-child represent the family norm; rather non-traditional families are on the rise. For instance, single-parent female-headed households increased by over 55% during the seventies, while single-parent male-headed households rose 39% [Cervero, 1986].

We are also witnessing a feminization of the labour force. More than two-thirds of married women between the age of 25 and 44 now work, compared to one-third 25 years ago [Cervero, 1986].

Undoubtedly, "suburban office settings represent a new, unexplored frontier for the city planning profession, posing unique challenges as well as unprecedented opportunities to be both proactive and creative" [Cervero 1986, p15].

This suburbanization wave has continued into the 1980s. The five fastest growing large metropolitan areas in U.S.A between 1980 and 1983 have been Houston, Dallas, Tampa, Phoenix, and Denver, all with annual growth rates over 2.7 percent and all exploding from their urban perimeters.

Among the 36 U.S. metropolitan areas of over one million population, suburbs grew at an annual rate of 1.25% from 1980 to 1983; while, by comparison, their central cities grew at the much slower pace of 0.42%.

The ethnic composition of suburbia is becoming as diverse as the older core cities in Canada. From 1970 to 1980, the U.S. black population in suburbs rose by 59.1% outstripping the 24% rate increase of suburban white; while the black population increased in central cities by 5.3% only during the same period [Cervero 1986].

Among the demand-side strategies examined, the Transportation System Management (TSM) measures such as, ridesharing and bus and High Occupancy Vehicles (HOV) lanes will likely play somewhat limited roles as long as jobs and housing remain out of balance in suburbia.

Since transportation is a derived demand, i.e. people travel in order to partake in activities occurring at the place of destination, transportation scholars have long argued that coordinated land use planning offers the most effective and enduring basis for improving mobility over the long run. Furthermore, the spatial proximity of residences and workplaces can have an important impact on suburban travel patterns and traffic conditions. This is presented in chapters 3 and 6, under the 'efficiency' concept.

3.3 The Predominant Travel Mode

The share of total trips has been shifting slowly from the automobile to public transportation modes in Los Angeles, Orange Country, San Jose, and Seattle. In contrast, most other U.S. metropolitan areas lost transit patrons during the seventies [Cervero 1986]; while Canadian Metropolises kept their transit ridership mostly due to higher transit subsidies, per capita, in Canada.

Most contemporary suburban office developments, for all intents and purposes, are effectively preordained for automobile usage. Employees find few realistic alternatives to driving their own vehicles to work, especially in suburbia.

As of the mid-eighties, most suburban office park settings are operating at tolerable congestion levels during peak hours, between LOS C and D. The fear of being stranded without a car is indeed one of the biggest deterrents to ridesharing in suburban work settings. A preponderance of suburban employees drive to work because they rely upon their vehicles during the course of a workaday [Cervero 1986].

Residential densities of at least eight dwelling units per acre, for instance, are normally considered necessary to economically justify fixed bus routes operating on 30 minute headway. Similarly, reasonably dense clusters of suburban employees are essential if public transit, private commuter buses, and carpools are to assemble trips without excessive route deviations and time delays.

Impact fee programs aim to deal with mounting congestion problems by expanding the supply-side roadway capacity rather than modifying commuter's travel habits. By providing more lanes of suburban freeways and arterials (supply-side solution), these ordinances could perpetuate the exodus of jobs and residents from downtowns presently served by transit [Cervero, 1986].

Certainly employer sponsorship of van pools and the institution of flex-time would help; however, any form of mass-commuting will have a difficult time competing with the private automobile. The recent ascendancy of Transportation Management Associations in Southern California have been particularly successful at promoting employee ridesharing [Cervero, 1986].

The Canadian metropolitan areas have not experienced the same degree of traffic congestion as their American counterparts. There are more than four times as many lanes of freeway available to the average American metropolitan resident compared with the analogous Canadian. Americans own and operate 50% more automobiles per capita. Patronage of public transit facilities is, on a per capita base, 2.5 times higher in Canadian urban regions than it is in the United States [Pisarski, 1987].

Consistent with these findings, Americans are much more likely to rely on the private automobile to commute to work than are urban Canadians. Americans travel 25% farther to work and as a result, American urban areas are more spread out. The large U.S. urban freeway system is an important contributory factor [Goldberg et al. 1986].

The rising predominance of the private vehicle as a commuting mode of transportation, from 80.6% to 85.9%, through the seventies and the decline of public transit, from 8.5% to 6.2%, is explained by Pisarski (1987) "...This high level of private vehicle availability to workers would appear to be a significant factor in each worker's decision process when deciding how to get to work" (p48). This is augmented by the availability of parking at the destinations either freely supplied or subsidized by merchants and employers.
Journey-to-work statistics confirm that in 1980, only 1.6% of all suburb-to-suburb work trips in the U.S. were made via public transit [Fulton, 1986].

The group ridership in the U.S., like car and van pooling, was found to be highest in non-metropolitan areas and declines with increasing area size, from 19.7% of commuters at the national level to 10% for metropolitan areas over a million. The loss of group ridership shifts from about 2/3 to drive alone and 1/3 to transit.

The transit commuter increase in share in a few large metropolitan areas seems to come from auto passengers rather than auto drivers as stated by Pisarski (1987). This would mean that occupancy rates in larger cities should be lower. "They are lower but not by the amount one would expect" [Pisarski, 1987, p51]; and the "central city to central city have the highest transit share, but trips originated or destined to central city also have strong transit elements." [Pisarski, p54].

According to the 1983 Nationwide Personal Transportation Study (NPTS) data, 31% of car poolers have trip length greater than 15 miles while only 15% of all workers have trip length greater than 15 miles. It may be concluded that longer commuting trips may lead to more carpooling.

Furthermore, the auto travel time was found to increase less than the average travel time, while the carpool time increased more than the average probably due to the increase in carpool distances.

3.4 Land Use Regulations

Cervero (1989) examines the linkage between mobility and commercial-office developments for major suburban office centres and corridors in America's largest metropolitan areas, with primary attention given to how the travel choices of workers and local traffic conditions are influenced by the following site characteristics: (a) employment densities, (b) site designs, (c) land use composition, particularly the level of mixed land use activities, (d) suburban levels of jobs housing balance, (e) land lotting and ownership patterns, and (f) parking provisions.

Specifically, the aforementioned study hypothesizes that the low density, single use, and non-integrated character of many suburban office-commercial centres and corridors has compelled many workers to become dependent on their automobiles for accessing work and circulating within developments or activity centres. Many suburban work settings are dependent on the private automobile as 'the' transportation mode.

The overwhelming majority of U.S. high-technology firms have chosen a suburban address [Urban Land Institute, 1986]. Many firms in the financial, insurance, and real estate service (FIRE) sectors, have likewise opted for the suburbs, moving their back office and clerical workers to branch facilities that are hooked up to the main office via telephone lines and communication satellites. Low land prices and the availability of pools of female labour force in the suburbs (second wageearners) have also fuelled the decentralization process [Cervero, 1986].

A variety of multivariate statistical techniques like, factor analysis, cluster analysis, and regression analysis, were employed by researchers in exploring patterns in carrying out specific hypothesis tests. These empirical evaluations were supplemented by more qualitative assessments based on literature reviews, site visits, and interviews. Together, it is felt by Cervero (1986) that "empirical and interpretative techniques offer a balance perspective into the transportation-land use link among America's Suburban Employment Centres (SECs)" (p27).

The average occupational breakdown of SEC employees in the U.S., reveals the dominance of white-collar workers. The largest group is clerical staff, comprising 22% of the workforce. This share closely matches the U.S. average, of 19% in 1982 [Cervero 1986].

While retail, hotel, restaurant, and other consumer land uses average higher daily trip generation rates than office functions on a square meter basis, most trips to such establishments occur in the evening, on the weekends, and during lunch time when the transportation system supply capacity is available at higher levels of service.

Indeed most Americans continue to live in one community and work in another. According to the U.S. 1980 census, the majority of Americans do not work in the community where they live [U.S. Bureau of Census, 1984]. Some workers simply prefer to separate where they spend stress-filled working hours and where they retire for the evening. A plausible explanation, however, is that a large number of suburban workers cannot afford to purchase available units even if they wanted to [Cervero, 1986b].

A similar mismatch in the location of people and jobs exists in Great Britain. The re-industrialization of Britain's economy, brought about higher than average concentrations of the unskilled and semi-skilled workforce in the inner city areas with diminishing access to the type of manufacturing jobs that they traditionally held [Fothergill and Gudgin, 1982] and [Castles and Kosack, 1985].

Cervero (1989) claims that with job-housing balance, local streets and collectors can also be used more efficiently. Local streets (representing around 85% of lane miles of roadway in the U.S.) have considerable untapped capacity, yet carrying only about 15% of vehicle mileage [Levinson, 1976]. By shortening trips, jobs-housing linkages would allow local streets to be utilized more fully, whether by foot, bicycle, or car, while deflecting cars from already over-burdened freeways. This is a debatable topic as it would leave our streets less livable and more pedestrian-accident prone.

More important than the ratio of jobs-to-housing is the share of workers who actually live in on-site units. Of course, it is not imperative that suburban employees live actually on a site to achieve the benefits of jobs-housing balance. More important is the match-up of housing with employees within a small subregion, say, within a three to five mile radius of the work place [Cervero, 1989]. This is captured by the 'zonal effficiency' concept in this research and presented in Chapter 3 and followed up in Chapter 6.

"In contrast to yesteryear's strict Euclidean zoning practice, most planners today advocate land use mixing as a way of both enriching working and living environments and cutting down on vehicular trip-making" [Porter, 1985].

Land use tenants mix is recommended as a solution in the vicinity of office parks, provided that, it is financially affordable by employees desiring to live in developments next to their jobs. The need to fuse suburban land use goes beyond job-housing linkages to include restaurants, shops, banks, and other commercial groups, to create 'suburban activity centres'.

Thus, in the absence of strong regional planning policies, a possible solution to traffic congestion is to balance the supply and demand over time i.e. the roadway network traffic demand and its capacity at the sub-regional level.

The reason why the planning and design of suburban workplaces is of such paramount importance is that many employment cen'.res in Canada, the U.S. and abroad are just beginning to take form. It is imperative to coordinate transportation and land use by establishing a link between supply and demand, like the SDLM models developed in Chapter 5 of this research.

The housing-employment zonal balance (zonal efficiency concept), transforms the OD trips into intra-zonal trips, i.e., more efficient zones (traffic congestion wise). The zonal efficiency concept is of particular interest to the research and it is scrutinized in chapters 3 and 6.
Unless these matters are taken seriously, the balancing and matching between the place-of-work and the place-of-residence, important 'growth control' measures are apt to become the only land use tool availble to curb traffic congestion.

While supply-side responses can relieve suburban congestion in the near term, they are rarely lasting solutions. The inherent weakness of building more road networks to increase capacity to serve suburban trips is that once mobility is relieved, the forces behind sprawl once again are set into motion.

3.5 Land Use and Congestion

Over 90% of the non-corridor SECs in the U.S. are served by controlled-access freeways. On average, these SECs have 7.3 directional miles of freeway and 5.6 grade-separated interchanges within a five mile range. This averages out to around 3,800 employees per directional freeway mile and 6,400 employees per interchange. The average spacing between interchanges is 2.5 miles.

The surveyed SECs by Cervero (1989), average around 3.85 parking spaces per 1,000 gross square feet of floor space, which comes out to a little over one space per worker.

The mean one-way travel times, distances, and speeds of the journey to work made by employees of the surveyed SECs are around eleven miles one-way at speeds of approximately 28 mph and taking around 24 minutes. This is farther, slower, and longer time-wise, than the journey to work made by a typical suburban employee in 1980 [Pisarski, 1987]. That worker travelled on average, around 9 miles in a little over 18 minutes at speeds of roughly 30 mph.

Thus on average, the share of SEC employees (or suburbanites) in these surveyed regions who relied on their cars for commuting to work exceeded that of the typical urban worker by 15 percent. The heaviest hour of SEC-oriented commuting appears to coincide more or less with the peak hours of other work locales [Cervero, 1989].

Trips generated in office parks (1987 ITE Manual), average almost twice as many vehicular trips per square foot as large general office buildings, reflecting the effects of low densities, single-use activities, and excess parking on vehicle usage [Cervero, 1989]. Most SECs have low FAR and employment densities, generally with FARs below 2.0 and fewer than 20 workers per acre.

Mixed-use environments could reduce trip generation levels, encourage walking and ridesharing, spread trip-making more evenly throughout the day, and allow parking facilities to be shared [Cervero, 1989].

The factor analysis was successful in providing a multivariate description of the land use and development dimensions of SECs [Cervero, 1989]. The extracted factors and their relationships to the original variables are logical and interpretable. The number of extracted factors suggests there are four key site features of SECs: density, size, design, and land use. **Among these dimensions, density is dominant.**

SEC groups with the highest densities averaged the highest share of vehicle pooling; and tend to have the greatest variety of land use, and in particular the largest retail components. The inference is clear: SECs that are denser and have restaurants, shops, banks, and other consumer services on-site, 'sub-cities' or 'super suburbs', are apparently able to lure workers out of their private automobiles and into carpools and vanpools, all things being equal.

In many ways, density performs a multiple role: by inducing congestion, it encourages people to find alternatives to driving to work. At the same time, higher densities enable alternative modes, like bus transit, to operate more efficiently and successfully compete with the private automobile. To the extent that viable alternatives to the automobile are available, the congestion-producing effects of high density suburbs may only be transitional.

Overall, the models presented by Cervero (1989), seem to confirm the hypothesis regarding the effects of mixed-use environments on commuting. Single-use office settings seem to induce solo-commuting, whereas work environments that are more varied, both on-site and nearby, generally encourage more ridesharing, walking, and cycling. Particularly important to ridesharing is the availability of consumer retail services at the place-of-work.

All the variables of the best fitting multivariate stepwise model for explaining average commuting speed to SECs, are based on available data, and seem logical. The overall model has low reasonable predictive abilities, as suggested by the R-squared statistics of 0.53. "The variable which reflects the relative level of highway capacity is EMP/FWYM" i.e., the trip density which is a measure of LOS [Cervero 1989, p143]. This is presented in Table 2.1.

The dependent variable, in Table 2.1, is speed, the average travel speed for journey to work (m.p.h.); while the independent variables are:

1. EMP/FWYM = Employees per directional mile of freeways within 5 mile of SEC
2. JOB/HOUS = Employees per on-site housing unit
3. EMP/ACRE = Employees per acre.

VARIABLE	BETA COEFF.	ST. ERROR	T STAT.	PROBABILITY
EMP/FWYM	-0.00059	0.00032	-1.852	0.0789
JOB/HOUS	-0.09093	0.04079	-2.229	0.0374
EMP/ACRE	-0.10190	0.05178	-1.968	0.0631
Intercept	37.22287	2.31963	16.047	0.0000

TABLE 2.1: FACTORS INFLUENCING AVERAGE COMMUTING SPEEDS

Stepwise regression results

26 observations. R-squared= 0.532. F statistic= 7.555. Probability= .0014.

Source: Cervero 1989, Table 6.6

"Thus size, density, and land use composition appear to be working in tandem to influence the LOS on nearby freeways. All things equal, suburban centres that are big, dense and housing-free in character" tend to impact traffic congestion the most on nearby freeways (Cervero 1989, p146).

Table 2.2 presents the multivariate analyses regression results for the factors influencing LOS. The dependent variable RWYLOS is the numeric index of LOS during the peak period on arterials serving SECs; ordinal values are assigned to LOS as follows: A=1, B=2, C=3, D=4, E=5, and F=6. While the independent variables are:

1. FAR = Floor area ratio = total floor space/ total land in SEC.
2. PROFSHAR= Percentage of workforce in management, administrative, or technical job classifications.
3. FLOORSPC= Total commercial-office-industrial floor space, in millions of square feet.

VARIABLE	BETA COEFF.	ST. ERROR	T STAT.	PROBABILITY
FAR	0.2320	0.0938	2.475	0.0166
PROFSHAR	-0.02189	0.0083	-2.619	0.0115
FLOORSPC	0.0291	0.0105	2.772	0.0077
Intercept	4.3448	0.4384	9.911	0.0000

TABLE 2.2: FACTORS INFLUENCING LOS

Main surface arterials serving SECs; Stepwise regression results

57 observations. R-squared= 0.272. F statistic= 6.377 Probability= .0009.

Source: Cervero 1989, Table 6.9

The workforce variable that was found to be most associated with roadway LOS was PROFSHAR. Where this percentage is high, traffic on surface streets tends to flow more smoothly. A logical explanation for this is that, although professional workers tend to be heavily auto-reliant, they also tend to enjoy more flex-time privileges, giving rise to a more even temporal distribution of trip-making during morning and evening hours [Cervero, 1989, p146].

Jobs-housing mismatching induces SEC workers to use motorized travel modes to get to work and to lower the incidence of walking and cycling. Many suburban office projects were found to be insensitive to the needs of pedestrians, cyclists, and transit users [Cervero, 1989].

4. COMMUTING PATTERNS

The traditional work trip to the central city [Pisarski, 1987] represents 53% of the destinations of all metropolitan bound trips in the U.S., with non-central trips accounting for the other 47% of total trip destinations. Thus the central city is still a majority destination in spite of the decentralization movement after WW2 to both suburbs and exurbs.

The suburbs usually form a ring around central cities, thus it is clear that all trips between central cities, between different metropolitan areas, and between central cities and their exurban areas will traverse suburban areas and use suburban roads.

There are 4.8 million metropolitan out-bound daily commuter work trips in the U.S. going to exurbia and other metropolitan areas, out of which 3.7 million trips between metropolitan areas and 1.1 million trips to non-metropolitan areas.

Furthermore, the 3.7 million trips consist of 2.0 million to the other suburbs and 1.7 millions are destined to the other central cities. It is seen that commuting between suburbs of different metropolitan area account for 2.0 million trips out of a total of 4.8 millions.

The 1.7 million inter-central city trips in the U.S. have the effect of twice as many trips in suburbia "...Patterns indicate that the share of suburban trips going to a different jurisdiction is increasing, suggesting that the 25.3 million intra-suburban trips may be increasing in length" [Pisarski 1987, p44].

When we superimpose the new demand pattern of inter-suburban trips, generally of a circumferential nature, on the existing supply of street networks, basically of a grid pattern, we realize the incompatibility between supply and demand patterns shedding light on the roots of the new traffic congestion in North America. This has seriously imperiled the metropolitan roadway system and the ability of the interstate system in the U.S. to accommodate the evolving traffic pattern.

As land and housing prices continue to sour, many residents are being squeezed out on to the exurban fringes, widening the mismatch between where people live and work. Consequently, the commuting patterns can be expected to become even more defuse and disorderly over the remainder of the century.

Pisarski (1987) found out that "Declines in public transit were greatest in metropolitan areas below one million" while "...Two of the five areas with over 5 million population, like L.A. and San Francisco, actually sustained gains in ridership." (p54). The NPTS and American Housing Survey (AHS) has confirmed the findings in different studies.

Another finding of Pisarski was that the proportion of the walking to work trip is highest in non-metropolitan areas followed by central cities and suburbs. As expected, walking trips to work tend to be very short trips, with 78% under a mile length and 98% under two miles. It is of interest to note that the walk-to-work population seems to be drawn from the transit mode.

Working at home trends seem to indicate a shift away from full-time working jobs. Recent surveys by the Bureau of Labour Statistics (Canada) shows that large numbers of working population report working at home for part of the work week. This will be deduced from the long form questionnaire of Statistics Canada of 1986.

An important finding by Pisarski in explaining the inter-suburban travel pattern increase is as follows: "Suburb-to-suburb commuters enjoy a considerable travel time advantage over suburb-to-central city commuters, about 7 minutes one way. This travel time advantage must clearly be playing a part in the shift of work travel to the suburb-to-suburb pattern" (p58).

A related finding (Pisarski, 1987) was that the suburb-to-suburb commuter trips are 50% shorter than suburb-to-central city trips. Thus the travel time advantage of seven minutes is due more likely to shorter distances rather than higher speeds. The large difference in trip length indicates the higher efficiency of inter-suburban trips since fewer miles of travel are generated; this may not last as more traffic is induced and the pattern becomes more pervasive.

4.1 Changing Commuting Patterns

Pisarski (1987) found that, in the 1980 U.S. Census, there are basically three booms affecting the commuting trends in America, and these are responsible for the growth in commuting trips witnessed in the last three decades: (1) the worker boom, (2) the suburban commuting boom, and (3) the auto commuting boom. They are presented in Fig. 2.1. Furthermore, Fig. 2.1 also presents the factors influencing each of the three booms and the trends for the factors influencing the auto commuting boom.

Between 1950 and 1980, in the U.S., the employed civilian labour force grew by more than 65% while the population grew only by 50%, that is an increase in employment of 40 million and an increase in commuters of 40 million not directly proportional to population.

By 1970 the population growth tapered off to 1% per year while the employment growth rate doubled. There are two possible explanatory parameters for labour force growth; the baby boom parameter and the increase in the female labour force. Even in areas where the population growth is negative, an increase in employment was noticeable.

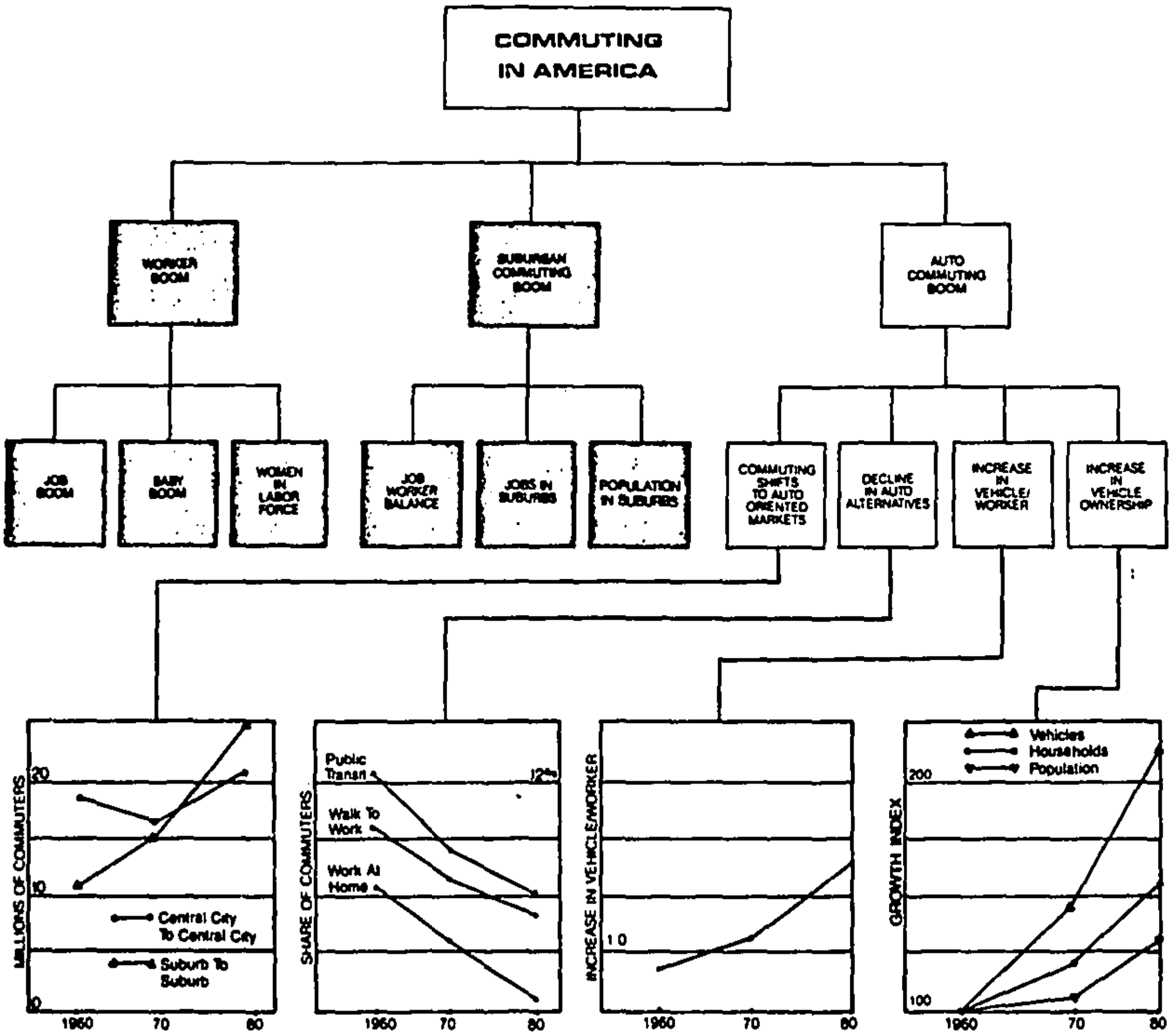


FIG. 2.1: THEMES OF CHANGE INFLUENCING COMMUTING IN AMERICA

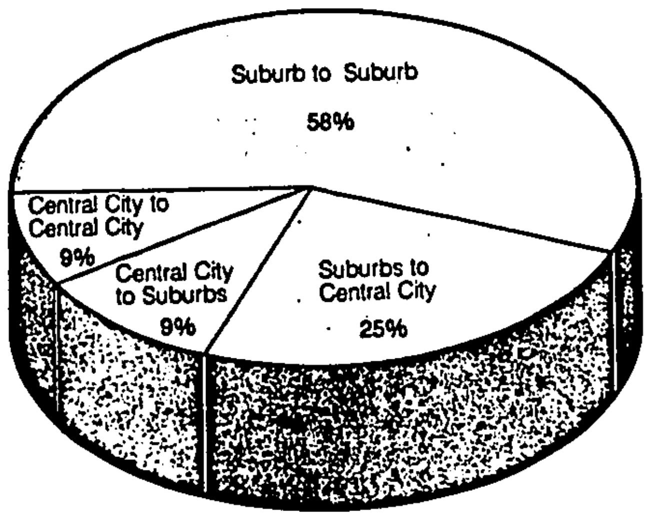
Source: Pisarski 1987; Fig. D.

The commuting growth has been concentrated in the suburbs due to the location of both the place-of-residence of the working population and their place-of-work. Thus, the origins and destinations of commuting trips have become more suburbanized, generating what might be labelled "The suburban commuting boom...its urban dominance (U.S.) has increased substantially over the years with more than 75% of the population now living in the metropolitan areas" [Pisarski 1987, p4].

The urban commuting pattern at present suggests that the traditional commuting pattern, suburbs to city centre trips in metropolitan areas, was a transitional stage, a result of a temporary imbalance in the form of temporary communities, when households moved to the suburbs but before EMP decentralization from city centres to the suburbs started.
"It is in the largest metropolitan areas where the suburbs are most dominant in commuting patterns. In smaller metropolitan areas, the suburb-to-central city and intra-central city trips are greater as a proportion of all work trips...(yet)...the relative growth by size do indicate that the suburbanization of jobs and commuting flows is widespread, affecting work travel patterns in all metropolitan size categories" [Pisarski 1987, p5].

The commuting growth rate in U.S. metropolises of one to three million, between 1960 and 1980, was dominated by the suburbs to exurbia (out of metro areas) growth at 219% the suburb to suburb at 163%, and the central city to suburbs at 198% [Pisarski, 1987, p44].

The total growth in metropolitan commuters is presented in Fig. 2.2, by market. The largest share in growth occurred in the suburb to suburb commuting reaching 58% while the traditional commuting accounted only for 25% of the growth.



		TO		
		Central City	Suburbs	Total
FROM	Central City	9%	9%	17%
	Suburbs	25%	58%	83%
	Total	34%	66%	100%

FIG. 2.2: SHARE OF COMMUTERS BY MARKET, 1960-1980.

Source: Pisarski 1987. Fig. 3-4.

The predominant commuter flow pattern in the U.S. is now the suburb to suburb trip; there are 25 million commuter trips per day, representing one third of all metropolitan commuting. The traditional commute between suburb and city centre, although still growing, is no more the dominant pattern. It ranks third, behind central city to central city trips in the U.S. The travel to work between metropolitan areas and non-metropolitan areas is also growing but is not of major impact.

The shifts in commuting patterns produced changes in commuting trip length and trip travel time.

The majority of households in the U.S. have two or more vehicles; the share of households without vehicles dropped from 22% to 13%. Two-vehicle households grew by 172% and three-vehicle households by almost a thousand percent. The average availability of vehicles to workers rose from 0.85 to 1.34 in 1980. "In this case vehicle per households and workers per household are highly symmetric...Another finding is that households without vehicles tend to be households without workers...Zero-vehicle households tend to be very small households located in larger central cities." [Pisarski, 1987, p6].

It may be concluded that the auto commuting boom resulted from a shift to an auto oriented market, a product of the decline in auto alternatives, and an increase of the vehicle per worker ratio and in vehicle ownership. And summarizing, the changes in commuting patterns may be grouped as follows [Pisarski, 1987]:

1. A rise to preponderance of the suburb-to-suburb commuting trip pattern, the many-to-many pattern.
2. The traditional commute, suburb-to-central city, the many-to-one pattern, is still growing but it is of lesser importance.
3. The suburban flow patterns are characterized by multi-directional local commuting flows.
4. A growing pattern flowing inwards from exurbia has been established.
5. Trip length has tended to increase over time in all categories of flow patterns, though shifts between categories was also established.

This research is mainly concerned with the first three items, proving the suburb-to-suburb traffic preponderance and establishing the multi-directional commuting flows in the suburbs, that is the many-to-many complex flow pattern. This is basically responsible for the dramatic decrease in transit commuter ridership in suburbia and consequently, the road traffic congestion. This direction is in concordance with the research of Cervero (1986 and 1989) and Bourne (1989).

4.2 Commuting Demand: Implications

A basic characteristic of commuting travel is the overall trip length and travel time; they are also among the most difficult variables to evaluate. Shorter trip length may result as jobs get closer to workers. "As the proportion of suburban work-trip origins that also terminate in the suburbs grows, overall average metropolitan trip length should decline. This should promise a significant increase in commuting efficiency" [Pisarski 1987, p8].

The dominant commuting pattern in metropolitan areas is: suburb-to-suburb at approximately twice the size of the 'traditional' pattern. The growth in the 'traditional' suburb-to-central city travel remains substantial.

The average travel time for all commuters is: 20.9 minutes in the U.S. for a typical journey of about 10 miles, and a speed of about 28 mph.

In large metropolitan areas, the average transit travel times are 1.7 to 1.8 more than the travel times of private vehicles, which partly explains the decline in transit ridership.

It is expected that the "future travel time and speed will be a function of travel demand interacting with transport supply" [Pisarski 1987, p9]. The related dependent variables, travel time and speed, are a function of length, travel demand patterns, and the characteristics of the transportation facility provided.
Furthermore, Pisarski states that the trip length has increased by an average of 18% for all modes between 1975 and

1980, the auto mode increasing more than the average, and the travel time for all U.S. commuters was 21.7 minutes which is slightly different from the AHS value of 20.9 minutes.

The following changes in modal demand due to the persistent trend towards greater use of the private vehicle for work travel were established by Pisarski (1987):

1. Continuous growth in the number of private vehicles.
2. 'Non-achievement' of the expectations of potential growth in transit ridership, walking to work, and working at home.
3. Relative and absolute decline of the use of all alternatives to the automobile.

4.3 Transportation Facilities: Implications

Transportation planning "based on a population growth as a principal determinant of future travel demand is seriously questioned ... No area, regardless of population growth rate, is immune from the need to respond to increasing travel demand ... The tremendous growth in suburban commuting has occurred in areas ill-prepared in terms of public facilities, roads and transit, to meet the challenge." [Pisarski 1987, p9].

The new trip patterns hold some prospects for future trips as they become shorter and more balanced in direction. "New patterns of employment and trip patterns will serve to reduce the importance of the "peak hour" and the "peak direction" as the driving forces in system design and operations" [Pisarski 1987, p9].

The potential for greater 'community balance' between workers and jobs in suburban areas exists as the EMP decentralization process continues. This will render suburban commuting more efficient.

The average household size has been shrinking for several decades. Between 1950 and 1980, it declined from 3.37 to 2.75 in the U.S. Baby boomers coming of age, the increase of women in the labour force and the single parent households tend to generate new and smaller households. This is amplified by higher divorce rates, and older persons living longer and living separately from their children.

The availability of vehicles per household has grown 60% between 1960 and 1980, from 1.03 to 1.61, in the U.S. while the availability of vehicles per capita has almost doubled. This is due to a decrease in household size, otherwise the vehicle/household ratio would have doubled. The vehicle per worker availability has also increased from 0.85 to 1.34.

5. THE EXURBAN MOVEMENT

An important contribution to the "back-to-the-country" movement is attributed to the outward shift of urban developments into rural areas, and the decentralization of the place-of-work that is within commuting range of central cities and suburbs. "Exurban development will demand that resources be ploughed into public services, facilities, and transportation systems that are very costly to provide over large areas at low densities" [Nelson et al. 1990, p92]. This is in conformity with Cervero (1986).

The American population has been shifting outwards from cities since WW2 due to rising income, improved highways, and U.S. government guaranteed federal home mortgages [Nelson et al. 1990].

Furthermore, "households have increasingly sought to escape from crime (Segelhorst and Brady, 1984), congestion (Cervero, 1985), pollution (Ridker and Henning, 1967; Li and Brown, 1980), and other negative externalities associated with central city living (Levin and Mark, 1977). There is also evidence that white families leave urban areas to avoid the concentration of racial minorities" [from Mills and Price, 1984; Nelson et al. 1990, p92].

Households first consider and then choose exurban locations for the four main reasons outlined by Nelson et al. (1990, p94). They are as follows: (a) the decentralization of EMP, which has been well documented in Cervero (1986); (b) the flexible work and commuting time, specially at managerial levels, allowing travelling at off-peak hours thus longer commuting is possible; (c) the costs of fixed and variable commuting is generally underestimated; and (d) telecommunicating potential in exurbia is an EMP decentralization force.

The increase in EMP opportunities can not explain the large exurban sprawl as pointed out in [Nelson et al, 1990]. The 'behavior'of the households play an important role, such as: "(1) the desire to escape urban environmental diseconomies and socioeconomic heterogeneity, (2) the pursuit of the classically American "Jeffersonian" rural ethic, (3) the desire to locate within and near open places and recreation opportunities of many types, and (4) the ability of households to select locations that offer levels of public services more commensurate with their needs than urban and suburban locations." [Nelson et al. p95]

Furthermore, exurban developments were made possible by the improvement of property service systems like, septic treatment, water wells, electric generators, incinerators, satellite TV and the declining land restrictions in relation to urban and suburban areas.

"Some contend that with the creation of excess capacity in urban and suburban areas, potential exurban development can be redirected into those areas", [Nelson et al. 1990, p97]. This is not the case of the GMA (Greater Montreal Area), where the eastern part of the island is relatively empty while Laval, the North and South Shores are growing rapidly.

6. THE NEW URBAN FORMS

Bourne (1989) tried to answer the question of whether 'new urban forms' are emerging in the Canadian context by testing five separate but related hypotheses. The empirical results obtained confirm the hypotheses of a continuous decentralization of population and EMP. These hypotheses relate to the changing form and structure of Canadian metropolitan areas.

The first hypothesis is concerned with the "deconcentration of the urban envelope" or the dispersed city hypothesis, "It asks whether or not the continuous and rapid decentralization of functions, employment, population, and services of the older central core to the expanding suburban margin has resulted in a new and highly deconcentrated urban form" and it asserts that, "it has clearly lead to further urban dispersion" [Bourne 1989, p314], leading to suburbanization and inner city decline.

The second hypothesis, the 'increasing social diversity and differentiation' or the 'social mosaic hypothesis', suggests a partitioning of the landscape into a less predictable mosaic, or a "social and spatial polarization and segregation in both city and suburb" [Bourne 1989, p314]. This view is neither shared by Cervero (1986) or Pisarski (1987). This might be conceived as a Canadian characteristic more in line with the findings of Goldberg et al. (1986).

The third hypothesis of Bourne (1989), is 'the elite inner city hypothesis' or the reverse status gradient: the gentrification and displacement of low income residents from inner cities. This hypothesis, if confirmed on a large scale, would have long term implications. The fourth and fifth hypotheses are related to the third; the labour market hypothesis: shifts in residential locations and commuting and the emergence of multi-nucleation.

"The specific hypothesis tested pertains to an increasing geographical separation of residence and workplace. This separation, in turn, raises the possibility of a deepening of the spatial mismatch between jobs and the resident labour force, at least as evidenced by changing length of the journey-to-work distances and the location of work-trip destinations", [Bourne, 1989, p319]. This was assesssed by both Pisarski (1987), and Cervero (1986) for U.S. cities.

The empirical analysis results on the distance-density relationships confirmed that the "traditional core-dominated relationships still hold in urban Canada" [Bourne, 1989, p316]. Population density, social status, rates of population change, demographic and family structure, EMP composition and housing mix all vary systematically with distance.

Furthermore, despite extensive decentralization, urban areas in Canada "are still spatially organized with respect to a single central node" [Bourne 1989, p316].

The urban landscape has dramatically expanded in recent years while the "average residential densities have declined almost everywhere in urban Canada...Despite the strong correlations between density and distance...The variability of the urban-density surface has also increased over time and is evident in declining R-square values" [Bourne 1989, p317]. This is presented in Table 2.3 [the functional form is: Y = B0 + B1(X)]. Where (x), the independent variable, is the distance from CBD and the dependent variable is the POP density.

The above may be attributed to a combination of factors: the higher rates of per capita consumption of land in suburbs, the smaller household sizes, the suburbanization of high density residential buildings, and the selective inner city redevelopment.

CMA	DATE	N	B0	B1	R-SQ.
Toronto	1971	-	14000	-0.111	0.454
	1981	602	9821	-0.077	0.408
Montreal	1971	-	17100	-0.103	0.335
	1981	657	14354	-0.117	0.313
Vancouver	1971	-	5400	-0.098	0.342
	1981	245	4953	-0.076	0.317
Ott.-Hull	1971	-	8500	-0.209	0.423
	1981	177	6343	-0.162	0.465
Edmonton	1971	-	6400	-0.135	0.290
	1981	139	4983	-0.148	0.329
Calgary	1971	-	10300	-0.114	0.120
	1981	115	6405	-0.082	0.093
Winnipeg	1971	-	5600	-0.126	0.202
	1981	134	5163	-0.154	0.203
Quebec	1971	-	12600	-0.270	0.434
	1981	126	8584	-0.211	0.312
Hamilton	1971	-	6100	-0.136	0.249
	1981	134	4888	-0.084	0.168
London	1971	-	11100	-0.192	0.260
	1981	71	5054	-0.217	0.254
Halifax	1971	-	7900	-0.354	0.500
	1981	62	4049	-0.206	0.441
Windsor	1971	-	6200	-0.213	0.520
	1981	56	3723	-0.154	0.282
Victoria	1971	-	5000	-0.294	0.618
	1981	53	2989	-0.117	0.410

TABLE 2.3: POP DENSITY-DISTANCE RELATIONSHIPS: 1971-1981.

Selected Canadian CMAs by CT. Regression analyses.

Each CT is an observation (N).

Source: Bourne 1989, Table 3.

Table 2.4 presents the multivariate analysis of over time (1971-83) population density variation with distance (in bands of 1 km from the centroid of the CBD) for the rate of population change with distance for 1981 Census Canada data [the functional form is: Y = B0 + B1(X) + B2(X) + B3(X)].

CMA	N	B0	B1	B2	R2-ADJ
Toronto *	41	9778	-385	5.2	0.689
Montreal	36	13386	-873	14.9	0.889
Vancouver	39	6013	-356	6.7	0.516
Ott.-Hull	22	6419	-580	14.4	0.881
Edmonton	16	3983	-231	5.4	0.514
Calgary	16	4543	-217		0.687
Quebec	18	7139	-473		0.681
Winnipeg	15	4934	-301		0.851
Hamilton	19	5636	-490	11.6	0.814
Kitchener	20	3280	-451	18.8	0.443
London	19	3003	-324	60.9	0.748
Halifax	18	4455	-539	15.7	0.712
Windsor	13	4201	-657	28.8	0.832
Victoria	13	3286	-506	18.8	0.650

TABLE 2.4: VARIATIONS in POP DENSITY-DISTANCE RELATIONSHIPS: 1981

Selected Canadian CMAs. Regression results.

* NB: Only Toronto has a B3 coefficient of 0.09.
In 1-km distance bands, each band is an observation (N).

Source: Bourne 1989; Table 4.

The relatively small determination factor (R-square, obtained from the linear regression analysis, Table 2.4) shows that the population deconcentration process is reflecting "considerable variability from region to region and among individual localities" while it confirms that the "new and massively dispersed urban form, however, is not substantiated", [Bourne 1989, p318], except for the GMA where R-sq. is 0.889.

Concerning the emergence of the reverse status gradient hypothesis; Bourne (1989, p322), states that "this conclusion calls into question the assertion of an elite and executive-dominated inner city"; and on the separation of workplace and residence or the mismatch hypothesis: "the spatial separation of workplace and residence in urban Canada has continued to increase in all areas studied". This was confirmed for the U.S. cities by Pisarski (1987).

On the journey-to-work trips in the larger Canadian urban areas Bourne (1989) stated that suburban EMP nucleation, "at least when measured by the relative size of workplace as commuting destinations, is not extensive" (p325); as seen from the Calgary CMA example; and "the multi-nucleated urban form...apparently has not yet arrived...Largely because of the widespread geographical dispersion of that employment". The assertions were based on a rather small coefficient of determination.

Points of concern in this research, are as follows: "the empirical evidence, ... supports the hypothesis of widespread urban decentralization in urban Canada, measured through the changes in the shape of population-density gradients and by the rate of intra urban population growth and redistribution. The new urban envelope is not, however, simply more decentralized and less densely developed. It has become much more complex, more convoluted, and internally a variable landscape" [Bourne 1989, p325].

7. THE DECENTRALIZATION PROBLEM

There are no ready-made solutions to the decentralization problem. Just as it has taken years for traffic build up to reach a point where suburbanites are beginning to take notice, it will no doubt take years to turn the situation around. We currently have the technical expertise and engineering know-how to deal with traffic congestion regardless of where it surfaces. Finding the money to do so remains a major problem. The most difficult obstacles, however, are behavioral and institutional; getting people to change their travel habits and getting governments and private industry to respond to emerging mobility dilemmas efficiently and creatively, [Cervero, 1986].

The traffic congestion in the suburbs is a dilemma; good arguments can certainly be made on both sides; Government intervention and the do-nothing approach. The do-nothing alternative relies on the proven prowess of the marketplace to guide the locational and behavioral choices of residents and business such that a steady-flow traffic situation ultimately prevails. Proponents of this approach note that many of today's transportation solutions: mass transit, ridesharing, HOV lanes, and the like were designed to relieve inner-city congestion and that trying to make them work in the suburbs is both futile and wasteful. Indeed, many of today's public initiatives run contrary to the travel preferences of most cities and suburban dwellers, [Cervero, 1986].

The trend analysis findings of Pisarski (1987) are summarized here in a way to bring forward points of interest for this research.

1. The baby boom: it is a one time phenomenon.
2. Women in the work force: there is indication of the desire and need of women to join the working force as of WW2.
3. Job growth: the current trends suggest possible shortages of labour in the future. This will bear pressure on the Administration to increase immigration, to lure more women to join the working force and to bring marginal members of the working force into the active community.
4. Household size: this is not so critical as only minor variations may be expected in the foreseeable future.
5. Vehicles ownership and availability: the demand for vehicles in contemporary society is a product of the kind of purposes people have for their vehicles, rather than a product of the kind of people within the population ... realistic future planning must be premised on personal vehicle

availability being a given for all commuters who wish to have one.

6. Travel mode choice: with 86% of all commuters using the auto mode at the national level in the U.S., it is hardly expected to have further significant shifts. This does not exclude important local or even regional important shifts.

7. Work trip length: the present trip length will not persist into the future and the potential for shorter trip lengths will be realized as jobs get closer to the worker, thus achieving a more efficient 'zonal system' (chapters 3 and 6).

8. REVIEW OF RELATED MODELLING AND RESEARCH

The research results contributing to the understanding of the decentralization of population and EMP were presented earlier in this chapter. They emphasized the decentralization problem and its implications and proposed ways and means to assess and implement solutions. Most relevant were the works of Pisarski (1987), Cervero (1986 and 1989), and Bourne (1989).

Complex and time consuming sequential UTMS, four-stage travel demand models, relating supply and demand exist. The four stages of the UTMS model were briefly presented in Chapter 1. Simple direct links relating supply and demand measures are lacking and are addressed in this research.

The long-range planning process was in decline in the 1970s and 1980s; many analyses used up most of their budget before even reaching the forecasting stage. Obviously, a viable alternative was needed to be more responsive to the decision-maker needs.

The NCHRP sponsored two research papers published as Special Report No. 186 and No. 187 (1978) to develop a quick response system. These reports are briefly presented in this chapter and shall be discussed in more detail in Chapter 5, as they represent the basic background for the supply-demand linkage model, the main objective of the research.

The research is set to by-pass the last stage of the UTMS model: the complex and data demanding stage, the assignment stage. This is achieved by developing a quick response system relating supply and demand measures at an aggregate level, the sketch planning level.

A condensed review of relevant research is presented in this section. A review of travel demand models relevant to the research are presented and the quick response systems developed in the NCHRP Report #187 are presented.

8.1 UTMS Model Review

The four stages of UTMS models were briefly described, as far as the research is concerned, in Chapter 1 (Sect. 6.2.1). At this point in the research, the task of calibrating and validating such a model are briefly described in the following steps:

1. The classification and coding of the road network of a metropolis. This involves the coding of tens of thousands of links and nodes. The estimated time is in thousands of hours.

2. The conduct of surveys of travel demand, the expansion of the data and its spatial aggregation into zones, districts and super districts, and the development of the corresponding origin-destination matrices.

3. The repetition of the above step for another set of compatible demand data for the validation process.

4. The conduct of traffic time-delay surveys to develop and calibrate volume delay functions to be used in the calibration-validation process. This is a very lengthy procedure.

5. The calibration and validation of the UTMS model. This is

a very time consuming process requiring hundreds of engineering hours.

6. The assignment of trips to the road network, using the calibrated model, and to compute trip-link statistics and to estimate trip-link frequency distributions by facility type and zonal aggregation.

7. The computation of traffic characteristics, like volumes, travel times, densities, ... and the comparison of the results with base data.

These steps summarize the basic task needed when a four-stage, sequential travel demand model is used to analyze travel demand in a metropolitan area. It is also correct to emphasize that such a task can only be performed by highly qualified persons and needs adequate UTMS software and computer facilities to implement.

Most of the work is needed to implement the trip assignment or fourth stage of the UTMS and this research is set to develop a model to by-pass such a stage for sketch planning only, thus eliminating the need to code thousands of nodes and links.

This simple, direct link between demand variations in person-trips and the resulting supply variations needed, in lane-km of road network, to obtain a certain LOS, is achieved through the development and testing of the SDLM models in Chapter 5. The SDLM eliminates the need of sophisticated software and complex computerization.

The list of existing relevant models in the following sub-sections shows that there is no model, to date, that relates demand and supply measures directly without utilizing at least some kind of network codification.

8.1.1 Models used in Canada and the U.S.

RTAC (1989) summarized the transportation planning models in Canada; the NCHRP Report #186, the U.S. DOT (1986) and other publications provided the relevant U.S. models. The following four-stage comprehensive transportation planning models, are of relevance. Each is followed by a short critique:

EMME/2: Multi-modal Equilibrium model (last edition 1993). It was developed at the University of Montreal in Canada and continuously up-dated by INRO Inc, 5160 Decarie Blvd, Suite #610, Montreal, P.Q. H3X 2H9, CANADA.

It is an interactive multi-modal equilibrium comprehensive, state-of-the-art, flexible model. 'It is widely used in Canada' and the U.S.

It is of the UTMS four-stage traditional type. It has no sketch planning approach, and must be developed through an extensive, time consuming process. It is used in this research to develop the SDLM models and is further defined in Chapter 4.

TMODEL/2: Transportation Model (last edition 1993).
It is developed and continuously up-dated by TMODEL Corporation, P.O.BOX 1850, VASHON, WA 98070, U.S.A.

It is a state-of-the-art analysis method for multi-modal transportation systems. It is a complete 4-stage model.

It is of the UTMS four-stage traditional type. It has no sketch planning approach, and must be developed through an extensive, time consuming process. It is available at McGill University; and is more fully scrutinized in Chapter 4.

QRS II: Quick Response System (last edition 1992)
Developed by NCHRP and up-dated by AJH Associates, Milwaukee,WI, 53217, U.S.A.

It is a four-stage UTMS model of the simple type.

It has no potential for a sophisticated calibration and validation process.It is of the aggregate type. It embodies all parameters of the NCHRP Report #187 as default figures. It is available at McGill University and is scrutinized in more detail in Chapter 4.

Most four-stage aggregate UTMS models are basically time consuming, data hungry, and they need to be calibrated for each particular use. These models have a dynamic input of results between the four stages through iterations. But most importantly is that these models have no short cut sketch planning simple approach. Other well known models are listed below:

TRIMS: Transportation Integrated Modelling System.
UTPS: Urban Transportation Planning System.

There are hundreds of other models, like TRANPLAN, SNAP, MINUTP, PC-TRAN, MADITUC, TORUS, DEMTEC having the same particularity of time consuming processes and are of minor relevance to this research.

Other aggregate models of interest are presented for completion's sake:

CAPM: The Community Aggregate Planning Model.
It is an 'outgrowth' of TRANS (Transportation Resource Allocation Study) as a quick response sketch planning tool composed of three models; trip generation, trip distribution and performance evaluation.
It does not relate directly supply-demand measures.

IBIMOD: IBI Group (1974-1986)
It is an aggregate comprehensive traffic prediction model with a limited capacity of 1300 nodes. It requires infrastructure coded data for the trip assignment phase.

8.1.2 International models

There are many more models developed and used internationally. This research does not intend to cover the broader scope, but a few relevant ones are presented for the sake of completion.

COMPACT: A Simple Transportation Planning Package (1973 ..., U.K.)

It is of the UTMS four-stage traditional type. It has no sketch planning approach, and must be developed through an extensive, time consuming process.

CRISTAL: Transport Planning Model (1972 ..., U.K.)

It has an interesting traffic estimation of benefits, but it does not relate traffic densities to demand.

Furthermore, an international modelling appraisal by activity (and mostly by country) is obtained from ISGLUTI (1988) for interaction models between land-use and transport. They are basically land use models with a transportation component.

The ISGLUTI models present an interaction between land use and transport. These models relate transport and its dynamic iterative process with land use. Further, they forecast land use spatial distributions categorizing EMP in groupings relating to this research, by occupational and industrial categories.

Therefore it would be ideal for this research to have a land use model developed into a sketch planning tool using similar methodology as for the SDLM models. Thus, results from one model are input to the other model and an interactive cycle is obtained. This would become a powerful sketch planning tool.

The ISGLUTI study mostly responds to the question of model reliability beyond simple calibration and spot validation; and their over time predictive ability is tested. Such details are beyond the scope of this research. A few relevant land use models are presented below:

ITLUP: Integrated Transportation and Land-Use Package
LILT: Leeds Integrated Land-Use/Transport Model
MEP: Marcial Echenique and Partners; Bilbao, Spain
TOPAZ: Technique for Optimal Placement of Activities in Zones

These models are of the comprehensive type and definitely are time consuming to implement, and they also need a large data base.

8.2 NCHRP Report No. 187

The National Cooperative Highway Research Program (NCHRP) commissioned works to obtain a quick response system to transport demand in the late 1970s. The results were presented in two reports: #186 and #187.

Report #186 recommended a quick response system to relate supply demand variables at the aggregate level, Report #187 provides such measures as aggregation of factors in the form of tables, graphs and averages for measures relating transportation planning variables.

These measures are to be used nation-wide as defaults in the absence of the availability of better data. Furthermore, simple manual techniques are presented, defining procedures and making use of the developed factors.

These factors are an aggregation of existing factors in the U.S. and do not relate to actual situations; their reliability in a given case is questionable. They do not have any form of control over results, and their sensitivity, as compared to actual UTMS modelling results, is expected to be very low.

The factors served a purpose in the design of simple studies, like impact analyses of small areas. The tremendous improvement in computer technology since their creation, has prompted the NCHRP to commission the development of computer software to replace part of the manual techniques. This is the QRS II model presented in the previous section.

This approach lacks the case study detailed analysis and the reliable results needed to relate the supply-demand measures, developed in this research, in Chapter 5. The SDLM models are not available in any factors in QRS II or the aforementioned reports.

There are three techniques described in Report #187 for trip assignment computations:

1. Traditional trip assignment methodology: the all-or-nothing assignment process is implemented using origin-destination matrices from the trip distribution stage. It needs road network details and is applicable to relatively small areas of study. It is time consuming and the computerized QRS II has rendered obsolete this methodology for large areas.

2. Traffic generation and decay methodology: this technique "is useful for evaluating the effect of a proposed traffic generator (shopping center, ...) on the highway system surrounding the development" (p113).

3. Traffic diversion/traffic shift methodology: this technology allows "the user to determine the effects changes in the level-of-service variables have on highway segment volumes." (p113).

Thus, the NCHRP Report #187 techniques are concerned with quick responses to the impact from traffic, mostly at the micro transportation levels i.e., site development. Consequently, the need for quick response methods at the macro, or sketch planning level, is emphasized.

8.3 Other Research

Additional research work was done, both in Canada and the U.S., and although of limited relevance, they are presented below for comprehensions' sake.

8.3.1 Hutchinson et al.

Several published papers by Prof. B.G. Hutchinson and former students at Waterloo University, Ontario, were viewed and the relevant ones are abstracted below:

1. Hutchinson, BG; Smith, DP. (1977)

"Transport Characteristics of 30 Canadian Urban Areas".
It is a study of Canadian cities using 1971 StatsCan Census data and in particular the new Census question on the place of work of employed residents.

The regression analysis of the travel distance (home to work) Vs. population per city shows that travel distances increases with city size in Canada, which is in conformity with Pisarski (1987) for U.S. cities.

Furthermore, the regression analysis of the labour force Vs. Census Tract POP and households (CTs acting as zones in this analysis) showed linearity with high determination coefficient. The Montreal CMA models are:

Labour Force = -0.044 + 0.375 * POP, R-sq. = 0.88; and

Labour Force = -0.076 + 1.30 * Households, R-sq. = 0.96.

The above linearity between labour force and POP is used in Chapter 6, for the forecast scenario translations.

2. Hutchinson, BG. et al. (1990):

"Modelling Urban Spatial Evolution and Transport Demand"
This paper points out the 'principal sources of error in trip patterns' as obtained from **'cross sectional-type trip distribution models and their inability to capture the spatial evolution (over time variations) of urban areas'** (p550). This

is confirmed by the research in Chapter 5. Furthermore, the paper presents the spatial evolution of Toronto urban region (a case study) and 'shows that the growth and change in commuting demands are strongly influenced by the socioeconomic biases in the distribution of labour force and employment' (p550).

3. Hutchinson, BG. (1978):
"A Framework for Short-Run Urban Transport Policy Responses". This paper presents a 'conceptual framework for short-run transport policies' (p93); a feed back info system is scrutinized and a 'dynamic framework of urban growth and change is introduced' (p93). It suggests that, for the Toronto region (case study), 'major transport capacity additions ... elicit short-run dynamic responses from the urban system which cannot be sustained without significant re-adjustments in activity patterns.'

The above confirms that a dynamic response between supply-demand measures is necessary, and that there is a need to establish a direct link between them for the short-run dynamic systems. This is the main objective of this research.

8.3.2 Zupan and Pushkarev

The work of Zupan and Pushkarev (1975) is of interest to the research as it has similar structures in regard to the relationships of supply and demand measures, but from a different perspective. The book of Zupan and Pushkarev, is a thorough work based on the Greater New York Area data i.e., a case study. The data transferability is questionable while the procedure utilized is logical and may be applicable to other case studies.

It is concerned, among other issues, with transit usage and mode split, and transit fare variations. It relates spatial distances from CBD and population density which is 'measured in two different dimensions-the floor space density of nonresidential concentrations, and the density of dwellings in residential areas.' (p3).

It deals with public transportation and its maintenance and costs which are supply-demand measures. Then it proceeds to match the 'service density of different modes to the prospective density of demand' (p4), for peak and off peak periods, which are its main objective.

On the demand size, the variables include, among others: density of the residential area, density of nonresidential clusters, distance between them, household size and income. On the supply side, the related variables are the fare, service frequency, and proximity of transit lines.

Furthermore, 'On the supply side, route spacing, service frequency, service span, and operating speed define the density of service in terms of vehicle hours per unit area ... comparisons with empirical situations' (p4) were made, through several examples, to validate the analysis.

A short outline of the work of Zupan and Pushkarev is presented herein. Three main modules constitute the main body of the work, and through the interaction between module components, and across modules, an estimate of public transit trips per square mile (a supply-demand link), is obtained using Exhibit 7.7 (p213). The main variables in Exhibit 7.7 are presented below:

1. <u>Trip attractions:</u>

Nonresidential floor space.
Distance from residential area.
Spatial location effects.

2. <u>Work trip mode choice:</u>

Net residential density.
Median family income.
'Adult' household size.
Bus frequency, rapid transit, and rail service.
Nonresidential floor space.

3. <u>Nonwork mode choice:</u>

Net residential density.
Median family income.
'Adult' household size.
Net residential density.
Nonresidential floor space.

A brief comparison with this research show that both have established relationships between supply and demand measures for a case study, but for different purposes.

This research is seeking to model supply-demand measures of road networks in metropolitan areas; whereas, the demand is the total inter-zonal (AM peak hour) trips (in equivalent passenger cars); and the supply is the road infrastructure (the lane-kilometres requirements) by facility type (freeways, expressways; and arterials).

The Zupan and Pushkarev research is concerned with the effects that transport demand has on transport modal split. It is a more detailed analysis with several variables.

8.3.3 Others

Research works of general relevance by author are presented below:

1. E.J. Miller et al.

The work of Miller et al. (1984) is of relevance as they presented the logical EMP aggregational groups by industry and by occupation, and these are used in Chapter 3.

2. R. Chapleau et al.

The work of Prof. Chapleau and former Ecole Polytechnique students in Montreal are of interest. They relate to population aging and dispersion. Spatial distributional population aging is presented for the GMA. These constitute an important background data information to the EMP decentralization problem addressed by this research.

3. Y. Bussiere et al.

The works of Bussiere et al.(1983, 1985, 1985b, 1987, 1987b, 1988) provide important analyses on the modal usage cross-classified by age and gender, for the GMA; also population aging and dispersion were analyzed. These provided valuable data on activity dispersion, an important part of the descriptive analysis, in Chapter 3.

4. Others

Other research works on the Greater Montreal Area (chosen as the research case study in Chapter 3) are presented in Chapter 3 as part of the descriptive analysis, and include the work of Lamonde et al. (1989).

8.4 Section Conclusions

It may be concluded that the UTMS is both an expensive and time consuming modelling process requiring more than a year from a qualified team of engineers and technicians to set up. In this research, aggregate relationships, between supply and demand measures are constructed to replace the trip assignment stage of the UTMS model, which is the most time-consuming stage. This is achieved through the development of a **"Supply-Demand Linkage Model" or SDLM in Chapter 5.**

The work of the National Cooperative Highway Research Program (NCHRP) Reports No. 186 and No. 187 is of prime concern and they represent the quick response to relate supply-demand aggregated measures in the form of tables, graphs, and factors.

This research is seeking a direct link between supply-demand measures which provides a quick response method for engineers, planners, and transportation officials in the form of a model. It is a similar solution to the one used in Report #187 but more reliable and applicable to a case study. However, being for a case study, it has limitations in application. Other relevant research works to specific topics in this research, are presented wherever needed throughout the research.

9. CHAPTER SUMMARY AND CONCLUSIONS

"Travelling long distances to shopping, work, friends, and other socializing opportunities will take its toll over time ... Exurban residents may come to view their life style less romantically and more pragmatically. Certain number of them may return to the cities and the suburbs", [Nelson et al. 1990, p98]. This may ultimately occur provided that exurbia is not transformed into a suburban conglomeration as is the case in the GMA outlying fringes.

We need first to understand the phenomena in progress to identify the forces behind it at the micro and macro scale levels. The suburban infra-structure was not designed to cope with the changing land use.

The under-estimated impact of urban construction standards on infrastructure, at the local and regional levels, was an important basic driving force behind traffic congestion. The application of standards would allow the control of land use activity in new developments. The implementation of a control system is needed that, based on quick estimates of the impact of variations in demand, will relate demand-supply measures at the sketch planning level. This is the main objective of the research.

The mobility implications of 'urbanized' suburbs are profound. A scattered commuter pattern now characterizes the 'cityscapes', seriously questioning the future of public transit and other shared-ride modes of transportation.

All signs point to greater auto-reliance in the future both in Canada and the U.S, although examples of suburban settings in the U.S. may not foretell the future of Canadian suburbs. Differences between the two countries (basically, the higher transit subsidies in Canada, which are being reduced at present) require different studies, relating to a specific research topic, on a case study basis as recommended by Pisarski (1987), Cervero (1989) and others.

Allowances of higher building densities in return for specific programs that remove employee vehicles from local streets could produce an incentive system whereby individual developers and companies self-regulate local traffic through coordinated Transportation System Management (TSM).

Performance zoning that allows densification could reduce transit subsidies in Canada, provided that a relationship is established to assess quickly, at the sketch planning level, the impact on congestion of such densification.

Auto disincentives, such as mandatory ceilings for parking supply, have historically proven to be more effective at getting people to alter their commuting habits in urban areas than have transit and ridesharing incentives.

Basically, most of these programs are 'auto equalizers': They aim to remove many of the built-in biases that encourage single-occupancy commuting, thereby placing vanpools and other travel modes on a more equal footing.

Although denser suburban work environments may increase congestion in the near term, in the long run, they concentrate activities so as to make ridesharing and mass transit viable alternatives to solo-commuting. When it comes to density in suburban work settings, a general tenet might be: 'short-term pain is necessary for a long-term gain', [Cervero, 1989].

Two sources of worsening congestion are: The abundance of free parking and the increasing numbers of jobs-housing mismatches. While land use decisions are made locally, their transportation impacts are felt regionally.

While it is unlikely that the private automobile ever will, and perhaps ever should, fall from its reign as the dominant mode of commuting, at the same time steps need to be taken to make ridesharing, mass transit, and cycling respectable alternatives. As suburbia continues to become the destination of more and more travel, it is essential that the joint influences of land use and transportation be carefully weighed when designing the workplaces of the future.

The automobile has dominated the commuting pattern for several decades and all attempts to boost public transit riderships has yield limited results. The auto mode of transportation outweighs all other modes combined and is the main cause of traffic congestion in both urban and suburban settings.

The potential for telecommunicating is still nascent; the continuous trend for the suburbanization of jobs will favour the private vehicle in the foreseeable future. The continuing suburbanization of workers and jobs could eventually lead to more balanced and consequently more efficient commuting system in suburbia.

Regional and long range planning are more acceptable in Canada than in the U.S. so it appears that Canadian cities and suburbs are willing to take action before the situation reaches crisis proportions. Suburban congestion is a problem in Canada but the problem, although similar, may not replicate the U.S. experience. Consequently, Canadian research is needed.

A "variety of research designs will be needed ... comparative **case studies** of small sets of cities in both countries by locally based researchers **following a common method**; and continued research at the macro scale drawing on census and other secondary sources" [Goldberg et al. 1986, p256].
Future work is necessary to expand and extend the works done by Pisarski, Bourne, Cervero and others through "**case studies** of selected cities to provide detailed trip pattern data to corroborate and extend the present understanding of commuting trends ... Facility-based analysis are required ... Traffic operations studies are needed to examine opportunities for enhanced use of available facility capacity responsive to

changed pattern of demand ... New research data is needed to overcome present weaknesses and gaps in our knowledge" [Pisarski 1987, p65].

Higher density mixed land use is advocated in a rather loose context, and extensive research is needed to understand its implications over time because densities that are too high would produce new cities while low densities may not be sufficient to reduce inter-suburban trips.

Weighing the 'do-nothing' and 'public intervention' alternatives, one is left with the sense that there is merit in both. The salvation of transportation, whether in city centres or suburbia, is that people and their environments are indeed adaptable.

The traditional solution to improve the capacity of existing roadway networks or to add new links to them to achieve a balance between supply and demand requires large financial resources. Increasing the network infrastructure, the supply-side solution, may be short lived. Such improvements may generate new traffic, and would lead to a vicious circle of attrition of funds until a final balance of supply and demand is theoretically achieved.

The supply-demand balance is difficult to achieve, yet not impossible provided that it is protected by a long range planning that would keep further developments within limits set forth in standards.

These standards should be easy to implement and to revise, over time, to maintain a selected LOS in the overall facility compatible with objectives. It is the aim of the research to supply the tools to implement the aforementioned by establishing a Supply-Demand Linkage Model.

Pisarski (1987, p10) defines the future research work as: "**detailed case studies** of a number of metropolitan areas to gain the detailed understanding of trends not possible at the national scale; analyses of changes in traffic demand patterns looking at facility volumes by direction and time relative to available capacity; and development of better data to support a more comprehensive understanding of perceived trends."

The process is very complex and must be based on extensive research because our decision today, or our 'do-nothing' choice, would have grave implications for the way we live and how our cities would look in the coming century.

CHAPTER 3

ANALYSIS OF TRAVEL DEMAND IN THE GREATER MONTREAL AREA

1. GENERAL INTRODUCTION

The literature review for employment decentralization in North America and the relevant modelling techniques, in addition to the demographic trends, and a comparison between Canadian and U.S. metropolises were covered in Chapter 2.

In this chapter, a descriptive analysis of the Greater Montreal Area, the selected research case study, is carried out in four parts:

A. REVIEW OF LOCAL DATA and CHOICE OF CASE STUDY
B. DESCRIPTIVE ANALYSIS: 1981 STATSCAN DATA
C. 1982-1987 STCUM DEMAND DATA
D. RELATIONSHIPS AMONG VARIABLES

The data in Part A were obtained through a survey of local research work, mostly written in french. Its aggregation format, using 1971 StatsCan CTs, is neither compatible with the STCUM demand data nor with the MOTQ supply data as described hereunder.

The data in Part B were retrieved from 1981 StatsCan special magnetic tapes for EMP by industry and by occupation, using the main frame computer at McGill. The 1981 CTs for the CMA are aggregated into 38 large traffic zones and an external zone. Several SAS programs were written to aggregate and retrieve the required data matrices.

The data in Part C are retrieved from the STCUM main frame MVS and constitute the main source of the demand data. The STCUM data are aggregated into 1496 zones and are compatible with municipal boundaries. Unfortunately, such boundaries are not compatible with the Census Tracts (CTs) of StatsCan.

Furthermore, the STCUM zonal boundary variations over time, relating STCUM surveys were not available. This rendered the research task more difficult, and forced the research to abandon a spatial descriptive analysis of the STCUM data. Exception are the 1982 and 1987 data surveys where zones have kept the same spatial boundaries.

The research in Part D analyzes, using SAS multivariate analyses software package, the relationships among dependent and independent variables using a summary of matrices retrieved from Part C. Furthermore, data compatibility problems are presented while their solution, at the sketch planning level, is presented in Chapter 6.

The descriptive analysis covers the 1971-1986 period using Census Canada (1981) EMP data and STCUM (1982-1987) demand data, while the local data review is extended to previous years. The supply and demand data were retrieved, through personal effort, from STCUM and StatsCan tapes.

The supply data, coded road network and volume delay functions, are presented in Chapter 4, and were obtained from the MOTQ using EMME/2 software. They are aggregated into 699 zones based on the 1496 STCUM zones. This forced the research to adopt, in Part C, the 1496 STCUM zones in order to have compatibility between DEM and supply data. Furthermore, this research maintained the closest possible zonal boundary fit with the 1981 StatsCan CTs used in Part B, while using the 1496 STCUM zones.

Thus, spatially, the research refers to: (a) available spatial districts in Part A, based on 1971 StatsCan CTs and/or municipal boundaries, used by local researchers; (b) StatsCan CTs aggregated into 38 zone, 12 Ds, and 6 SDs in Part B, based on 1986 StatsCan CTs; and (c) STCUM 1496 zones aggregated into 38 zones, 12 Ds, and 6 SDs in Part C.

Part A: REVIEW OF LOCAL DATA and CHOICE OF CASE STUDY

A-1 INTRODUCTION

Part A presents the review of local data as obtained from publications as referenced. It is presented in two parts, relating the case study to: (a) its Canadian context; and (b) its North American context. Then the criteria for the choice of the case study is presented followed by the travel demand characteristics of the case study; the Greater Montreal Area.

A-2 THE CANADIAN CONTEXT

One of the questions raised in this research is whether the EMP decentralization phenomena that we are witnessing in the U.S. metropolises is going on in the Canadian CMA'S in general and in the GMA in particular and to what extent.

Coffey and Polése (1988), did an interesting study on Canadian agglomerations by addressing the question of decentralization vs. decongestion. Those agglomerations, in their study, having more than a hundred thousand persons are of special interest to this research.

Data in Tables 3.1, 3.2, and 3.3 were obtained from Coffey and Polése and are presented in modified form.

REGIONS		EMPLOYMENT		ABS	%GRTH	NTL	STL	REGIONAL	
POP	No.	1971	1981					Tot	M
300+	10	3961	5503	1542	38.9	1410	231	-99	-60
100-300	16	975	1284	309	31.7	347	27	-65	-13
50-100c	11	249	332	83	33.3	89	2	-8	-5
50-100p	8	178	255	77	43.0	64	3	10	-1
25-50c	19	227	312	85	37.6	81	-2	6	-3
25-50p	20	204	313	109	53.4	73	1	35	-3
others		1934	2482	548	28.3	689			
Tot Canada		7728	10481	2753	35.6	2753	51	-51	--

TABLE 3.1: AGGREGATE EMP GROWTH by REGION SIZE.

Canada 1971-81.

EMP figures in 1000s. Legend in footnote #1[1]

Source: Coffrey and Polése (1988).

Table 3.1 presents EMP statistics classifying large urban areas as "economic centres surrounded by functionally dependent urban fields extending over a radius of 100 Km", the 100 Km distance is based on a one hour travel time. When agglomerations of less than 100,000 persons are located within a radius of a 100 Km from larger urban centres of more than 100,000, they were called "centrals"; and "peripherals" are those located further away.

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(1) Legend:
NTL = national effect
%GRTH = percentage growth; 1971-81 period
RGNL = regional effect
M = manufacturing
ABS = absolute growth
STL = structural effect

The regional effect on the manufacturing industry between 1971 and 1981 is negative, for all regions whether centrals or peripherals, of small or big size [Table 3.1].

The shift-share analysis in its "regional effect" measures the relative growth of a region. Table 3.1 shows that the 300+ CMAs had above average growth rates because their economic structure are endowed with higher growth sectors. This was defined as the "structural effect".

REGION POP	NTL	STL	REGIONAL	
			TOT	M*
300+	91.4	15.C	-6.4	-3.9
100-300	112.2	8.8	-21.0	-4.1
50-100c	107.1	2.6	-9.7	-5.5
50-100p	82.9	3.9	13.2	1.1
25-50c	94.8	-1.9	7.1	3.5
25-50p	66.6	1.2	32.2	2.5

TABLE 3.2: AGGREGATE EMP PCT GROWTH.

Canada 1971-81.

EMP figures in PCT.

Source: [Coffey et al. 1988]. Tables 1, 2, 3 re-arranged.

The (M*) in Table 3.2 indicates the part of the regional effect that is directly due to changes in the level of manufacturing (M) EMP. The largest negative regional effect in regions of size 300+ was due largely to a loss in the manufacturing EMP.

There appears to be two forces at work, producing employment dispersion, the shift of the manufacturing employment into service EMP, the regional effect; this is being partly balanced by the structural effect. This resulted in decongestion [Coffey and Polese]. These are the same findings of this research (Chapter 6).

The employed labour force (ELF) experienced the largest rate of growth in the services sector, especially in the production industry; the finance, insurance and real estate (FIRE); and the consumer sectors have increased between 1971 and 1981 by 141.2%, 79.4%, and 74.8% respectively.

It may be thought that EMP are shifting away from large urban centres, especially the manufacturing industry, while the service industry has kept its share over the study period. This shift towards service industries in Canada is in advance of other developed countries like Japan, Germany, Switzerland but comparable with the U.S. [Bailly and Willat, 1987].

Table 3.3 summarizes the EMP growth over time between 1971 and 1981, for Canada nationwide by industry. They are categorized in two groups for EMP agglomerations having POP greater than or less than 100,000 (100+, <100), the peripherals and the centrals.

INDUSTRY	REGION SIZE 100+	REGION SIZE <100 CEN	PER	GRTH RATE
goods:	49.8	28.9	23.1	29.6
Primary	50.9	14.1	35.1	12.0
M 1	40.3	34.0	25.7	33.7
M 2	54.0	32.3	13.7	38.9
M 3	59.7	31.0	9.3	28.0
Constr.	53.9	24.1	22.0	39.9
services:	64.5	18.3	17.2	59.0
Transp.	57.4	22.7	19.9	38.6
community	70.4	15.3	14.2	59.9
utility	52.4	24.6	23.0	62.4
whole-sale	65.4	19.8	14.8	63.0
Retail	61.2	19.8	19.1	50.4
FIRE	71.7	15.0	13.2	79.4
Non-Prof	60.4	19.8	19.8	49.9
Consumers	64.6	18.3	17.0	74.8
Prod.	79.7	11.5	8.8	141.2
Publ ser	58.3	19.7	22.0	43.3
Grand Tot	61.2	20.7	18.1	48.2

TABLE 3.3: EMP GROWTH by INDUSTRY.

Canada 1971-81.

EMP figures in PCT. Legend in footnote #[2]

Source: [Coffey et Polese, 1988]. Table 6.

EMP in cities (Table 3.3) of more than a hundred thousand (100+) POP grew by 61.2%, while those of less than a hundred thousand (<100) grew only by 20.7% (CEN) and 18.1% (PER) as compared to an average global growth rate of 48.2%.

(2) Legend:
Prof. = professionals
Transp. = transportation
Prod. = production
Constr. = construction
Pub ser = public service
CEN = central agglomeration
PER = peripheral agglomeration

The above shows clearly that there is an EMP shift towards the larger POP agglomerations. The 61.2% EMP growth in large POP agglomerations is composed of a growth of 49.8% in the goods industry and 64.5% in the services industry. The service EMP industry stayed mostly constant in large urban areas, for instance it represented 63.9% of total EMP in 1971 and 64.8% in 1981 in the Canadian CMAs.

The decentralized form of government in Canada, its low regional level of intervention in implementing inter-regional highway networks, and the higher level of immigration to city centres are a few of the factors that lead to a lesser degree of decentralization of urban areas as compared to U.S. cities. For instance, in 1971, 16% of all Canadians were born outside Canada as compared with only 4% in the U.S. [Dansereau, 1988].

The large movement of the black population to the centres of U.S. cities after WW2 has enlarged the gap between central cities and their peripheries, thus, contributing to the central city decline and the rise of the suburbs as new economic realities. At the same time the immigration in masses to central cities in Canada kept their vitality [Dansereau, 1988].

A-3 NORTH AMERICAN METROPOLITAN AREAS

A descriptive comparative analysis of Canadian and U.S. metropolitan areas and their growth over time is necessary to shed some light on our case study in its North American context.

Table 3.4 presents comparative ratios of male labour force for Canadian cities; for city centres and metropolitan areas, categorized by general type of occupation.

YEAR	WHITE		COLLAR	BLUE		COLLAR	HIGHER		PROF.
	1961	1971	1981	1961	1971	1981	1961	1971	1981
Toron.	1.16	0.98	0.90	1.07	1.02	1.07	0.72	0.95	1.10
MTL	1.06	1.07	1.03	1.07	1.06	1.09	0.83	0.77	0.86
Vanc.	0.98	0.95	0.90	1.12	1.10	1.14	0.96	1.06	1.02
Ottawa	0.86	0.87	0.85	1.09	1.08	1.03	1.11	1.10	1.08
Edmin.	0.98	1.01	1.02	1.00	0.97	---	1.04	1.05	1.00
Winn.	1.04	1.07	---	1.00	0.97	---	0.90	0.90	---
Quebec	0.96	1.00	0.97	1.16	1.10	1.15	0.91	0.86	0.89

TABLE 3.4: MALE LABOUR FORCE DISTRIBUTIONS.

Canada 1961-1981. Comparative ratios; city centre/metropolitan areas.

Legend in footnote #3[3].

Source: [Dansereau, 1988]; Table 1, modified.

The higher professional category represent managerial staff and the like, and were separated as they exhibit a distinct

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(3) Legend:
Higher professionals include: directors, managers, teachers, & health, technical, social, religious and artistic professionals.
White collar include: management & service EMP.
Blue collar include: all other EMP, except primary industry.

transportation behavioral class. They enjoy flex time and consequently may not travel during the morning rush hours.

Tables 3.4 and 3.5 show that Toronto and Montreal have similar concentrations in all three categories of their workforce with the exception that Toronto has a distinctly higher male professionals in its city centre as of 1961.

As a matter of fact Montreal has the lowest male ratios in the higher professional bracket of all Canadian CMA's. This may imply that there are higher female professional levels in Montreal central city which may be explained by a larger decentralization of the higher professionals in the male population in the Greater Montreal Area.

YEAR	HIGHER PROF.		WHITE COLLAR		BLUE COLLAR	
	1971	1981	1971	1981	1971	1981
Toronto	0.84	1.05	1.04	0.97	0.98	0.96
MTL	0.90	1.06	0.96	0.94	0.98	0.96
Vancouver	1.02	1.20	0.77	0.72	1.09	1.02
Ottawa	0.88	1.17	0.94	0.76	1.00	0.93
Edminton	0.60	0.74	1.08	1.14	1.02	1.02
winnipeg	0.89	0.93	1.12	1.16	0.89	0.89
Quebec	0.74	0.88	0.85	0.87	1.12	1.08
Halifax	0.90	1.28	0.88	0.70	1.06	0.96

TABLE 3.5: MALE-FEMALE LABOUR FORCE DISTRIBUTIONS.

Canada 1971-1981. Comparative ratios; city centres/metropolitan areas.

Source: [Dansereau, 1988]. Table 3.

While the immigration inflow (flux) to Toronto chose their POR mostly in its Municipal area; in Montreal they were established more in suburbs like St.Laurent, and the Town of Mount Royal (TMR).

An important distinction may also be noted, from Table 3.6, is that Toronto has a larger proportion of its service industry, due to an early start in the suburbanization movement (Dansereau, 1988), in the suburbs as compared with the Montreal. Thus, Toronto enjoys a better distribution of labour force between city and suburbs.

DESCRIPTION	1971	1981	1985
Population, metropolitan area	1.05	0.91	0.85
Goods & services EMP:			
Consumption - total	0.81	0.82	na
Production: Transport + Commerce	1.10	1.02	0.95
FIRE	0.73	0.63	0.50
Construction	0.71	0.61	0.59
Total	0.88	0.76	0.67
Governmental: Education, Health	0.93	1.01	na
Global, goods & services	0.86	0.84	na

TABLE 3.6: POP and EMP DISTRIBUTIONS; 1971-1985.

Comparative ratios; Montreal/Toronto.

Legend in footnote #4[4].

Source: [Lamonde et al, 1988]. Table 5.3, modified.

---

(4) Legend
Population ratios of 1985 are for 1986.
na = data not available

The Toronto CMA's population is increasing at a faster rate than in Montreal. As can be seen from Table 3.6, the ratio has changed from 1.05 to 0.91 between 1971 and 1981.

Results in Table 3.6 show that Montreal has lost two percentage points to Toronto in the goods and service industry between 1971 and 1981, from 0.86 to 0.84.

This is apparently due, to a large extent, to the anglophone emigration from Montreal to Toronto and elsewhere in Canada; also the political crisis lead many new immigrants to shift away from Montreal.

MANUFACTURING EMP	**MONTREAL CMA**		**TORONTO CMA**	
	1971	**1981**	**1971**	**1981**
Unemployment rates	7.7%	9.3%	5.4%	4.9%
Food & beverage (1)	32.0	34.7	10.0	10.2
Furniture, wood,...	22.2	24.1	6.2	6.8
Textile, clothing,...	82.7	72.2	7.2	7.8
Paper & printing	23.3	30.0	14.4	14.3
Machines & equipment (2)	77.3	94.1	29.2	29.7
Metal prod. & transf. (3)	33.9	37.2	13.6	11.2
Other groups	---	---	11.8	13.2
Others	12.6	13.0	7.6	7.8
Total	284.0	305.3	309.1	349.5

TABLE 3.7: MANUFACTURING EMPLOYMENT.

Montreal and Toronto CMAs; 1971-1981.

Unemployment in percentages. EMP figures in 1000s.

Sources: 1. StatsCan data.
2. [Lamonde et al. 1988]. Tables 5.1, 5.2, 5.3 modified.

Table 3.7 presents a comparison between the manufacturing EMP in Toronto and Montreal CMA's; where the points [1, 2, and 3] are shown in the table. Consequently, the comparison is limited to 'Others' category due to data compatibility (footnote #[5]).

The overall EMP percentage growth for Montreal and Toronto, from 1971 to 1981, for the manufacturing (M) EMP industry (the figures are obtained from Table 3.7 and the computations are in footnote #[6]), are presented below:

1. Montreal (M) EMP grew by 7.5%; while
2. Toronto (M) EMP grew by 13.1%.

And their comparative variation ratios, Montreal/Toronto, are: (a) For 1971, 92%; and (b) For 1981, 87%.

Footnote #5:
Montreal and Toronto CMA's have different minor variations in their categorized manufacturing EMP; they are presented in Table 3.7 and the variations are defined as follows:
1. The 'food and beverage' category in Toronto, excludes tobacco, which is included in the 'other groups'.
2. The 'machines and equipment' category in Toronto, excludes petrochemical, rubber, and the like, which are also included in the 'other groups'.
3. The 'metal prod. and transf.' category in Toronto, excludes first metal transformations which are included in the 'other groups'.

Footnote #6:
[(305.3 - 284.0) / 284.0] * 100 = 7.5%
[(349.5 - 309.1) / 309.1] * 100 = 13.1%
(284.0 / 309.1) * 100 = 92%
(305.3 / 349.5) * 100 = 87%

The above computed EMP ratios for the manufacturing industries in Toronto and Montreal show greater differences between 1971 and 1981, a full five percentage points. Furthermore, the unemployment rates have increased, over time, in Montreal while they have decreased in Toronto showing a net difference of 4.4% in 1981.

U.S. METROPOLIS	POPULATION VOLUME			UNEMPLOYMENT RATE		
	1970	1980	1984	1970	1980	1984
UNEMPLOYMENT: LOW RATE						
Boston	3710	3663	3695	3.7	5.3	4.3
Atlanta	1684	2138	2380	3.0	5.5	4.9
Dallas-F.W.	2352	2931	3348	3.1	4.5	3.7
Denver	1238	1618	1791	3.7	5.2	4.7
Kansas City	1373	1433	1477	3.4	6.4	5.6
Minneap.-S.P.	1982	2137	2231	3.3	4.5	4.8
Phoenix	971	1509	1715	3.9	5.9	3.8
UNEMPLOYMENT: HIGH RATE						
Cleveland	3000	2834	2788	3.5	8.1	9.4
New-Orleans	1100	1257	1319	5.0	5.9	9.4
St.Louis	2429	2377	2398	4.9	8.1	8.1
Cincinnati	1613	1660	1674	3.8	7.2	8.5
Colombus	1149	1244	1279	3.5	5.9	7.5
Portland	1047	1298	1341	6.1	6.4	8.1
Seattle	1837	2093	2208	8.2	6.6	8.1
UNEMPLOYMENT: MEDIUM RATE						
Baltimore	2089	2199	2245	3.5	7.5	6.3
Houston	2169	3100	3566	3.0	4.1	6.7
Indianapolis	1111	1167	1195	3.9	7.2	6.9
Miami	1888	2644	2799	3.7	6.7	6.7
Philadelphia	5749	5681	5755	3.7	7.0	6.8
Total	38491	42983	45204	3.9	6.2	6.4

TABLE 3.8: U.S. SECOND RANKED METROPOLIS. POP and unemployment; 1970-84.

POP figures in 1000s and PCT.

Source: [Lamonde et al. 1988]; Tables 5.4, 5.5.

These statistics place Montreal among second ranked North American metropolises and Toronto among first ranked, like N.York, Chicago, Los Angeles and San Francisco.

The second ranked U.S. metropolis are presented in Table 3.8 (Dansereau). The research case study, presented in next section, is the Greater Montreal Area or GMA. Tables 3.8 to 3.10 show the private sector EMP for the second ranked metropolises in the U.S. which constitute the context where the GMA fits.

The unemployment categorizations in Table 3.8 are based on 1984 data. The GMA unemployment rate ranks among the high rate which are classified based on the latest statistics available (1984 in the table). Unemployment rates are considered high when they are above 7.5% and they are low when below 6%.

The comparison, over time, between Table 3.9 (1970 data) and Table 3.10 (1982 data) show that the service EMP has increased at the expense of manufacturing EMP in all metropolitan areas without exception. This proves that the transformation of manufacturing EMP phenomena into service EMP is a characteristic, not only to Montreal and Canada but to both countries; Canada and the U.S.

U.S. METROPOLIS	M	RET	SER	OTHER	TOTAL
UNEMPLOYMENT: LOW RATE					
Boston	32.0	19.4	22.8	25.8	1354
Atlanta	25.6	19.5	17.7	37.2	557
Dallas-F W	32.1	18.9	16.9	32.1	863
Denver	23.3	21.4	21.4	33.9	380
Kansas City	29.5	19.8	17.8	32.8	447
Minneapolis-St Paul	32.4	19.6	19.8	28.2	693
Phoenix	26.9	21.9	20.9	30.3	276
UNEMPLOYMENT: HIGH RATE					
Cleveland	43.9	17.1	16.4	22.6	1029
New-Orleans	17.6	19.1	21.1	42.2	310
St Louis	37.0	17.8	18.8	26.4	777
Cincinnati	40.5	17.6	16.9	25.0	492
Colombus	32.6	21.5	19.2	26.6	316
Portland	28.0	18.9	20.7	32.4	309
Seattle	31.0	19.6	18.7	30.7	510
UNEMPLOYMENT: MEDIUM RATE					
Baltimore	33.0	20.3	18.7	28.0	605
Houston	23.9	17.6	18.7	39.8	712
Indianapolis	36.5	19.0	15.2	29.3	361
Miami	15.2	23.8	24.4	36.6	630
Philadelphia	38.1	17.3	19.3	25.3	1818
Total	32.2	19.0	19.3	29.5	12430

TABLE 3.9: SECOND RANKED U.S. METROPOLIS. EMP PCT by industry; 1970.

EMP figures in 1000s and PCT. Footnote #[7].

Source: [Lamonde et al. 1988]; Tables 5.4, 5.5.

It is of interest to note that during the period 1970-1982 (Tables 3.8 to 3.10), the manufacturing EMP share in the second ranked metropolis, tend to be lower in the low unemployment group; while the service EMP is more active in the first rank metropolises and it increases at a higher rate [Lamonde et al, 1988, p93].

(7) Legend: Tables 3.8, 3.9, and 3.10
Ret = retail
Fn = finance
Ser = service

Furthermore, the first ranked metropolises are in a positive vicious circle of growth; while the second ranked metropolises are in a negative vicious circle, because their manufacturing industry is 'anaemic' and less developed and consequently it looses more EMP [Lamonde et al, 1988, p95].

U.S. METROPOLIS	M	RET	FN	SER	OTHER	TOTAL
<u>UNEMPLOYMENT: LOW RATE</u>						
Boston	25.6	18.6	7.9	32.5	15.5	161
Atlanta	18.7	20.5	8.5	23.9	28.5	878
Dallas-F W	24.5	19.9	8.5	21.5	25.6	137
Denver	18.2	20.2	8.3	25.2	28.1	732
Kansas City	22.5	19.8	8.6	18.1	31.0	554
MNAPOLS-SP	26.1	20.0	8.9	26.0	19.0	950
Phoenix	20.2	23.6	8.5	25.9	21.8	458
<u>UNEMPLOYMENT: HIGH RATE</u>						
Cleveland	32.4	19.1	6.0	24.7	17.8	102
New-Orleans	13.3	21.2	6.7	25.8	33.1	454
St Louis	25.8	19.5	6.7	27.1	21.0	873
Cincinnati	30.7	20.5	6.6	24.9	17.4	578
Colombus	23.4	22.9	10.0	25.7	18.0	430
Portland	23.3	21.5	8.6	24.6	22.0	457
Seattle	24.5	21.0	8.4	24.5	21.5	768
<u>UNEMPLOYMENT: AVERAGE RATE</u>						
Baltimore	22.7	21.3	8.3	28.7	19.1	697
Houston	19.7	18.0	6.8	23.0	32.5	151
Indianapolis	28.0	21.4	9.5	21.1	20.0	418
Miami	14.2	23.1	9.5	28.7	24.5	979
Phildelphia	26.6	18.2	7.7	30.1	17.5	196
Total	23.5	20.0	8.0	26.0	22.5	168

TABLE 3.10: SECOND RANKED U.S. METROPOLIS. EMP PCT by industry; 1982.

EMP figures in 1000s and PCT. Footnote #6.

Source: [Lamonde et al. 1988]; Tables 5.4, 5.5.

A-4 THE GREATER MONTREAL AREA: CASE STUDY

The Greater Montreal Area, was chosen as the research case study. This research has as its primary objective to model, at the sketch planning level, measures of transport supply and demand. Further, the model is used to assess the "Impact of Employment Decentralization on Metropolitan Road Networks" i.e., the impact of EMP variations (a demand measure) on traffic congestion or the LOS.

This is achieved through an empirical case study approach, as recommended by Pisarski (1987) and others, as discussed in Chapter 2. The resulting supply-demand linkage model (SDLM) is presented in Chapter 5.

The Greater Montreal Metropolitan Area has been adopted for the case study; for the following reasons:

1. Montreal is one of the three largest Canadian metropolitan areas.
2. Statistics Canada data are readily available.
3. Local travel demand and supply data and information are available.
4. The characteristics of urban decentralization are demonstrated within the metropolitan area, with employment and residential growth in Laval, North and South Shores of the

GMA, and decentralization in the City Centre. This is discussed further in this chapter.

A-4.1 Population Growth Trends and Projections

The population growth rates of the GMA are given in Tables 3.11 and 3.12. These were obtained by combining several tables, from different authors, all based on Statistics Canada data. They were aggregated into districts and their growth rates were computed. The forecasts for the years 1991-96-2001 were obtained from a reference scenario based on the Bureau de la statistique du Quebec (BSQ, 1984) data.

It is important to note that, in Table 3.11, the very low rate of population growth in the GMA, between 1976 and 1981 and the low rate registered for the 81-86 period may be partly explained by the socio-political environment in Quebec. Further, the variable POP registered in the CBD is partly due to variations over time in its spatial boundaries.

Tables 3.11 and 3.12 present the POP growth and forecasts for the Montreal CMA. In Table 3.12, the CBD and Centre were combined into one aggregation.

POR (home based)	1966	1971	1976	1981	1986
<u>MONTREAL Is.</u>					
East	163	227	268	273	280
Centre	26	16	11	9	11
CBD	1316	1244	1106	996	975
West	418	473	485	481	488
S.total	1923	1959	1870	1760	175
<u>NORTH OF MONTREAL Is.</u>					
Laval	196	228	246	268	284
NS	112	144	185	231	255
S.total	308	372	431	499	539
<u>SOUTH OF MONTREAL Is.</u>					
Longueuil	n.a	98	n.a	124	125
SS excl Long.	n.a	315	n.a	452	474
S.total	338	413	514	577	600
GMA	2569	2743	2814	2836	2892

TABLE 3.11: GMA POP: 1966 to 1986.

POP figures in 1000s. Legend in footnote #8[8].

Sources: 1. MOTQ (1988); Table 1.
2. [Lamonde et al. 1989]; Table 2.1.

The POP forecasts, in Table 3.12, shows that Montreal Is. (MTL) POP forecasts are almost constant over time from 1991 to 2001; while the POP forecasts for the City Centre are negative i.e., there is a POP decentralization expectancy in parallel with the EMP decentralization in progress. This decentralization process is discussed and its impact is assessed quantitatively in Chapter 6.

<u>(8) Legend:</u>
SS = South Shore
NS = North Shore
Lav = Laval
Long = Longueuil
excl = excluding

POR (home based)	1981	1986	BSQ SCENARIOS 1991	1996	2001
MONTREAL Is.					
East	273	280	294	304	316
Centre	1005	986	958	935	913
West	481	488	495	503	512
S.total	1759	1754	1747	1742	1741
NORTH OF MONTREAL Is.					
Laval	268	284	301	319	338
NS	231	255	282	313	346
S.total	499	539	583	631	683
SOUTH OF MONTREAL Is.					
Longueuil	124	125	127	128	129
SS excl Long	452	474	497	521	547
S.total	577	600	624	649	676
GMA total	2836	2892	2954	3023	3099

TABLE 3.12: GMA POP GROWTH FORECASTS: 1981-2001.

POP figures in 1000s.

Sources: 1. MOTQ (1988); Table 1.
2. BSQ (1984).
3. [Lamonde et al, 1989]; Table 2.1.

A-4.2 Employment Growth and Forecast

Several authors have scrutinized EMP variations over time for the GMA and have prepared EMP forecasting based on several designed scenarios. The works of [Lamonde et al, 1989], [Bussiere et al, 1985 to 1989] are of relevance.

Tables 3.13 and 3.14 show the evolution of EMP by industry over time from 1971 to 1986, and forecasts for the years 1991, 1996 and 2001 based on BSQ (1984) population growth forecasting.

INDUSTRY	1971	1981	1986	BSQ-84 SCENARIOS		
				1991	1996	2001
A. MANUFACTURING INDUSTRY:						
Food, beverage,...	32	35	30	29	28	27
Furniture, wood,...	22	24	22	19	19	18
Textile,clothing,..	83	72	57	53	46	40
Paper, printing	23	30	30	29	29	28
Machines & equip't	77	94	97	94	96	95
Metal 1st transf	34	37	34	38	43	46
others	13	13	12	10	8	7
S.total	284	305	282	272	269	261
PCT**	30.6	24.1	21.0	18.9	17.9	16.9
B. CONSUMPTION INDUSTRY:						
Commerce	147	225	251	291	305	308
Recreation	27	35	53	56	59	61
Housing, restauration	34	62	75	90	98	106
Others	20	39	43	46	49	51
S.total	227	360	422	483	511	526
PCT**	24.5	28.5	31.4	33.5	34.0	34.1
C. PRODUCTION INDUSTRY:						
Transp, communication	94	127	121	126	126	127
FIRE	57	85	86	98	102	103
Construction	33	66	78	84	89	93
S.total	184	277	285	309	317	322
PCT**	19.8	21.9	21.2	21.4	21.1	20.9
D. PUBLIC AND GOVERNMENTAL SERVICE INDUSTRY:						
Education	62	86	90	107	120	134
Health care	62	106	122	131	143	156
Public administration	49	70	70	70	74	77
S.total	174	262	282	308	337	367
PCT**	18.8	20.7	21.0	21.4	22.5	23.8
Total	869	1204	1271	1372	1434	1476
Others	58	61	71	*69	*67	65
Grand total	927	1265	1342	1441	1501	1541

TABLE 3.13: GMA EMP DATA and FORECASTS by INDUSTRY: 1971-2001.

EMP figures in 1000s.
* Figures obtained by interpolation.
** Rows added; percentage of Section total from Grand total.

Sources: 1. [Lamonde et al. 1989]; Table 4.1
2. MOTQ (1984); modified tables.

Table 3.13 presents EMP data and forecasts for Montreal's CMA aggregated by industry and categorized by function as obtained from [Lamonde et al. 1989] and MOTQ (1984). The table has been re-arranged; figures were added by interpolation to complete the table; and the percentage rows were computed. The EMP growth forecasts represent internal EMP categorizations, and relative share by category at a point in time.

The following points are of interest when comparing the 1986 data to the 2001 forecasts:

1. The manufacturing industry relative share is forecasted to decrease from 21.0% to 16.9%; while the total EMP is forecasted to increase by 14.8% [(1541-1342)*100/1342].
2. The consumption industry relative share is forecasted to increase from 31.4% to 34.1%; an important increase.
3. The production industry relative share is forecasted to decrease slightly.
4. The public and government service industry relative share are forecasted to increase from 21.0% to 23.8%.

Thus, the 2001 forecasts show a decline in manufacturing industries (1) balanced by an increase in service industries (2 and 4). This is discussed further in Chapter 6.

Table 3.14 categorizes EMP into manufacturing (M) and service (S) industries by district, and shows EMP variations over time, from 1971 to 1986, and MOTQ forecasts for the period 1991 to 2001.

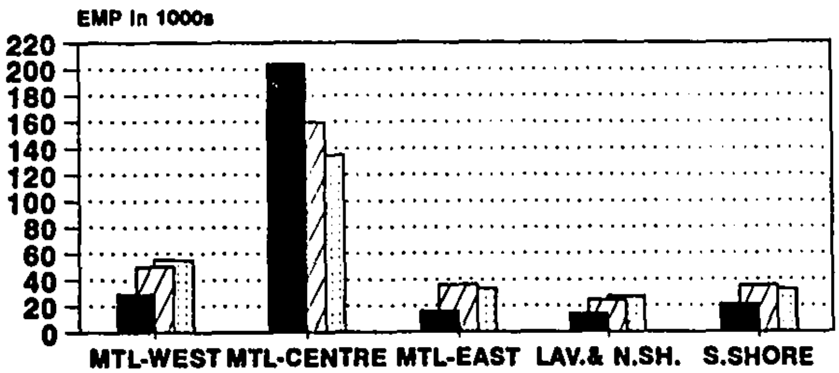
CMA DIVISION		1971	1981	1986	BSQ-84 SCENARIOS 1991	1996	2001
MONTREAL Is.							
Centre	M	185	139	116	95.5	81.7	67.5
	S	385	445	466	488	491	486
West	M	47.5	71.6	74.0	81.8	90.1	94.1
	S	87.8	152	175	205	235	240
East	M	16.1	36.3	32.6	31.1	31.4	30.6
	S	25.8	56.0	65.5	77.2	85.7	92.8
Total	M	248	247	222	209	203	192
	S	499	653	706	770	801	819
NORTH OF MONTREAL Is.							
Laval	M	4.3	10.7	12.3	na	na	na
NS	M	14.4	24.3	27.1	95.7	107	117
	S	30.2	69.3	81.2	na	na	na
SOUTH OF MONTREAL Is.							
Long	M	6.8	13.3	11.6	na	na	na
SS	M	21.2	34.5	31.9	31.4	32.1	31.7
	S	28.6	84.8	99.8	120	137	154
Total	M	284	305	282	271	269	259
	S	585	899	989	1099	1165	1215
Others		58.0	na	70.8	na	na	66.7
Other	S EMP	27.3	92.6	102	114	121	125
Grand total		927	na	1342	na	na	1541

TABLE 3.14: GMA EMP DATA and FORECASTS by DISTRICT: 1971-2001.

EMP figures in 1000s.

Sources: 1. [Lamonde et al. 1989]; Table 4.1
2. MOTQ (1984). Tables Modified.

GMA MANUFACTURING EMPLOYMENT

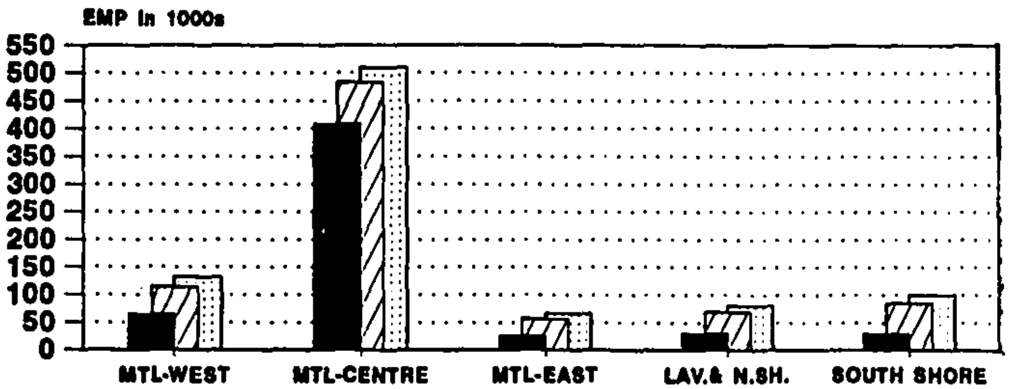


	MTL-WEST	MTL-CENTRE	MTL-EAST	LAV.& N.SH.	S.SHORE
1971	29	204	16	14	21
1981	50	160	36	24	35
1986	55	135	33	27	32

1971 1981 1986

FIG. 3.1: GMA MANUF. EMP by SD: 1971-86
Source: Lamonde et al.

GMA SERVICE EMPLOYMENT



	MTL-WEST	MTL-CENTRE	MTL-EAST	LAV.& N.SH.	SOUTH SHORE
1971	65	408	26	30	29
1981	114	483	56	69	85
1986	132	509	66	81	100

1971 1981 1986

FIG. 3.2: GMA SERVICE EMP by SD: 1971-86
Source: Lamonde et al.

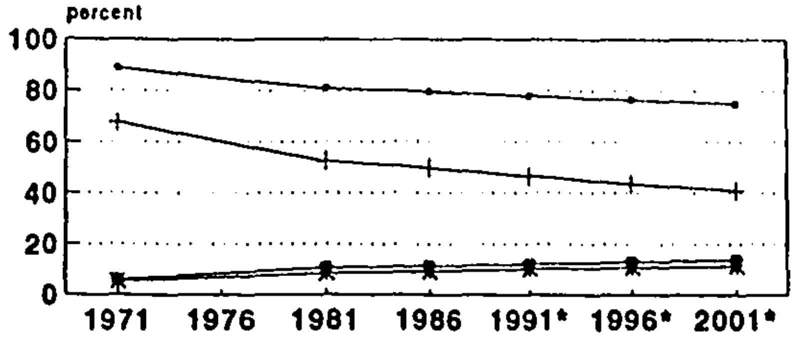
Further computations on the tabulated data were done and the descriptive results are shown in Figures 3.1 and 3.2; data are from [Lamonde et al. 1985 and 1989] and are presented in bar chart format showing the variation over time of EMP in the GMA districts.

The Montreal City Centre, the prime objective of the research, shows that though the manufacturing EMP is decreasing over time, decentralizing and re-allocating into service industry, the services EMP is increasing during the same period; yet the overall result is decentralization, as can be seen in Figures 3.3 and 3.4.

Fig. 3.3, with data from Lamonde et al. (1989), shows an overall decentralization of the ELF in MTL in general and a stronger decentralization in Montreal City Centre, while there is an increase in EMP elsewhere. The 1991-2001 forecast, obtained by elaborate handling of data, also reflects the same conditions [Lamonde et al. 1989].

Furthermore, Fig. 3.4, with data from [Lamonde et al], shows that EMP in Montreal CBD was decentralizing between 1971 and 1986 and it is expected to continue. This is in conformity with the findings of Cervero (1989) and Pisarski (1987) for the U.S., and Bourne (1989) for Canada.

GMA EMPLOYMENT TRENDS

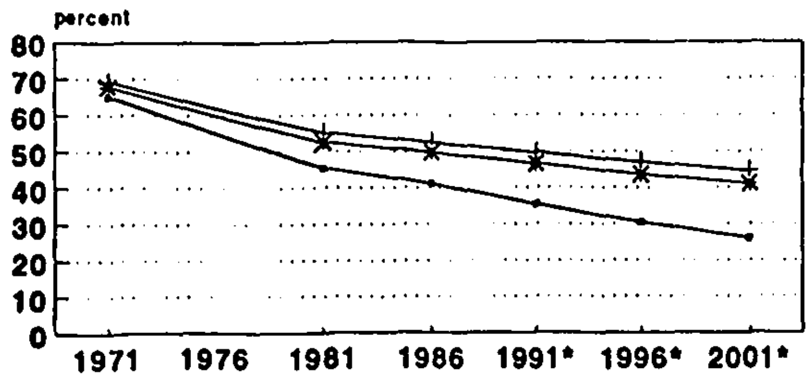


	1971	1976	1981	1986	1991*	1996*	2001*
MTL	88.8		80.9	79.5	77.9	76.4	75
MTL-CNTR	67.7		52.5	49.8	46.5	43.6	41.1
LAV & N.SH.	5.3		8.4	9.2	10.1	10.7	11.3
S.SHORE	5.9		10.7	11.3	12	12.9	13.7

MTL + MTL-CNTR * LAV & N.SH. S.SHORE

FIG. 3.3: GMA EMP TREND by SD: 1971-2001
Source: Lamonde et al.
* Forecast figures

CBD EMPLOYMENT TRENDS



	1971	1976	1981	1986	1991*	1996*	2001*
MANUFG	65.1		45.4	41.2	35.4	30.4	26.1
SERVICES	69.1		55.2	52.5	49.6	47	44.6
TOTAL	67.7		52.5	49.8	46.5	43.6	41.1

MANUFG + SERVICES * TOTAL

FIG. 3.4: CBD EMP TREND by SD: 1971-2001
Source: Lamonde et al.
* Forecast values

Due to the fact that manufacturing and service industries employ more than 90% of the total available labour force, we shall concentrate our research work on these. It is good to note that the variation of the manufacturing EMP over time is continually declining in the Montreal city centre. It is further discussed in Chapter 6.

A-4.3 Trip Orientation

The STCUM published origin-destination (OD) matrices i.e., trip production-attraction data, establishes the trip orientation between the GMA districts. The variations over time of the travel pattern, from the traditional trip to the more complex and convoluted many-to-many pattern, discussed in Chapter 2 [Bourne, 1989], is quantified in terms of traffic density distributions in Chapter 6.

Table 3.15 gives total productions (Pr) and attractions (At) for the auto and transit modes; for the morning rush hours (6 to 9 AM) for a week day in autumn. The GMA zones were aggregated into eight super-districts, and grouped by the survey years of 1974, 1978, and 1982.

YEAR	1 9 7 4		1 9 7 8		1 9 8 2	
	Pr	At	Pr	At	Pr	At
MONTREAL Is.						
CBD	14.1	215	18.6	212	19.0	228
Centre	375	342	365	343	348	335
East	90.3	57.4	98.2	64.2	106	64.2
West	203	181	206	184	224	194
Total	683	795	688	803	697	822
SOUTH OF MONTREAL Is.						
East	115	58.8	126	64.4	143	75.2
West	34.0	13.3	38.8	15.6	38.3	14.5
Total	48.8	72.0	164	80.1	181	89.7
NORTH OF MONTREAL Is.						
Laval	88.2	38.7	96.7	44.7	108	52.7
NS	50.4	27.2	62.6	28.8	70.9	32.6
Total	139	65.9	159	73.5	179	85.3
CMA	970	933	1011	956	1057	997
Not defined	16	54	20	75	53	113
Grand Total	986	986	1032	1032	1110	1110

TABLE 3.15: GMA TRIP PRODUCTIONS and ATTRACTIONS: 1974, 1978, 1982. Morning rush hours (6 to 9 AM). Auto and public transit modes only.

Person-trip figures in 1000s.

Source: MOTQ (1988); Table 6.

Table 3.16 presents an origin-destination trip matrix for auto and public transit modes for the 6 to 9 AM peak period for an autumn week day in 1982.

As expected, the transit share of trips is more than 50% in the CBD and City Centre and decreases dramatically in the other districts involving longer commuting distances and lower population densities.

OD		MONTREAL		ISLAND		SOUTH SH.		LAV	NS	Pr
		CBD	CENT	EAST	WEST	EAST	WEST			
CBD	A	2.2	3.1	0.3	1.4	0.7	0.2	0.2	0.1	8.[illegible]
	T	3.8	4.1	0.2	1.1	0.2	0	0.06	0.0	9.4
CENT	A	23.0	76.8	11.1	24.3	4.4	0.7	4.7	1.7	147
	T	65.2	89.4	5.7	16.2	1.7	0.04	1.0	0.2	180
EAST	A	4.1	20.5	17.1	4.4	1.4	0.1	1.5	1.0	50.0
	T	12.7	20.4	12.5	1.9	0.2	0	0.1	0	47.8
WEST	A	19.1	29.4	1.9	69.3	1.8	1.3	2.1	0.7	126
	T	31.9	17.6	0.4	32.4	0.3	0.03	0.1	0	82.7
SS.E	A	13.7	16.9	3.3	6.8	43.9	1.2	0.4	0.3	86.4
	T	20.7	8.3	0.2	1.2	12.5	0.03	0.02	0	42.8
SS.W	A	3.7	3.2	0.4	10.6	2.1	9.5	0.2	0.1	29.5
	T	2.5	0.7	0.01	0.4	0.1	0.2	0	0	4.0
LAV	A	5.7	20.4	3.4	12.8	0.8	0.2	23.6	2.8	69.5
	T	8.4	6.6	0.4	1.7	0.1	0	10.8	0.3	28.2
NS	A	4.0	11.8	6.0	6.0	0.5	0.1	6.0	22	56.2
	T	2.9	1.3	0.1	0.2	0	0	0.4	0.8	5.8
At		223	330	62.7	191	70.8	13.5	51	30	972

TABLE 3.16: GMA OD MATRIX BY SD; 1982

6 to 9 AM; auto and transit modes.

Person-trip figures in 1000s. Legend in footnote #[9].
Source: MOTQ (1988); Table 7.

OD	MODE	CC	SUBURB	Pr
CC	A	105	50	155
	T	163	26	189
	TOT	268	76	344
	PCT	**28**	**8**	
SUBURB	A	153	266	418
	T	134	77	211
	TOT	287	343	629
	PCT	**29**	**35**	
At	A	258	315	573
	T	297	104	400
	Tot	554	419	973

TABLE 3.17: GMA OD MATRIX: CITY CENTRE and SUBURBS; 1982.

6 to 9 AM; auto and transit modes only.

Person-trip figures in 1000s and PCT.
Source: Table 3.16.

---

(9) Legend:
A = auto person-trips
T = transit person-trips

The CBD and Centre districts are aggregated as the City Centre (CC), while all other districts are considered to be suburbs. The following statistics present the spatial OD relationships between OD pairs during the rush hours; the data are from Table 3.16 for the GMA in 1982 and presented in Table 3.17.

Table 3.17 results show that:

1. The suburb-to-suburb person-trips represent 35% of total
2. The suburbs-to-CC person-trips represent 29% of totaL.
3. The CC-to-suburbs person-trips represent only 8% of total.
4. The CC-CC person-trips represent 28% of total.

The above results, confirms for the GMA, the findings for the U.S. by Pisarski (1987), that the most important trip orientation is the suburb to suburb trip, accounting for 35% of all commuting trips.
This is the complex many-to-many trip orientation as contrasted with the traditional many-to-one. Furthermore, this also confirms the hypothesis of the 'emergence of new travel pattern' in Canada by Bourne (1989).

A-4.4 Modal Split

The transport modal split is well documented for the GMA by the STCUM, the transit company of Montreal. Over time modal split published figures were obtained from STCUM for the years 1974, 1978, 1982, and 1987. These are presented in Tables 3.18 through 3.20.

DESCRIPTION	MODE	1974	1978	1982
MODAL SPLIT BY AGE:				
<18 yrs	All	133.9	133.8	149.7
	T%	75.4	75.5	67.8
18 to 64	All	838.0	881.9	940.7
	T%	33.0	31.6	32.3
65 plus	All	14.2	15.1	19.2
	T%	42.7	46.2	42.9
MODAL SPLIT BY GENDER:				
Female	All	374.8	414.6	467.6
	T%	56.6	52.9	49.7
Male	All	611.3	616.2	642.1
	T%	28.1	27.3	28.2
MODAL SPLIT BY PURPOSE:				
Work	All	741.1	762.9	776.6
	T%	31.4	29.8	29.3
Education	All	177.2	188.7	212.1
	T%	74.4	74.7	75.3
Others	All	67.8	79.2	121.0
	T%	29.0	23.8	21.5
Total	All	986.1	1030.8	1109.7
	T%	39.0	37.9	37.2

TABLE 3.18: GMA MODAL SPLIT by AGE, GENDER and PURPOSE: 1974, 1978, 1982. 6 to 9 AM; total person-trips (all) and PCT transit (T%).

Figures in 1000s.

Source: STCUM published data.

The female's transit ridership have stabilized back to the 1974 level, while the male's transit share has declined; an overall decline in transit ridership is registered between 1974 and 1982.

Male and female modal choice differences are evident and probably due to higher earning levels of the male population. The comparatively higher female ratios in Montreal City Centre (as compared to Toronto, Tables 3.4 and 3.5) in 'high professional occupations' would be a balancing factor.

The work trip by transit mode is declining over time during the rush morning hours, while the education trips using the transit mode have slightly increased from 74.4% (1974) to 75.3% (1982).

This leads to the conclusion that the decline of transit ridership share by the age group less than 18 years, mostly captive passengers, is probably due to a decrease in school-home distances i.e., walking and bicycle riding become viable modes of transport.

Furthermore, a lower transit patronage of the 18-64 age group, usually motorized workers (excluding walking and bicycle riding modes), confirms the absolute decline of transit trips share between 1974 and 1982.

The results in Table 3.19 are highly logical and to be expected; the higher the auto ownership per households (HHLD), the lower the transit patronage.

AUTO-OWNERSHIP/HHLD	MODE	1974	1978	1982
0 Cars	All	131.8	123.6	127.7
	T%	85.5	89.1	91.7
1 Car	All	597.5	591.6	618.2
	T%	35.8	35.9	35.9
2 Cars	All	213.7	257.2	303.9
	T%	23.3	21.3	21.0
3 Cars	All	34.8	45.8	47.3
	T%	18.2	17.9	18.6
4+ Cars	All	8.3	12.7	12.5
	T%	12.6	12.9	12.8
Total	All	986.1	1030.8	1110
	T%	39.0	37.9	37.2

TABLE 3.19: GMA MODAL SPLIT by AUTO-OWNERSHIP: 1974, 1978, 1982.

6 to 9 AM; all modes.

Person-trips figures in 1000s and PCT transit.

Source: STCUM published data.

Table 3.20 presents the household size (p/h) variations over time by district computed from STCUM published data: (a) trips per household (t/h) and (b) trips per person (t/p).

DISTRICT	1 9 7 4 YEAR			1 9 7 8 YEAR			1 9 8 2 YEAR		
	t/h	t/p	p/h*	t/h	t/p	p/h*	t/h	t/p	p/h*
MONTREAL Is.									
CBD	0.4	0.2	2.0	0.5	0.3	1.7	0.5	0.3	1.7
Cent	1.0	0.3	3.3	1.0	0.4	2.5	1.1	0.4	2.8
East	1.5	0.4	3.8	1.5	0.5	3.0	1.7	0.6	2.8
West	1.5	0.5	3.0	1.6	0.6	2.7	1.8	0.7	2.6
Average	1.1	0.4	2.8	1.2	0.4	3.0	1.3	0.5	2.6
SOUTH OF MONTREAL Is.									
SS	1.7	0.5	3.4	1.8	0.6	3.0	2.1	0.7	3.0
NORTH OF MONTREAL Is.									
Laval	1.8	0.5	3.6	1.9	0.6	3.2	2.2	0.7	3.1
NS	1.7	0.5	3.4	1.9	0.6	3.2	2.3	0.7	3.3
GMA	1.3	0.4	3.3	1.4	0.5	2.8	1.6	0.6	2.7

TABLE 3.20: GMA HOUSEHOLD SIZE by DISTRICT: 1974, 1978, 1982.

* Persons per households (p/h) were calculated.

Source: STCUM published data.

Consequently, the figures are of an indicative nature. The household size figures in Table 3.20 show an overall trend of decline. This is further discussed in Chapter 6.

Table 3.21 presents the GMA modal split by age groups as related to 1982 POP. The five transport modes presented are: transit by bus (T), transit by school bus (T Sch), auto drivers (A driv), auto passengers (A pass), and other. The (TOT%) column (column #8) represent the total percentage trips (all modes) by age group, and the POP% represent the percentage of the 1982 population by age group.

AGE	POP%	T	T SCH	A DRIV	A PASS	OTHER	TOT%	MOB*
0-4	6.27	--	--	--	--	--	--	--
5-9	6.27	0.88	39.7	--	9.43	19.2	6.00	0.96
10-14	6.76	5.98	37.9	--	6.65	16.7	6.39	0.95
15-19	8.28	17.3	22.5	2.36	8.11	9.39	8.61	1.04
20-24	9.98	17.5	0	11.0	12.8	7.80	11.9	1.19
25-29	9.70	11.6	0	14.8	11.7	7.86	12.0	1.24
30-34	8.85	8.48	0	15.4	9.59	6.72	11.0	1.24
35-39	7.91	6.38	0	15.0	8.56	5.21	10.0	1.26
40-44	6.51	5.21	0	11.6	6.66	3.79	7.77	1.19
45-49	5.40	4.83	0	8.41	5.58	3.51	6.09	1.13
50-54	6.08	5.50	0	8.33	5.89	3.77	6.30	1.04
55-59	4.83	4.47	0	5.51	4.83	3.52	4.64	0.96
60-64	4.17	4.04	0	3.89	3.99	3.46	3.71	0.89
65-69	3.60	3.74	0	2.15	3.04	3.76	2.79	0.78
70-74	2.59	2.45	0	1.02	1.78	2.70	1.66	0.68
75-79	1.52	1.21	0	0.35	0.83	1.72	0.80	0.58
80 +	1.21	0.53	0	0.11	0.59	0.95	0.39	0.32
Tot PCT	100	100	100	100	100	100	100	

TABLE 3.21: GMA MODAL SPLIT by AGE GROUP; 1982

Age groups as PCT of 1982 POP.

* Mobility ratio computed (column #8 / column #2)
POP and person-trip figures in PCT.

Source: [Bussiere et al. 1987]; Table 4.

The comparison between columns POP% and TOT%, in Table 3.21, provides the mobility by age group in 1982. This is computed and presented in the column MOB. The age group with the maximum mobility is seen to be 35-39 years as expected, the management group, followed by the 29-34 and 25-29 groups.

A-5 SUMMARY and COMMENTS

Part A presented the local data review and the data availability limited most of the review to the year 1982 while forecasts for the 1986-2001 period were presented. Also a descriptive statistical analysis and a time series study were presented for the case study, the Greater Montreal Area, in its Canadian-North American context. The corresponding 1987 demand data are presented in Part C of this chapter.

Though statistical data were found relating to several sections of this chapter, with the exception of the STCUM data, they do not have the same basis for comparison purposes and are of general value to the research.

Furthermore, even the STCUM data are hard to relate over time at a disaggregate level and they are split into three basic temporal groups: 1970 data, 1974 to 1978 data and 1982 to 1987 data. The latter is of most importance to the research and was quoted on several occasions.

The following paragraphs and figures present a few points of common interest from this part of the chapter.

In the morning rush hours, work trips alone represent around 70% of the total trips and about 30% of them are by transit, bus and light rail. Next in line are educational trips accounting for about 25% of total trips. They mostly boost the transit transport mode, as they are captive passengers, about 75% of education trips use the transit mode, including the school bus mode.

The work and educational trips represent more than 90% of all purpose morning trips and have common morning peak travel time. The work flex-time, flexible morning starting time for work and education trips, is of lesser than expected impact in the GMA. This is further emphasized by the low peak hour factor value (PHF= 0.70), computed in Part C of this chapter.

As the auto-ownership per household increases, the transit ridership decreases. This is observed to be true over time, i.e there is a strong correlation between auto ownership per household and transit ridership. This is proven in Part D of this chapter.

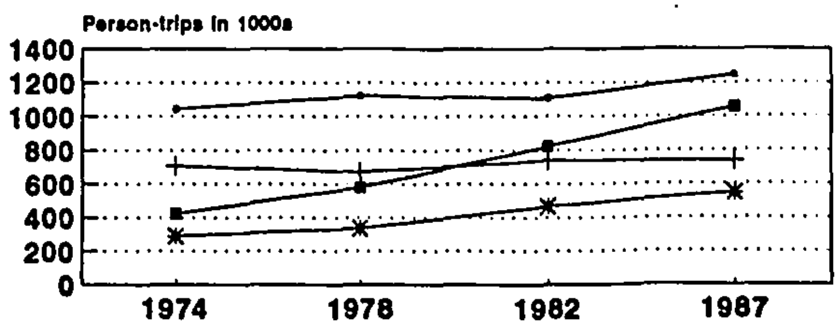
The reviewed GMA data were supplemented, whenever possible, with data from other sources or by computations to fill in empty cells in tables, as documented.

Data for Figures 3.5 and 3.6 were compiled from STCUM. The variation over time in Fig. 3.5, shows that the EMP HBW person-trips and shopping purposes are increasing at matching rates.

The educational trips, highly dependent on population growth and aging, are barely increasing, while the single most important component in the 'others' category is recreation, and it is booming. This is again in conformity with U.S. findings: people are making more recreational trips, strongly influenced by the higher auto-availability per person.

The research, deals with the AM peak hour traffic, and is concerned mainly with work and educational trip purposes.

GMA PERSON-TRIPS by OCCUPATION
1974-1987

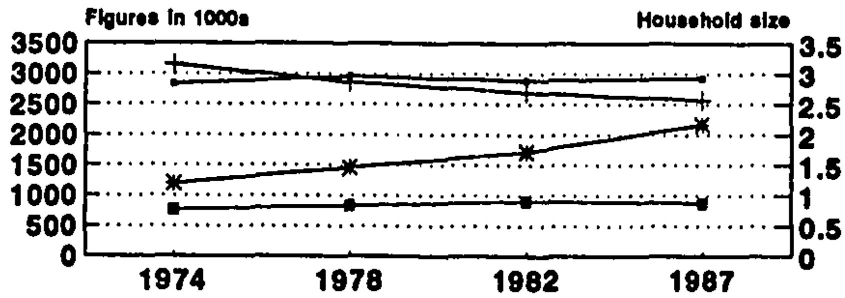


	1974	1978	1982	1987
WORK	1045	1123	1108	1245
EDUCTN	708	672	739	737
SHPG	290	337	468	547
OTHERS	424	581	822	1056

WORK + EDUCTN * SHPG ■ OTHERS

FIG. 3.5: GMA TRIPS by OCCUP: 1974-87
Data source: STCUM

GMA: POP, HHLD, AUTO, TRANSIT
Person-trips: 1974-1987



	1974	1978	1982	1987
POPN	2835	2954	2895	2930
HH SIZE	3.15	2.86	2.7	2.57
AUTO	1197	1461	1722	2171
TRANSIT	768	836	913	880

POPN + HH SIZE * AUTO ■ TRANSIT

FIG. 3.6: GMA: POP, HHLD, AUTO, TRANSIT
1974-1987.
Data source: STCUM

Fig. 3.6 shows four GMA parameters: population, household size, auto person-trips, and transit person-trips, and their temporal variations. Population growth rate is very low, and the household size is decreasing over time, in conformity with U.S. findings.

Transit ridership shows a modest increase until 1982, a decrease in 1987, and a further decrease is in progress lately due to lower governmental subsidies and recent rise in ridership fares.

The auto person-trip is continuously increasing over time and this is expected to continue. This is of concern to the research, as it is the main cause for traffic congestion in metropolitan areas.

The research base demand data is provided in Part C of this chapter. And it is modelled by zones in Part D and by super districts in Chapter 6. Part B presents the EMP distributions by occupation and by industry.

CHAPTER 3

Part B: DESCRIPTIVE ANALYSIS: 1981 STATSCAN DATA

B-6 RESEARCH DATA BASE

The available historical data permits time series analysis, while more detailed case study data at one point in time, namely the 1981 StatsCan data, is scrutinized in more depth to show EMP spatial distribution by trip purpose.

The 1981 Montreal, home-based work (HBW) person-trip data, person-trip origin-destination information by census tract, were obtained from StatsCan, on special magnetic tapes produced by their Customers Services Section. The tapes have the person-trip data, for the total employed labour force (ELF) by gender, industry, and occupation. The data were coded by place-of-residence (POR) and by place-of-work (POW).

In this research the gender data were aggregated due to their relatively low impact at the sketch planning level. Though the more relevant EMP category is by occupation, both the occupational and industrial POW data categories were retrieved and analyzed.

The total ELF categorized, at the POW, by occupation are aggregated based upon behavioral characteristics as related to transportation modal choice. The aggregation process is influenced by the work of Miller et al. (1984), and others in this regard; the following aggregated groups were chosen, and are defined below:

TO: Total occupational; are all occupational ELF, HBW trips.

M: Managerial; aggregated data including:

1. Managerial, administrative, and related occupations.
2. Teaching, and related occupations.
3. Medicine, and health occupations.
4. Technological, social, religious, artistic, and related occupations.

S: Service; aggregated data including:

1. Clerical, and related occupations.
2. Sales occupations.
3. Service occupations.

L: Blue collars (labour); aggregated data including:

1. Primary industry occupations .
2. Processing industry occupations.
3. Machining, product fabrication, assembling, and repairing occupations.
4. Others.

Listed below are EMP aggregations, categorized by industry, the choice of groupings are influenced by the work of Miller et al. (1984) and others in this regard, the following aggregated groups were chosen, and are defined below:

TI: Total industrial; are all industrial ELF, HBW trips.

P: Primary industry; aggregated data including:

1. Manufacturing industry.
2. Primary industry.

C: Construction industry; aggregated data including:

1. Construction industry.
2. Transportation, communication, and other utilities.

D: Trade is an important industry, it is kept disaggregated.

F: FIRE industry; aggregated data including:

1. Finance, insurance, and real estate (FIRE).
2. Community, business, and personal services.

A: Public Administration industry; aggregated data including:

1. Public administration industry.
2. Defence staff.

The research data needed for the travel demand model calibration for the year 1987 are not available from StatsCan due to the fact that the 1986 StatsCan Survey dropped questions relating to the place-of-Work.

Consequently the data are obtained from the STCUM, the Montreal transit company. The STCUM data are presented in Part C of this chapter.

B-7 TRAFFIC ZONES

The Greater Montreal Area (GMA) including the North Shore (NS), Laval (Lav) or Jesus Island, Montreal Island (MTL), and the South Shore (SS), is divided into 38 large traffic zones or super-zones respecting the 1981/1986 Census Tract delimitations and respecting traffic watersheds.

The choice of the zone boundaries is a personal contribution, the criteria for the work were derived from actual practice and were influenced by the work of McCoomb and Rice (1983) and others (Dial et al. 1980, Baas,K.G, 1981) as per criteria defined below:

1. The traffic zone boundaries should define traffic watersheds.
2. Arterial and distributor streets are usually enclosed in the zone and do not constitute their boundaries.
3. Freeways and expressways in urban or suburban areas are usually completely enclosed in traffic zones provided they have at least one interchange within the zone. i.e controlled access.
4. Freeways and expressways represent boundaries between zones if they have no interchanges in the zone i.e. no access, or if they are significant barriers.
5. Whenever possible, the zone boundaries should represent municipal boundaries in order to relate research results to local interests.
6. Railway lines represent zone boundaries (if they are barriers), while stations are treated as highway interchanges

as they represent intermodal relays and traffic usually is allowed to move around them, i.e. they are accessible.

7. Rivers and land barriers (ridges) define traffic sheds and are respected as such.

8. The relatively large size of zones allowed the aggregation, in most cases of CTs, into more homogenized rounded shapes (footnote #[1]).

9. The research concern on the impact of EMP decentralization is addressed while choosing zones by implementing a rather unique criterion; to keep certain ratios between parameters of adjacent zones as follows:

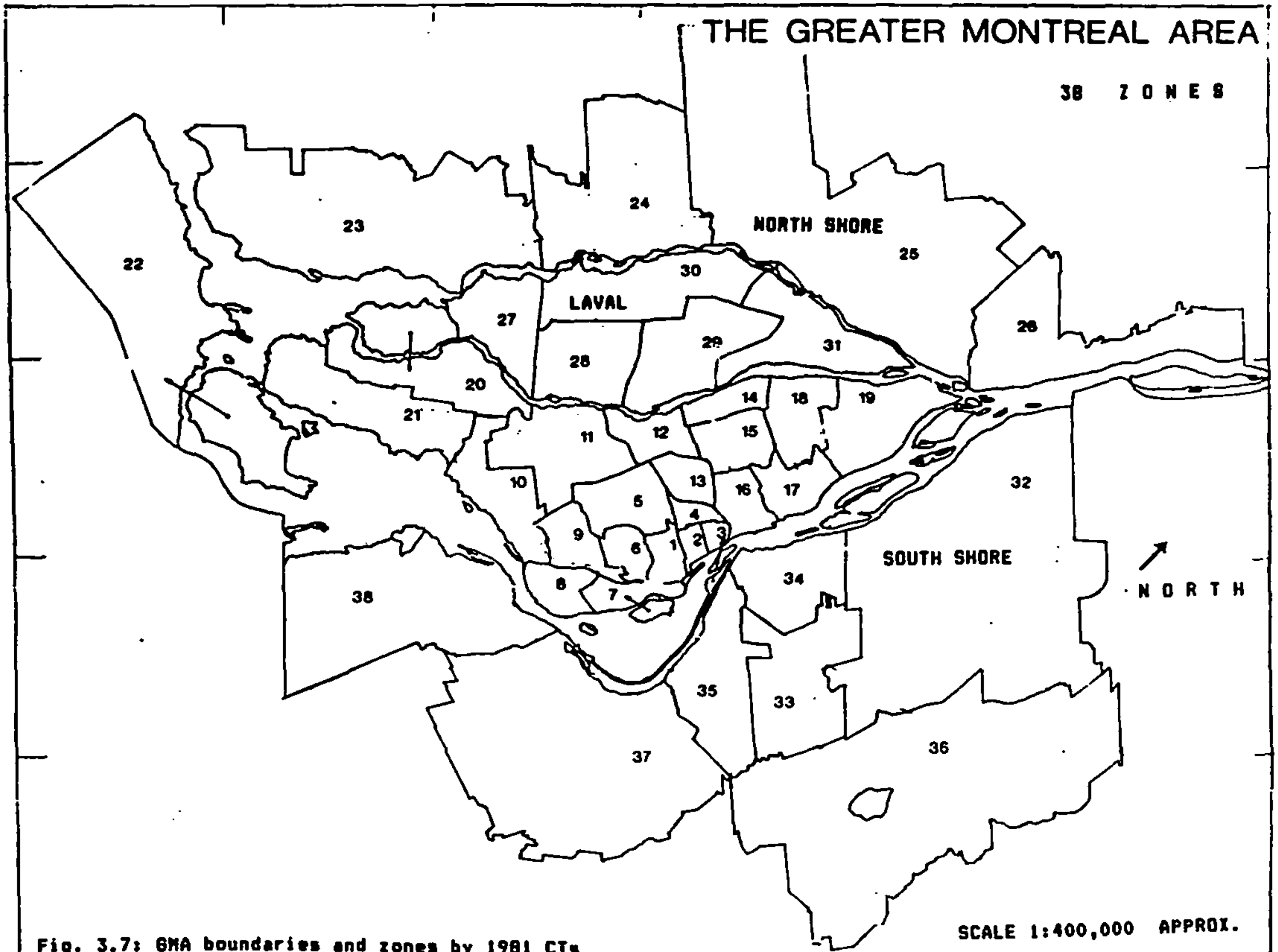
   a. ELF ratios between central adjacent zones is limited to three.

   b. The ratio of land area between adjacent zones in the central region was kept around two in order to have scenarios having limited ELF ratios, other factors being constant.

   c. Points (a) and (b) above were less respected when creating zones in the North and South shores due to their low population densities.

10. Traffic zone boundaries respect traffic screen lines to implement better model calibration, model validation, and data control.

Footnote #1
McCoomb, L.A. and Rice, R.G. "The Role of Statistic Canada Data in Urban Transportation Planning", RTAC Forum, Vol.5, Number 2, Ottawa, 1983. (pp: 82-98)



SCALE 1:400,000 APPROX.

Fig. 3.7: GMA boundaries and zones by 1981 CTs

Figure 3.7 shows the zonal aggregations of the CMA 1981 Census Tracts into 38 zones, and are compatible with 1986 CTs.

The aggregation of CTs into the 38 zones and the equivalency between zone numbers and CT numbers are given in Appendix A, as part of the SAS program.

B-8 ORIGIN-DESTINATION MATRICES

The 1981 Census Survey data are obtained from two special magnetic tapes prepared by the Customers Service Section of Statistics Canada; by occupation and by industry, files No. CTD81B40 and CTD81B50.

B-8.1 Coded Data by Place-Of-Work

The StatsCan 1981 Census questionnaire, produced by the Customers Service Section, was coded into eight groups. They define the POW and the POR for the HBW trips by CT for Canadian CMAs and CAs; as follows:

1. Resident CT
2. Another CT
3. Rest of CMA
4. At home
5. No usual POW in CMA
6. Outside CMA
7. Outside Canada
8. CT not stated

Codes 1 and 2 have clearly defined ODs and they are aggregated; codes 3 and 5 represent ELF in the CMA with undefined destination and are distributed proportionally to each district destination. Codes 4 and 7 are of no immediate concern to the research, while code 6 represents external destination trips and shall be treated as an external zone similar to the trip origin code 99999.

Code 8 needs special consideration as it represents the fact that the questions were not properly answered, i.e. the error part.

Tables 3.22 and 3.23 present the cross tabulations of the HBW trips of the ELF aggregated by industry and by occupation.

CODES	1+2	3	4	5	6	7	8
M	3180	302	117	18	123	10	206
S	4627	486	141	53	115	10	411
L	3001	492	72	91	128	5	351
TO	10799	1280	331	163	366	24	969

TABLE 3.22: 1981 ELF: HBW PERSON-TRIPS by OCCUPATION.

Figures in 100s (footnote #2[2]).

Source: 1981 StatsCan special magnetic tapes.

<u>Footnote #2:</u>
NB: Total number of employees is the same by industry or by occupation, any difference is due to StatsCan rounding up of figures to the nearest five as applied to small size CTs to provide confidentiality.

Table 3.22 shows that the blue collar (L) occupational group has the highest relative figures in code 8, while there are no important variations when the ELF is aggregated by industry. This clearly implies a relationship of the error part in the survey and the level of education of the respondents. This finding is of importance when surveying communities with lower educational levels.

Furthermore, RTAC (1988) points out that gender variations are also an important parameter in code 8 data.

CODES	1+2	3	4	5	6	7	8	TL
P	2659	365	44	15	79	3	236	3401
C	1497	183	44	79	89	4	152	2048
D	1894	260	52	18	47	2	162	2438
F	4152	413	184	33	120	8	350	5249
A	603	59	6	18	31	7	64	788
TI	10808	1278	329	163	366	25	968	13937

TABLE 3.23: 1981 ELF: HBW PERSON-TRIPS by INDUSTRY.

Figures in 100s. Abbreviations are defined in aggregations.

Source: 1981 StatsCan special magnetic tapes.

Table 3.24 compares figures obtained from StatsCan 1981 Census using two different sources:

<u>Source A:</u>

Data are obtained from StatsCan special magnetic tapes, files CTD81B50 and CTD81B40, processed in this research, using SAS software and the computer mainframe at McGill University, and downloaded on to the PC. Part of the results were produced in tables 3.23 and 3.24.

Source B:

Data are obtained from StatsCan profile series B, Catalogue #95-959; the male and female data were aggregated.

CODE SOURCE	1,2,3	4	5	6	7	8	TL
A	12079	330	163	366	24	969	13931
B	12498	330	153	371	24	555*	13931
(A)-(B)	-419	00	10	-5	00	414	__

TABLE 3.24: 1981 STATSCAN DATA COMPARISON by SOURCE.

ELF; HBW person-trips.

Figures in 100s. * Figure obtained by balancing total ELF.

Source: 1981 StatsCan data.

The data in codes 1,2,3 in Table 3.24 were aggregated; an important relative difference in the code 8 data is noticeable: there is a sizable difference in code 8 data between source A and B, thus there was a problem with the tape coding.

Furthermore, a few of the least populated zones in the North and South shores had zero EMP i.e. zero destination trips. A quick survey of the STCUM data shows EMP levels to be low in the above mentioned zones, yet far from zero.

The data in the 'CT not stated' i.e. code 8 was distributed in two batches:

1. The first part, the difference between (A) and (B), by factoring up the attractions (based on their productions) to the districts with zero EMP, to bring the results in line with the STCUM figures. Although this is a rather rough approximation, the accuracy is sufficient for the purposes of descriptive analysis.

2. The remainder, the larger part, shall be distributed proportionally to all zones (similar to codes 3 and 5).

The CMA original matrices for the 38 zones were aggregated into 12 districts, and 6 super districts. Code 6 trips were entered as an external trip destination district and its values were not factored up. The district matrices are presented in Table 3.26 onwards.

Samples of the computer programs to retrieve StatsCan data, downloading, and the aggregation of CTs into 38 zones and districts and the factoring-up process are presented in Appendix A.

B-8.2 Coded Data by Census Tract

The 1981 Census POW data were obtained from StatsCan as a result of a special survey question asking residents to identify their usual place-of-work, whether they worked the previous week or not, and coding their reply as seen in the above section.

The resulting 80,000 or more observations in the CMA were coded, cross tabulated by CT of POR and POW, and cross classified by industry in tape CTD81B50 and by occupation in tape CTD81B40.

The tapes give directional HBW trips by POW and POR for a weekday in autumn of 1981. These data may be transformed from home to work linkages into total daily or peak work trip matrices by developing trip generation factors reflecting absenteeism and the like on a weekday work trip making.

The RTAC (1988) (footnote #[3]), observed that absenteeism including illness, vacation and other assorted reasons represented between 7 and 8 percent of ELF. Furthermore, only between 85 and 95 percent of the ELF show up at their work location. This is pursued further in Chapter 6.

Footnote #3:
RTAC. 1988 The Strategic Modelling Technical Committee, "Census place of work data: Transportation planning Applications".

The RTAC report states that travel between home and work is the single most important component of urban travel, 'accounting for the majority of peak period travel which is most sensitive to travel cost factors such as congestion' [RTAC 1988, p10].

The 'design hour' used in urban transportation facilities is largely set by work travel demand. 'The AM peak rather than the PM peak has been taken as the 'design hour' in using the place-of-work data' [RTAC, 1988, p11], to forecast future demands. And generally speaking, though the AM and PM peaks are similar, the 'AM peak is easier to simulate than the PM peak', because it is dominated by the non-discretionary work and education trips.

It is of interest to note that the transportation modal split between AM and PM peaks is slightly different, with the auto share being somewhat larger in the PM peak, due mostly to the more discretionary PM trip types and to the more diversified PM travelling pattern.

In the Toronto Metropolitan Area it was found that the HBW trips represented about 70 percent of the peak period trip making and a factor of 1.6 (RTAC 1988, footnote #[4]) could be

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Footnote #4:
Factor= 2 * 0.85 * 0.93, where the factors are:
2 = stand for two way trips

used to transform the work linkages into daily HBW person-trip matrices.

B-9 ORIGIN-DESTINATION by DISTRICTS and SUPER DISTRICTS

The 38 zone OD matrices are an important representation of the POW locations by occupation and industry. They show trip linkages and provide solid grounds for the trip orientation in the CMA in 1981. To better visualize the results, larger aggregation of the 38 zones are needed and are identified in the research as districts (Ds) and super districts (SDs).

The 38 zone matrices are not presented because they do not constitute an important dimension at the descriptive analysis level. The aggregation criteria were similar to the one used for the 38 zones, except that the control on the components of each district is more relaxed, concerning areas and total trips per district.

The resulting district HBW person-trip OD matrices, by occupation and by industry, are presented in Tables 3.26 onwards. The matrices for total trips are the same for the

0.85 = reflects 15% absenteeism
0.93 = reflects 7% of vacations and the like.
This is assuming uniform distribution of the no shows.

occupational and industrial purposes yet, they are both shown (one in the appendix) for the sake of completeness and to illustrate the differences obtained in StatsCan data due to rounding and expanding to maintain the confidentiality of information in sparsely inhabited CTs.

Figure 3.7 shows the boundaries for the 38 zones used in Part B; these boundaries were based on 1986 CTs and are compatible with 1981 CTs. It is most unfortunate that local data and StatsCan data have low compatibility levels.
Listed are the SDs, the Ds and their zones (Zs) equivalencies in Table 3.25.

SDs	LOCATION	Ds	Zs
1	City Centre	1, 2, 3	1-9, 13
2	Montreal West	5	10, 11, 20, 21
3	Montreal East	4, 6	12, 14-19
4	Laval	7	27-31
5	North Shore*	8, 9	22-26
6	South Shore*	10, 11, 12	32-38

TABLE 3.25: EQUIVALENCE BETWEEN ZONAL AGGREGATIONS.

NB: * zone #22 is part of NS in Part B only, elsewhere is in SS.

The zonal OD matrices retrieved from the 1981 StatsCan data by occupation and industry are aggregated by district and presented in tabular form, as follows: (a) occupational matrices presented in Tables 3.26 to 3.29, and (b) industrial matrices presented in Appendix A, Tables A1 to A6.

OD1	D1	D10	D11	D2	D3	D4	D5
D1	30418	1090	152	5528	3330	1886	2644
D10	34829	47281	4123	8223	8555	3518	6359
D11	16480	10740	10554	3447	3551	2955	2958
D12	8958	3238	275	1715	8321	771	5629
D2	42529	2637	407	53935	10526	13707	13878
D3	47590	2204	363	14627	54604	3971	18593
D4	30087	2423	521	23666	6849	48808	14976
D5	25077	1302	189	12843	10623	5942	76086
D6	32843	2582	938	15415	7367	14084	8360
D7	17426	1458	221	14027	5177	13172	17695
D8	7870	690	273	4754	2012	7698	3727
D9	10238	701	146	5993	3467	4706	24069
EXT	13141	4217	1063	5344	5820	4451	10911
TL	317486	80563	19225	169517	130202	125669	205885

OD2	D6	D7	D8	D9	D12	EXT	TOTAL
D1	3329	415	778	1016	650	1100	52336
D10	7817	838	1234	1599	1054	4120	129550
D11	8319	559	596	775	510	4850	66294
D12	1304	296	239	307	195	1975	33223
D2	11666	2628	2137	2731	1798	3190	161769
D3	5229	1183	1814	2348	1524	3250	157300
D4	19296	4726	1932	2429	1639	2605	159957
D5	4202	2201	1100	1440	948	3150	145103
D6	55112	2237	1892	2408	1614	2890	147742
D7	7244	40768	1493	1931	1273	3275	125160
D8	13647	3787	532	634	413	2225	48262
D9	2673	9902	733	891	587	4030	68136
EXT	7547	3159	915	1128	761	.	58457
TL	147385	72699	15395	19637	12966	36660	1.35E6

TABLE 3.26: 1981 OD MATRIX: TOTAL HBW PERSON-TRIPS.

Montreal CMA by district (from EMP by occupation).

Source: 1981 StatsCan customers service, magnetic tapes.

OD1	D1	D10	D11	D2	D3	D4	D5
D1	12134	434	59	1789	1173	493	680
D10	12323	12176	743	2397	2457	972	1234
D11	7136	3503	2379	1353	1059	1117	895
D12	2170	743	60	420	1553	174	953
D2	15374	913	113	15050	3208	2651	3348
D3	17077	896	97	5451	14915	1250	4753
D4	7817	610	129	4300	1225	8594	2406
D5	12566	644	85	4974	4208	2245	22328
D6	7837	620	239	3071	1391	2457	1435
D7	6396	456	68	3707	1384	3977	4365
D8	2392	149	52	1033	446	1657	542
D9	3944	234	50	1445	1078	1470	5230
EXT	4874	1033	274	1612	1121	1002	1973
TL	112040	22411	4348	46602	35218	28059	50142

OD2	D6	D7	D8	D9	D12	EXT	TOTAL
D1	1082	134	177	241	123	545	19064
D10	2184	300	262	366	197	1395	37006
D11	3241	216	144	203	111	1720	23077
D12	300	78	36	48	24	675	7234
D2	3467	848	443	605	319	1280	47619
D3	1572	477	402	553	290	1165	48898
D4	5147	1279	286	394	210	745	33142
D5	2133	942	282	388	213	1205	52213
D6	12946	527	337	462	255	825	32402
D7	2351	10209	366	501	276	995	35051
D8	3871	884	89	119	67	670	11971
D9	877	2682	150	209	117	1105	18591
EXT	1861	896	162	218	118	.	15144
TL	41032	19472	3136	4307	2320	12325	381412

TABLE 3.27: 1981 OD MATRIX: MANAGEMENT by OCCUPATION.

Montreal CMA. HBW person-trips.

Source: 1981 StatsCan customers service, magnetic tapes.

OD1	D1	D10	D11	D2	D3	D4	D5
D1	14356	386	28	1881	1257	535	1070
D10	16978	22015	1670	2935	2831	1007	1982
D11	7099	4313	5810	1205	1136	867	936
D12	5745	1740	140	840	3568	332	2335
D2	21262	941	104	22558	4130	4524	5109
D3	24671	697	125	6071	24568	1437	7258
D4	17020	921	131	9265	2611	19364	6213
D5	10475	422	65	5227	4221	2227	35408
D6	18910	920	234	6333	2668	5418	3044
D7	8309	576	73	5975	1992	4963	6843
D8	4154	252	81	2063	847	2910	1352
D9	4604	356	40	2589	1275	1769	10167
EXT	5113	1336	263	1653	1760	1275	3339
TL	158696	34875	8764	68595	52864	46628	85056

OD2	D6	D7	D8	D9	D12	EXT	TOTAL
D1	1059	199	331	463	298	290	22153
D10	2343	274	520	728	487	1415	55185
D11	2448	169	223	315	207	1405	26133
D12	595	114	105	149	96	530	16289
D2	4124	859	837	1171	771	1045	67435
D3	1977	316	784	1094	719	1155	70872
D4	6807	1575	719	1003	670	765	67064
D5	12[illegible]5	816	481	676	454	1110	62787
D6	22945	741	751	1051	702	760	64477
D7	2490	20131	582	817	543	1100	54394
D8	4163	1631	171	234	153	605	18616
D9	830	4416	267	366	247	1325	28251
EXT	1855	877	243	344	229	.	18287
TL	52841	32118	6014	8411	5576	11505	571943

TABLE 3.28: 1981 OD MATRIX: SERVICES by OCCUPATION.

Montreal CMA. HBW person-trips.

Source: 1981 StatsCan customers service magnetic tapes.

OD1	D1	D10	D11	D2	D3	D4	D5
D1	3928	270	65	1858	900	858	894
D10	5528	13090	1710	2891	3267	1539	3143
D11	2245	2924	2365	889	1356	971	1127
D12	1043	755	75	455	3200	265	2341
D2	5893	783	190	16327	3188	6532	5421
D3	5842	611	141	3105	15121	1284	6582
D4	5250	892	261	10101	3013	20850	6357
D5	2036	236	39	2642	2194	1470	18350
D6	6096	1042	465	6011	3308	6209	3881
D7	2721	426	80	4345	1801	4232	6487
D8	1324	289	140	1658	719	3131	1833
D9	1690	111	56	1959	1114	1467	8672
EXT	3154	1848	526	2079	2939	2174	5599
TL	46750	23277	6113	54320	42120	50982	70687

OD2	D6	D7	D8	D9	D12	EXT	TOTAL
D1	1188	82	270	312	229	265	11119
D10	3290	264	452	505	370	1310	37359
D11	2630	174	229	257	192	1725	17084
D12	409	104	98	110	75	770	9700
D2	4075	921	857	955	708	865	46715
D3	1680	390	628	701	515	930	37530
D4	7342	1872	927	1032	759	1095	59751
D5	864	443	337	376	281	835	30103
D6	19221	969	804	895	657	1305	50863
D7	2403	10428	545	613	454	1180	35715
D8	5613	1272	272	281	193	950	17675
D9	966	2804	316	316	223	1600	21294
EXT	3831	1386	510	566	414	.	25026
TL	53512	21109	6245	6919	5070	12830	399934

TABLE 3.29: 1981 OD MATRIX: LABOUR (L) by OCCUPATION.

Montreal CMA. HBW person-trips.

Source: 1981 StatsCan customers service magnetic tapes.

B-10 DATA ANALYSIS and AGGREGATIONS.

The matrices in the previous tables and those in Appendix A are utilized in this section to produce charts to help visualize their characteristics.

Fig. 3.8 represent in pie chart format, the 1981 StatsCan daily HBW person-trips; aggregated by trip purpose into occupational and industrial totals, from totals in Tables 3.26 to 3.29 and A1 to A6 (Appendix A).

The services at 42% (572 thousand trips) represent the largest occupational group which is in conformity with Canadian and U.S. cities; while the FIRE, and service industries at 37% (507 thousand trips) also represent the largest industrial group.

MONTREAL CMA: 1981 TOTAL HBW TRIPS
STATSCAN DATA

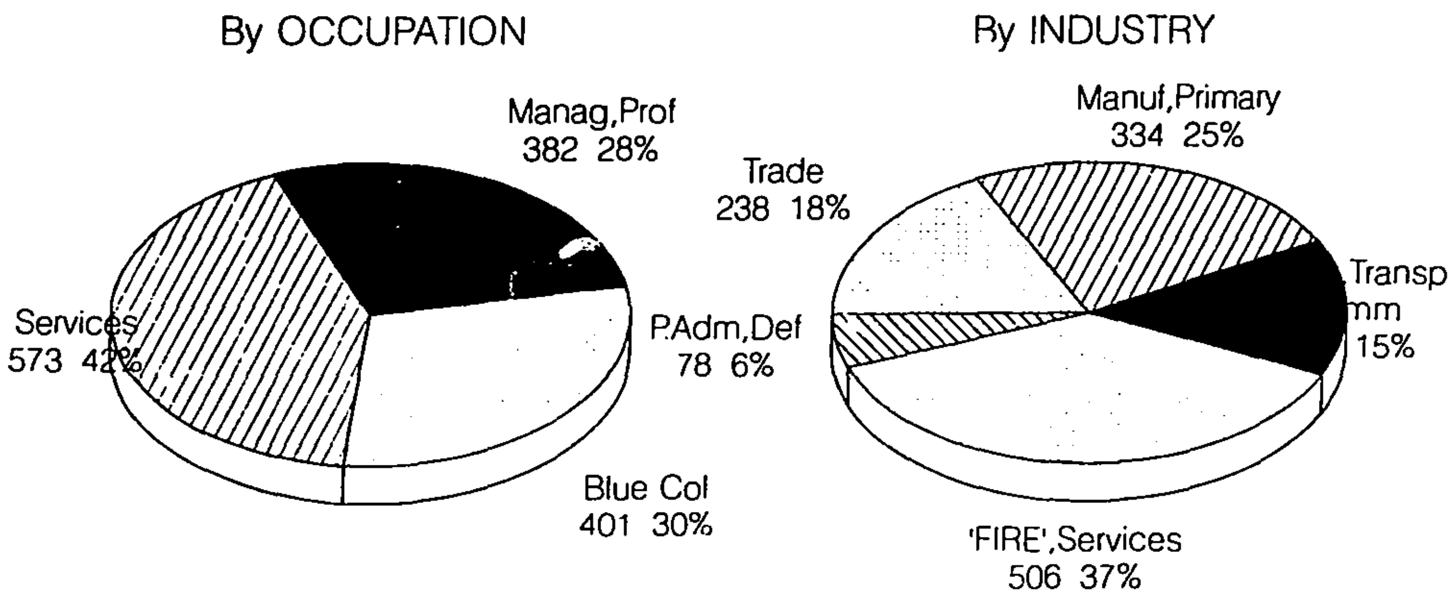


FIG. 3.8: MTL CMA: 1981 TOTAL HBW TRIPS
Person-trips in 1000s & percent

B-10.1 EMP by Occupation and Aggregations

EMP data aggregations by occupation are more representative of trip patterns than by industry. The availability of forecast scenarios by industry (Chapter 6), prompted this research to utilize aggregations by industry.

The research descriptive analyses of EMP by occupation is utilized to control the spatial aggregations of districts and super districts based on the relationships between their attractions and productions by occupation.

District matrices by occupation are shown in bar chart form in Figures 3.9 through 3.12, they are plots of ELF data by occupation from Tables 3.26 through 3.29. Districts with high attractions (high destinations) are, as would be expected, in MTL (districts 1 and 5) but mostly in the CBD (district 1). They are the EMP districts where there is a high imbalance between productions and attractions.

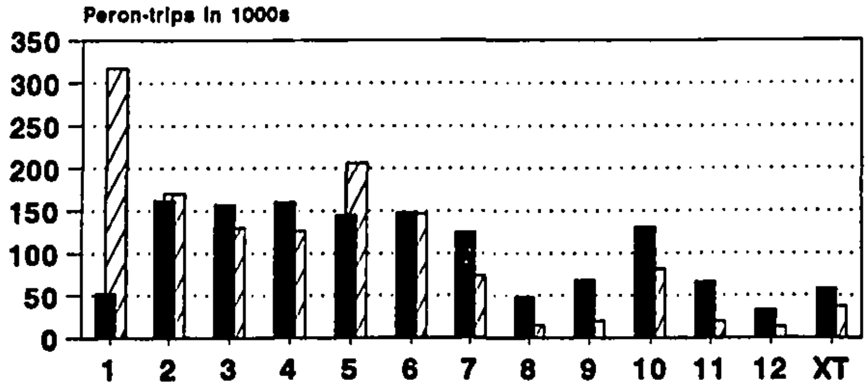
Districts with high percentages of trips originating from, in the AM peak, are known as the 'bed room' districts and are located in the suburbs; specially districts 8 and 9 which represent the North Shore.

Districts 1, 2 and 3 constitute SD #1, and are of particular interest. District #1 (CBD) is a strong EMP 'attractor' in all occupational groups. District #2, the North-east continuation of the CBD that includes Westmount; and District #3, the South-east continuation of the CBD (refer to Fig. 3.7); are both attractors for labour (blue collar labour), while the service and managerial occupational groups have about a balanced supply-demand of productions and attractions in them. These are 'efficient districts' in terms of total Employed Labour Force (ELF) and constitute, together with the CBD, SD #1 i.e., the City Centre.

Furthermore, zones 7 and 8 (Lasalle and Lachine) in D #3 exhibit strong POP decline trends similar to CBD [Lamonde et al. 1989] (Chapter 6), and these are aggregated as a part of the City Centre (SD #1).

District #5 is also of special interest; it is performing as a city centre. It has a net attraction balance of total ELF, and furthermore, it has strong services and labour (blue collar) attraction ability while it is practically balanced concerning managerial jobs.
Consequently, D #5 is a 'super suburb', a high activity super centre and it is kept separate and re-named as SD #2. It has low POP and EMP densities and it is spatially distant; consequently, it is excluded from the City Centre.

MONTREAL CMA: 1981 TOTAL HBW TRIPS
STATSCAN DATA



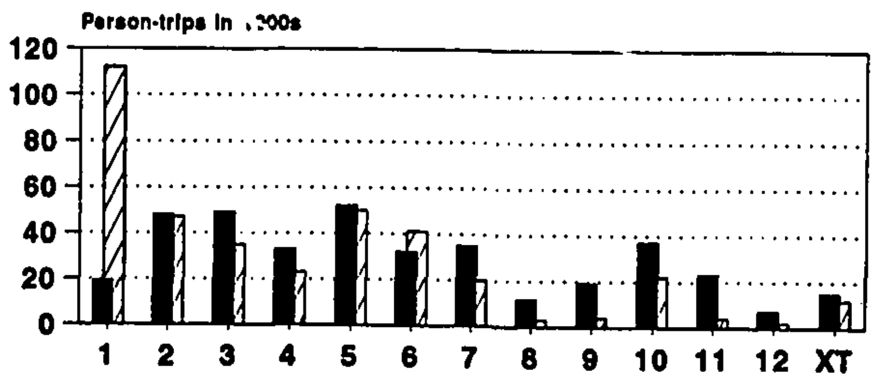
	1	2	3	4	5	6	7	8	9	10	11	12	XT
ORIGINS	52	162	157	160	145	148	125	48	68	130	66	33	58
DESTIN.	317	170	130	126	206	147	73	15	20	81	19	13	37

DISTRICT No.

■ ORIGINS ▨ DESTIN.

FIG. 3.9: MTL CMA: 1981 TOTAL HBW TRIPS

MONTREAL CMA: 1981 HBW MANAGEMENT TRIPS
STATSCAN DATA



	1	2	3	4	5	6	7	8	9	10	11	12	XT
ORIGINS	19	48	49	33	52	32	35	12	19	37	23	7	15
DESTIN.	112	47	35	23	50	41	20	3	4	22	4	2	12

DISTRICT No.

■ ORIGINS ▨ DESTIN.

FIG. 3.10: MTL CMA: 1981 HBW MANGT TRIPS
By occupation.

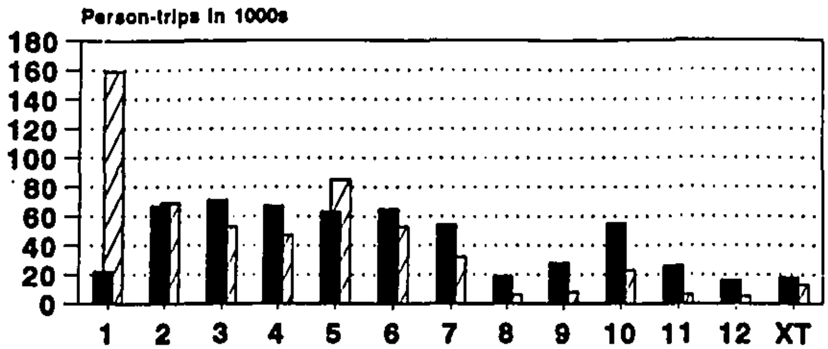
The aggregations of districts 4 and 6 into SD #3 came as a result of their geographical location within the Montreal Is. and due to their similarity in trip attraction-production behaviour in general and service EMP trips in particular. The service EMP trips is of concern to the research (Chapter 6), because EMP is decentralizing from the City Centre and relocating, mostly in SDs 2 and 3, within MTL [Lamonde et al, 1989].

The other aggregations of zones and districts into SDs (SDs 4, 5, and 6) respond to geographical restraints: Laval (Jesus Is.), North Shore, and South Shore.

It is of interest to note that Longueuil, a district in SS, has higher POP and EMP densities than the surrounding area and may have a special status in the analysis of the South Shore. But the main research interest is to analyze the impact of EMP decentralization from the City Centre and consequently Longueuil is not considered any further.

The South Shore is more balanced in terms of supply-demand of EMP than NS, especially D #10 which includes Longueuil. Growth forecasts are stronger for Laval and the BSQ has separate data for Laval. And as a matter of fact, Laval data are given at equal level of importance with MTL and Quebec City in BSQ (1990).

MONTREAL CMA: 1981 HBW SERVICE TRIPS
STATSCAN DATA



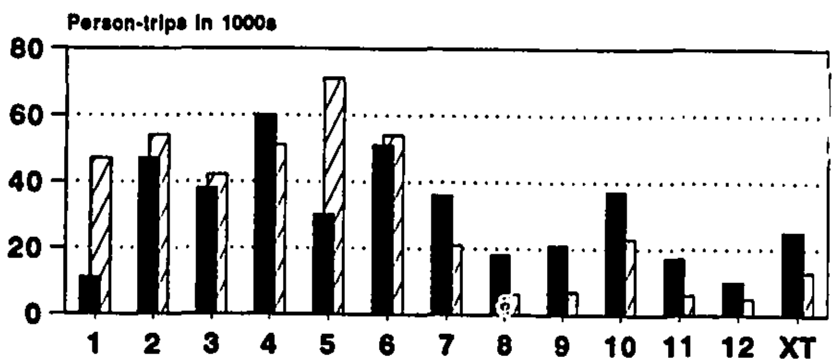
	1	2	3	4	5	6	7	8	9	10	11	12	XT
ORIGINS	22	67	71	67	63	65	54	19	28	55	26	16	18
DESTIN.	159	69	53	47	85	53	32	6	8	23	6	5	13

DISTRICT No.

ORIGINS DESTIN.

FIG. 3.11: MTL CMA: 1981 HBW SERV. TRIPS
By occupation.

MONTREAL CMA: 1981 HBW LABOUR TRIPS
STATSCAN DATA



	1	2	3	4	5	6	7	8	9	10	11	12	XT
ORIGINS	11	47	38	60	30	51	36	18	21	37	17	10	25
DESTIN.	47	54	42	51	71	54	21	6	7	23	6	5	13

DISTRICT No.

ORIGINS DESTIN.

FIG. 3.12: MTL CMA: 1981 HBW LABOUR TRIP
By occupation.

The spatial aggregations of the CMA into six super districts are the base for the supply-demand linkage model (SDLM) development in Chapter 5. The aggregated data is proven to be successful in further analysis throughout the research in general and in the cross sectional analysis in Chapter 5 in particular.

The occupational data are presented in proportional pie chart format in Figures 3.13 through 3.18 showing productions (origins) and attractions (destinations) by SD.

The pie charts highlight that, at the super district level, the highest levels of service EMP (destinations) are actually in the City Centre (45%) and in Montreal West (41%). Furthermore, while SD1 and SD2 have more EMP jobs than ELF residences; the other SDs are EMP exporters.

MONTREAL CITY CENTRE: TOTAL HBW TRIPS
1981 STATSCAN DATA

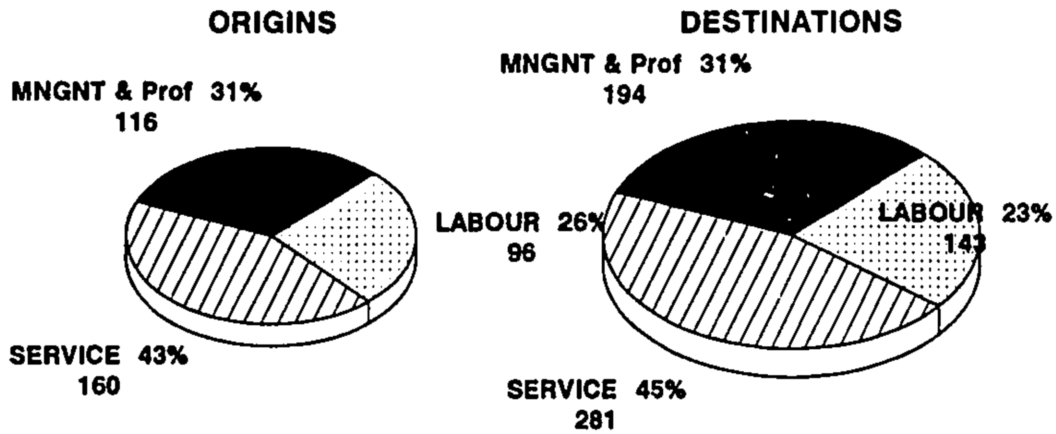


FIG. 3.13: CITY CENTRE: 1981 HBW TRIPS
By occupation; total person-trips.
Figures in 1000s

MONTREAL WEST: 1981 TOTAL HBW TRIPS
STATSCAN DATA

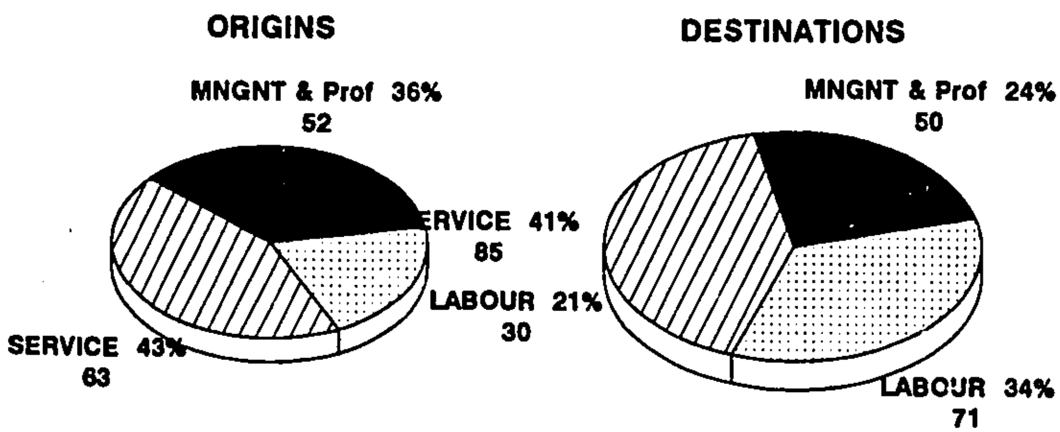


FIG. 3.14: MTL WEST: 1981 HBW TRIPS
By occupation; total person-trips.
Figures in 1000s

MONTREAL EAST: 1981 HBW TOTAL TRIPS
STATSCAN DATA

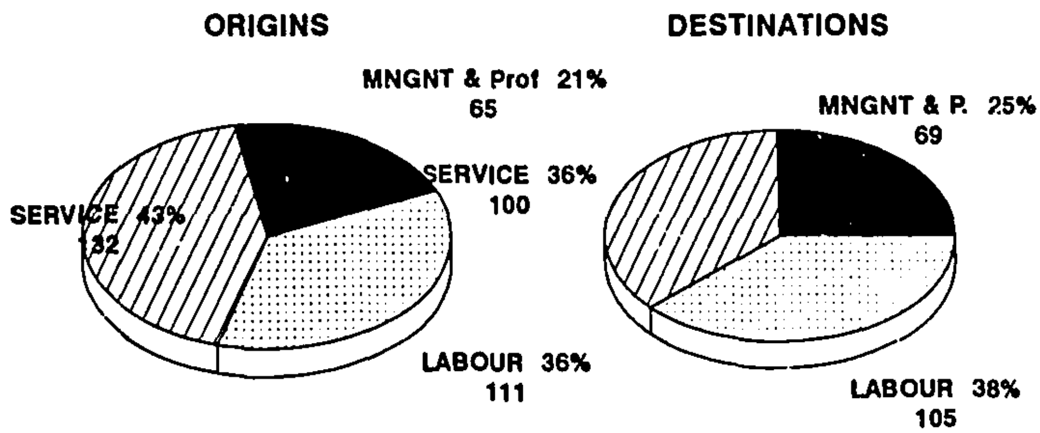


FIG. 3.15: MTL EAST: 1981 HBW TRIPS
By occupation; total person-trips.
Figures in 1000s

LAVAL: 1981 TOTAL HBW TRIPS
STATSCAN DATA

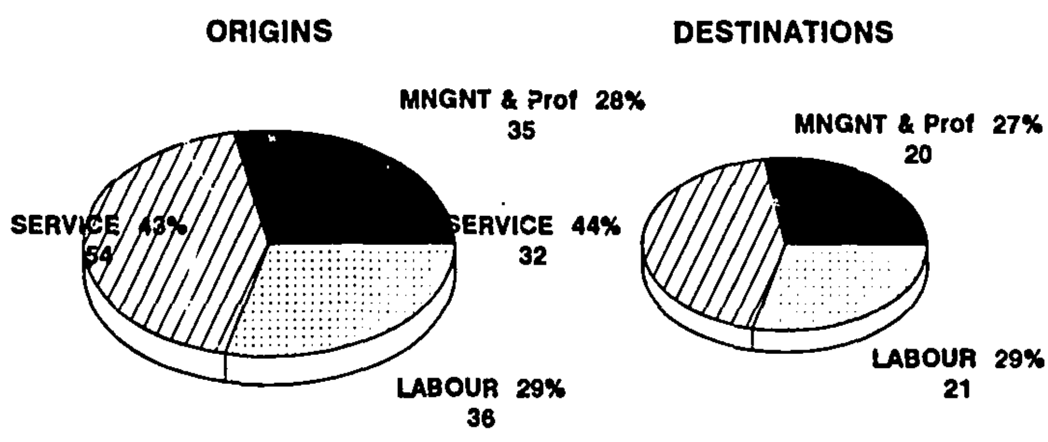


FIG. 3.16: LAVAL: 1981 HBW TRIPS
By occupation; total person-trips.
Figures in 1000s

NORTH SHORE: 1981 TOTAL HBW TRIPS
STATSCAN DATA

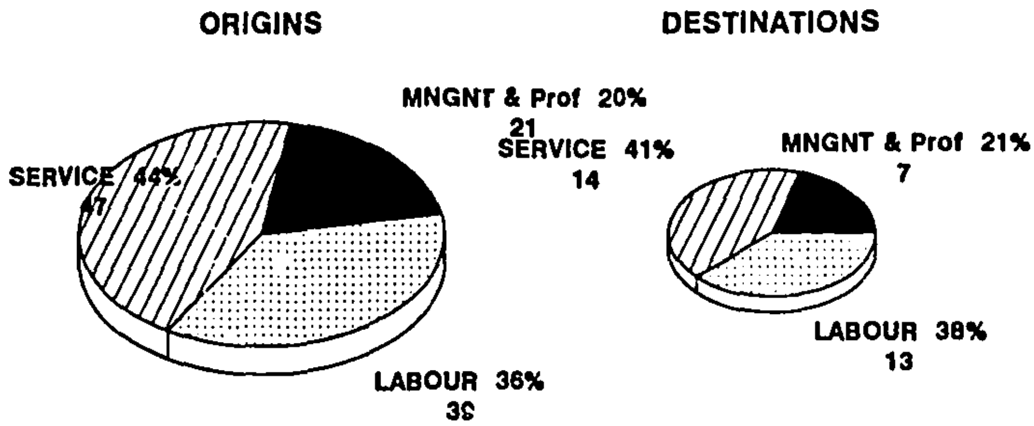


FIG. 3.17: N.SH: 1981 HBW TRIPS
By occupation; total person-trips.
Figures in 1000s

SOUTH SHORE: 1981 TOTAL HBW TRIPS
STATSCAN DATA

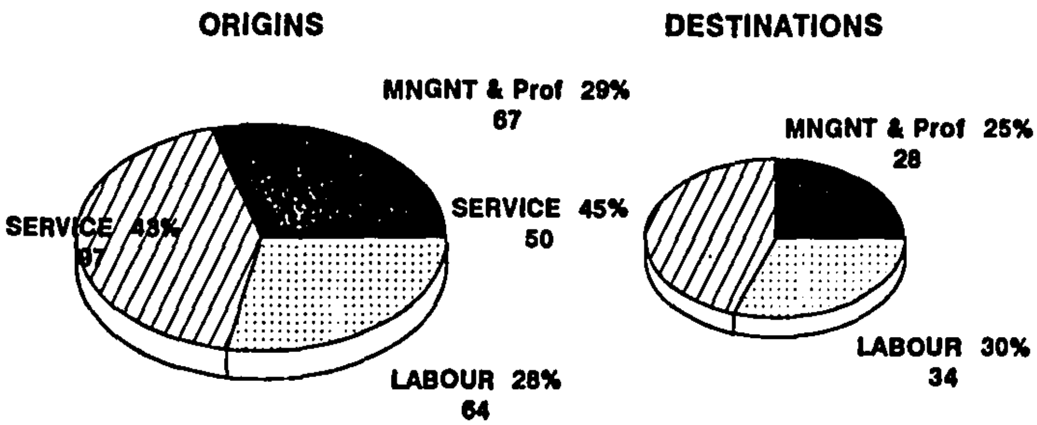


FIG. 3.18: S.SH: 1981 HBW TRIPS
By occupation; total person-trips.
Figures in 1000s

B-10.2 EMP by Industry

The EMP data by industry relate the research SD1 data to MTL and GMA research data, for compatibility purposes, and are needed to understand and relate to other research works like [Lamonde et al. 1989]. Table 3.30 presents StatsCan 1981 data obtained from Appendix A, Tables A.1 to A.6.

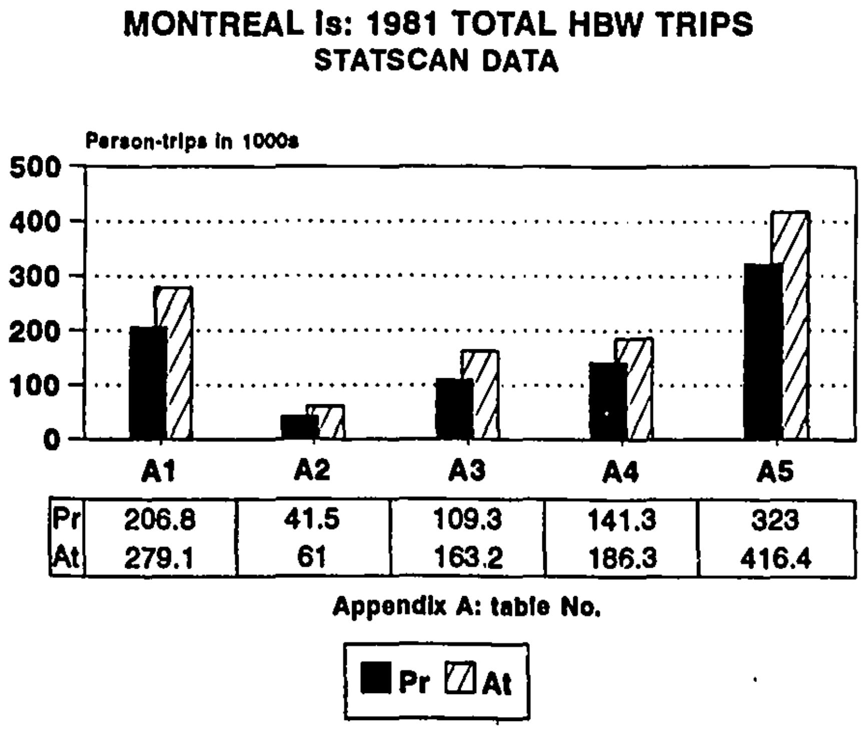
TABLE	IND.	MONTREAL ISLAND (MTL) Pr	At	TOTAL	CITY CENTRE (SD1) Pr	At	TOTAL
A.1	MNFG	206.8	279.1	485.9	86.1	125.4	211.5
A.2	PUBLC	41.5	61.0	102.5	16.5	41.6	58.1
A.3	CONST	109.3	163.2	272.5	44.2	93.8	138.0
A.4	TRADE	141.3	186.3	327.6	60.0	86.7	146.7
A.5	FIRE	323.0	416.4	739.4	163.9	277.0	440.9
TOTAL		821.9	1106.0	1927.9	370.7	624.5	995.2

TABLE 3.30: 1981 EMP Pr and At by INDUSTRY; MTL, SD1.

Summary of matrices. Person-trip figures in 1000s.

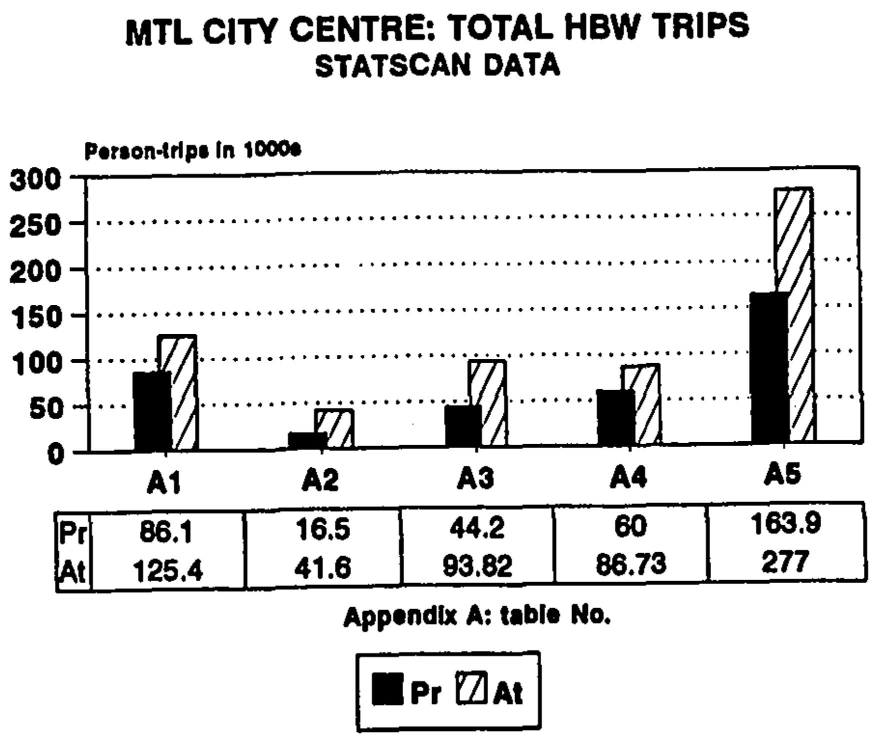
Data source: StatsCan special magnetic tapes.

Figures 3.19 and 3.20 present in bar chart form the 1981 HBW person-trip data in Table 3.30; Pr and At for both, MTL and SD1. The At are bigger than the Pr in all five EMP categories i.e., the Montreal Is. is a net attractor of EMP. Furthermore, the aggregation A.5 'FIRE', an important component of the service industry, has the largest net At positive balance.



	A1	A2	A3	A4	A5
Pr	206.8	41.5	109.3	141.3	323
At	279.1	61	163.2	186.3	416.4

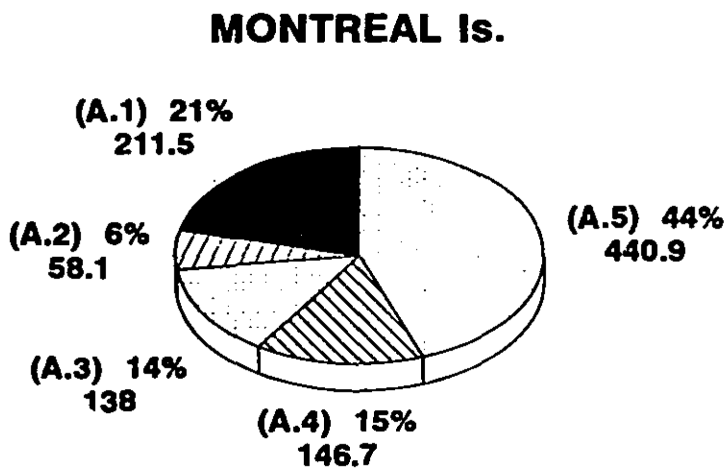
FIG. 3.19: MTL: TOTAL HBW TRIPS
By Industry; total person-trips.



	A1	A2	A3	A4	A5
Pr	86.1	16.5	44.2	60	163.9
At	125.4	41.6	93.82	86.73	277

FIG. 3.20: CITY CENTRE: HBW TRIPS
By Industry; total person-trips.

MTL and CITY CENTRE: HBW TRIPS (At + Pr)
1981 STATSCAN DATA



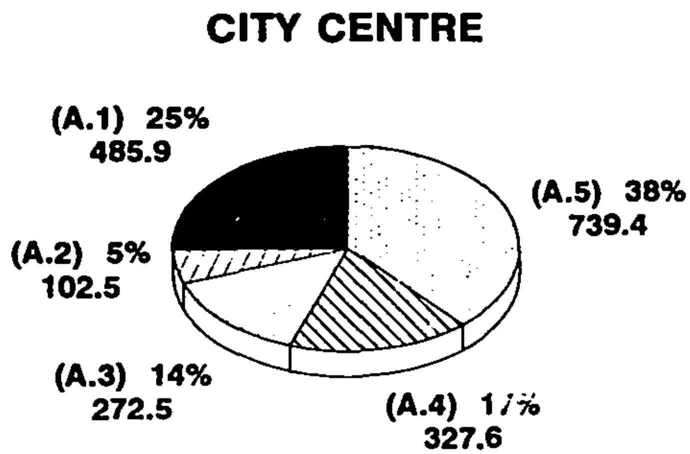


FIG. 3.21: MTL & SD1: 1981 HBW TRIPS
By industry; At & Pr person-trips.
Figures in 1000s

Figure 3.21, in double pie chart form, shows that service industry (aggregations A.2, A.4, and A.5) represent 65% of all HBW trips in MTL and 60% in SD1.

The SD1 data are directly related data to the research City Centre and show that the service EMP share is bigger in MTL outside SD1 i.e., the service EMP decentralization was in progress in 1981. This is further discussed in Chapter 6.

B-11 ZONAL EFFICIENCY

The intra-zonal trips are of special interest to this research as they represent a measure of zonal efficiency. The research intends to put this topic in perspective. Furthermore, the zonal efficiency is quantified as a result of applying the SDLM models in Chapter 6 and thus, the quantified zonal efficiencies (SD efficiencies in the research) become a minor research contribution.

The balance between total EMP attractions and productions or between zonal supply and demand, is a measure of zonal (D or SD) efficiency; the bigger the IZ-trips, the higher the zonal efficiency is expected to be. This is seen in figures 3.22 and 3.23. Furthermore, the larger the percent of IZ-trips, the lower the percentage of trips producing inter-zonal traffic and consequently a higher inter-zonal LOS (lower traffic density) is expected if all other parameters are unchanged (like the infrastructure).

The bar charts in Figures 3.22 and 3.23 depict the supply-demand efficiencies for the districts and super-districts. The intra-zonal (IZ) trips are shown as percentages of zonal attractions and zonal productions e.g., SD1 in Fig. 3.23 has 129 thousand IZ-trips and they represent 35% of all EMP trips produced and 21% of all EMP trips attracted to SD1.

It is of interest to note that in D1, there are 30 thousand IZ-trips and they represent 58% of all work trips originating from and destined to the district i.e., persons residing and working in the same district; but they represent only 9% of the total in-bound work force needed. Thus D1 has low efficiency in supplying residences to persons working in the district but has good efficiency in supplying EMP to residents.

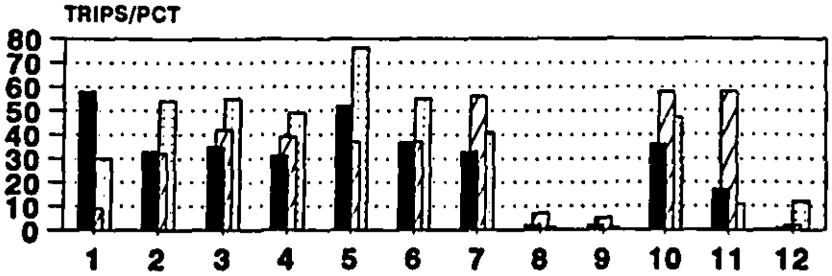
Theoretically speaking, maximum efficiency districts would have 100% in both counts i.e., referring to Fig. 3.22, [ORIG. PCT] and [DEST. PCT] or all trips are intra-zonal trips. Looking from a slightly different point of view, in both figures, the first step towards zonal efficiencies would be measured by a balance in supply-demand between the POR and the POW as advocated by Cervero and others.

This is not entirely satisfactory unless a person elects to have both of his POR and POW in the same district [Cervero, 1989] i.e., we may have a 100% balance between supply and demand without achieving an important zonal efficiency because, although there is a numerical balance between EMP and residences, yet residents in one district are attracted to work in a different district. There is a mismatch between zonal POR and POW.

Figures 3.22 and 3.23 were constructed in a way that the above mismatch is succinctly depicted and they truly represent the supply-demand measure of efficiency, between the POW and the POR, by relating the IZ-trips to attractions and productions. Thus, two conditions must be met to classify a zone as efficient:

1. To have large [Orig. PCT] and [DEST. PCT]; say more than 50%.
2. To have a minimum difference between [ORIG. PCT] and [DEST. PCT].

MONTREAL CMA: 1981 TOTAL HBW TRIPS
DISTRICT SUPPLY-DEMAND EFFICIENCY
STATSCAN DATA



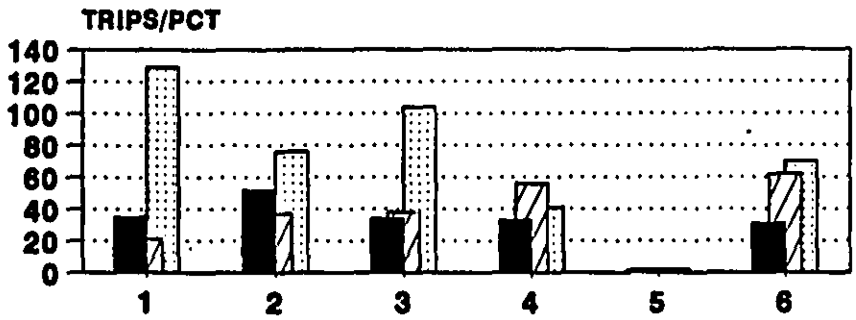
	1	2	3	4	5	6	7	8	9	10	11	12
ORIG. PCT	58	33	35	31	52	37	33	2	2	36	17	1
DEST. PCT	9	32	42	39	37	37	56	7	5	58	58	2
IZ-trips	30	54	55	49	76	55	41	1	1	47	11	12

DISTRICT No.

■ ORIG. PCT ▨ DEST. PCT ▤ IZ-trips

FIG.3.22: SUPPLY-DEMAND EFFICIENCY by D.
Intra-zonal trips (IZ-trips)
Figures in 1000s or in PCT

MONTREAL CMA: 1981 TOTAL HBW TRIPS
SUPER-DISTRICT SUPPLY-DEMAND EFFICIENCY
STATSCAN DATA



	1	2	3	4	5	6
ORIG. PCT	35	52	34	33	2	31
DEST. PCT	21	37	38	56	2	62
IZ-trips	129	76	104	41	2	70

■ ORIG. PCT ▨ DEST. PCT ▤ IZ-trips

FIG.3.23: SUPPLY-DEMAND EFFICIENCY by SD
Intra-zonal trips (IZ-trips)
Figures in 1000s or in PCT

Then, the lower of the two figures (ORIG. PCT or DEST. PCT) represent the zonal efficiency. Referring back to Fig. 3.22, D1 has an EMP efficiency of 9% only and this is a main concern in all CBD's and is the main source of traffic congestion.

It may be stated that efficiency at both levels, attractions and productions, are needed to call a certain zone efficient. Above 50% figures, at both levels (ORIG. and DEST.), would probably qualify a zone as efficient in terms of zonal work force supply-demand. Further research is needed on this subject.

CHAPTER 3

Part C: 1982-1987 STCUM DEMAND DATA

C-12 RESEARCH DATA BASE

The demand data, used in the travel demand model and the SDLM, were obtained from the STCUM files, contained in their computer main frame MVS using SAS software.

Data were available for the survey years: 1970, 1974, 1978, 1982, and 1987. As mentioned earlier in the General Introduction, it is unfortunate that only the 1982 and 1987 data base relationships were comparable, regarding the zone numbers and spatial GMA boundaries.

The demand data retrieved and used in this research are for the year 1982 (partial), and more in depth for the year 1987, because all modelling works use the latest 1987 data.

The STCUM (1987) data survey by phone, was carried out during evening hours on autumn weekdays and then expanded using 1986 StatsCan data. Thus, the data are actually for the year 1986 but labelled 1987.

The survey sample of 4.86% of GMA households, had a reliable response of around 80%. It was conducted over a period of several months; consequently, the weekly and monthly variations were aggregated. Responses tended to aggregate the home departure time into half-hour intervals leading to non-realistic peak hour factors (PHFs).

To capture the morning peak hour period and the PHF, trip variations during the day were retrieved in 15 minute periods for the morning rush hours, 6 AM to 9 AM, for work and education trip purposes only. The data were further categorized, time-wise, in two groups: midnight to 6 AM, and 9 AM to midnight to complete the 24 hours period.

The multi-modal trips were elaborately coded using binary formats, in a way that data can be retrieved using any modal designation priority. Data retrieval for the research was categorized in two priorities: automobile and surface transit priority for 1987.

The surface transit priority was used in the travel demand model calibration as it better represents the City Centre as destination where the congestion is high and where the travel pattern, for bi-modal trips, usually starts at the POR by an auto-trip to a multi-modal station or transit station and continues by a transit-trip to the POW.

The data obtained were categorized into trip purposes: work, education, home return (footnote #[1]), others, and no-trips.

Furthermore, each trip purpose was further classified by mode: auto, surface transit, rail (metro and train) transit, and others. The auto mode was cross classified as: auto driver and auto passenger to obtain auto occupancy ratios.

More than a hundred OD matrices for the 38 zones were retrieved from the 1987 STCUM data bank. Additional zonal matrices for 1982 and 1987 were also retrieved to calibrate production and attraction regression models. Zonal car ownership data were also retrieved.

Footnote #1:
The STCUM data base treats the return home trip as an aggregated trip purpose thus, any trip is a directional one starting at POR. Except, of course, the home return trip.

C-13 BOUNDARIES for the RESEARCH ZONES

The boundaries for the 38 large zones, defined in Part B and outlined in the General Introduction to this chapter, were used wherever compatible with the STCUM 1496 zones, otherwise the boundaries of the 1496 STCUM zones are used. Consequently the criteria for zone boundaries, as defined in Part B, remain unchanged. The zones are shown in Fig. 3.24.

As mentioned earlier, the zone boundaries are based on the 1496 zones defined by the STCUM in 1970 and redefined in 1982. Apparently the defining criteria for the STCUM zones were related to the road network system at that time.

The STCUM 1496 zones were aggregated into 38 zones, when they are located within the CMA boundaries, following closely the boundaries established in Part B (CT boundaries) and one external zone (EXT) representing the STCUM zones located outside the CMA.

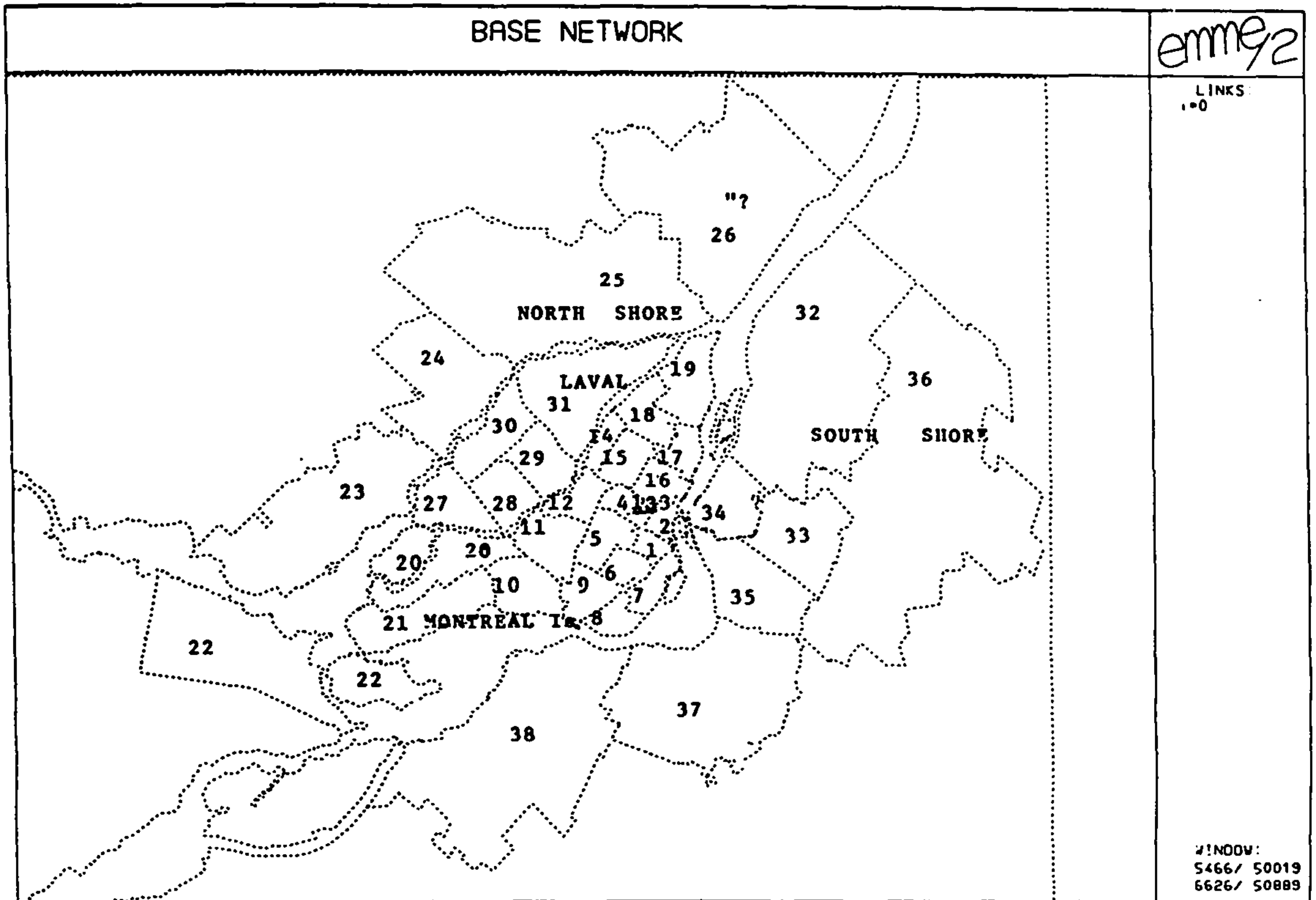


FIG. 3.24: GMA PLAN; 1496 STCUM ZONES AGGREGATED INTO 38 ZONES

DATE: 92 12 08
MODULE: 2.13
INRODEMO...MGH

The zonal equivalency, between the research 38 zones and the 1496 STCUM zones, is given in Appendix B as part of the SAS software program (Proc Format). Furthermore, the aggregation of the 38 zones into 12 districts (Ds) and 6 super districts (SDs), as seen in Part B, was revised and zone #22 was shifted into SD6 as mentioned earlier Part B.

C-14 1987 ORIGIN DESTINATION MATRICES

The available matrices would fill more than three hundred pages of the thesis so only a summary and the most relevant aggregated results are listed in the following subsections. The data were strictly retrieved and compiled from the MVS of the main frame computer through personal efforts and the writing of several SAS programs.

A search of four sequential 15-minute time periods, between 6 AM and 9 AM, for work and educational purpose trips, the morning peak traffic, concluded by adopting the 7:00 to 8:00 AM as the morning rush hour.

This is an aggregate analysis and does not take into consideration the spatial peaking traffic variations over time. It is an extremely complex issue beyond the scope of the research and it is not of importance at the sketch planning level.

C-14.1 Work Trips

The work purpose person-trip constitutes the largest component of the morning rush hour trips, 6:00 to 9:00 AM period. Tables 3.31 and 3.32 summarize the total HBW person-trips, by mode, time of day and modal priorities.

Table 3.31 presents the 1987 HBW person-trips with surface transit (surf. Tr.) priority for trips using a multi-modal transportation system. The designation "STCUM magnetic tapes" is used for all data retrieved from the MVS of the main frame computer.

TIME MODE	**0-6**	**6-7**	**7-8**	**8-9**	**9-24**	**DAILY**
Auto	40.34	144.0	249.9	206.8	237.5	878.6
Surf.Tr.	9.712	41.54	80.16	53.76	46.63	231.8
Rail Tr.	0.910	6.876	21.65	19.60	14.24	63.3
Others	1.211	4.555	15.27	20.13	30.49	71.7
Total	52.2	197.0	367.0	300.3	328.9	1245

TABLE 3.31: 1987 TOTAL HBW TRIPS: SURFACE TRANSIT PRIORITY.

By mode and time of day. Summary of OD matrices.

Person-trip figures in 1000s.

Data source: STCUM magnetic tapes.

Similar to Table 3.31, Table 3.32 presents, the total HBW person-trips by mode and time of the day for the auto-mode priority.

TIME MODE	0-6	6-7	7-8	8-9	9-24	DAILY
Auto	40.95	149.0	261.0	210.8	239.6	901.5
Surf.Tr.	9.370	397.1	77.45	52.77	45.89	225.2
Rail Tr.	0.636	3.679	13.26	165.1	12.87	47.0
Others	1.211	4.555	15.27	20.13	30.50	71.7
Total	51.8	197.0	367.0	300.3	328.9	1245

TABLE 3.32: 1987 TOTAL HBW TRIPS: AUTO PRIORITY.

By mode and time of day. Summary of OD matrices.

Person-trip figures in 1000s.

Data source: STCUM magnetic tapes.

The results in Tables 3.31 and 3.32 show that the trip difference between the auto and surface transit priorities is rather small, in the order of 3% on totals; certainly, it also varies spatially and by time of the day.

TIME MODE	0-6	6-7	7-8	8-9	9-24	DAILY
Auto driver	36.37	126.4	220.1	186.6	216.0	785.5
Auto pass.	4.274	222.8	40.27	22.92	20.62	110.4
Total	40.6	148.7	260.4	209.5	236.7	895.9

TABLE 3.33: 1987 TOTAL HBW TRIPS: AUTO DRIVERS and PASSENGERS

Auto priority by time of day. Summary of OD matrices.

Person-trips figures in 1000s.

Data source: STCUM magnetic tapes.

Table 3.33 presents the auto mode, auto mode priority, cross classified as auto driver and auto passenger. This permits the computation of the auto occupancy ratio.

Results from 15 minutes trip counts permitted the computation of the peak hour factor, (footnote #2) **PHF=0.70**. The surveyed results were probably biased as the answer to the time leaving home question were excessive at the hour and half past while those at 15 and 45 minutes past the hour were comparatively small. Furthermore, this is an aggregated PHF at the home end and not for the City Centre: that is, the spatial variation over time was not taken into consideration.

The auto-occupancy factor is obtained from results in Table 3.32, for the 7-8 AM peak, and is: **auto-occupancy=1.18**. The data analysis shows that 87% of the auto-passengers do not own cars i.e., 87% of the auto passengers are captive drivers.

Thus, car sharing in the GMA is much lower than the average found in the U.S., with an average aggregate occupancy factor of 1.38 [NCHRP special Report #187, 1978] which is used as a default value in some UTMS models.

C-14.2 Education Trips

The education purpose trip is the next in importance, after work purpose trips, contributing to the morning rush hours

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Footnote #2:
PHF = 261029 / (4 * 92978) = 0.702

congestion. Table 3.34 presents the educational purpose trip summary by mode and time of day for the auto priority.

TIME MODE	0-6	6-7	7-8	8-9	9-24	DAILY
Auto	0.428	3.610	31.51	41.16	53.52	132.0
Surf.Tr.	0.283	8.926	131.4	119.5	77.16	337.3
Rail Tr.	0.019	0.289	3.902	4.648	10.16	19.0
Others	0.082	0.390	30.20	121.8	96.08	248.5
Total	0.812	13.21	197.0	287.1	236.9	736.8

TABLE 3.34: 1987 EDUCATION PURPOSE TRIPS.

Auto-priority by mode and time of day. Summary of OD matrices.

Person-trips figures in 1000s.

Data source: STCUM magnetic tapes.

Table 3.34 ıesults show that the education purpose person-trips, obtained from the 38 zones OD matrices for the GMA, represent 53% (or 197.0/367.0) of total person-trips during the AM peak hour, while they represent only 12% (or 31.51/261.0) of the auto mode i.e., most educational purpose trips, during the AM peak hour, use surface transit mode (66.70%) as expected.

C-14.3 Total Trips

The total person-trips were retrieved from the STCUM using a separate program in order to double check the results by comparing a result with the sum of its components.

PURPOSE MODE	WORK	EDUC.	HOME RET.	OTHER	ALL PURPOSE
Auto	901.5	132.0	1744	1169	3947
Surf.Tr.	225.2	337.3	662.1	177.7	1402
Rail Tr.	46.96	190.1	77.72	371.8	180.9
Others	71.65	248.5	482.9	218.6	1022
Total	1245	736.9	2967	1603	6552

TABLE 3.35: 1987 DAILY TRIPS by MODE and PURPOSE.

Auto-priority. Summary of OD matrices.

Person-trip figures in 1000s.

Data source: STCUM magnetic tapes.

Table 3.35 presents the total daily person-trips, by mode and by purpose for the GMA. The STCUM data coding system considers all return home trips as a special purpose trip thus, whenever person-trips are quoted, data are given for one-way trips, from home outbound.

TIME MODE	0-6	6-7	7-8	8-9	9-24	DAILY
Auto	48.37	166.3	344.0	321.3	3046	3926
Surf.Tr.	11.37	52.24	217.7	182.9	959.7	1424
Rail Tr.	0.892	4.106	17.61	22.30	136.0	180.9
Others	2.019	6.011	50.44	155.2	808.0	1022
Total	62.6	228.7	629.8	681.7	4950	6552

TABLE 3.36: 1987 TOTAL TRIPS by MODE and TIME OF DAY.

Transit priority. Summary of OD matrices.

Person-trip figures in 1000s.

Data source: STCUM magnetic tapes.

Table 3.36 presents the total person-trips in the GMA aggregated by mode and by time of day. The auto mode alone represent 60.24% of the daily person-trips, the main source of congestion on the road network.

Table 3.36 results show that although there are more total person-trips made between 8:00 and 9:00 AM, in equivalent passenger car figures, there are more 7:00 to 8:00 AM trips.

C-15 ZONAL DATA

The STCUM data bank is also coded by POR thus, the retrieval of zonal data (attractions, productions, and others) are possible. The data retrieval were limited to 1987 due to budget restraints yet a very few variables were picked for 1982 to complete basic concepts. The 699 zones and their areas in square kilometres, and their x-y coordinates (centre of gravity coordinates) were obtained from the MOTQ.

Table 3.37 presents the zonal car ownership, aggregated into auto-ownership per person: 1, 2, 3, and 4+. The last column gives the total number of cars per zone, compiled from several matrices.

Z	PERSONS/ZONE 0	1	OWNING 2	CARS: 3	4+	CARS/ ZONE
1	30034	12320	458	0	0	13236
2	31733	10643	186	0	0	11015
3	31366	10529	189	0	0	10907
4	44363	15961	315	0	0	16591
5	99599	40653	2385	100	19	45818
6	61974	32516	1157	143	20	35359
7	71757	33076	1108	120	0	35652
8	48044	26421	1137	68	23	29014
9	54985	28376	1798	125	25	32472
10	20965	13216	898	100	20	15412
11	43003	25717	1471	102	0	28965
12	64514	38750	1834	65	22	42723
13	74479	28664	730	22	0	30190
14	68518	33561	1716	188	0	37557
15	86387	44471	3148	229	25	51579
16	89754	39820	1173	105	0	42481
17	55762	32772	1471	64	0	35906
18	42018	25503	1503	64	0	28701
19	28726	18283	1071	21	0	20488
20	56780	37766	4999	268	19	48663
21	36409	28327	2675	213	18	34406
22	23965	20043	2102	107	82	24976
23	32171	23447	2351	145	55	28859
24	38118	29087	3293	165	21	36273
25	44337	29776	3401	155	19	37138
26	43377	28962	3653	194	0	36850
27	16961	12800	1286	87	41	15838
28	34928	24563	2204	242	0	29697
29	48363	35975	2477	134	61	41636
30	31248	22898	2519	116	20	28384
31	25510	20288	1263	213	27	23588
32	37003	26477	2926	164	59	33116
33	33633	21779	2573	98	19	27314
34	75264	46669	3059	200	44	53607
35	79002	49287	4262	106	40	58329
36	40286	30090	3748	284	45	38663
37	24698	17617	2299	74	0	22437
38	31016	18870	2665	53	0	24359

TABLE 3.37: 1987 ZONAL CAR OWNERSHIP.

Summary of zonal matrices.

Data source: STCUM magnetic tapes.

Z	CARS	AREA-KM2	HHLD	POP	DEN
1	13236	7.5	25454	42812	5708
2	11015	4.5	23278	42562	9458
3	10907	5.6	20575	42084	7515
4	16591	5.2	29215	60639	11661
5	45818	24.3	59085	142755	5875
6	35359	13.2	43435	95810	7258
7	35652	19.8	46290	106082	5358
8	29014	16.0	29355	75693	4731
9	32472	22.6	36561	85309	3775
10	15412	36.9	13996	35199	954
11	28965	35.0	27142	70293	2008
12	42723	20.2	46347	105200	5208
13	30190	9.2	47928	103895	11293
14	37557	13.1	42160	103982	7938
15	51579	22.5	51141	134260	5967
16	42481	18.4	61722	130852	7112
17	35906	18.5	37796	90109	4871
18	28701	27.9	24275	69110	2477
19	20488	40.4	17128	48100	1191
20	48663	69.2	32756	99851	1443
21	34406	63.6	23098	67661	1064
22	24978	207.2	15782	46330	224
23	28859	200.4	19457	58169	290
24	36273	105.5	23958	70683	670
25	37138	357.6	25630	77689	217
26	36850	297.4	24742	76205	256
27	15838	36.4	10245	31175	856
28	29697	30.9	22397	61937	2004
29	41636	34.8	32846	87079	2502
30	28384	43.3	17859	56800	1312
31	23588	98.6	15980	47321	480
32	33116	334.2	21104	66629	199
33	27314	72.4	18558	58123	803
34	53607	45.0	48441	125258	2784
35	58329	78.1	45522	132717	1699
36	38663	527.9	25524	74452	141
37	22437	226.7	14614	44705	197
38	24359	326.2	17081	52604	161

TABLE 3.38: 1987 ZONAL CARS, AREAS, HOUSEHOLDS, POP, DEN (POP).

Summary of zonal matrices.

Data source: STCUM and MOTQ.

Table 3.38 presents 1987 zonal data retrieved from STCUM, MOTQ, and computational results for cars, population, number of dwellings, areas in square kilometres, and population densities per zone in persons per square kilometres. Zones 4 (SD1), and 13 (SD3) have the highest population densities while, zones 5, 15, and 16 in MTL; and zones 34, and 35 in the South Shore have more than a hundred twenty thousand inhabitants.

C-16 OTHER RESEARCH FINDINGS

The following four sub-sections present a short descriptive analysis of the 1982-87 socio-demographic STCUM data.

C-16.1 Cross Tabulations: Mode, Auto-Ownership

Table 3.39 presents the person-trip cross tabulation of auto-ownership per household by mode; the rail transit mode is split into its two components: metro and train.

Results in Table 3.39 show marginal figures for the train mode of transport as a total and relative to the auto mode.

CARS PER HHLD MODE	0/HHLD	1/HHLD	2+/HHLD	TOTAL
Auto	96	1983	1873	3952
Surf.Tr.	426	630	342	1398
Metro	818	69	17	904
Train	2	8	4	14

TABLE 3.39: 1987 TOTAL TRIPS by MODE and AUTO-OWNERSHIP per HOUSEHOLD.

Summary of zonal matrices.

Person-trip figures in 1000s.

Data source: STCUM magnetic tapes.

Table 3.40 presents the 1987 person-trips by auto-ownership as obtained from a summary of zonal matrices.

AUTO OWNERSHIP	0 CAR	1 CAR	2 CARS	3+ CARS
Persons	1800	1020	71	5
Person-trips	4090	2810	216	16
Trips/person	2.27	2.75	3.04	3.2

TABLE 3.40: 1987 TOTAL TRIPS by AUTO OWNERSHIP.

Summary of zonal matrices.

Person-trip figures in 1000s and ratios.

Data source: STCUM magnetic tapes.

Table 3.40 shows an important link between auto ownership and person trips in the GMA. The greater the availability of cars, the more trips are made. This may be a further indication of the growth of other purpose trips like recreational trips.

Listed below are other statistics computed using the STCUM 1987 matrices:

1. The average available number of cars per household is: 1.04 auto/hhld.

2. The average available number of cars per person is: 0.40 auto/person.

3. The total number of households is: 1.13 million.

4. The average household size is: 2.58 persons/hhld.

C-16.2 Cross-Tabulations: Mode, Time of Day

Table 3.41 presents a tabulation of the percentage share by mode and trip purpose, for the morning peak hour traffic flow, 7-8 AM one way in person-trips, and the corresponding figures for 24 hours.

MODE	**TOTAL PERSON-TRIPS**		**HBW PERSON-TRIPS**	
TIME	**7-8 AM**	**DAILY**	**7-8 AM**	**DAILY**
Auto	54.6	59.9	68.1	70.6
Surf.Tr.	34.6	21.7	21.8	18.6
Rail transit	2.8	2.8	6.0	5.0
Other	8.0	15.6	4.1	5.8
Auto mode	61.3	73.4	75.8	79.1
Surf.Tr.	38.7	26.6	24.2	20.9

TABLE 3.41: 1987 DAILY and PEAK HOUR TRIP SHARE.

By mode for total and HBW trips.

Person-trip figures in PCT.

Data source: STCUM magnetic tapes.

It is evident that, referring to Table 3.41, the most important mode with the largest share leading to congestion, is the auto-mode accounting alone for more than fifty percent of the total trips.

The 'other' modes, mostly walking and bicycles, and the rail transit mode do not contribute to vehicular traffic flow on the road network and consequently are not considered. The results, auto and surface transit mode trips, are shown in the lower part of Table 3.41.

Furthermore, at the traffic congestion level, the equivalent passenger car (EPC) is used in computations of traffic density and the like. The EPC for a bus (one surface transit) is 2 and a bus has an average occupancy in peak hour of 50 persons i.e., a bus person-trip is equivalent to 0.04 auto person-trip. This is based on NCHRP (1978) bus equivalent and bus occupancy default values (footnote #[3]) which is consistent with HCM (1985).

Thus, the modal share in the morning peak hour in terms of traffic flow are listed below:

1. 98.7% (footnote #[4]) of the HBW trips, in equivalent passenger cars, are made using the auto-mode.

Footnote #3:
1 bus has an average of 50 passengers and is equivalent to 2 passenger cars (traffic congestion wise) on the road network.

Footnote #4:
From Table 3.31: 100 * 249935 / (249935 + 0.04 * 80157) = **98.73%**

2. 97.5% (footnote #[5]) of all purpose trips, in equivalent passenger cars, are made using the auto-mode.

Therefore, it may be concluded that, the effect of other than the auto-mode on road traffic congestion in the morning peak hour, is marginal (in equivalent passenger car terms) to the research for sketch planning purposes.

The results in Table 3.41 show that the auto-mode represents 61.3% of the total AM peak hour person-trips and 75.8% of the HBW trips, thus emphasizing its predominance.

C-16.3 Tabulations: Age Groups, Other Results

Table 3.42 presents the 1987 population categorized in three age groups in person-trips, and week-day trips per person. It is relevant to note that the 1987 POP with no trip made the previous day of the survey, was 0.595 millions. This is rather large.

Table 3.42 confirms the well known fact that the 18-64 age group has the largest person trip ratio. Further, it was seen in Part A that the 35-39 age group had the highest daily person-trip per capita.

Footnote #5:
From Table 3.36: 100 * 344040 / (344040 + 0.04 * 217674) = 97.53%

AGE GROUP	0-17	18-64	65+	TOTAL
Persons	648.7	1999	293	2930
Person-trips	1610	5020	535	7165
Trips/Person	2.48	2.51	1.83	2.45

TABLE 3.42: 1987 ESTIMATED TRIPS by AGE GROUP.

Person-trip figures in 1000s and ratios.

Data source: STCUM magnetic tapes.

C-17 DATA ANALYSIS and COMMENTS

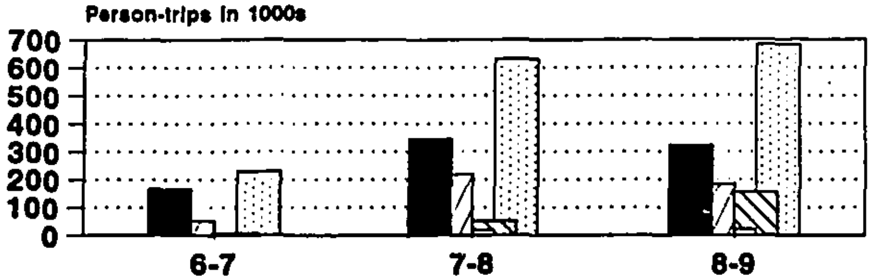
The research demand data were presented and commented upon in the previous sections, and further considerations shall be highlighted in due course in chapters 4, 5, and 6.

There are minor differences in total parametric values between zonal totals and OD data totals. This is due to rounding up of figures and probably minor differences in expansion factors used to expand the survey sample into total POP. Though, the data shown in each table or figure are consistent.

Fig. 3.25 presents the morning rush hours period, 6 to 9 AM, in total person-trips in the GMA. Although the total trips per hour are greater for the hour starting at 8 AM, the peak hour for the vehicular traffic is the 7 to 8 AM as discussed earlier. It depicts the auto-mode as the dominant mode.

Fig. 3.26 presents the morning rush hours HBW person-trips. The peak hour is more evident for the work purpose trips.

1987 GMA RUSH HOURS TRIPS by MODE
STCUM DATA

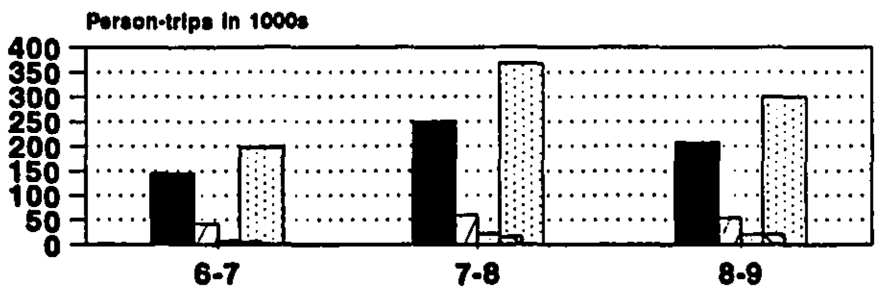


	6-7	7-8	8-9
auto	166	344	321
surf.T.	52	218	183
rail T.	4	18	22
others	6	50	155
total	229	630	682

auto surf.T. rail T. others total

FIG. 3.25: 1987 GMA RUSH HOURS TRIPS
By mode; person-trips.

1987 GMA RUSH HOURS WORK TRIPS
STCUM DATA by MODE



	6-7	7-8	8-9
auto	144	250	207
surf.T.	42	60	54
rail T.	7	22	20
others	5	15	20
total	197	367	300

auto surf.T. rail T. others total

FIG. 3.26: 1987 GMA RUSH HOUR WORK TRIPS
By mode; person-trips.

The minor differences in the morning rush hour period, between 7-8 and 8-9 AM person-trips is an outstanding characteristic of the Greater Montreal Area. It may be attributed to several factors:

1. Time-flex, flexible time to start work; implemented in most governmental offices in the case study.
2. The highly subsidized public transport system in Canada. This permits the spatial spread of the traffic peak because it takes more time to travel using the transit mode.
3. The relatively expensive parking spaces and their low availability in the City Centre.
4. The in-bound congestion at most river crossings and consequent preference for the mass transportation system.

Another salient feature of the GMA is the low auto-occupancy figure of 1.18 as compared to 1.38 for the U.S. It may be attributed to:

1. The lack of car-pooling, van-pooling, and very few ride-sharing trips.
2. The highly subsidized public transport system and its spatial spread and frequency, do not encourage ride-sharing of any kind.

CHAPTER 3

Part D: RELATIONSHIPS AMONG VARIABLES

D-18 INTRODUCTION

This research investigates the relationships between demand and supply measures as represented by traffic lane densities (DEN) at the sketch planning level, a direct measure of LOS as presented in Chapter 1. DEN is obtained from the trip-link frequency distribution and is modelled against demand (DEM) in Chapter 5 in order to develop the SDLM models.

To obtain the "Impact of Employment Decentralization on Metropolitan Road Networks", the SDLM models are applied on EMP and POP forecasting scenarios in Chapter 6. There is a need to translate POP and EMP data into DEM equivalent data to be used in the SDLM models. This is done in two parts:

1. At the zonal aggregation level in Part D.
2. At the super district aggregational level in Chapter 6.

This split analysis was necessary, at this level in research progress, due to missing information about aggregational data which are obtained from the cross sectional analyses in

Chapter 5. Furthermore, the SDLM final supply-demand measures are not defined yet; consequently, the relationships among several variables and supply-demand measures are explored herein to establish their potential for use in the SDLM.

Also presented herein are several factors computed from the research data base (mostly from Part C) which are useful in scenario data translations in Chapter 6 and in descriptive analyses of the case study.
Finally a summary statement on Chapter 3 is presented.

D-19 RELATIONSHIPS AMONG VARIABLES

Several models are calibrated from data retrieved from the STCUM for use in the research in general and in Chapter 6 in particular. Other GMA data sources, covered in the first three parts of this chapter are of importance as supplemental information and define over time trends in general and are of great importance to the research for EMP forecasting by industry, also presented in Chapter 6.

Several models are calibrated at the zonal aggregation level, using multivariate analyses, relating demand variables, while model calibrations at the SD aggregation level are presented in Chapter 6.

D-19.1 Dependent-Independent Variables

Several independent variables and their relationships are scrutinized at the zonal aggregation level such as: (a) work trips (TW); (b) population (POP); (c) households or dwelling units (DU); (d) total car ownership (CAR); and (e) peak hour work trips (PHW). Table 3.43 presents the zonal data summarized from STCUM 1987 survey matrices at the POR.

Three dependent variables are scrutinized: (a) total trip productions (Pr); (b) total trip attractions (At); and (c) total intra-zonal trips (IZ). Furthermore, two dependent measures and their relationships with the dependent variables are analyzed: (a) total net demand (DEM), defined as [DEM=Pr+At-IZ]; and (b) total demand (DEM2), defined as [DEM2= Pr+At]. The dependent variables are also presented in Table 3.43, DEM and DEM2 are computed each time in the multivariate analyses.

Z	AVERAGE DAY FIGURES				PEAK HOUR (7-8 AM) FIGURES			
	CAR	DU	POP	TW	PHW	Pr	At	IZ
1	13236	25454	42812	29953	2498	2693	32385	578
2	11015	23278	42562	24260	2045	2184	14640	253
3	10907	20575	42084	17580	2008	2214	5486	216
4	16591	29215	60639	27243	2264	2534	5258	168
5	45818	59085	142755	56268	6984	8951	16085	183
6	35359	43435	95810	41468	5907	7137	9861	1307
7	35652	46290	106082	44274	6921	8615	6387	2356
8	29014	29355	75693	32856	6651	7333	4478	1627
9	32472	36561	85309	32973	6674	8002	6120	1431
10	15412	13996	35199	16178	3816	4063	10086	878
11	28965	27142	70293	33432	6973	8486	17846	2259
12	42723	46347	105200	49005	9772	10900	16454	2120
13	30190	47928	103895	42006	6226	7141	8949	1144
14	37557	42160	103982	41215	7490	9000	6719	1869
15	51579	51141	134260	58573	12076	13733	10555	2426
16	42481	61722	130852	52803	8502	10211	11706	1756
17	35906	37796	90109	38619	7742	9051	5861	1566
18	28701	24275	69110	29784	7004	7900	6390	1081
19	20488	17128	48100	20035	4611	5830	5374	1706
20	48663	32756	99851	42330	13232	15936	6153	2967
21	34406	23098	67661	27330	7986	10202	11095	2420
22	24978	15782	46330	18425	5591	6342	2184	1492
23	28859	19457	58169	21440	5349	6674	3130	1826
24	36273	23958	70683	29244	8106	9821	5863	3230
25	37138	25630	77689	28868	7331	8748	3870	2600
26	36850	24742	76205	29581	8529	10813	4982	3668
27	15838	10245	31175	12695	3366	4190	1406	605
28	29697	22397	61937	26010	7234	9733	4514	1483
29	41636	32846	87079	39369	9889	13251	9531	2974
30	28384	17859	56800	24050	6217	7956	2483	848
31	23588	15980	47321	19629	5339	6692	2534	859
32	33116	21104	66629	28021	9015	9924	6118	3089
33	27314	18558	58123	24881	5650	6705	4710	1505
34	53607	48441	25258	55394	10792	12714	11178	4503
35	58329	45522	32717	54834	12218	14611	7856	3993
36	38663	25524	74452	29032	8485	9006	4077	2889
37	22437	14614	44705	17780	4691	5803	3661	2135
38	24359	17081	52604	19123	4166	4679	2365	1551

TABLE 3.43: INDEPENDENT-DEPENDENT ZONAL VARIABLES.

Independent zonal variables: CAR, DU, POP, TW, PHW,
Dependent zonal variables: Pr, At, IZ.

Summary of POR matrices.

Data source: STCUM magnetic tapes.

D-19.2 Multivariate Analyses

The multivariate analyses results, using SAS 'Proc Reg' software, are presented in Table 3.44. They are grouped by the dependent variable, 17 analyses are presented.

DEP. VAR	I.VAR	B0	B1	R2	R2(ADJ)
DEM	POP	8167.31	.083896	0.1482	0.1246
DEM	CAR	7313.24	.215742	0.1535	0.1300
DEM	PHW	8254.76	.867115	0.1393	0.1154
DEM	TW	3273.43	.334942	0.4288	0.4129
DEM	DU	5919.38	.275483	0.3330	0.3145
Pr	POP	4523.68	.050688	0.1980	0.1757
Pr	TW	2133.13	.184964	0.4784	0.4639
Pr	PHW	-40.337	1.20035	0.9765	0.9759
At	POP	5396.63	.034292	0.0299	0.0030
At	TW	1856.78	.184214	0.1566	0.1332
At	PHW	8031.57	-.02641	0.0002	*
IZ	POP	1753.00	.001083	0.0009	*
IZ	TW	716.48	.034236	0.1589	0.1355
IZ	PHW	-263.52	.306824	0.1684	0.6078
DEM2	POP	9920	.084980	0.1412	0.1174
DEM2	TW	3989.91	2212.99	0.4837	0.4693
DEM2	PHW	7991.24	1.17394	0.2370	0.2158

TABLE 3.44: GMA ZONAL REGRESSION MODELS

Summary of zonal matrices. There are 38 observations per model.
* Meaningless result.

Data source: STCUM magnetic tapes.

In only two of the analyses in Table 3.44, the independent variables have more than 50% explanatory powers on the dependent variables; namely; Pr Vs. PHW and IZ Vs. PHW (PHW= peak hour work trips, generated and attracted). The PHW have strong explanatory powers on trip productions and intrazonal trips.

Furthermore, multivariate analyses involving all the five independent variables in Table 3.43, are carried out using SAS 'Proc Reg', 'step reg' for the dependent variables; DEM, At, Pr, IZ, and DEM2, at 0.1500 significance level for variables to enter the model.

The results are presented in Table 3.45 and show that a maximum of three independent variables, out of five, are retained and that for only a few dependent variables (shown in tables as variables I.VAR 1,2,3 and their respective coefficients B1, B2, B3).

DEP. VAR	I.VAR 1,2,3	B0	B1	B2	B3	R2
DEM	CAR,TW,DU	4490.84	-.5201	1.4323	-.6806	0.6408
DEM2	TW,DU,CAR	4369.07	-.422144	1.452206	-.740993	0.6545
At	CAR,TW,DU	4577.22	-.708370	1.343298	-.597992	0.5806
Pr	PHW,-----	-40.336	1.200350	--------	---------	0.9765
IZ	POP,PHW,-	311.374	-.014721	0.376996	---------	0.7479
TW	POP	1630.91	0.4022			.9447*
PHW	POP	1664.54	0.06715			.5306*
PHW	CAR	-236.89	0.2221			.8785*
PHW	CAR,POP	-93.70	0.3079	-0.03735		.9156*

TABLE 3.45: GMA ZONAL STEP REGRESSION MODELS.

There are 38 observations per model. * Adjusted R-square values.
NB: Step-regression was implemented on <u>all independent variables</u> in Table 3.43. The table shows the retained variables only.

The multivariate step regression analyses, presented in Appendix C-C1, shows that the independent variable POP alone has 94.47% explanatory powers on the dependent variable TW which is expected to be high. The other variables increased the determination coefficient up to 96.08%; consequently, the model should stay with one independent variable, the POP.

The DU variable has high collinearity with POP variable and it is dropped temporarily from the analyses. The CAR variable has higher explanatory powers on PHW and should be used whenever auto ownerships forecasts are available; otherwise, POP may be used. Definitely, wherever the coefficient of determination is low, the use of factors is appropriate and preferable. The next section presents such factors for the case study.

The demand (DEM), an important dependent variable, the total AM peak hour trips are tested and used in Chapter 5 to develop the SDLM models using the calibrated EMME/2 travel demand model, Chapter 4.

The multivariate analyses of the last group of four independent variables in Table 3.45 shows high explanatory powers amongst them. This is expected as these variables are directly related.

D-19.3 Case Study Factors

The following statistics, which may be labelled 'other research findings', were computed for the GMA using summaries of matrices retrieved from the STCUM data bank and from STCUM publications:

A. AUTO OCCUPANCY, IN 1987:

1. The daily average is: 1.141 passengers per car.
2. The morning period average (midnight to 6 AM) is: 1.118.
3. The peak morning hour (7-8 AM) is: 1.183
4. The rest of the day factor (9 AM to midnight) is: 1.095.

B. 1982-1987, DATA COMPARISON:

1. The share of the HBW trips changed from 16.8% to 19.0%, a net increase.
2. The share of the HB-education trips stayed constant at 11.2%

C. 1987 MORNING RUSH HOURS, COMPARATIVE STATISTICS:

1. The HB-work trip, all modes, rush-hours to daily average, the ratio is: 69.4%
2. The HB-education trip, all modes, rush-hours to daily average, the ratio is: 67.49%
3. The HB-work trip, all modes, rush-hours to all purpose trips, the ratio is: 56.1%

4. The HB-work trip, auto mode, rush hours to all purpose trips, the ratio is: 72.3%.

5. The Peak hour to morning rush hours, auto mode, the ratio is: 0.409.

6. The Peak hour to average daily traffic (ADT), auto mode, the ratio is: 0.096. This is in conformity with the HCM 1985.

D-20 CHAPTER FINALE

This section briefly outlines Chapter 3 features in its four parts, a research data compatibility, and the chapter comments.

D-20.1 Research Data Compatibility

The research data in this chapter are grouped basically into three main sources and were presented in parts A, B, and C. Such groupings, were based as much as possible on common spatial boundaries.

The data in Part A, the 'Review of Local Data', had to be defined on presentation due to their different spatial boundaries, yet the most relevant work of [Lamonde et al.

1989], providing the EMP scenarios in Chapter 6, are based on StatsCan 1971 CTs with minor variations.

The EMP data retrieved from the special magnetic tapes of StatsCan for 1981, and presented in Part B, are of particular interest. They provide the EMP distributional characteristics by industry and occupation and relate spatially EMP data for SD1, MTL and GMA for 1981. They are needed to understand and relate to other research works like [Lamonde et al. 1989].

The 1981 CTs were aggregated into 38 large zones and are compatible with the 1986 CT boundaries. It is unfortunate that such data are neither available for 1986 nor shall be available for 1991. The special tapes used had coding problems and minor discrepancies in both NS and SS.

The demand data, are utilized in chapters 4, 5, and 6 and constitute a main research component. They were presented in Part C. The demand data are spatially aggregated into 38 zones based on the STCUM 1496 zones but unfortunately incompatible with CTs boundaries. The research used large scale maps and super-imposed the 1496 STCUM zones over the 1981 CTs and physically matched them with minimum variations relative to the 1496 STCUM zone boundaries.

The implications are that the STCUM data are used in model calibrations and consequently in the development of the SDLM models, while the other data were used in the descriptive analyses and in forecasting scenarios in Chapter 6. This spatial data compatibility problem is resolved, at the scenario level in Chapter 6, by translation into matching spatial boundaries, using spatial proportions between compatible data.

D-20.2 Chapter Comments

This chapter presented the research review for the demand data and the retrieval of OD and zonal data matrices, both from StatsCan and STCUM. This is the backbone of the research.

Three appendices; A, B, and C are complimentary to this chapter; they are presented (in a sample form) to supplement the chapter's data presentation. As mentioned earlier, more than a hundred matrices were retrieved.

The recommendations of Pisarski (1987) and others for needed research on a case study basis (continuing the literature review in Chapter 2) were adopted and the reasons for the choice of the Greater Montreal Area as the research case study was presented.

The EMP spatial distributions by industry and occupation were analyzed and presented in bar- and pie-charts which when coupled with the data review in Part A; they constitute the descriptive analysis.

The demand data were presented in Part C and the dependent and independent variables were investigated and modelled using SAS multivariate analyses at the zonal level of aggregations. This work is completed at the SD spatial level of aggregations in Chapter 6.

Spatial data compatibility problems were outlined, in preparation for data translations into compatible formats for the scenario details level in Chapter 6.

CHAPTER 4

TRAVEL DEMAND MODEL: MODEL CALIBRATION-VALIDATION

1. INTRODUCTION

This chapter presents the calibration and validation of a sequential, four-stage, travel demand model. The travel demand models were briefly defined in Chapter 1, presented in Chapter 2, and are further discussed here. The EMME/2 model is selected for application. It is described in detail in this chapter. The output supply-demand measures from the EMME/2 calibrated model (dependent and independent variables) are modelled into the 'supply-demand linkage model' (SDLM) in Chapter 5.

The sequential, four-stage model, or the Urban Transportation Modelling System (UTMS) in general, and the three available software packages, are presented in section 2 of this chapter.

The previous chapter presented the demand data, grouped in four parts: Part A, 'Review of Local Data'; Part B, 'Descriptive Analysis of 1981 StatsCan EMP Data'; Part C, '1982-1987 STCUM Demand Data'; and Part D, 'Relationships Among Variables', including the chapter finale. The data in Part C represent travel demand and are used in the calibration of the selected travel demand model: the EMME/2 model (ME stands for 'modal equilibrium' in english and EM in french).

The infrastructure data, the nodes and links of the road network, were obtained from the Ministry of Transport of Quebec (MOTQ). These are presented in this chapter, section 3.

2. FOUR-STAGE TRAVEL DEMAND MODELS

2.1 Preview

The estimation of travel demand for transportation facilities is a basic component of the urban transportation planning system. The comprehensive four-stage sequential models, developed in the late 1960s and throughout the 1970s, were large-scale aggregate models, data hungry, demanding, complex, and time consuming to use. They are suited for long-range planning and detailed analysis and forecasting.

The EMME/2 model is an aggregate model and needs large data base to calibrate and validate while the behavioral models, though they need less data, the needed data must be more detailed, and must include socio-economic data. The latter models are still in the experimental stage to a large extent and are having mixed degrees of success.

Most behavioral modelling were done on transport modal split and were concerned about parameter (model variables) transferability. The modelling process is dependent on personal choice of travel and it is usually constrained by spatial, temporal, social, and economic factors. Consequently, we need to use a proven UTMS model of the aggregate type: the EMME/2 four-stage, state-of-the-art, travel demand model. This is further discussed in the following paragraphs.

"In order to achieve a conceptually and analytically tractable formulation of the travel demand problem, it is necessary to work at a more aggregate level of system representation than that of the individual trip maker ... Further, it is typically aggregate values that are required in planning ... as opposed to predictions of individual activities or experiences." [Meyer and Miller, 1984, p230].

Aggregations are usually done at three-levels: spatial, temporal and socio-economic. There are basically three techniques to analyze the transport demand:

1. Simplified techniques like, trend analyses and elasticity based models (pivot point), and manual methods.

2. The aggregate models or UTMS.

3. The behavioral models, [Meyer and Miller, 1984].

This research uses zonal aggregations in the process of calibration and validation of a sequential model, in this chapter; it develops a supply-demand linkage model, in Chapter 5, as a quick response system; and it uses the developed model, in Chapter 6, in a manual technique to assess the impact of the decentralization of EMP.

The UTMS, calibrated and validated in this chapter, is a sequential travel demand model, as defined in the Transportation Planning Handbook (1992). It is composed of the traditional four-stage modelling system which was described in Chapter 1.

2.2 Travel Demand Models

"The sequential model structure is usually composed of four major models, each representing a different aspect of the traveller's decision ... they are more prevalent (than other model types)" [Transportation Planning Handbook 1992, p109].

In Chapter 1, a description of the four-stages and their use in the research was outlined, while in Chapter 2, the time consuming process of model calibration and validation was described. In this section, a short description of the three UTMS models available for the conduct of the research is outlined and the choice of the EMME/2 model is reviewed.

2.2.1 QRS II model

To reduce, wherever possible, the time consuming process in the four stage sequential model, especially the assignment and the calibration-validation part, a quick response system (QRS) was developed based on the NCHRP Special Report #187 (1978), as commissioned by the U.S. Department of Transport.
QRS was first introduced as a manual technique in 1978 (NCHRP Report #187). QRS described several related analyses: trip generation; trip distribution; traffic assignment; highway spacing; etc. In 1981, the Federal Highway Administration (FHA) released the first QRS microcomputer version.

The QRS II, the up-dated version of QRS, is an aggregate model and it is calibrated using default land use, auto-occupancy, trip productions, retail employees, and other figures from the NCHRP Report #187. All non-available (to the user) parameters mentioned earlier are built in as default figures. Furthermore, the model's algorithms do not permit the calibration of origin-destination matrices (OD) and it has a limited capacity of 2500 highway network links and 1750 network nodes.

Furthermore, QRS II lacks the detailed calibration needed for the research and consequently was discarded. Further, the default parameters used in the U.S. may not be transferable to Canadian metropolises as discussed at length in chapters 2 and 3. For instance, the auto-occupancy ratio for the U.S. is 1.38 (1978) while it is 1.18 (1987) for the case study.

2.2.2 TMODEL/2

Both TMODEL/2 and EMME/2 software packages, incorporate a sequential four-stage model calibration and validation potential. They have the needed flexibility to calibrate and validate the gravity model and its deterrence functions for the GMA.

There are a few important considerations that tipped the balance in favour of choosing EMME/2; mainly:

1. The supply data (road network nodes and links) obtained from the MOTQ were coded using EMME/2, and are in the EMME/2 work environment.

2. The supply data is transferable to TMODEL/2, it has to be further aggregated using EMME/2 at MOTQ and then transferred. MOTQ did not approve the retrieval of the complete data set, therefore this option was not viable and the EMME/2 model had to be used at MOTQ offices.

3. The coding of nodes and links must be continuous and sequential in TMODEL/2; this is not required in EMME/2. Thus, each time links or nodes are deleted or created in TMODEL/2, all the numbering is changed automatically by the software and thus a node may have several different code numbers depending on the number of revisions while EMME/2 keeps the same code number throughout the research. Consequently, TMODEL/2 lack flexibility.

4. The total number of inter-zonal trips is limited to 32000 in TMODEL/2. There is no limit in EMME/2. This may be a problem when aggregations by super district are applied.

5. TMODEL/2 has the calibration-validation process built in as a module, while EMME/2 needs the process to be worked out, this emanates from its structured flexibility and consequently EMME/2 lacks fixed proven procedures, like a calibration and validation modules. It is a software package for professionals.

6. Both TMODEL/2 and EMME/2, have an integrated plotting module to compare histograms and scattergrams of matrices.

The above have tilted the balance to EMME/2, especially points 1 to 4, and the research had to live with the inconveniences of point 5.

2.2.3 EMME/2 model

The EMME/2 software package was chosen for the calibration and validation of an aggregate travel demand model for this research. It is a sequential, four-stage, state-of-the-art, complex travel demand model as briefly outlined above.

The EMME/2 Manual is comprised of seven chapters and three appendices: chapters 1 and 2 present an overview; Chapter 3, basic concepts; Chapter 4, module descriptions, and the main body of the software; chapters 5 and 7, utilities; and Chapter 6, a simple presentation of algorithms used. Appendix A has error messages; Appendix B, glossary terms; and Appendix C, the description of the internal data bank files.

EMME/2 operations are conducted using modules based on simplified algorithms and are briefly described hereunder.

1. EMME/2 modules:

EMME/2 is a modular software package presented in six sections, each with several modules: (1) utilities; (2)

network editor; (3) matrix editor; (4) function editor (volume delay); (5) assignment procedures; and (6) results.

There are neither calibration nor validation modules; a small program using the matrix section was defined and a 'macro' was written for the iterative process. The macro is presented in Appendix D of this research; it is written using 'escape' language and it optimizes the several steps required for the calibration-validation process. EMME/2 provided the basic 'macro'.

2. EMME/2 algorithms:

Simplified algorithms for the four-stage process are presented in Chapter 6 in the EMME/2 Manual while the gravity model formulations are presented in section 3 of this chapter. The algorithms of EMME/2 are categorized in two:

1. 'two dimensional balancing', trip calibration; and
2. 'three dimensional balancing', it is a simultaneous trip calibration and validation process.

Furthermore, these may be applied to one or more transport modes.

In principle, any adequate deterrence function can be calibrated, EMME/2 has a complex and powerful matrix section, yet the validation process (3-dimensional balancing) can only be implemented using the multiplicative function and it is applied in parallel with the calibration process i.e., it is a calibration-validation process.

3. GRAVITY MODEL CALIBRATION and VALIDATION

The gravity model in general and its formulation in the UTMS models in particular is based on Newton's Gravity Law it has been in use for several decades in transport planning. It simply translates Newton Gravity Law into transportation engineering terminology. It is the third stage of the travel demand model: the trip distribution stage. In simple terms:

The attractiveness between two zones i and j (attraction between two masses i and j), is proportional to the trip productions at i and trip attractions at j, and inversely proportional to some power of the distance between i and j (or the travel time), also known as the 'impedance' between i and j.

The calibrated gravity model or stage 3 of the travel demand model, for the GMA presented in section 6 of this chapter have:

1. An exponential function, also known as 'entropy model'
2. A multiplicative function, also known as 'Fratar type'.

The next equation is obtained from figure 4.19, p113, Transportation Planning Handbook (1992):

$$T_{ij}=P_i\frac{F(t_{ij})Aj}{\sum_z F(t_{ij})A_j}$$

where:

- Tij= the number of trips produced by zone i and attracted to zone j, in competition with zones z
- F()= the decay or deterrence function; represents the rate at which a zone's attractiveness declines with increasing travel time
- tij= the minimum inter-zonal travel time
- Pi = the trip productions at zone i
- Aj = the trip attractions at zone j
- z = the total number of zones

Another way of looking at the Gravity model is supplied in Papacostas [1987, p264]: it is the probability (pij) that a trip produced at zone i is attracted to zone j in competition with the attractiveness of all zones z; in equation form:

Tij = pij * Pi **Eq. 4.1**

where:

$$p_{ij}=\frac{F(t_{ij})Aj}{\sum_z F(t_{ij})A_j}$$

The decay or 'deterrence' function (impedance) is usually assumed to be the inverse of the mean inter-zonal travel time. It is obtained from the trip assignment stage, and used as a first estimate in the calibration process of the trip distribution stage.

3.1 Calibration-Validation Process

In the calibration process, the reverse process of the two-dimensional balancing module is used. The "two dimensional balancing" module is used to balance a demand matrix (trip distribution) using the calibrated model.

Several types of deterrence functions in multiplicative, multiplicative-exponential or exponential form may be used. It is a multiple-step iterative process; a 'macro' was used to automate the iterative process. The following exponential function was calibrated:

$$Cij = \exp(-T * kij) \qquad \text{Eq. 4.2}$$

where:

- Cij= the 'distributional trip cost' or impedance coefficients between zones i and j.
- T= 'theta', the calibration variable, from trip frequency distribution.
- kij= the impedance (travel-time) between i and j.

The calibration-validation process, combines the calibration and validation steps (in EMME/2) into one process called the 'three dimensional balancing' module. The STCUM base year data is used in the calibration step while the independent screenline traffic counts (MOTQ data, presented in this chapter) are used to implement the validation step as recommended by the ITE Handbook (1992). The multiplicative deterrence function is the only available function for this process and is given by:

$$\mathbf{Tij = ai * bj * Gij * Cij} \qquad \textbf{Eq. 4.3}$$

where:

Tij= are the expected calibrated and validated trips from i to j. It is a demand matrix.

ai= alpha-i; zone-i production distributional coefficients. This is a scalar matrix for the calibration distributional coefficients.

bj= beta-j; zone-j attraction distributional coefficients. This is a scalar matrix for the calibration distributional coefficients.

Gij= gamma-ij; third dimension distributional coefficients. This is a two-directional OD matrix for the validation distributional coefficients.

Thus, the two steps of calibration and validation are combined into an iterative process that may be implemented manually through the several modules involved or automated through the use of a 'macro'.

3.2 Iteration Criteria

The criteria for limiting (stopping) the trip distribution iterative process may be arbitrarily linked to the maximum number of iterations, the goodness of fit between the trip length frequency distributions of observed and computed trips, i.e. the maximum relative error on origin and destination sums; or both criteria, whichever is first reached [EMME/2, IV-3.22-1, 1992].

3.3 Iteration Convergence

The convergence of the gravity model, using a negative deterrence function, "was proven by Evans (1967) while Evans (1971) and Evans (1973) showed that the calibration of the parameter T (theta, Eq. 4.2) is done by determining a value of T which results in a predicted OD matrix ... (that) has the same total travel time, ..." [EMME/2 1992, pVI-3]. Thus, T is calibrated when the total travel time (demand weighted) is the same between observed and estimated OD trips, [EMME/2, 1992].

A difference around three percent (Meyer and Miller 1984, EMME/2 1992, and Handbook of Transportation Planning 1992) between observed and estimated travel time, is considered a good fit.

4. 1987 MOTQ DATA

The supply data (coded nodes and links), and the volume delay functions were obtained from the main frame computer of the Ministry of Transport of Quebec (MOTQ) using the EMME/2 software package and the traffic screenline counts, from MOTQ publication (1987).

4.1 Network Aggregations: Links and Nodes

The network had to be aggregated prior to its retrieval because the full data bank was not available for retrieval. Further, the EMME/2 software available to the research had a limit of 1250 nodes and later on was expanded to 5000 nodes which was not enough either.

Furthermore, no external computer network links were permitted, through a modem or in any other form, thus all preliminary aggregations had to be done at MOTQ offices.

Intra-zonal commuting would mostly use the local and collector (or distributor) road networks. These trips represent people having their place of residence and their destinations in the same zone, whether for work, education, or any other purpose. Consequently, the local and collector roads, used mostly for intra-zonal trips, should be deleted from the network reflecting the level of zonal aggregation in this research.

The GMA road classification system, developed by MOTQ staff, was done in the 1980-1982 period using older data and based on the 1965 HCM highway classification in force at that time. Though most of the network was updated in 1987, its classification was not.

Although the infrastructure was physically upgraded, the local and collector road class remained unchanged. Consequently, the aggregation of the network (to delete the collector and local road links) could not be done across the board. The following was considered:

1. The 1965 HCM classification had more classes than the recent 1985 HCM and 1984 AASHTO.
2. Most of the suburban areas, except those in Montreal central districts, would have large areas without any road network at all if an across the board deletion process is carried out.
3. The distributor roads crossing the zonal boundaries were retained in order to reflect an inter-zonal network supply compatible with inter-zonal trip demand across zonal boundaries.

The aggregation of the network had to proceed in two steps:

1. The coded data were reduced from 7500 to 5000 nodes and the corresponding 19000 links to 12500 links, which is the maximum possible with the expanded EMME/2 software capacity available to this research on temporary basis.

2. The data were further aggregated, using EMME/2 PC i486-33 Mhz to 2699 nodes, and 8205 links. This is the final size of the infrastructure network.

The enormous task described would not be possible to achieve without minor discrepancies relating to the updating of the local and collector road types.

The process of deleting links resulted in having several nodes between adjacent intersections. These nodes had to be deleted too by joining two adjacent intersections with one link, having the same parameters.

Furthermore, since the research objective is to retrieve the trip-link frequency distribution data per zone, cancelling all the intermediate links between intersections would produce much smaller link data especially in the sparsely inhabited suburbs.

It was decided to keep about half of the nodes between intersections throughout the GMA, provided there was no more than one node left between adjacent intersections, unless the additional node represented a link directional change.

Samples of the supply-data and the aggregated road network of the GMA, are presented in figures 4.1 to 4.4.

Fig. 4.1 presents the freeways, expressways, the centroids and their links. Fig. 4.2 presents the minimum path (in time units) on the calibrated-validated model from centroid 1 (Zone #1 or CBD) to all centroids. Fig. 4.3 presents the road network (infrastructure) adopted in the modelling process for Zone #1. It is worthwhile to note the few nodes kept between road junctions. Fig. 4.4 presents Laval (SD #4) showing its road network and zone boundaries.

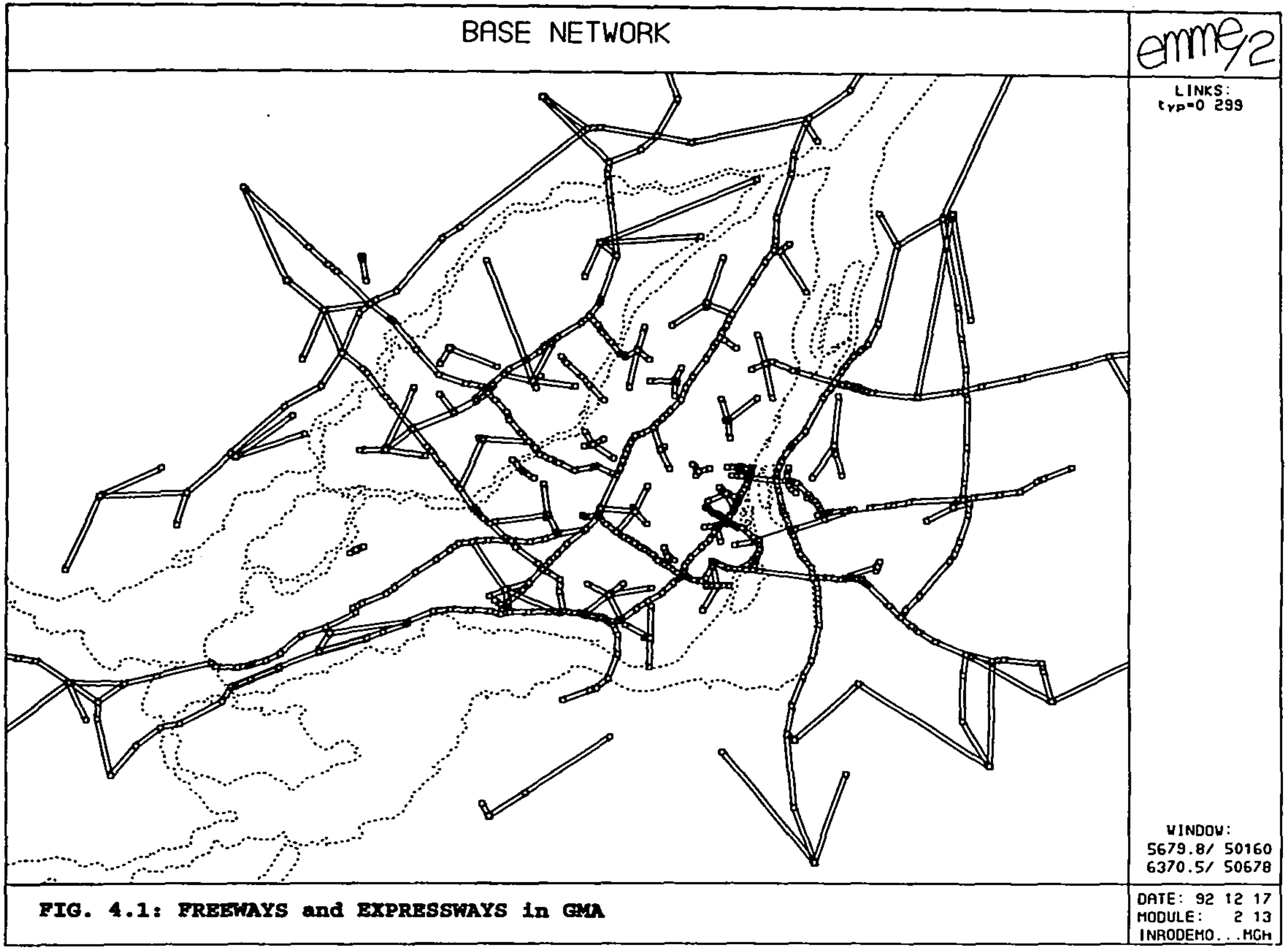


FIG. 4.1: FREEWAYS and EXPRESSWAYS in GMA

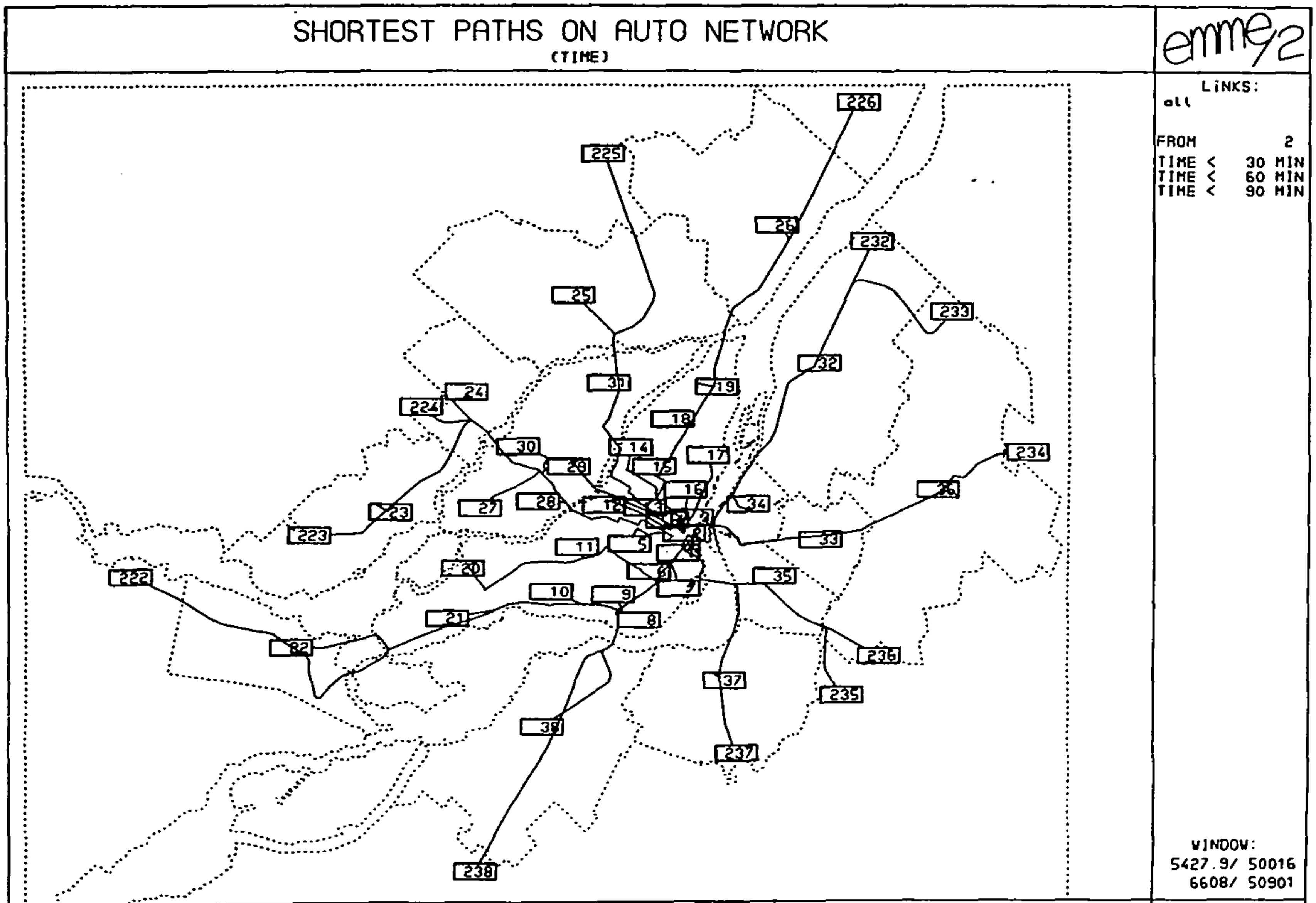


FIG. 4.2: SHORTEST TIME PATH from CBD

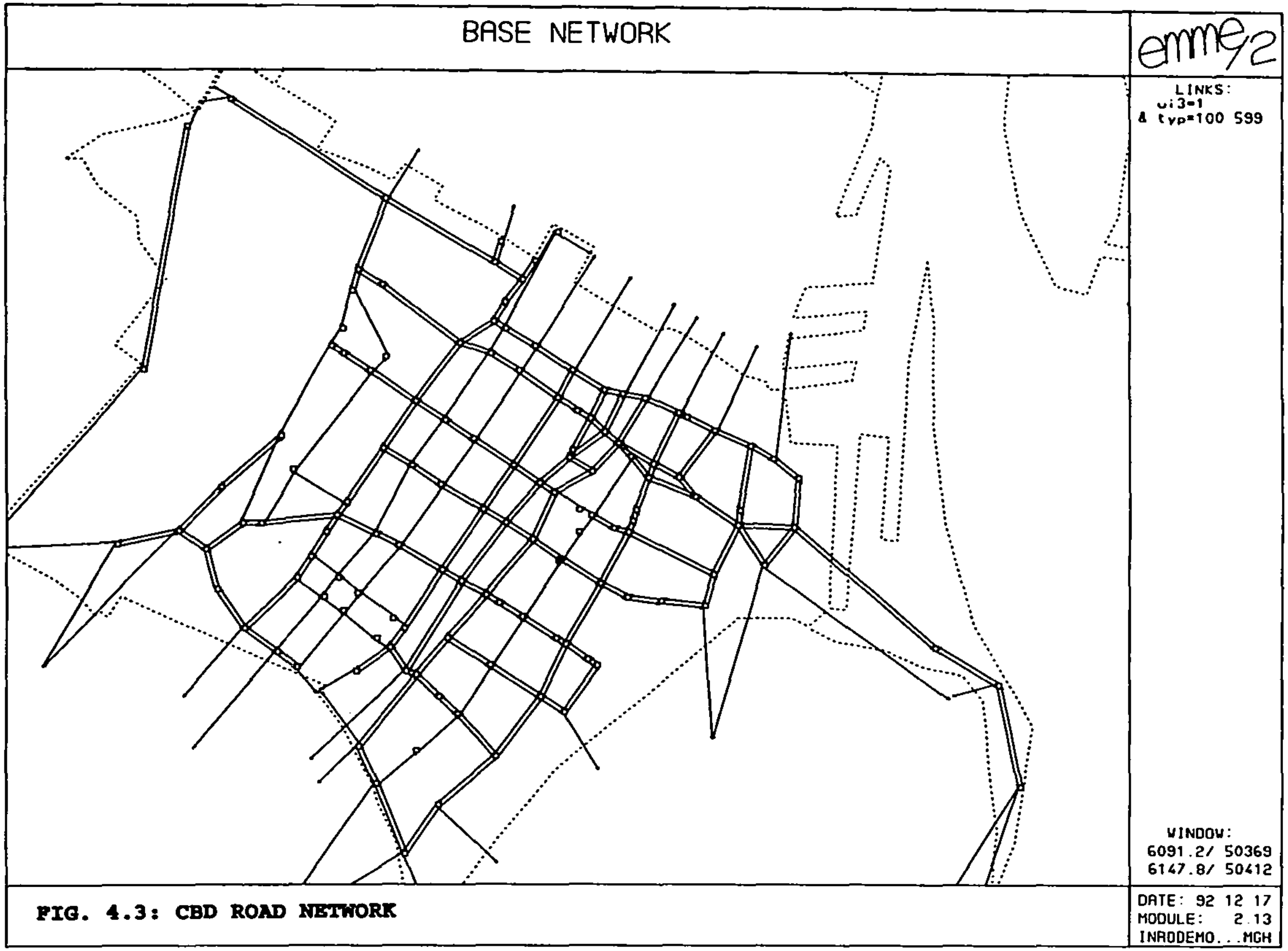


FIG. 4.3: CBD ROAD NETWORK

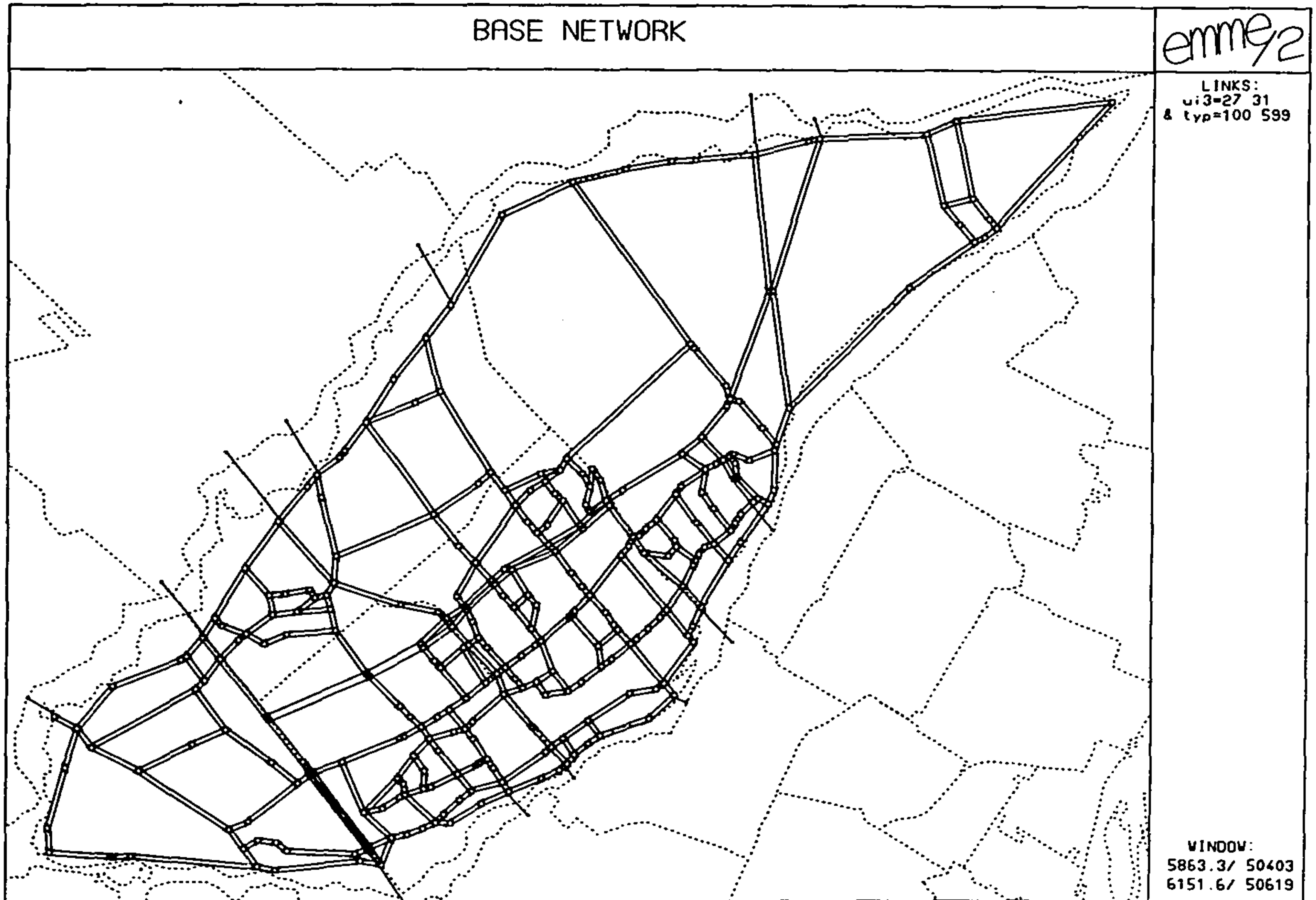


FIG. 4.4: LAVAL ROAD NETWORK SHOWING ZONE LIMITS

4.2 Volume Delay Functions

The volume delay functions (VDF) were obtained from MOTQ and are classified in Table 4.1 by land use and cross classified by facility type. VDF #13 and those numbered higher than #15 were created by the research, based on MOTQ's VDFs, to portray better transitional conditions.

Land use/ Facility type	**CBD #1**	**comm. #2**	**indust. #3**	**resid. #4**	**rural #5**
FRWY #1	1	1	1	1	1
EXPWY #2	3	3	3	3	3
ART.Major #3	6	7	6	4	19
ART.Minor #4	8	8	9	6	18
Collector #5	11	10	8	11	8
Local #6	12	12	12	12	12
Ramp #7	2	2	2	2	2
Exurban * #9	13	13	13	13	13
Centroid * #0	14	15,16,17	15,16,17	15,16,17	15,16,17

TABLE 4.1: VOLUME DELAY FUNCTIONS by FACILITY TYPE and LAND USE.

Footnote #1[1].

Original source: MOTQ.

The centroidal links has more than one VDF per land use to convey the spatial effect, the relatively long distances in suburbia. They are assigned in a way that the time needed for

Footnote #1:
* Additional VDF created in the research.
VDF numbers > 15 were created in the research.

connection to the centroid is reasonable (the time per centroid is calculated using 2/3 of its diagonal length and a speed of 30 km/hr.).

Furthermore, MOTQ VDF #12 was split in four, while upgrading the collector-local road classification, as detailed hereunder, to convey better their locational attributes (urban, suburban, exurban):

1. VDF #25 in Montreal
2. VDF #26 in Laval
3. VDF #27 in S.Shore
4. VDF #28 in N.Shore

VDFs 25-28 are shown in Table 4.1 as VDF #12. Codings were used throughout as link attribute types in EMME/2 and are described in footnote #[2].

The general form of the VDF, applicable to the auto mode, is presented in Eq. 4.4. The MOTQ version is also presented in Eq. 4.5.

$$\mathbf{VDF = a*v + T0 \{1 + b* [(v/c) \exp f]\} + P} \qquad \mathbf{Eq.\ 4.4}$$

Where;
v = volau= traffic volume per directional lane in EPC
c = directional traffic lane capacity in EPC

Footnote #2:
Example: highway type 542 represent a collector road (#5), in a residential area (#4), and it has two lanes (#2); consequently, has a VDF #11 as obtained from Table 4.1.

a = alpha, travel constant related to link length
b = beta, traffic volume constant
f = phi, is v/c exponent
P = parking or other time constant at the destination
VDF = fd= volume delay function in time units (minutes).

The VDF has three components in this research, as seen from Eq. 4.4:

1. a*v term captures the time delay in links due to their length and traffic volume.

2. T0 {1 + b* [(v/c) exp f]} term captures the time delay in links due to heavy traffic, expressed by the exponential volume to capacity (v/c) ratio.

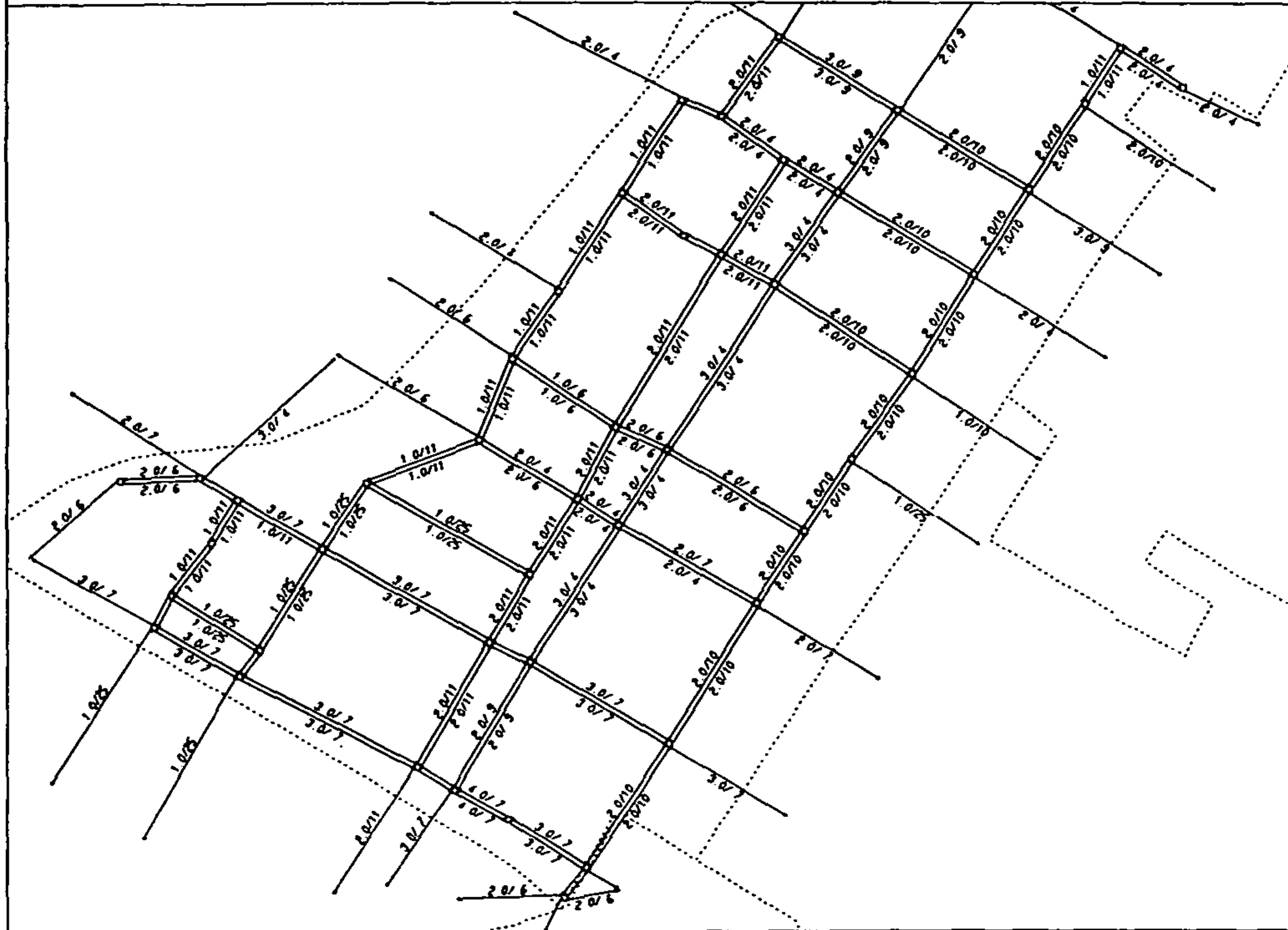
3. P term captures the time delay at the destination i.e., the time needed to park or to exit the road network.

Traffic volumes (coded as volau in EMME/2) are measured in 'equivalent passenger cars' (EPC) and T0 is the free flow travel time between nodes i and j.

Fig. 4.5 presents a sample EMME/2 plot showing the directional lane and the VDF numbers for Zone #4.

BASE NETWORK

NO. OF LANES / VOLUME-DELAY FUNCTION



emme/2

LINKS:
ui3=4
& typ=100 599

WINDOW:
6084.5/ 50409
6122.3/ 50437

DATE: 92 12 17
MODULE: 2 13
INRODEMO MGH

FIG. 4.5: ROAD NETWORK of Z #4; SHOWING # of LANES/ VDF.

The VDF basic form that captures the time delays in the network due to traffic congestion as related to link capacity, was modified by MOTQ staff into the following general form, where the capacity was reduced by the peak hour factor (PHF):

VDF=a'*L*{1+b'*[(v'/(c'*La))exp f]}+ L*a"* v'/La Eq. 4.5

where;
f, and all primed variables relate to those in Eq. 4.4.
a' = alpha prime
b' = beta prime, usually 0.15
L = link length
La = number of directional lanes
v' = directional traffic volume per link for all lanes
c' = directional capacity per link (all lanes) including PHF.

Eq. 4.5 was calibrated by MOTQ staff in the early 1980s using the 'floating vehicle concept", a method used in the 1965 HCM to determine operating speed. Several trips were made to calibrate each VDF and for each land use. A plot of a few VDFs is presented in Fig. 4.6.

MOTQ insisted on the privacy of their data, thus their volume delay functions shall not be published in this research. A few of the VDFs modified versions as adapted to the research are presented in Table 4.2 and plotted in Fig. 4.6.

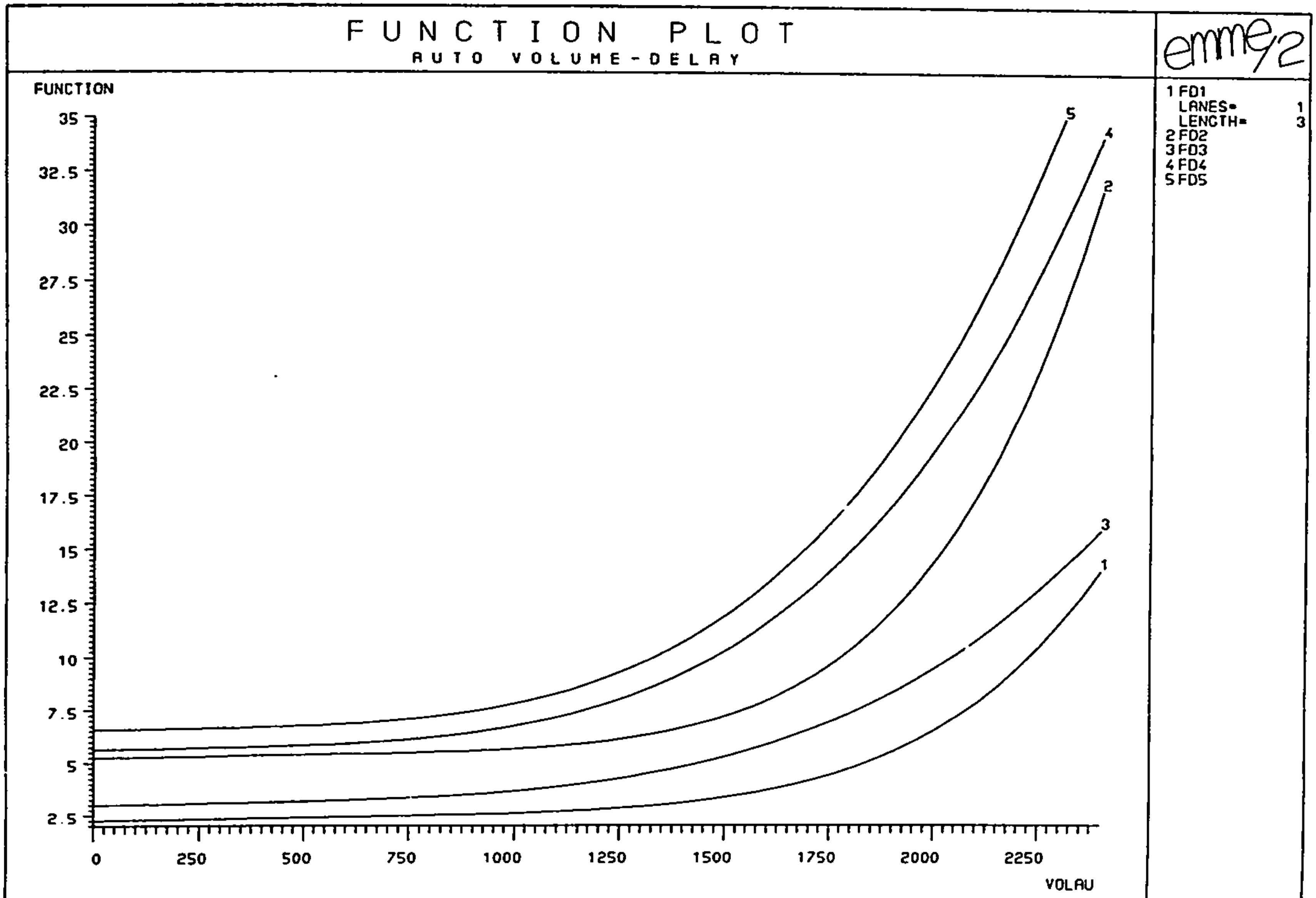


FIG. 4.6: PLOT OF VDFs 1 to 5

The volume delay functions, obtained from MOTQ, were slightly modified and their numbering revised as discussed earlier. In particular, the built in peak hour factor (PHF) was removed from the functions. This is so in order to avoid the use of the PHF computed in Chapter 3, Part C; and to reflect better its spatial and temporal variations, which are difficult to capture at the aggregate network level.

The VDFs were factored up by 1.25 to compensate for the additional temporal delays due to peaking. The 1.25 factor was obtained after several trials in the model validation process by comparing the model estimated flows on bridges and their corresponding internal screenline figures.

Table 4.2, presents five volume delay functions adopted for the research and Fig. 4.6 shows a plot of them for one directional lane of an arbitrarily chosen length of 3 km. Variables were defined for equations 4.4 and 4.5.

fd1 = L * 0.75* (1+ (.15* (v/ (1343*La)) exp 6)) + (L * .0001* v/La)
fd2 = L * 1.75* (1+ (.15* (v/ (1343*La)) exp 6)) + (L * .0001* v/La)
fd3 = L * 1.00* (1+ (.15* (v/ (1053*La)) exp 4)) + (L * .0001* v/La)
fd4 = L * 1.88* (1+ (.15* (v/ (1003*La)) exp 4)) + (L * .0001* v/La)
fd5 = L * 2.19* (1+ (.15* (v/ (1003*La)) exp 4)) + (L * .0001* v/La)

TABLE 4.2: VDF EQUATIONS

Original source: MOTQ

4.3 Screenline Traffic Counts: 1987 MOTQ Data

The screenline traffic counts are needed to control the model calibration with demand data obtained from a different source to validate the model after calibration, [Transportation Planning Handbook, 1992]. The screenline counts are classified spatially in two groups:

1. External screenline counts. They are the directional vehicle-trips, GMA inbound and outbound at the boundary of the study area.
2. Internal screenline counts. They are the directional vehicle-trips, using bridges and tunnels (river crossings data) between the GMA spatial components; Montreal Island, Jesus Island (Laval), the North and South shores.

Two different data sources for the screenline traffic counts were used in order to obtain the needed data:

1. MOTQ official estimate from permanent counter stations
2. Transports Quebec (1987), from counter stations which show the temporal data variations by the hour of the day, the day of the week and, the month of the year.

SITE #	NODE i	NODE j	VOL 6-9	*VOL 7-8	ROAD# **	LOCATION
101	2008	2034	na		A15S	Prevost
101	2034	2008	na		A15N	"
102	2011	2014	na		R117S	St. Jerome
102	2014	2011	na		R117N	"
103	2150	2167	na		A125S	Mascouche
103	2167	2150	na		A125N	"
104	2049	2166	1678	686	A25S	"
104	2166	2049	530	217	A25N	"
105	2144	2178	na		A40W	Repentigny
105	2178	2144	na		A40E	"
106	2130	2145	na		R138W	"
106	2145	2130	na		R138E	"
107	2109	2113	716	293	A30W	Verchere
107	2113	2109	651	266	A30E	"
108	3011	3014	na		R223E	St. Math.
108	3014	3011	337	138	R223W	"
109	3006	3008	1700	695	A20W	St. Hil.
109	3008	3006	2010	822	A20E	"
110	4001	4002	541	221	R116W	Wilfrid
110	4002	4001	551	225	R116E	"
111	9704	9706	na		R112W	Richelieu
111	9706	9704	na		R112E	"
112	9703	9715	1052	430	A10W	
112	9715	9703	1072	438	A10E	
113	9807	9785	1918	518	A35N	Chambly
113	9785	9807	1266	784	A35S	"
114	9817	9818	631	258	A15S	Candiac
114	9818	9817	1399	572	A15N	"
115	9952	9945	942	385	R138N	Martin
115	9945	9952	na		R138S	"
116	9962	9961	1296	530	R132N	Beauhanois
116	9961	9962	na		R132S	"
117	9865	9970	1071	438	A20W	Dorion
117	9970	9865	2428	993	A20E	"
118	8008	8012	1428	584	A40E	"
118	8012	8008	883	361	A40W	"
119	5602	8019	na		R344E	Oka
119	8019	5602	na		R344W	"
120	2301	2302	403	165	R148E	Mirabel
120	2302	2301	na		R148W	"

TABLE 4.3: 1987 EXTERNAL SCREENLINE COUNTS.

6 to 9 AM vehicle-trips. Computed 7 to 8 AM vehicle-trips

NB: for * and ** see footnote #3.

Source: MOTQ and MOTQ (1987) publications.

The Transports Quebec (1987), published data, was gathered using pneumatic and other electronic automatic traffic counters located in fixed permanent or temporary stations. These data aggregated all transportation vehicle types, including trucks, and usually recorded vehicle axles.

4.3.1 External screenline counts

The external screenline counters were located beyond the GMA-CMA boundaries. Table 4.2 presents the screenline counts as obtained from MOTQ, showing trips from node (i) to node (j). Footnote #[3] relates to Table 4.3.

4.3.2 Internal screenline counts

The internal screenline counts are presented in Table 4.4. They represent the directional inbound and outbound traffic between the four main components of the GMA. The inbound vehicle-trips in the morning rush hours constitute bottle neck locations in the GMA and are a main source of congestion.

Footnote #3:
Note the many 'na' (data not available).
* Computed figures using STCUM proportions between rush hours and peak hour AM traffic from Chapter 3.
** Added road numbers.

The MOTQ data was based on the same approach as the Transports Quebec, but used the aggregated total figures and simulated (at the analysis stage) a disaggregation between light vehicles (automobiles) and heavy vehicles (buses and trucks) as presented in Table 4.4 below.

The MOTQ data is more reliable than Transports Quebec data and consistently has larger values. It has a better fit with the STCUM data as shall be seen in the model validation process. Footnotes (3) and ([4]) relate to Table 4.4.

Table 4.4 is presented in two parts, to provide the names of the corresponding bridges and tunnel.

<u>Footnote #4:</u>
t+b = trucks and buses
tot = total
volume (1): MOTQ data
volume (2): Transports Quebec data

SITE	NODE	NODE	VOLUME (1)				VOLUME (2)	
#	i	j	6-9 auto	7-8 auto	7-8 b+t	7-8 tot	6-9 tot	7-8 tot
2022	4105	4104	na					
2021	4104	4105	na					
2141	9668	9553	16405	5886	180	6426		
2142	9554	9665	5674	2506	305	3421		
2092	1579	1580	3190	1424	215	2069		
2091	1580	1579	15247	6857	204	7469		
2061	2208	2360	3242	*1327		1460	3045	1206
2062	2360	2208	na					
2162	8022	8030	6601	2867	210	3497	6055	2592
2161	8030	8022	1512	729	82	975	1552	590
2041	2343	2352	5014	*2051		2256		
2042	2352	2343	9345	*3822		4204		
2151	8702	8803	11184	4093	132	4489	10944	3833
2152	8803	8702	2959	1262	187	1823	3180	1304
2012	8017	8051	6235	2751	258	3525	6224	2640
2011	8051	8017	1858	834	129	1221	2354	879
2121	5472	5918	15706	5616	114	5958		
2122	5918	5472	4310	1835	157	2306		
9021	5119	4726	1681	*688		757	1547	577
9022	4726	5119	11752	*4807		5288	8005	3402
2101	2186	2158	674	281	35	386	613	262
2102	2158	2186	2920	1353	39	1470	2658	1135
2072	2214	2068	na					
2071	2068	2214	na					
9011	6618	5618	3933	1752	826	4230		
9012	5618	6618	17446	6302	242	7028		
2052	2345	2337	na					
2051	2337	2345	3096	*1266		1393		
9031	4733	4728	5027	*2056		2262		
9032	4728	4733	12965	*5303		5833		
9051	3390	3311	3524	*1441		1585	3237	1231
9052	3311	3390	10728	*4388		4827	7648	3176
9061	3348	2463	5449	*2229		2452		
9062	2463	3348	12246	*5009		5510	18131	7082
2082	2083	2074	na					
2081	2074	2083	1865	*763		839	1669	634
2111	3955	3978	13157	*5381		5919	13214	4878
2112	3978	3955	9072	*3710		4081	9254	3409
2032	3113	3102	2550	*1043		1147		
2031	3102	3113	9683	*3960		4356		
9042	4270	4200	1522	*623		685		
9041	4200	4270	5597	*2289		2518		
2131	7832	7890	5148	*2106		2317		

TABLE 4.4: 1987 INTERNAL SCREENLINE COUNTS.

6-9 AM and 7-8 AM, vehicle-trips.

See footnotes 3 and 4.

Sources: MOTQ and Transports Quebec (1987).

SITE #	NODE i	NODE j	ROAD#	BRIDGE/TUNNEL
2022	4105	4104	R148N	Arthur-Sauve
2021	4104	4105	R148S	"
2141	9668	9553	A15N	Champlain
2142	9554	9665	A15S	"
2092	1579	1580	A40E	Ch.D.Gaulle
2091	1580	1579	A40W	"
2061	2208	2360	R335S	David
2062	2360	2208	R335N	"
2162	8022	8030	A20E	Galipeault
2161	8030	8022	A20W	"
2041	2343	2352	A15N	Gedeon-Ouim.
2042	2352	2343	A15S	"
2151	8702	8803	R138N	Mercier
2152	8803	8702	R138S	"
2012	8017	8051	A40E	I.A.Tourtes
2011	8051	8017	A40W	"
2121	5472	5918	R134N	J.Cartier
2122	5918	5472	R134S	"
9021	5119	4726	R117N	Lachapelle
9022	4726	5119	R117S	"
2101	2186	2158	R138E	Legardeur
2102	2158	2186	R138W	"
2072	2214	2068	A25N	Lepage
2071	2068	2214	A25S	"
9011	6618	5618	A13N	Louis-Bisson
9012	5618	6618	A13S	"
2052	2345	2337	R117N	Marius-Dufresne
2051	2337	2345	R117S	"
9031	4733	4728	A15N	Mederic-Martin
9032	4728	4733	A15S	"
9051	3390	3311	A19N	Papineau
9052	3311	3390	A19S	"
9061	3348	2463	A25N	Pie IX
9062	2463	3348	A25S	"
2082	2083	2074	R125N	Prefont.-Prevost
2081	2074	2083	R125S	"
2111	3955	3978	A25N	H.Lafontaine
2112	3978	3955	A25S	"
2032	3113	3102	A13N	Vachon
2031	3102	3113	A13S	"
9042	4270	4200	R335N	Viau
9041	4200	4270	R335S	"
2131	7832	7890	R112N	Victoria

TABLE 4.4: Continued.

5. 1987 STCUM and MOTQ DEMAND DATA

The demand data were obtained from the STCUM. A description of this data base was presented in Chapter 3, Part C. In this section, the matrices used in the model calibration shall be presented.

Matrices for the 12 external zones, were obtained from the external screen line counts through an elaborate process. Using the external zone's attractiveness to the 38 internal zones from STCUM and the external screenline counts as their attractiveness; and the MOTQ and STCUM GMA external trips.

The spatial difference between the CMA, the GMA, and the outer screenline traffic counter stations are an important source of data variations for the external zones. The spatial distances primarily represent sparsely inhabited areas, yet these may represent important variations in vehicle-trip volumes relative to the external zone counts.

For the purpose of the research, use is made of only the internal zone's results thus, the external zone trip variations influence on the internal zone trip length frequency distribution is likely to be of minor importance.

5.1 Internal Zone Matrices

The internal 38-zone matrices were obtained directly from STCUM retrieved matrices. Table 4.5, presents the 7-8 AM peak hour total auto person-trips, using the surface transit mode priority definition (Chapter 3, Part C). They are the 1987 internal origin-destination matrix for total EPC person trips; presented in three pages.

Tables 4.5 and 4.6 trips were aggregated and converted into equivalent passenger car (EPC) trips, as outlined in Chapter 3, Part C. The total column represent the sum of productions for the 38-zones while the total (T) row represents the sum of attractions for the 38-zones.

Table 4.6 presents the 1987 internal origin-destination matrix for total, EPC person trips, surface transit modes (surface transit priority mode), 7-8 AM peak hour in three pages. Appendix C presents other origin-destination matrices for daily person-trips by mode, and by purpose.

OD	1	2	3	4	5	6	7	8	9	10	11	12	13
1	633	173	0	122	199	100	149	139	183	50	150	112	43
2	345	278	81	80	62	43	51	0	19	130	18	125	60
3	205	135	230	46	136	66	64	0	63	20	129	93	160
4	135	253	71	163	173	95	73	23	0	18	118	114	242
5	1432	349	126	292	1926	991	87	60	255	247	696	573	462
6	1524	260	61	170	856	1410	294	61	303	164	532	203	78
7	1655	225	221	119	523	585	2547	526	429	185	329	127	39
8	932	273	114	45	339	318	518	1683	566	630	496	91	114
9	1556	238	44	189	822	874	158	116	1536	679	468	288	73
10	319	60	20	0	180	198	286	100	500	947	422	100	40
11	814	228	21	85	932	469	40	41	123	393	2391	695	233
12	1287	392	243	262	968	413	64	84	122	165	1407	2208	660
13	576	536	145	413	472	111	113	77	19	116	432	810	1229
14	621	145	66	66	365	87	22	43	87	41	536	1095	440
15	902	659	222	528	812	255	101	106	70	243	640	1430	834
16	708	909	610	457	527	175	163	22	64	121	478	433	934
17	910	614	552	170	239	185	66	89	22	20	199	381	177
18	662	474	245	105	313	60	61	21	41	123	186	570	622
19	227	494	433	21	165	41	60	21	39	41	21	124	185
20	1892	320	78	219	1277	394	199	138	314	1691	2036	643	120
21	2009	191	19	0	399	731	64	241	253	1376	1225	278	78
22	419	141	0	31	156	96	31	64	118	772	547	97	0
23	316	198	34	70	240	67	39	17	36	150	317	235	33
24	448	480	19	0	323	122	0	39	59	143	567	490	275
25	336	611	19	218	252	71	19	0	19	19	180	520	217
26	832	668	279	160	133	54	37	58	17	53	131	257	271
27	216	199	17	42	261	0	0	0	99	132	444	305	105
28	1055	234	66	140	601	264	17	42	344	371	1151	717	203
29	1039	592	88	211	689	105	89	40	48	228	644	1705	319
30	558	222	76	101	273	52	43	17	35	160	552	596	147
31	468	249	178	104	329	144	56	0	11	108	141	816	225
32	1435	901	280	109	235	118	74	54	16	75	19	110	174
33	946	652	177	160	118	200	63	42	19	21	79	58	40
34	1280	820	310	111	242	89	212	45	22	155	200	152	177
35	2303	709	266	166	488	809	459	106	60	291	429	182	161
36	918	692	170	164	103	72	0	41	18	44	73	83	54
37	654	345	119	56	204	144	182	184	83	171	126	38	0
38	594	137	60	0	197	138	180	238	311	432	178	97	40
T	33161	15056	5760	5395	16529	10146	6681	4578	6323	10725	18687	16951	9264

TABLE 4.5: 1987 INTERNAL ZONES OD MATRIX: AUTO MODE.

Total EPC person trips, 7-8 AM peak hour
Data source: STCUM

OD	14	15	16	17	18	19	20	21	22	23	24	25	26
1	35	20	96	36	71	61	63	102	0	17	21	0	42
2	55	91	228	0	35	0	14	0	0	21	0	0	18
3	45	85	268	19	89	46	0	74	0	0	0	48	0
4	0	88	179	21	136	72	148	25	0	80	41	0	21
5	0	148	275	70	21	17	39	141	0	19	44	45	20
6	41	40	303	58	86	18	55	258	40	21	0	0	0
7	20	61	162	127	64	61	81	185	0	0	20	0	23
8	45	68	91	0	45	45	45	225	0	23	0	23	0
9	40	62	85	20	92	57	163	167	25	25	0	18	0
10	40	0	0	20	0	20	240	495	52	19	20	0	0
11	103	259	205	62	126	21	265	325	37	41	0	92	21
12	225	560	211	186	201	80	42	149	0	62	145	65	20
13	366	425	310	61	104	35	22	130	0	0	40	0	0
14	2010	893	558	152	498	153	66	145	0	41	19	82	40
15	575	2561	1096	368	492	247	51	190	0	19	24	25	91
16	185	826	1860	350	418	232	72	89	0	39	0	0	112
17	173	585	1337	1683	514	487	23	84	0	22	69	39	42
18	425	947	454	474	1127	330	21	61	20	0	42	0	21
19	124	289	473	611	391	1752	21	21	0	0	0	83	102
20	80	59	78	19	119	61	3183	3048	178	40	38	0	0
21	65	36	57	22	0	93	664	2597	184	0	58	0	0
22	35	27	18	0	0	17	505	1851	1592	0	0	27	0
23	70	112	39	19	55	35	57	177	0	1948	737	92	55
24	40	146	179	39	99	59	64	125	19	281	3496	206	0
25	343	195	187	187	354	210	19	19	0	18	352	2787	76
26	207	328	840	365	375	585	18	0	36	0	18	133	3904
27	35	38	62	0	21	24	34	177	0	135	61	39	0
28	167	158	188	42	65	0	119	152	0	65	60	45	0
29	547	329	341	64	91	26	179	165	0	43	400	41	22
30	129	189	179	46	95	40	57	118	0	100	306	0	17
31	332	440	109	21	192	72	66	21	0	91	31	104	47
32	145	220	354	461	172	176	0	0	0	0	0	0	0
33	61	98	161	119	79	21	0	79	19	0	0	0	0
34	67	333	395	133	241	177	22	22	0	22	22	22	44
35	101	186	354	81	123	185	0	61	0	0	19	0	85
36	24	69	233	169	59	36	0	18	0	21	21	0	0
37	20	40	41	0	20	17	0	0	19	0	22	0	269
38	0	0	0	0	38	0	18	80	0	0	0	0	40
T	6975	11011	12006	6105	6708	5568	6436	11576	2221	3213	6126	4016	5132

TABLE 4.5: Continue.

OD	27	28	29	30	31	32	33	34	35	36	37	38	Total
1	0	0	39	0	0	25	0	64	0	24	0	20	2789
2	27	42	91	35	0	16	21	111	106	0	0	0	2203
3	0	0	24	0	19	0	48	27	22	21	0	0	2182
4	0	0	0	0	0	38	21	24	0	0	25	0	2397
5	0	21	157	98	0	0	0	89	25	0	0	21	8746
6	41	69	79	0	0	0	40	78	60	21	86	0	7310
7	19	102	66	19	0	61	59	104	83	0	37	70	8934
8	0	68	23	20	0	23	45	68	23	41	110	176	7326
9	20	25	50	0	0	20	66	72	62	39	60	63	8272
10	0	28	38	0	0	0	0	0	20	18	37	0	4219
11	41	99	149	107	47	0	21	81	21	21	21	0	8630
12	20	173	451	37	35	24	62	83	38	20	22	20	11206
13	20	106	218	19	47	62	45	112	0	0	27	17	7215
14	42	66	240	44	174	44	22	122	87	0	0	0	9112
15	0	25	213	50	120	76	101	79	80	25	29	29	13368
16	0	78	102	24	37	84	20	176	98	0	16	37	10456
17	0	79	68	0	20	78	59	225	44	87	0	0	9342
18	0	0	42	0	64	82	42	145	20	21	37	0	7858
19	0	0	62	0	41	21	21	43	41	21	0	0	5989
20	0	54	234	40	21	21	0	19	19	42	19	0	16693
21	0	35	36	0	0	22	0	18	0	18	18	0	10787
22	0	42	17	0	0	0	17	0	17	0	12	48	6697
23	154	299	401	57	57	17	0	0	0	0	17	0	6150
24	44	149	449	359	127	0	0	0	0	0	0	40	8886
25	0	168	542	81	249	162	0	40	19	0	0	0	8489
26	0	18	60	18	0	112	111	88	88	0	156	17	10427
27	656	93	365	147	44	21	0	0	0	0	0	0	3772
28	154	1547	661	108	82	0	0	0	0	26	0	0	8844
29	106	514	3262	259	385	71	0	24	66	20	0	0	12752
30	21	465	1132	850	99	0	0	40	70	0	21	0	6806
31	61	161	588	120	891	0	0	20	20	0	19	21	6256
32	0	58	35	0	16	3347	306	1134	265	138	20	0	10447
33	21	0	0	0	0	216	1549	915	741	165	63	0	6882
34	0	0	89	0	0	797	843	4779	548	234	155	44	12804
35	0	40	0	24	0	395	586	1547	4289	80	385	40	15010
36	0	0	0	0	0	565	608	978	522	3123	84	0	8962
37	0	0	33	0	0	52	88	273	505	47	2265	72	6089
38	0	0	40	0	0	0	20	78	123	0	57	1547	4643
T	1447	4624	10056	2516	2575	6452	4821	11656	8122	4252	3798	2282	308950

TABLE 4.5: Continued.

It is of interest to note that the surface transit mode (Table 4.6) in the 7-8 AM peak has less trips than during the 8-9 AM hour, but when adding total EPC trips, the AM peak hour is switched to 7-8 AM. This is due to the fact that usually the urban-suburban transit riders start their journey to work later than the auto exurban drivers; and transit trips tend to be short trips.

Furthermore, matrix diagonal (Table 4.6) figures representing intra-zonal trips outside MTL, are important while other figures (inter zonal trips) are mostly zeros. This goes to prove that in exurbia, where POP densities are low, the surface transit trips are extremely low except for the short trips.

Although total person trips by surface transit (grand total of 212216) are relatively high as compared with the auto mode (grand total of 308950) and represent 68.7%, in EPCs they represent (grand total of 8489 EPC) only 2.74% and thus are marginalized at the sketch planning aggregation levels i.e., as far as road traffic congestion is concerned.

OD	1	2	3	4	5	6	7	8	9	10	11	12	13
1	260	173	22	163	140	456	143	67	0	20	154	63	33
2	351	103	229	191	417	83	82	0	39	0	87	156	160
3	290	246	218	231	254	73	0	23	19	0	19	224	88
4	818	528	168	439	538	311	122	53	22	0	122	264	330
5	1644	448	113	613	3795	1011	99	61	789	43	1293	971	813
6	1581	155	79	41	639	965	283	128	465	84	253	142	67
7	1274	272	0	104	347	813	1645	597	194	39	188	20	146
8	1797	455	68	91	250	387	523	2410	546	227	318	159	68
9	1382	454	0	72	781	890	80	191	1189	344	422	97	114
10	619	80	0	40	100	140	0	40	280	659	100	20	40
11	795	296	0	208	872	252	0	21	144	82	2442	1288	173
12	1358	756	100	226	1019	185	36	21	89	20	1110	2887	621
13	583	452	166	456	764	82	44	46	65	19	183	1145	919
14	989	540	22	218	350	102	43	0	44	0	339	1761	443
15	1858	878	177	278	639	375	48	25	76	0	338	956	789
16	1187	1332	339	248	499	304	23	81	88	0	232	474	623
17	1005	563	164	111	307	220	46	47	43	0	42	81	131
18	1037	661	103	63	185	84	20	20	0	0	208	336	166
19	575	454	62	21	0	62	0	0	0	0	0	41	123
20	678	159	21	40	347	198	0	42	99	533	493	195	0
21	712	57	18	0	116	251	0	54	169	318	145	43	0
22	31	0	12	0	0	21	0	0	0	0	0	17	0
23	0	0	0	17	0	19	0	0	0	17	19	0	0
24	39	0	0	99	0	0	0	0	0	0	19	60	0
25	91	19	0	0	0	0	22	0	0	0	91	71	0
26	54	112	205	18	36	0	0	0	0	0	21	36	18
27	75	21	0	24	0	0	24	0	18	0	24	186	18
28	446	54	44	126	154	91	0	0	78	0	375	176	160
29	592	204	44	41	257	73	0	0	23	0	59	744	87
30	187	57	18	39	19	34	0	0	23	0	88	217	38
31	243	144	21	0	61	41	0	0	0	0	74	478	62
32	497	248	19	20	74	19	19	0	0	0	19	19	16
33	1041	428	21	81	163	44	0	21	0	21	0	0	105
34	1663	975	89	200	421	89	111	22	67	0	67	89	177
35	3749	888	85	145	385	334	82	81	65	20	103	142	0
36	277	174	0	0	56	72	18	18	0	0	18	0	0
37	210	140	0	0	44	55	0	17	0	0	0	40	36
38	358	118	0	0	40	253	0	140	106	53	20	0	20
T	30346	12644	2627	4664	14069	8389	3513	4226	4740	2499	9485	13598	6584

TABLE 4.6: 1987 INTERNAL ZONES OD MATRIX: TRANSIT MODE.

Total EPC person trips, 7-8 AM peak hour.

Data source: STCUM

OD	14	15	16	17	18	19	20	21	22	23	24	25	26
1	0	19	40	0	0	20	0	0	0	0	0	0	0
2	0	23	69	18	0	0	0	13	0	0	0	0	0
3	29	98	529	73	44	42	0	0	0	0	0	0	0
4	27	163	275	0	0	26	0	0	0	0	0	25	0
5	19	42	128	20	148	0	114	29	0	0	0	0	0
6	21	23	41	0	21	0	0	96	0	0	0	0	0
7	0	0	105	81	0	0	0	61	0	0	0	0	0
8	0	45	273	0	0	0	45	68	0	0	0	0	0
9	0	0	60	20	0	0	42	100	0	0	0	0	0
10	0	0	40	0	0	0	80	339	0	0	0	0	0
11	65	100	41	0	40	0	62	21	0	0	0	0	0
12	293	277	286	21	0	20	48	0	0	0	22	0	0
13	147	697	628	60	108	87	27	0	0	0	0	0	0
14	1473	796	604	66	194	62	0	0	0	0	0	0	0
15	921	2734	1126	459	217	51	0	0	0	0	0	0	0
16	231	554	1872	536	99	44	0	20	0	0	0	0	0
17	155	167	1792	1257	296	143	0	0	0	0	0	0	0
18	935	333	927	530	1465	41	20	0	0	0	0	0	0
19	0	103	432	267	167	2736	0	0	0	0	0	0	83
20	0	0	38	0	0	0	2491	3459	0	0	0	0	0
21	0	0	0	0	0	0	275	2183	2	0	19	0	0
22	0	0	0	0	0	0	32	157	140	0	0	0	0
23	0	0	34	0	0	0	0	0	0	1721	270	0	0
24	0	21	0	0	0	0	0	0	0	0	2189	21	21
25	19	0	22	39	0	0	0	0	0	22	459	2217	0
26	18	0	145	18	0	405	0	0	0	0	0	51	3583
27	0	0	17	0	17	0	0	0	0	80	0	0	0
28	0	0	189	0	0	0	44	0	45	0	0	0	0
29	111	0	0	0	55	26	0	0	0	0	0	0	0
30	19	0	63	0	40	21	20	0	0	0	125	0	0
31	42	20	34	0	21	58	0	0	0	0	0	22	0
32	19	19	193	19	0	0	0	0	0	0	0	0	0
33	0	0	103	0	0	0	22	0	0	0	0	0	0
34	44	44	200	44	89	22	0	0	0	0	0	22	0
35	0	42	224	44	0	0	0	0	0	0	20	0	0
36	0	0	43	0	0	0	29	0	0	0	22	0	18
37	0	0	0	0	40	20	0	0	0	0	0	0	180
38	0	0	60	20	0	0	0	0	0	0	0	0	0
T	4588	6320	10633	3592	3061	3824	3351	6546	1472	1823	3126	2358	3885

TABLE 4.6: Continue.

OD	27	28	29	30	31	32	33	34	35	36	37	38	Total
1	0	0	0	0	0	0	0	74	19	0	0	0	1866
2	0	0	0	0	0	0	44	22	0	0	0	0	2087
3	0	0	25	0	0	0	0	25	21	0	0	0	2571
4	0	0	47	0	0	0	0	0	33	0	0	0	4311
5	0	51	48	0	0	0	0	14	19	0	0	0	12325
6	0	0	21	0	0	0	0	42	106	0	0	0	5253
7	0	20	20	0	0	0	0	20	41	18	0	0	6005
8	0	0	0	0	0	0	0	0	68	0	0	23	7821
9	0	0	0	0	0	0	0	25	0	0	0	0	6263
10	0	0	0	0	0	0	0	0	0	0	0	0	2577
11	0	21	21	0	26	0	0	0	0	0	0	0	6970
12	0	0	60	0	22	20	0	21	19	0	0	0	9537
13	0	0	52	0	0	0	0	76	41	0	0	0	6847
14	0	0	40	0	40	0	0	0	0	0	0	0	8126
15	0	0	19	23	25	0	0	23	49	0	0	0	12084
16	0	0	39	0	47	0	21	172	127	0	0	0	9192
17	18	0	0	0	0	0	0	100	20	0	0	0	6708
18	0	20	0	64	0	0	0	0	63	0	0	0	7281
19	0	0	0	0	0	21	0	0	0	21	0	0	5168
20	0	19	0	0	0	0	0	0	19	0	0	0	8831
21	0	0	0	0	0	0	0	0	0	0	0	0	4385
22	0	0	0	0	0	0	0	0	0	0	0	31	1703
23	57	0	0	0	0	0	0	0	0	73	17	0	2244
24	0	45	64	143	0	20	40	0	0	0	0	0	2781
25	0	132	129	19	235	0	0	0	0	0	0	0	3587
26	0	0	0	0	0	0	0	0	0	0	34	0	4754
27	387	415	284	370	93	0	0	0	0	0	0	0	2053
28	309	1978	819	49	38	0	0	0	0	0	0	0	5175
29	22	679	1306	63	307	0	0	22	0	0	0	0	4715
30	16	139	401	1714	290	0	0	0	0	0	0	0	3568
31	0	468	287	13	1225	0	0	0	0	0	0	0	3314
32	0	0	0	0	0	2021	371	192	58	0	0	0	3842
33	0	0	0	0	0	39	2360	224	709	0	0	0	5382
34	0	0	0	0	0	44	67	4634	1042	44	0	44	10310
35	0	0	20	0	0	0	335	768	3254	0	44	20	10850
36	0	0	0	0	18	29	977	117	121	2008	37	0	4052
37	0	0	0	0	0	0	0	22	99	0	2204	0	3107
38	0	0	0	0	0	18	0	95	0	0	0	3270	4571
T	809	3987	3702	2458	2366	2212	4215	6688	5928	2164	2336	3388	212216

TABLE 4.6: Continued.

5.2 External Zone Matrices

External zones, those outside the study area (GMA) limits, are grouped in two components:

1. Those located between the GMA and CMA, disaggregated into 11 zones. This is an STCUM data.
2. Those located between the CMA and the external screenline counters, disaggregated into 12 zones. This is an MOTQ data.

The total 23 external zones were further aggregated as follows: the 11 zones, having relatively small trip volumes, were integrated into their spatial equivalent 12 zones (simply adding adjacent zones), thus there are only 12 external zones. The 12 external zones, which were finally selected essentially represent the freeways and expressways as they enter the GMA i.e., the inbound-outbound GMA external vehicle trips. This is usual practice.

The absence of any road side OD survey lead to the decision to distribute the exterior vehicle trips as per attractiveness of their corresponding GMA peripheral zones for the outbound trips. This is very approximate as it does not represent properly the external corridor attractiveness which is of minor impact on the research as it seeks the GMA inbound peak hour traffic. The GMA inbound trips were distributed as per attractiveness of the 38 internal zones. This gives more reliable results.

Critical missing data in Tables 4.3 and 4.4 were computed by isolating the GMA peripheral zones, in the North Shore, and using supplemental data from other STCUM matrices. This approximate, lengthy procedure, may have resulted in minor errors.

Further, the MOTQ internal screenline figures are smaller than the STCUM figures when aggregated for the 3-dimensional validation process and were revised in section 6.2.1. Table 4.7 presents the resulting total external trips for the GMA converted to equivalent passenger car trips and aggregated by origin, or zonal productions, and by destination, or zonal attractions.

The relatively large attractions for the external zones (numbered with 2 as prefix added to the internal adjacent zone number, in EMME/2 coding) are noted in Table 4.7, and these may be attributed in part to the large spatial differences between GMA-CMA and outer screen line boundaries. These figures were revised at the calibration-validation process as discussed earlier.

Z	Pr	At	Z	Pr	At
1	2654	31278	26	9830	4800
2	2174	14110	27	3737	1338
3	2225	5302	28	8720	4352
4	2579	5078	29	12023	9211
5	9035	15538	30	7009	2383
6	7132	9523	31	6037	2432
7	8524	6171	32	9837	5908
8	7373	4322	33	6651	4538
9	7899	5913	34	13048	10795
10	4010	9750	35	14566	7585
11	8415	17245	36	[illegible]	3928
12	10773	15895	37	5712	3526
13	7146	8645	38	4745	2263
14	9020	6492	222	1590	3957
15	13953	10197	223	267	1049
16	10080	11307	224	9676	4971
17	8977	5660	225	955	1660
18	8058	6172	226	1072	1578
19	5747	5189	232	487	1317
20	15703	5942	233	792	5513
21	10030	10719	234	433	4357
22	6298	2095	235	38	2576
23	5981	3031	236	955	1783
24	8753	5654	237	576	1199
25	7960	3723	238	920	1616

TABLE 4.7: 1987 ZONAL PRODUCTIONS and ATTRACTIONS.
EPC trips, internal and external zones.

5.3 Demand Matrices

The total trip travel demand OD matrix for AM peak hour, in passenger car equivalent (EPC) trips , excluding trucks, are presented in Tables 4.8 to 4.10. It should be noted that there is no data available for zone #235 inbound, which is expected to be low; consequently 1 EPC trip was entered to complete the matrix in Table 4.9. These are shown with (*).

Table 4.8 presents the GMA AM peak outbound equivalent passenger car trips computed as described in the above section.

TO FROM	222	223	224	225	226	232	233	234	235	236	237	238
1	28	7	35	12	8	9	40	31	18	9	8	12
2	28	7	35	12	8	9	40	31	18	9	9	12
3	34	9	42	14	9	11	48	37	22	11	10	14
4	45	12	56	19	12	15	64	49	29	15	14	19
5	138	36	172	58	37	46	195	152	90	45	42	58
6	94	25	117	39	25	31	133	103	61	31	28	39
7	92	24	115	39	25	31	131	101	60	31	28	39
8	106	28	133	45	29	35	151	117	69	35	32	45
9	82	22	102	34	22	27	116	90	53	27	25	34
10	44	11	54	18	12	14	62	48	28	14	13	18
11	105	28	131	44	28	35	149	116	68	35	32	44
12	113	30	142	47	31	38	161	125	74	37	34	47
13	95	25	119	40	26	32	135	105	62	32	29	40
14	123	33	154	52	33	41	175	136	80	41	37	52
15	208	55	260	87	56	69	295	229	136	67	63	87
16	102	34	160	43	28	34	145	113	66	34	31	43
17	102	27	127	43	28	34	144	112	66	34	31	43
18	141	37	175	59	38	47	199	155	92	46	43	59
19	59	15	73	25	16	20	83	64	38	20	18	25
20	172	45	215	72	47	57	245	190	112	55	52	72
21	96	25	120	40	26	32	136	106	63	32	29	40
22	75	20	94	32	20	25	107	83	49	25	23	32
23	90	24	113	38	25	30	128	99	59	30	27	38
24	148	39	185	62	40	49	210	163	96	48	45	62
25	83	22	104	35	23	28	118	92	54	28	25	35
26	107	28	133	45	29	36	151	118	70	36	32	45
27	60	16	75	25	16	20	85	66	39	20	18	25
28	133	35	166	56	36	44	188	146	86	43	40	56
29	138	36	173	58	38	46	196	152	90	45	42	58
30	143	38	179	60	39	48	203	158	93	47	43	60
31	79	21	99	33	22	26	112	87	52	26	24	33
32	112	29	139	47	30	37	158	123	73	36	34	47
33	77	20	96	32	21	26	110	85	50	26	23	32
34	166	44	207	70	45	55	236	183	108	53	50	70
35	182	48	227	76	49	61	258	200	119	59	55	76
36	221	58	275	92	60	74	313	243	144	71	67	92
37	57	15	70	24	15	19	80	62	37	19	17	24
38	79	21	99	33	22	26	113	87	52	26	24	33

TABLE 4.8: 1987 TOTAL AM PEAK OUTBOUND MATRIX.

In EPC trips.

Table 4.9 presents the GMA AM peak inbound EPC trips, completing the external computed trips.

FROM TO	222	223	224	225	226	232	233	234	*235	236	237	238
1	170	29	1039	102	114	47	85	47	1	99	62	98
2	77	13	471	46	52	20	38	20	1	45	28	45
3	30	5	180	18	20	8	15	8	1	17	11	17
4	28	5	169	17	19	8	14	8	1	16	10	16
5	28	14	518	51	57	23	42	23	1	50	31	50
6	52	9	317	31	35	14	26	14	1	30	19	30
7	34	6	209	21	23	9	17	9	1	20	12	20
8	24	4	143	14	16	6	12	6	1	14	9	14
9	33	5	199	20	22	9	16	9	1	19	12	18
10	55	9	336	33	37	15	27	15	1	32	20	32
11	96	16	586	58	64	26	48	26	1	56	35	57
12	87	15	533	52	59	24	43	24	1	51	32	50
13	48	8	290	29	32	13	24	13	1	28	17	28
14	36	6	219	23	24	10	18	10	1	21	13	21
15	57	10	344	34	38	15	28	15	1	33	20	33
16	62	10	376	37	41	17	31	17	1	36	22	36
17	31	5	192	19	21	9	16	9	1	18	11	18
18	34	6	210	21	23	9	17	9	1	20	12	20
19	29	5	174	17	19	8	14	8	1	17	10	17
20	33	6	201	20	21	9	16	9	1	19	12	18
21	60	10	363	36	40	16	30	16	1	35	22	35
22	11	2	66	7	8	3	6	3	1	7	4	7
23	17	3	100	10	11	5	8	5	1	10	6	10
24	31	5	192	19	21	9	16	9	1	18	11	18
25	21	3	126	12	14	6	10	6	1	12	7	12
26	26	4	161	16	18	7	13	7	1	15	10	15
27	7	1	45	4	5	2	4	2	1	4	3	4
28	24	4	145	14	6	7	12	7	1	14	9	14
29	52	9	315	31	35	14	26	14	1	30	19	30
30	13	2	78	8	9	4	6	4	1	8	5	8
31	13	2	81	8	9	4	7	4	1	8	5	8
32	33	6	203	20	22	9	17	9	1	19	12	19
33	25	4	151	15	17	7	12	7	1	14	9	14
34	60	10	365	36	40	16	30	16	1	35	22	35
35	42	7	254	25	29	11	21	11	1	24	15	24
36	22	4	134	13	15	6	11	6	1	13	8	13
37	20	3	119	12	13	5	10	5	1	11	7	11
38	12	2	72	7	8	3	6	3	1	7	4	7

TABLE 4.9: 1987 TOTAL AM PEAK INBOUND MATRIX.

In EPC trips.

Footnote #5[5].

Table 4.10 presents the total EPC AM peak trips, excluding trucks, for the GMA internal 38-zones.

Footnote #5:
* No data are available.

OD	1	2	3	4	5	6	7	8	9
1	545	154	1	111	174	107	132	120	154
2	308	239	80	77	73	40	47	1	18
3	187	126	204	50	127	59	54	1	54
4	154	239	68	159	172	95	67	22	1
5	1286	316	112	276	1808	883	78	53	254
6	1360	226	55	145	751	1233	261	58	278
7	1454	203	186	105	457	532	2223	472	370
8	873	252	99	42	297	287	461	1535	503
9	1377	223	37	162	730	779	137	107	1350
10	299	54	17	2	156	173	240	86	434
11	724	206	18	82	827	407	34	36	111
12	1149	367	209	232	654	356	56	72	107
13	513	473	130	370	435	97	97	67	19
14	571	149	57	66	324	78	21	36	75
15	851	598	195	458	714	233	87	90	63
16	654	831	530	396	468	162	138	23	58
17	815	544	472	148	216	167	58	77	21
18	608	431	211	91	272	55	52	19	34
19	220	438	367	19	139	38	50	18	33
20	1624	277	67	186	1090	341	167	118	269
21	1724	163	17	1	341	627	54	205	221
22	354	119	1	26	131	82	26	54	99
23	266	166	29	60	202	57	33	14	30
24	378	403	16	5	271	103	1	33	50
25	287	514	16	183	212	60	17	1	16
26	702	567	245	135	114	45	31	49	14
27	185	168	14	36	219	1	1	1	84
28	909	199	58	124	513	226	14	35	293
29	903	508	76	179	592	92	75	34	41
30	478	189	65	87	230	45	36	14	31
31	405	216	151	87	280	123	47	1	9
32	1231	770	236	93	201	100	63	45	13
33	847	569	150	139	107	170	53	36	16
34	1159	738	265	103	224	79	184	39	22
35	2123	640	228	147	429	697	390	93	54
36	785	590	143	138	89	64	1	35	15
37	560	297	100	47	174	124	153	156	70
38	517	121	50	1	168	129	151	207	267

TABLE 4.10: 1987 INTERNAL ZONES OD MATRIX, excluding trucks.

In EPC trips.

OD	10	11	12	13	14	15	16	17
1	43	134	97	38	29	18	83	30
2	109	19	113	58	46	78	195	1
3	17	109	89	139	39	76	252	20
4	15	105	109	220	1	82	164	187
5	210	650	530	429	1	127	238	60
6	142	460	178	69	36	35	257	49
7	157	286	108	40	17	51	141	111
8	541	433	84	99	38	59	90	38
9	588	414	247	67	34	52	74	18
10	829	360	85	36	34	1	2	17
11	334	2131	648	204	90	223	174	52
12	140	1238	2000	586	204	484	192	157
13	98	372	738	1079	315	392	292	54
14	34	467	1008	392	1763	790	499	131
15	204	555	1249	740	529	2289	977	332
16	102	413	388	816	167	722	1657	321
17	17	169	324	155	153	500	1213	1477
18	103	167	496	531	404	812	428	425
19	34	18	106	162	104	248	419	527
20	1448	1736	550	101	67	50	67	16
21	1172	1037	236	66	55	30	48	18
22	649	460	821	1	29	23	15	1
23	127	267	198	28	59	94	34	16
24	120	477	415	231	34	124	150	33
25	16	156	441	182	289	164	158	159
26	45	111	218	229	175	276	713	308
27	111	374	266	89	29	32	53	19
28	312	986	611	179	140	133	167	35
29	192	544	1470	272	465	277	287	54
30	135	468	512	125	109	159	154	39
31	91	122	710	192	281	371	93	18
32	63	17	93	147	123	186	307	388
33	19	66	49	39	51	82	140	100
34	130	171	132	158	59	282	342	114
35	246	366	160	135	85	158	309	70
36	37	62	70	45	20	58	198	142
37	144	106	34	2	17	34	34	1
38	366	151	82	35	1	1	3	1

TABLE 4.10: Continue.

OD	18	19	20	21	22	23	24	25	26
1	60	52	53	86	1	14	18	1	35
2	29	1	12	1	1	18	1	1	15
3	77	41	1	62	1	1	1	40	21
4	114	62	124	21	1	67	34	1	18
5	25	14	38	120	1	16	37	38	17
6	73	15	46	222	34	18	1	1	1
7	54	51	68	159	17	1	1	1	19
8	38	1	40	193	1	19	1	19	1
9	77	48	139	145	21	21	1	15	1
10	1	17	206	433	44	16	17	1	1
11	108	18	226	274	31	34	1	77	18
12	16	68	38	125	1	52	123	55	17
13	93	34	20	109	1	2	34	1	1
14	428	132	55	122	1	34	16	69	34
15	424	210	43	160	1	16	20	21	76
16	356	197	61	76	1	33	1	1	94
17	447	416	19	71	1	18	58	33	35
18	1020	279	19	51	17	1	35	1	18
19	337	1609	18	18	1	1	1	70	90
20	100	51	2799	2734	150	34	32	1	1
21	20	78	572	2292	156	1	50	1	1
22	1	14	426	1563	1408	1	1	1	1
23	46	29	48	149	1	1723	633	77	46
24	83	50	54	105	16	236	3047	174	1
25	298	177	16	16	1	16	319	2453	64
26	315	512	15	1	30	1	15	114	3460
27	1	20	29	149	1	117	51	33	1
28	55	1	102	128	2	55	50	38	1
29	79	23	150	139	1	36	336	34	18
30	82	35	49	99	1	84	263	1	14
31	162	63	55	18	1	76	26	88	40
32	145	148	1	1	1	1	1	1	1
33	66	18	1	66	16	1	1	1	1
34	207	150	18	18	1	18	18	20	37
35	103	156	1	51	1	1	17	1	71
36	50	30	1	15	1	18	19	1	1
37	19	15	1	1	16	1	18	1	235
38	32	1	15	67	1	1	1	1	34

TABLE 4.10: Continue.

OD	27	28	29	30	31	32	33	34	35	36	37	38
1	1	1	33	1	1	21	1	57	1	20	1	17
2	23	35	76	29	1	13	20	94	89	1	1	1
3	1	1	1	1	16	1	40	24	20	18	1	1
4	1	1	2	1	1	32	18	20	2	1	21	1
5	1	20	134	82	1	1	1	75	22	1	1	18
6	34	58	67	1	1	1	34	68	56	18	72	
7	16	87	56	16	1	51	50	88	72	1	31	59
8	1	57	19	17	1	19	38	57	23	34	92	149
9	17	21	42	1	1	17	55	62	52	33	50	53
10	1	24	32	1	1	1	1	1	17	15	31	1
11	34	84	126	90	41	1	18	68	18	18	18	1
12	17	145	382	31	31	21	52	71	33	17	18	17
13	17	89	186	16	40	52	38	98	2	1	23	14
14	35	55	204	37	148	37	18	103	73	1	1	1
15	1	21	180	43	102	64	85	68	70	21	24	24
16	1	66	88	20	33	71	18	157	89	1	13	31
17	1	66	57	1	17	66	50	194	38	73	1	1
18	1	1	35	3	54	69	35	122	20	18	31	1
19	1	1	52	1	34	19	18	36	34	19	1	1
20	1	46	197	34	18	18	1	16	17	35	16	1
21	1	29	30	1	1	18	1	15	1	15	15	1
22	1	35	14	1	1	1	14	14	1	1	10	1
23	132	251	337	48	48	14	1	1	1	4	15	1
24	37	128	381	309	107	1	2	1	1	1	1	34
25	1	148	462	69	221	136	1	34	16	1	1	1
26	1	15	50	15	1	94	93	74	74	1	133	14
27	571	99	321	142	42	18	1	1	1	1	1	1
28	145	1399	596	93	71	1	1	1	1	22	1	1
29	90	466	2806	221	339	60	1	21	55	17	1	1
30	18	398	971	800	98	1	1	34	59	1	18	1
31	51	159	509	102	810	1	1	17	17	1	16	18
32	1	49	29	1	13	2914	276	963	226	116	17	1
33	18	1	1	1	1	184	1420	780	658	139	53	1
34	1	1	75	1	1	672	712	4248	513	199	130	39
35	1	34	1	20	1	332	509	1338	3767	67	326	35
36	1	1	1	1	1	476	560	828	445	2725	72	1
37	1	1	28	1	1	44	74	231	429	40	2014	61
38	1	1	34	1	1	1	17	70	103	1	48	1463

TABLE 4.10: Continued.

See footnote #5

6. EMME/2 CALIBRATION and VALIDATION

The calibration and validation processes are presented in this section, using: (a) the demand matrices from section 5; (b) the volume delay functions from sub-section 5.4; (c) the calibration 'macro' presented in Appendix D; and (d) the EMME/2 description from sub-section 2.3.3.

To calibrate the volume delay functions, the MOTQ staff, apparently used a general vehicle street count including all mechanised vehicles having two or more axles i.e., automobiles, buses, and trucks. Also unfortunately, STCUM did not compile any truck data.

Truck traffic usually is concentrated in industrial areas and on freeways and expressways. Further, peaking of truck traffic occurs after 9:00 AM, i.e. beyond the GMA peak hour (7-8 AM).

The MOTQ (1984) publication shows that truck concentrations on the Trans-Canadian and Decarie freeways are consistent with available literature. MOTQ staff estimates give truck percentages of up to 8% on Montreal Island and up to 14% elsewhere during truck peak periods.

Faced with the missing truck data, the research adopted an additional 6% passenger car equivalent factor for the full demand matrix. This is a rather conservative figure as it would probably not occur on the whole road network. Truck traffic may build up to higher percentages in industrial areas, yet the estimated upper bound limit of 6% represents the truck congestion level on freeways during the morning peak hour.

6.1 Model Calibration

There is no module called 'calibration' in EMME/2, as compared to TMODEL/2 and QRS II. The calibration process proceeds, as explained in the gravity model calibration-validation in section 3 earlier, in two steps:

1. To do an assignment of travel demand in EPC trips to obtain the mean travel time
2. To do the calibration using the mean travel time inverse as an OD impedance matrix.

The calibration and calibration-validation processes are detailed in the following sub-sections.

6.1.1 Assignment stage

The assignment stage is one of the most time consuming parts of the gravity model calibration. It assigns OD pairs to the network in an all-or-nothing first step, i.e. no capacity constraint, and then it implements the VDF searching to minimize travel time at each iteration by skimming 'vine trees' to obtain the critical path between OD pairs to reach a 'modal equilibrium' (ME) between all competing routes.

In this research, there is only one mode (using EPC trips) and a pre-distribution modal split is implemented as presented in Chapter 1. This is due to the marginal effect, at the research aggregation level, of surface transit mode (less than 3%) and thus there are no competing modes for each OD pair in the modal equilibrium assignment.

The optimal assignment (assignment #10 of scenario #25) stopped at iteration #40 and was retained. Its results are:

1. The mean travel time is: 28.68 minutes
2. Its standard deviation is: 26.00 minutes
3. The relative 'Rgap' (footnote #6[6]) is: 2.35%, which is below 3%.

<u>Footnote #6:</u>
'gap' stopping criteria: gap = T - S:
It is the total travel time on the network minus the total travel time on the minimum path (travel on minimum equal paths length); ideally, T = S; it has time units (minutes).
The normalized gap (Ngap) is obtained using EPC trips as weight and also has time units (in minutes).
The relative gap (Rgap) is: **Rgap = [(T - S)/ S]* 100**; it is the stopping criteria and was kept around 3%.
Rgap and Ngap are output by EMME/2 at the end of each iteration. The Rgap decreases with each iteration while the Ngap fluctuates into a decreasing pattern (it is dependent on the previous iteration gap).

The EMME/2 steps are as follows:

1. Complete the set up by loading the demand matrix, and the volume delay functions.
2. Use EMME/2 modules 5.11 and 5.21, and do an auto assignment (footnote #[7]). Use default stopping criteria and 40 iterations.
3. Use module 3.16 (plots histograms of matrices and computes simple statistics) and compute the mean and standard deviation of the travel time between centroids.
4. Use module 2.41 (it does network computations using network attributes) to compute the trip density per link and check for abnormalities.
5. Use module 6.11 (generates reports containing auto assignment results) to check minimum paths, and control specific travel points like, bridge crossings, links with zero volumes, excessive speeds, etc...
6. Save the final trip time impedances in a full matrix (mf61) and present in Appendix D. Use the inverse of the mean travel time as a starting value for T (theta).

Footnote #7:
Stopping criteria: Rgap or Ngap (EMME/2 1992, Chapter VI), EMME/2 continues iterating until the pre-set iteration number or pre-set 'gap' is reached (which ever first).
Module 5.11 prepares the scenario for the auto assignment by referring to the matrices to be used and the stopping criteria to be implemented.
Module 5.21 implements the auto assignment for the scenario and the criteria introduced by module 5.11.

6.1.2 Model calibration process

The calibration stage makes use of the 'macro' in Appendix D to do the reverse steps for 2-dimensional balancing in EMME/2; this is module 3.22 (matrix balancing or balancing of demand: '2-dimensional' for model calibration; and '3-dimensional' for the model calibration-validation process).

The final calibrated model coefficient T (theta) is: 0.052859, and the Cij exponential distributional (mf69) matrix is in Appendix D. The process stopped at macro iteration #15 (named trial in Appendix D), and the total trip vehicle-time difference was 0.52%.

The following steps were performed:

1. Use the 'macro' to find the best value for T (theta) to produce a minimum total travel time difference between observed and computed (estimated) demand matrices.
2. Plot a superimposed, observed and computed, demand weighted, trip length (time) frequency distribution. The result is given in Fig. 4.7 which shows superimposed histograms of travel time weighted by total demand matrix before and after 2-dimensional balancing. This is quantified by the 0.52% in vehicle-time difference, which is well within the 3% (ITE Handbook, 1992; Meyer and Miller, 1984) tolerance limit.

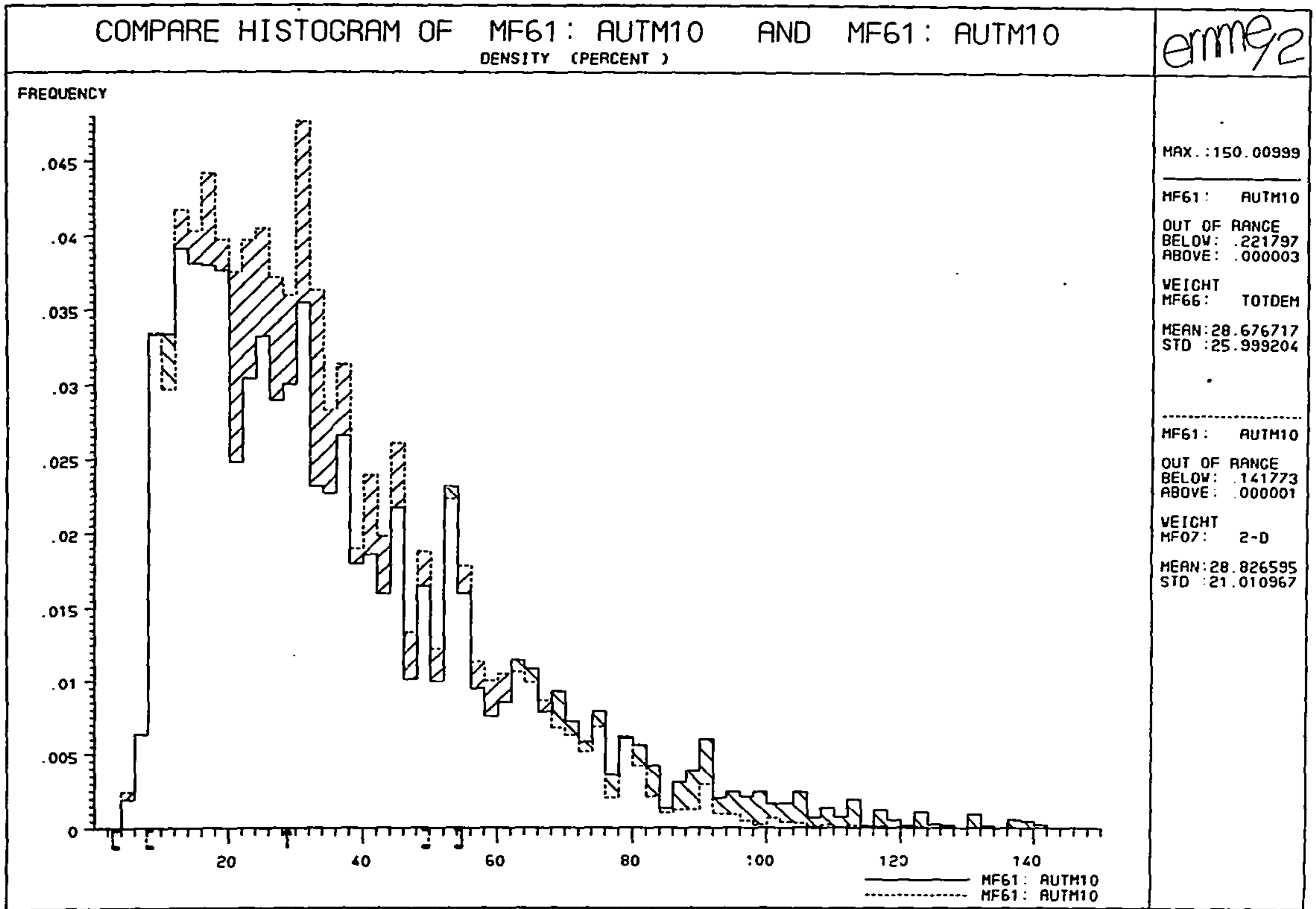


FIG. 4.7: TWO-DIMENSIONAL BALANCING HISTOGRAMS.

Figure 4.7 was plotted for two-minutes class intervals, excluding zero time, i.e. excluding intra-zonal trips which represent around 25% of all trips. This is an important trip reduction across zonal boundaries in the morning peak hour traffic.

6.2 Model Calibration-Validation

There is not a module nor even a mention of the validation process in EMME/2, yet due to its flexibility it is possible to do a simultaneous calibration-validation process using the 3-dimensional balancing, for a multiplicative type gravity model.

The Transportation Planning Handbook (1992) of the Institute of Transportation Engineers, an authority on the subject, has qualified the screenline traffic control of the balanced model to be a validation process, as it uses data from a different source than the calibration process.

The previous practice considered validation to be a process to be conducted over time and its inadequacy was proven in the U.K. where variations of ten to thirty percent and over were registered, [Meyer and Miller, 1984].
The process used to calibrate-validate the model is outlined in the following two sub-sections.

6.2.1 Data control

The two independent data sources, MOTQ and STCUM, have produced important differences at the internal screen line summations; the STCUM values are consistently larger in the North Shore (NS) and South Shore (SS) productions and attractions.

Table 4.11 defines zone groups or 'ensembles'. These zone groups are used as indices in the three dimensional balancing or validation to control travel data between internal screenlines.

```
ga01: 23, 24, 25, 26
ga02: 27, 28, 29, 30, 31
ga03:  1,  2,  3,  4,  5,  6,  7,  8,  9, 10
ga03: 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21
ga04: 22, 32, 33, 34, 35, 36, 37, 38
ga05:223,224,225,226
ga06:222,232,233,234,235,236,237,238
------------------------------------
gb01: ga01, ga05 :North Shore
gb02: ga02       :Laval
gb03: ga03       :Montreal
gb04: ga04, ga06 :South Shore
-----------------------------
gs01: gb01, gb02, gb03
gs02: gb04
```

TABLE 4.11: ZONE 'ENSEMBLES': a,b,s definitions.

Reference: EMME/2 1992.

The 50 zones (38-internal and 12-external) are aggregated into six 'ensembles' numbered 'ga' which are in turn aggregated into four 'ensembles' numbered 'gb' and these are further aggregated into two large 'ensembles' numbered 'gs'.

Table 4.12 presents the demand matrix (mf66) aggregated into zone groups in three different matrices for 'ensembles' ga, gb, and gs.

OD	ga01	ga02	ga03	ga04	ga05	ga06	sum
ga01	13123	2926	14079	846	1803	3280	36056
ga02	1446	11994	21402	421	2330	4230	41823
ga03	1967	4352	142621	5457	4208	3513	162118
ga04	580	399	31362	33773	1806	1865	69785
ga05	455	522	5559	1077	22	29	7664
ga06	274	276	2863	577	46	61	4097
sum	17844	20469	217887	42150	10216	12978	321544

OD	gb01	gb02	gb03	gb04	sum
gb01	15403	3448	19638	5231	43720
gb02	3776	11994	21402	4651	41823
gb03	6174	4352	142621	8970	162118
gb04	2707	674	34226	36276	73882
sum	28060	20469	217887	55128	321544

OD	gs01	gs02	sum
gs01	18852	228809	247661
gs02	36276	37607	73882
sum	55128	266416	321544

TABLE 4.12: MATRICES OF 'ENSEMBLES' a,b,s.

The demand matrix (mf66) was factored up (from mf20 matrix) to improve the South Shore balance between trip productions and attractions in order to satisfy the 3-dimensional constraint (the validation process) for traffic screenlines when comparing data between STCUM and MOTQ.

6.2.2 Calibration-validation process

The calibration-validation stage uses the 3-dimensional balancing process by implementing matrices from Table 4.12 above and comparing them to the calibration process matrices. The following procedural steps were followed:

1. Do groupings of the interior (river crossing traffic counts) and exterior screenline traffic counts for the OD 'gs-ensemble'; a total of four gs-indices are obtained.

2. Compute the equivalent passenger car, screenline traffic volume, for each OD pair (i.e. four indices for the four gs ODs) as follows: index #1, gs1-gs1=36276; index #4, gs2-gs2=228809; index #2, gs1-gs2=32129; index #3, gs2-gs1=13827.

3. Use module 3.21 (matrix calculator module) to compute the matrices for input into module 3.22 (matrix balancing module) like, attraction and production matrices, for the 50 zones, using the total demand matrix (mf66).

4. Use module 3.22 to run the 'three-dimensional' (3-d) balancing; save the results as follows:

(a) Balancing matrix (mf9) or the matrix distributional coefficients (using matrix #mf66).

(b) Origin matrix coefficients (mo9) or calibration alphas, the distributional production multiplicative coefficients.

(c) Destination matrix coefficients (md9) or calibration betas, the distributional attraction multiplicative coefficients.

(d) 3-d index coefficients or validation gammas, the 3-d balancing coefficients which are presented below (index numbers are the same as those in 2 above): #1=0.694; #2=0.793; #3=0.669; #4=1.563.

5. Plot superimposed, demand weighted, frequency distribution curves for (a) observed and (b) computed travel times as follows (matrices used are presented in Appendix D):

(a) Demand weighted trip length (travel time, matrix #mf61= 'autm10'; demand matrix weight= #mf66) frequency distribution curves.

(b) Demand weighted trip length (travel time matrix #mf61= 'autm10'; demand matrix weight= #mf9) frequency distribution curves.

6. Repeat the above six steps revising each time the gs-matrices (and consequently the screenline counts at some locations, its a long and time consuming process).

7. Comment on the results which are presented in Fig. 4.8 and show a remarkable improvement on those of Fig. 4.7 (2-d balancing, 0.52% fit). It is noticeable the close fit between observed and computed frequency curves.

Figure 4.8 was plotted for two-minutes class intervals, excluding zero time, i.e. excluding intra-zonal trips which represent around 25% of all trips. This is an important trip reduction across zonal boundaries in the morning peak hour traffic.

The many trials made to obtain the calibration and validation coefficients, coupled with the infrastructure aggregation difficulties, the missing data and the data retrieval process made this chapter the most time consuming.

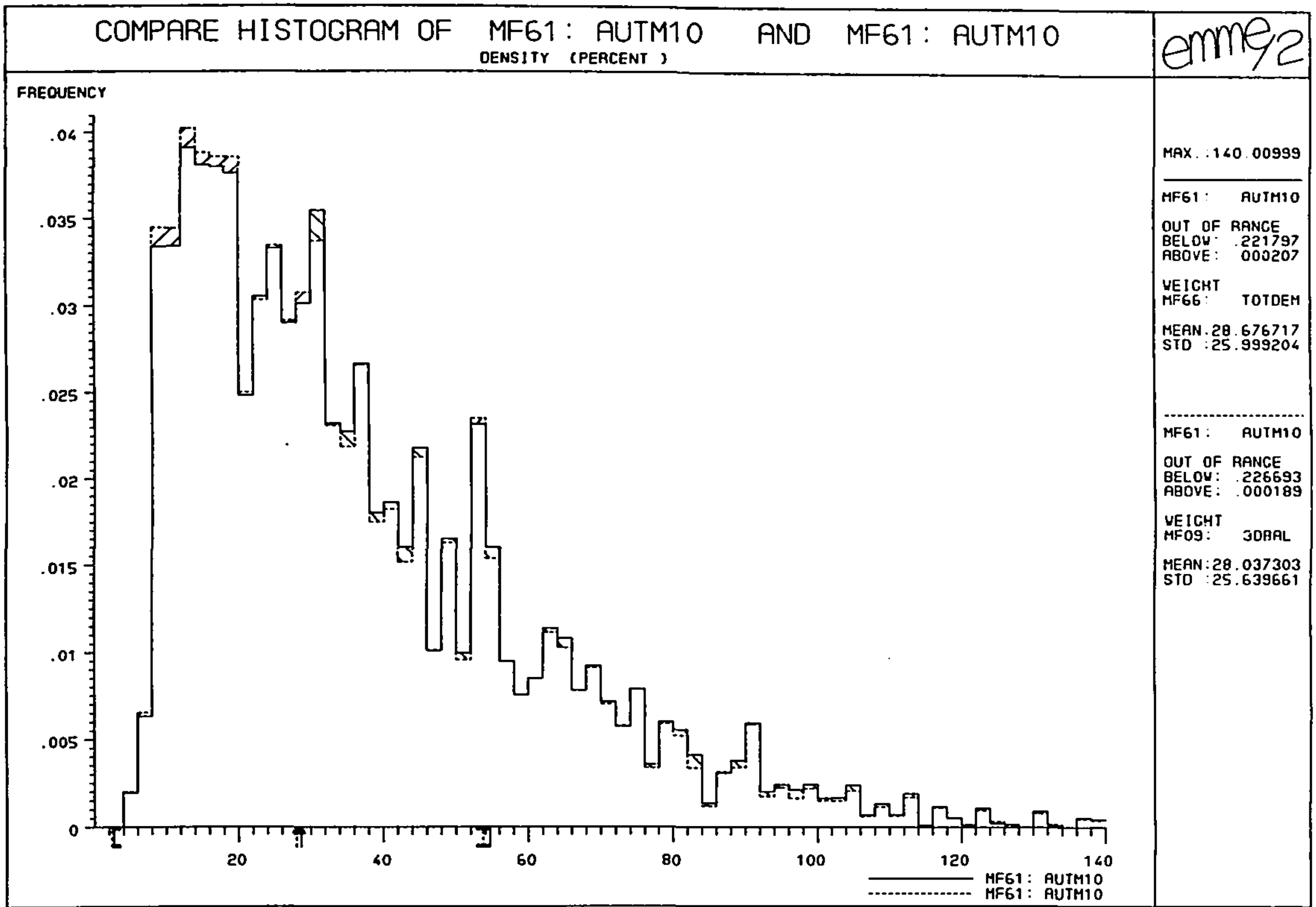


FIG. 4.8: THREE-DIMENSIONAL BALANCING HISTOGRAMS

7. CONCLUSIONS and COMMENTS

This chapter has consolidated the data, both on the supply and demand sides, and has allowed for the development of the tools needed to implement the main research objective: to develop and model supply-demand measures into a supply-demand linkage model or SDLM. This is the main purpose for Chapter 5 which is the most important research chapter.

Many problems were encountered in the process, mostly relating to data aggregation, availability and reliability.

The demand data, retrieved from the STCUM data bank, were found to be more complete and consequently more reliable than the Transports Quebec (1987) data. Thus, the GMA internal zone demand matrices (obtained from STCUM), were adopted without change. While the external zones (obtained from 3 sources; STCUM, MOTQ, and Transports Quebec) were aggregated and manipulated, especially in the validation part of the calibration-validation process.

The trip length frequency distribution curve of the calibrated model (Fig. 4.7), when compared with (Fig. 4.8), the calibrated-validated model leads to the following comments:

1. Fig. 4.7 shows a lower level of fit than Fig. 4.8.

2. Fig. 4.8 shows a high level of fit between the observed and computed (estimated) demand for the calibrated-validated model. This model is adopted and shall be used for the scenarios in Chapter 6.

3. The calibrated-validated travel demand model presented simulates total travel demand in EPC trips for the 7-8 AM peak hour traffic for all purpose trips. It is a pre-distributional modal split UTMS model.

The spatial aggregation of the GMA into 38 large traffic zones for sketch planning analysis proved to be problematic in EMME/2 calibration process.

The few centroidal (centre of gravity of zones) loading points in EMME/2 had to be expanded (loading points increased to around a hundred) to produce less congestion at the adjacent nodes and consequently, reduce the number of iterations required in the assignment stage to around 40 which are still quite high.

Furthermore, the above aggregation problem lead to traffic aggregations in corridors for zones having river boundaries, i.e., 'end zones'. This has produced zero traffic volumes in almost one third of the 'end zone' links.

The 'interior zones' i.e., zones spatially surrounded by other zones, had only about 5% links with zero traffic volumes. This shows that the expansion of the loading points was partially successful.

The cross sectional analysis in Chapter 5 shall resolve the problem whether to use or not to use the zero volume links, in further analyses.

This chapter has presented the calibration and validation of a travel demand model: the EMME/2 model. Thus, all preparatory work and the tools required to develop the Supply-Demand Linkage Model (SDLM) are now complete. The assignment stage of EMME/2 shall be extensively used in Chapter 5, to obtain the traffic densities per link, their distributions, and their statistical parameters in response to variations in demand.

CHAPTER 5

SUPPLY-DEMAND LINKAGE MODEL

1. INTRODUCTION

In this chapter, the Supply-Demand Linkage Model (SDLM) is developed for the case study of the Greater Montreal Area.

The demand data and its spatial variations for the analysis year of 1987 were presented in Chapter 3, parts C and D, and they were further discussed in Chapter 4, Section 5.

All base year demand matrices used in this chapter represent data for an average autumn day in 1987 for the 7-8 AM peak traffic and are given in equivalent passenger car trips (EPC) for all surface motorized vehicles. The data sampled in 1987 were expanded using 1986 StatsCan population survey and consequently, the data are for the 1986 survey year but are nominally called 1987 base year data.

The supply data, in the form of a road network of the GMA, are required for the calibrated gravity model, and are used by the EMME/2 model, as presented in Chapter 4.

The main congestion problems are experienced at all inbound river crossings where lane capacities are exceeded, even during the 1987 base year, as seen in Chapter 4.

The spatial distribution characteristics of the demand and supply data for the GMA are scrutinised by seeking linkages between supply and demand variables across the GMA, and by attempting to establish their spatial relationships within a cross-sectional elastic demand model.

An upper bound for the demand data is established as the maximum forecast growth for demand (DEM) in the GMA provided that traffic mobility loss is within tolerable limits.
The DEM upper bound produced a 5% (additional 5% of all links have their capacity exceeded) drop in mobility based on its 1987 GMA level. This corresponds roughly to a drop of the LOS of one level. i.e., the trip-DEN frequency distribution shapes are maintained with minimal link-capacity excesses.
An increase in DEM beyond its upper bound showed higher than expected mobility loss and was dropped. This is a very complex topic beyond the scope of this research.

The above excesses may be explained by the higher DEM causing inter-SD traffic to shift to higher order facilities; and this is partly due to the deletion of the lower order facilities as discussed in Chapter 4.

This is of further importance as it establishes the upper bound of the applicability range of the SDLM which is the DEM upper bound.

Understanding the GMA is of prime concern to the research; this is achieved by analysing its distributional frequencies of traffic density (DEN) for the 1987 base year and its DEN frequencies for the upper bound of DEM. This is in order to establish the spatial distributions of the SDLM dependent variable: traffic density (DEN) by facility type.

The results of the cross-sectional analyses show rather low explanatory powers of the independent variables. Several independent and dependent variables were scrutinized. The best multivariate analyses results were achieved using the demand (DEM) as the independent variable, and the mean of traffic density (DEN) as the dependent variable. This is the aggregate Level-Of-Service (LOS) of the road network, as presented in Chapter 1.

The results of the quasi-experimental approach, undertaken here, is accomplished by incrementally increasing the DEM and observing the DEN variations through incremental scenarios, and modelling their relationships. This has produced a successful travel demand model: the Supply Demand Linkage Model (SDLM). The SDLM is developed in two parts:

1. By varying DEM incrementally and uniformly across the GMA, and using the assignment stage of the calibrated EMME/2 model to obtain the supply measures: the variations of DEN resulting from incremental variations of DEM are determined. The outcome of this step is the development of the Base SDLM.

2. By varying DEM incrementally in SD #1 (SD1) and holding DEM constant in all other SDs, to obtain the effect of spatial demand variations (EMP and POP decentralization) in Montreal City Centre (SD1) on the mean of the road network DEN, and computing the variations in DEN. This is an indication of the aggregate LOS variation. The outcome of this step is the development of the SDLM Sub-model.

The developed and recommended SDLM Base model shows that the independent variable demand (DEM) has 99.61% explanatory powers on the dependent variable DEN, the mean traffic density in the GMA; 19 times out of 20. This is an excellent simulation.

Sensitivity analyses, comparing results from SDLM models and the sophisticated EMME/2 model, are carried out at three levels: (a) DEM upper bound, (b) DEM lower bound and (c) 1987 cross-sectional DEM. It proved the reliability of the developed SDLM model, both the Base SDLM component and the Sub-model.

The differences obtained in applying the highly complex, state-of-the-art EMME/2 model and the SDLM to the Greater Montreal Area were in the order of 5% at the three above mentioned sensitivity analyses levels. This is a good result and thus, verifies the developed SDLM models.

2. CONTEXT for MODEL DEVELOPMENT

The work of other researchers was discussed at some length in Chapter 2. In this section, more specific procedures are discussed relating to quick response modelling systems. A quick response system, relating a set of transport parameters, as described in the NCHRP Reports #186 and #187 (1978) was developed into a software package, the QRS II (discussed in Chapter 4, section 2.2.1). The software uses Report #187 parameters as default values.

The differences between Canadian and U.S. metropolises were established in Chapter 2. Consequently, there is a need to investigate the relevant parameters at the cross-sectional level and to find relationships for use in the Canadian context. The task is tremendous, and in this research, a special approach is presented relating supply and demand measures, culminating in the development of the SDLM model as presented in the following sections.

The very complex and time consuming, four-stage sequential travel demand model (also known as UTMS), was presented in Chapter 1 and Chapter 4. It has taken months to aggregate the DEM data and to manipulate and retrieve the road network infrastructure (supply) data in order to calibrate the model for the Montreal case study.

The development of the SDLM is undertaken here to by-pass the most problematic stage of the complex four-stage, sequential travel demand model, which is the network assignment stage. Thus, this eliminates the need to code the infrastructure with its thousands of nodes and links and furthermore, it eliminates the time consuming calibration-validation process.

3. DEMAND ELASTICITY MODELS

There are basically three methods to compute 'demand elasticity models' Meyer and Miller (1984, p236), quoting the U.S. Department of Transportation (1980) define these as follows:

A. 'Quasi-experimental approaches', labelled 'incremental' in this research; where services are altered under relatively controlled conditions and responses to actual service changes are monitored.

B. 'Time series analyses of demand levels ...', simplest approach.

C. 'Derivation of elasticities from cross-sectional demand models'.

'Of these three methods, the quasi-experimental approach is probably the one which is most readily usable by planners under most circumstances.' [Meyer and Miller, p236].

The NCHRP Report #186, states under the 'CONCLUSIONS AND SUGGESTED RESEARCH' heading, that;
'... A pivot point approach to estimate changes using an available data base is suggested, based on elasticity and sensitivity-type relationships'(p28).
And '... The potentially most beneficial approach is based on elasticity relationships which provide variation in one parameter based on variation in another... It is recommended that a set of elasticity measures be developed and categorized (i.e., type of urban area, size, geographic location) which can be provided in the form of tables or graphs for quick response to broad policy questions...' (p29).

Furthermore, the '...analyst should know what some of the key variables within the demand function are, whether they have a positive or negative impact on demand, and the sensitivity of demand to changes in these variables. These three issues are captured within the concept of *demand elasticity*', [Meyer and Miller, p235].

'A demand elasticity is thus a measure of sensitivity of demand to changes in system conditions'. [Meyer and Miller, p235]. In this research the terms have a different interpretation; we are investigating required changes in supply requirements due to changes in DEM and the term *supply elasticity* would probably be more appropriate; considering supply variation as a function of demand while assuming constant aggregate LOS.

The above mentioned recommendations lead to the following three steps for this research to accomplish its objective:

1. To do a cross-sectional analysis to understand the 1987 GMA supply and demand measures and their distribution, by analysing and modelling them, using Method C above, at first, which is presented in sections 4 and 5.
This permits (a) the choice of the modelling variables and their spatial aggregation levels to be used in the SDLM, and (b) the attempt to obtain a cross-sectional SDLM travel demand model.

2. The modelling of the relationships between supply and demand measures, the DEN and DEM variables [defined in (1)

above], obtained using Method A above, and the development of the SDLM models which are presented in Section 6.

3. The conduct of a sensitivity analysis of the developed model and the use of the model in forecasting as outlined in chapters 1 and 6, and presented in Section 7.

The research concept is to develop an aggregate travel demand model for supply-demand variables not used in such modelling methodology before. This stems from the fact that, for the first time, the 1985 Highway Capacity Manual has related directly the LOS of the road network to its traffic density as presented in Table 1.1 (Chapter 1).

4. TRIP DENSITY FREQUENCY DISTRIBUTIONS

As mentioned in the Introduction, understanding the case study is of prime concern to the research. This section presents the distributional frequencies of traffic density for the GMA, at the cross-sectional level for the 1987 base year data and the DEM upper bound distributions (a hypothetical forecast year having 20% uniform DEM increase), in order to establish the spatial distributions of the dependent variable: traffic density (DEN), and its variation by facility type.

The GMA road network was classified by facility type into two segments; type (F) freeways and expressways, and type (A) arterials respectively; referred to as 'freeways' and 'arterials'. This classification is according to their function at the aggregate sketch planning level; type (F) accommodating mostly inter SD travel, while type (A) accommodates intra SD travel.

4.1 Upper and Lower Bounds of DEM

The criteria to establish the upper and lower bounds for variations in DEM are two:

1. POP growth forecasts and EMP decentralization.
2. Mobility considerations limiting the applicability of the calibrated travel demand model in Chapter 4.

The BSQ population growth scenarios were scrutinized to establish an upper bound for demand growth for the GMA, which is the maximum expected growth that can be applied to the GMA while the reduction in traffic mobility in all super districts is in the order of 5% i.e., the number of additional links (as compared with base year DEM) with traffic density exceeding capacity. This is a rough estimate of the drop of the aggregate LOS of roughly one level. It is a very complex issue, beyond the scope of this research.

The lower bound for demand is taken as the 1987 base year demand because it is not expected that a net total decrease in the GMA population will occur. Further scrutiny of EMP variations showed a possible decrease in SD1. A further step was implemented and a uniform decrease of 5% in POP was implemented. It showed that there is decongestion at critical road segments, as expected, and was not further pursued.

The overall growth for the 1996 forecast year shows that even the optimistic growth scenarios in any GMA zonal aggregations represent population growths of less than 20%. Consequently, this level is tentatively selected. The 2001 optimistic scenarios may surpass the 20% figure in some areas but they are deemed to be unrealistic (see Chapter 6).

A further step was implemented and a 25% growth, upper bound scenario, was tried. It was found that several zones would attain gridlock traffic conditions (much more than 5% DEN variations exceeding capacity) for the existing network.
The above, means that there will be a high loss in mobility across the GMA, and consequently the applicability of the 'modal equilibrium' concept (EMME/2, Tmodel/2, QRS II,...) becomes questionable, a non-linear relationship. This is due to the fact that the rate of traffic dissipation from stop and go conditions (unstable flow) is lower than the rate of traffic build-up i.e., there is an unstable flow represented

by point B, in Fig. 1.2 (Chapter 1) which is not captured by any travel demand model. It is a very complex issue.

Thus, the upper bound is confirmed at a uniform DEM increase of 20% in the GMA to avoid mobility problems. And the 20% increase in demand represents around 25 years of uniform POP growth. This may occur in a few zones but it is not likely to occur in the GMA as a whole.

4.2 Zonal Data

The data for input to the modelling process are based on zonal characteristics. Each zone constitutes an observation point in the model i.e., we have 38 zones and consequently, 38 observations. Data are considered at the zonal level first, and then for aggregations of zones.

The upper bound scenario of a 20% uniform DEM increase in the GMA, was simulated using the calibrated EMME/2 model. The augmented demand was assigned and the variable DEN was computed per link by zone and by facility type.

The zonal link-density frequency distributions for the GMA, Montreal Island, and other aggregations are produced using the EMME/2 assignment stage output facility. The output data were used as input to SAS software. Two programs were developed, for the upper bound (uniform 20% growth) and for the 1987 base year.

The dependent variable DEN, per link, is computed using data from EMME/2 and Eq. 5.1. While to compute DENA (DEN for arterials) and DENF (DEN for freeways) from Eq. 5.1, ZLLA and ZLLF are used instead of ZLL, VAU (link traffic volume) and TAU (travel time per link) were also retrieved by facility type:

DEN = VAU * TAU / (ZLL* 60) **Eq. 5.1**

Where;

ZLL = LAN*LEN, (other variables in footnote #1[1])

Table 5.1 presents the mean (average) zonal DEN i.e., the statistical mean of DEN for all links in a zone computed using SAS, and their corresponding LOS, obtained from Table 1.1 (Chapter 1). Also presented are the corresponding upper bound figures to compare with and to establish the range of applicability for the SDLM.

The GMA network traffic was performing rather well during the morning peak hour in 1987. As seen in Table 5.1, the lowest

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Footnote #1:

DEN = mean traffic density (also link DEN) in EPC/KM per Z, D, or SD
ZLL = mean lane-link length (also link length) in km per Z, D, or SD
ZLLA= ZLL for arterial streets in km per Z, D, or SD
ZLLF= ZLL for freeways and expressways in km per Z, D, or SD
DENA= DEN in arterial streets in EPC per km
DENF= DEN in freeways and expressways in EPC per km
TAU = mean link travel time (also per link) in minutes
SPD = mean link speed (also per link) in km/hr
VAU = mean link traffic volume (also per link) in EPC
Z = zone number (also centroid number)
LAN = number of directional lanes
LEN = mean link-length (or link length) in km

aggregate LOS registered was LOS D in five out of the 38 zones: zones 3 and 13 are in MTL Centre; zone 20 is in MTL West; zone 12 is in MTL East; and zone 29 is in Laval.

Z	BASE DEM		1.2 * DEM		Z	BASE DEM		1.2 *DEM	
	DEN	LOS	DEN	LOS		DEN	LOS	DEN	LOS
1	8.78	B	12.69	C	20	24.37	D	39.20	E
2	11.21	B	15.84	C	21	12.37	C	17.42	C
3	19.61	D	29.39	E	22	4.15	A	6.14	A
4	16.73	C	26.23	E	23	3.58	A	5.37	A
5	15.28	C	21.80	D	24	9.32	B	13.37	C
6	10.38	B	15.21	C	25	3.96	A	6.37	A
7	6.32	A	9.90	B	26	16.71	C	29.90	E
8	4.04	A	5.94	A	27	12.82	C	23.65	D
9	13.38	C	19.22	D	28	15.97	C	29.47	E
10	8.96	B	15.55	C	29	19.01	D	34.83	E
11	16.08	C	24.09	D	30	6.13	A	11.14	B
12	22.76	D	35.08	E	31	12.38	C	22.77	D
13	20.42	D	28.25	E	32	14.64	C	20.73	D
14	20.11	C	27.47	E	33	5.32	A	7.99	B
15	14.62	C	20.08	D	34	11.34	B	17.39	C
16	12.51	C	18.40	C	35	6.89	A	10.63	B
17	12.70	C	18.95	D	36	3.23	A	4.94	A
18	11.68	B	15.58	C	37	2.57	A	4.05	A
19	8.86	B	14.72	C	38	4.26	A	7.37	A

TABLE 5.1: ZONAL DEN and AGGREGATE LOS

For the 1987 year and DEM upper bound.

Four of the above five zones are located on Montreal Island. All five zones have important through traffic, i.e. they are traversed by important freeways. This may explain the higher DEN (lower LOS). Furthermore, Table 5.1 shows that although several zones, at the upper growth boundary, have reached an aggregate LOS E, their capacities on average were not reached (DEN < 41.4, Table 1.1, Chapter 1).

4.3 Aggregated Data

The GMA was spatially divided into 38 large zones resulting in 38 observations for the DEM variable. They were further aggregated into twelve districts (Ds), and six super districts (SDs). The results were summarized in Chapter 3, Part C.

The aggregated centroidal loading in the calibrated EMME/2 travel demand model has produced zero traffic volumes for approximately 35% of the links in peripheral zones, but they accounted for less than 5% of links in interior zones (Chapter 4). This lead to the need for a new zonal aggregation in Montreal Island, grouping those interior and peripheral zones:
(1) MTLin = interior zones (zones #4,5,6,9,13,15).
(2) MTLot = peripheral zones (the remaining zones in MTL).

Frequency distributions (for a DEN class of 4 EPC/km) for a range between 2 and 102 were retrieved for each of the 22 aggregation groups (12 Ds plus the 10 groups in Table 5.2) by facility type (all roads, arterial roads, and freeway and expressway roads), to give a total of 66 frequency distributions for each of the base year and the upper bound condition.

The aggregations by district are not presented as they do not have enough observations (zones) to analyze; although traffic densities (DEN) are available by link, DEM is only available by zone. Thus, there are as many observation points as there are zones in a district, and they are not enough to do statistical analyses.

The frequency distributions showed the variations of the traffic densities (DEN) in equivalent passenger car (EPC) trips per kilometre (km) across the GMA and these are presented in Tables 5.2 and 5.3.

LOC.	BASE YEAR MEAN	STDEV	<20	<40	DEN >100	UPPER BOUND MEAN	STDEV	<20	<40	DEN >100
SD1	11.85	21.35	81.4	92.0	0.8	17.29	30.55	75.0	87.8	2.3
SD2	15.44	42.52	78.4	90.6	2.1	23.94	64.63	72.1	85.0	4.8
SD3	15.13	23.79	73.7	90.3	1.7	22.39	38.35	65.2	83.4	3.3
SD4	14.52	40.57	81.8	90.6	1.7	26.68	93.82	73.7	87.2	4.5
SD5	8.64	23.86	86.1	94.2	0.9	14.09	42.21	80.7	91.9	2.6
SD6	8.23	46.42	90.5	96.6	0.6	12.50	68.97	83.6	94.4	1.1
MTLin	14.56	21.73	74.7	89.9	0.9	20.95	30.25	67.2	84.5	2.5
MTLot	13.08	29.90	80.2	91.8	1.5	19.75	45.86	73.5	86.6	3.4
MTL	13.49	27.89	78.7	91.2	1.3	20.08	42.17	71.8	86.0	3.1
GMA	12.02	34.71	82.4	92.7	1.2	18.66	56.77	75.2	88.4	2.7

TABLE 5.2: DEN FREQUENCY DISTRIBUTION SUMMARY

DEN distributions for base year and upper bound conditions.

DEN in EPC/KM and DEN range in percentages.

Six trip link-density frequency distributions are presented in Figures 5.1 and 5.2, as a sample, three for the base year and three for the upper bound scenario and they represent key aggregations for the research; they are presented after Table 5.4 (next section) where they are further discussed.

Table 5.2 presents a comparison between the base year DEN and its upper bound, representing a 20% uniform increase in demand. Furthermore, a DEN range of 0 to 100 is grouped into three basic levels, representing different traffic congestion levels and summarizing the main characteristics of DEN frequencies, namely:

1. DEN < 20 EPC/km, represents the desirable range for comfortable (de-congested) driving.
2. DEN between 20 and <40 EPC/km represents the uncomfortable driving range, and unstable traffic flow is attained throughout the upper half of the range.
3. DEN between 40 and 100 EPC/KM represent the stop and go situation i.e, road network gridlock or unstable flow.
4. DEN greater than a hundred is impossible to attain, they represent the data outliers.

Points (3) and (4) above may also be explained by the shift of traffic to upper level facility types due to the cancellations of the collector and local roads in Chapter 4.

It may be noted in Table 5.2 that the limit of mobility, defined as DEN>=40, has dropped 5.2% in the links of Montreal Island (MTL), from 91.2% to 86.0% and 4.3% in the GMA, from 92.7% to 88.4% due to the 20% increase in demand. Furthermore, the mean DEN has increased by 6.59 EPC/km in MTL, from 13.49 to 20.08; while, the figure for the GMA is 6.68 EPC/km.

It is remarkable that the standard deviation of DEN has increased out of proportion. For instance, in MTL it has increased from 27.89 to 42.17 i.e., the DEN population has spread out, an increase in demand produced a more spread frequency distribution. This is due to the re-assignment of traffic in EMME/2, and this process is captured by the volume delay functions.

Table 5.3 presents a comparison of statistics for the base year, corresponding to the aggregations in the link-density frequency distributions, by facility type.

LOC.	ARTERIALS:				DENA	FREEWAYS & EXPRESSWAYS:				DENF
	MEAN	STDEV	<20	<40	>100	MEAN	STDEV	<20	<40	>100
SD1	9.78	18.98	85.1	94.4	0.5	33.41	30.73	42.7	66.2	3.8
SD2	12.85	42.38	82.2	92.2	1.5	29.69	40.59	57.1	81.8	5.2
SD3	13.11	19.96	76.4	92.6	1.1	53.76	47.34	21.3	45.9	13.1
SD4	9.64	29.28	87.3	93.9	0.9	49.40	77.09	42.4	66.7	8.1
SD5	5.38	18.62	90.3	96.0	0.3	22.93	36.19	67.5	86.3	3.8
SD6	5.89	48.62	94.0	97.9	0.2	20.61	27.93	70.6	89.4	2.4
MTLin	11.57	18.15	80.6	93.4	0.4	45.83	30.09	12.5	53.6	6.3
MTLot	11.22	28.06	82.7	93.5	1.1	31.12	39.63	56.3	74.4	5.4
MTL	11.32	25.70	82.1	93.5	0.9	34.97	37.89	44.9	68.9	5.6
GMA	9.55	32.84	85.9	94.7	0.7	30.82	42.25	55.0	76.9	4.7

TABLE 5.3: BASE YEAR FREQUENCY DISTRIBUTIONS by FACILITY TYPE.

DENA and DENF in EPC/km and density range in percentages.

As expected, in Table 5.3, the arterial roads have lower traffic densities (DENA) than the expressways. This is due to the affinity of freeways to attract more trips because of the drivers perception that freeways are less congested. Also a freeway lane has higher capacity.

Furthermore, as mentioned earlier, this may be due to zonal infrastructure aggregations i.e., the elimination of local and collector roads (Chapter 4).

Table 5.4 presents the trip link-density frequency statistics data for the 1987 base year for SDs, MTLin, MTLot, MTL and GMA. The district and zonal data are presented in Appendix E1.

4.4 Synthesis of Distribution Results

It is of interest to note, from Table 5.2, that the GMA has a mean of 12.02 EPC/km i.e., an aggregate LOS B. DEN for MTL Island is 13.49 EPC/km and for Jesus Island 14.52 EPC/km, representing a LOS of C for both while, the North (8.64) and South (8.23) shores both have LOS B.

A comparison between Montreal Island spatial components (Table 5.4) shows that subdividing the island into inner (MTLin) and peripheral (MTLot) zonal aggregations may better represent the functionality of the road network, yet it does not improve the aggregational characteristics of DEN and ZLL variables relative to their super districts level i.e., they do not form distinct groupings as far as DENs, in the impact analyses, are concerned.

LOC.	N OBS	VAR	MIN	MAX	SUM	MEAN	STD DEV
SD1	2434	ZLL	0.03	11.22	2041.1	0.84	0.87
		ZLLA	0.03	11.22	1708.1	0.77	0.80
		ZLLF	0.18	9.87	333.1	1.56	1.19
		DEN	0.00	324.53	28844	11.85	21.35
		DENA	0.00	324.53	21728	9.78	18.98
		DENF	0.00	152.49	7116.0	33.41	30.73
		TAU	0.03	10.55	1781.3	0.73	0.75
		SPD	3.74	80.00	78526	32.26	8.68
		VAU	0.00	6949.0	1.93E6	787.03	1287.5
SD2	1003	ZLL	0.04	10.96	1436.6	1.43	1.30
		ZLLA	0.04	7.02	1045.8	1.23	1.11
		ZLLF	0.12	10.96	390.8	2.54	1.68
		DEN	0.00	777.30	15486	15.44	42.52
		DENA	0.00	777.30	10914	12.85	42.38
		DENF	0.00	365.05	4571.7	29.69	40.59
		TAU	0.03	14.05	1363.2	1.36	1.29
		SPD	3.49	79.64	34227	34.12	12.93
		VAU	0.00	8046.0	0.88E6	870.80	1355.0
SD3	1230	ZLL	0.07	8.79	1616.7	1.31	1.04
		ZLLA	0.07	7.53	1450.7	1.24	0.90
		ZLLF	0.36	8.79	166.0	2.72	2.01
		DEN	0.00	247.29	18610	15.13	23.79
		DENA	0.00	190.98	15331	13.11	19.96
		DENF	4.97	247.29	3279.1	53.76	47.34
		TAU	0.09	6.80	1554.3	1.26	0.85
		SPD	5.66	70.78	36906	30.00	7.98
		VAU	0.00	7478.0	1.1E6	893.44	1252.3
SD4	806	ZLL	0.08	10.24	1071.2	1.33	1.28
		ZLLA	0.08	10.24	795.9	1.13	1.06
		ZLLF	0.24	7.16	275.2	2.78	1.70
		DEN	0.00	464.28	11704	14.52	40.57
		DENA	0.00	426.52	6813.3	9.64	29.28
		DENF	0.00	464.28	4890.5	49.40	77.09
		TAU	0.07	12.72	1204.6	1.49	1.54
		SPD	3.78	80.00	17898	34.61	10.68
		VAU	0.00	8357.0	0.62E6	761.93	1416.6
SD5	431	ZLL	0.15	31.96	1548.1	3.59	4.82
		ZLLA	0.15	31.96	1000.9	2.85	4.05
		ZLLF	0.76	27.92	547.2	6.84	6.36
		DEN	0.00	279.49	3723.3	8.64	23.86
		DENA	0.00	261.84	1888.9	5.38	18.62
		DENF	0.00	279.49	1834.4	22.93	36.19
		TAU	0.16	35.95	1479.1	3.43	4.36
		SPD	8.01	80.00	17019	39.49	14.70
		VAU	0.00	6530.0	152861	586.68	1166.7

TABLE 5.4: GMA, MTL, SDS; 1987 BASE YEAR SUMMARY STATISTICS.

For DEN, ZLL, TAU, SPD, VAU (continues).

LOC.	N OBS	VAR	MIN	MAX	SUM	MEAN	STD DEV
SD6	1961	ZLL	0.02	75.60	4118.5	2.10	4.02
		ZLLA	0.02	75.60	3192.2	1.91	4.13
		ZLLF	0.18	20.56	926.3	3.17	3.11
		DEN	0.00	1660.1	15857	8.09	46.42
		DENA	0.00	1660.1	9837.5	5.89	48.62
		DENF	0.00	302.64	6019.3	20.61	27.93
		TAU	0.04	47.27	3922.5	2.00	3.11
		SPD	1.26	80.00	74879	38.18	12.78
		VAU	0.00	7809.0	0.96E6	486.43	996.66
MTL	4667	ZLL	0.03	11.22	5094.5	1.09	1.06
		ZLLA	0.03	11.22	4204.5	0.99	0.93
		ZLLF	0.12	10.96	889.9	2.08	1.60
		DEN	0.00	777.30	62939	13.49	27.89
		DENA	0.00	777.30	47972	11.32	25.70
		DENF	0.00	365.05	14967	34.97	37.89
		TAU	0.03	14.05	4698.7	1.01	0.96
		SPD	3.49	80.00	149659	32.07	9.70
		VAU	0.00	8046.0	3.89E6	833.08	1294.0
MTLin	1286	ZLL	0.04	7.53	1298.8	1.01	0.85
		ZLLA	0.04	7.53	1093.4	0.93	0.78
		ZLLF	0.18	7.05	205.4	1.83	1.15
		DEN	0.00	285.17	18719	14.56	21.73
		DENA	0.00	285.17	13585	11.57	18.15
		DENF	0.90	152.49	5133.3	45.83	30.09
		TAU	0.04	6.80	1178.5	0.92	0.70
		SPD	4.17	79.25	40107	31.19	8.31
		VAU	0.00	6949.0	1.26E6	978.87	1436.7
MTLot	3381	ZLL	0.03	11.22	3795.6	1.12	1.12
		ZLLA	0.03	11.22	3111.1	1.02	0.98
		ZLLF	0.12	10.96	684.5	2.17	1.72
		DEN	0.00	777.30	44221	13.08	29.90
		DENA	0.00	777.30	34387	11.22	28.06
		DENF	0.00	365.05	9833.6	31.12	39.63
		TAU	0.03	14.05	3520.2	1.04	1.04
		SPD	3.49	80.00	109552	32.40	10.16
		VAU	0.00	8046.0	2.63E6	777.62	1231.0
GMA	7865	ZLL	0.02	75.60	11832	1.50	2.56
		ZLLA	0.02	75.60	9193.5	1.32	2.41
		ZLLF	0.12	27.92	2638.6	2.94	3.16
		DEN	0.00	1660.1	94223	11.98	34.71
		DENA	0.00	1660.1	66512	9.55	32.84
		DENF	0.00	464.28	27711	30.82	42.25
		TAU	0.03	47.27	11305	1.44	2.15
		SPD	1.26	80.00	269453	34.26	11.32
		VAU	0.00	8357.0	0.57E7	725.85	1242.4

TABLE 5.4: Continued.

NB: Zonal and district statistics are presented in Appendix E1.
Variables are defined in footnote #1.

The three super districts in MTL (SD1, SD2, and SD3) are found to represent more distinctive groups with their mixed concentrations of zero traffic volume links, and they relate better to locally retrieved data in Chapter 3 such as forecasting scenarios of BSQ (1984) and Lamonde et al. (1989).

Furthermore, using again Table 5.4, SD2 and SD3 are seen to have higher DEN (15.44 and 15.13) than SD1 (11.85). This leads to a possible grouping of SD2 and SD3 thus, MTL may be divided into two parts: (1) City Centre (SD1), and (2) suburbs (SD2 and SD3) for modelling purposes.

Figures 5.1 and 5.2 represent three key aggregations for the research: SD1, MTL, and GMA. The SD1 frequencies are basic to highlight the impact of the decentralization of EMP in the City Centre, described in Chapter 3.

It is of interest to note that the shape of the frequency distributions is not the one of a 'normal distribution' due to their skewness to the right. Yet, due to the large sample used, the 'Central Limit Theorem' applies. It states that "If the sample size is sufficiently large, then the mean x of a random sample from a population has a sampling distribution that is approximately normal, regardless of the shape of the relative frequency distribution of the target population" [Sincich, 1989, p281]. Consequently, the normal distribution equations apply to the trip link-density frequency distributions, regardless of their shape.

Figures 5.1-1 to 5.1-3 present the trip link-density frequency distributions for the 1987 base year for SD1, Montreal Island (MTL), and the Greater Montreal Area (GMA). For each aggregation a frequency distribution for DENF, and DENA is presented in Appendix E-E2.

Figures 5.2-1 to 5.2-3 present the upper bound trip density frequency distributions for DEN; for SD1, MTL, and GMA. Densities greater than 100 may be considered outliers (or traffic gridlocks, as explained earlier), as they are not possible to achieve, and are aggregated. They represent less than 1.5% of all links during the AM peak hour.

A comparison between Fig. 5.1 (base year) and Fig. 5.2 (DEM augmented by 20%) shows an increase in skewness to the right in parallel with an increase in demand e.g., the increase of DEN above capacity (DEN-mean>= 38) for SD1 has changed from 91.95% link mobility to 87.76%. The figures for MTL are from 91.24% to 95.98%, and for the GMA are from 92.68% to 88.40% respectively.

Therefore there is a drop in mobility of 4.19% in SD1, 5.26% in MTL and 4.48% in the GMA. All the mobility variations are around 5%, a selected reasonable level, representing a drop of one level in the aggregate LOS. Thus, the DEM upper bound of 20% uniform growth is confirmed.

Further, a similar comparison between the link-frequency distributions for arterials and freeways for SD1 (base year), figures E5.1-4 and E5.1-5 in Appendix E1 and Fig 5.1-1, shows that the real congestion is in the City Centre and occurs on freeways where mobility is at its lowest: 66.20%; while on the arterials it is 96.17% which is higher than the overall DEN mean of 91.95%, as expected.

Similarly, a comparison of base year frequencies for MTL and the GMA show similar trends as for SD1. For instance: for MTL it is 68.93% for Freeways and 93.49% for arterials (the mean is 91.95%); while for the GMA it is 76.86% for freeways and 94.72% for arterials (the mean is 92.68%). These data confirm the higher attraction affinity of freeways as presented in the Introduction to this chapter.

The previous tables and Figures 5.1, and 5.2 present the statistical data necessary to improve the interpretation of the results of scenarios in Chapter 6. Furthermore, such data have provided the necessary background to understand the spatial distribution of the trip-link density through its population, mean, standard deviation, minima and maxima.

PERCENTAGE OF DEN

```
DEN    DENSITY in EPC/KM                       CUM                CUM
MIDPOINT                              FREQ    FREQ   PERCENT   PERCENT


  2   |**************************     1244    1244    51.11     51.11
  6   |******                          282    1526    11.59     62.70
 10   |****                            203    1729     8.34     71.04
 14   |***                             153    1882     6.29     77.32
 18   |**                               99    1981     4.07     81.39
 22   |*                                66    2047     2.71     84.10
 26   |*                                68    2115     2.79     86.89
 30   |*                                49    2164     2.01     88.91
 34   |*                                44    2208     1.81     90.71
 38   |*                                30    2238     1.23     91.95
 42   |*                                47    2285     1.93     93.88
 46   |                                 24    2309     0.99     94.86
 50   |                                 20    2329     0.82     95.69
 54   |                                 10    2339     0.41     96.10
 58   |                                  6    2345     0.25     96.34
 62   |                                 13    2358     0.53     96.88
 66   |                                  9    2367     0.37     97.25
 70   |                                  6    2373     0.25     97.49
 74   |                                 16    2389     0.66     98.15
 78   |                                  5    2394     0.21     98.36
 82   |                                  2    2396     0.08     98.44
 86   |                                  6    2402     0.25     98.69
 90   |                                  6    2408     0.25     98.93
 94   |                                  4    2412     0.16     99.10
 98   |                                  2    2414     0.08     99.18
102   |                                 20    2434     0.82    100.00
      -----+----+----+----+----+-
          10   20   30   40   50

              PERCENTAGE
```

FIG. 5.1-1: 1987 BASE YEAR DEN DISTRIBUTIONS: SD1.

Trip link-density frequency distribution. All roads.

PERCENTAGE OF DEN

```
DEN    DENSITY in EPC/KM                        CUM                CUM
MIDPOINT                              FREQ     FREQ   PERCENT   PERCENT


  2    |*************************     2312     2312     49.54     49.54
  6    |*****                          492     2804     10.54     60.08
 10    |****                           351     3155      7.52     67.60
 14    |***                            306     3461      6.56     74.16
 18    |**                             212     3673      4.54     78.70
 22    |**                             179     3852      3.84     82.54
 26    |**                             141     3993      3.02     85.56
 30    |*                              110     4103      2.36     87.92
 34    |*                               91     4194      1.95     89.87
 38    |*                               64     4258      1.37     91.24
 42    |*                               80     4338      1.71     92.95
 46    |*                               52     4390      1.11     94.06
 50    |                                38     4428      0.81     94.88
 54    |                                32     4460      0.69     95.56
 58    |                                15     4475      0.32     95.89
 62    |                                20     4495      0.43     96.31
 66    |                                15     4510      0.32     96.64
 70    |                                12     4522      0.26     96.89
 74    |                                20     4542      0.43     97.32
 78    |                                20     4562      0.43     97.75
 82    |                                15     4577      0.32     98.07
 86    |                                 9     4586      0.19     98.26
 90    |                                 9     4595      0.19     98.46
 94    |                                 6     4601      0.13     98.59
 98    |                                 4     4605      0.09     98.67
102    |*                               62     4667      1.33    100.00
       -----+----+----+----+----+
           10   20   30   40   50

              PERCENTAGE
```

FIG. 5.1-2: 1987 BASE YEAR DEN DISTRIBUTIONS: MONTREAL ISLAND.

Trip link-density frequency distribution. All roads.

PERCENTAGE OF DEN

```
DEN   DENSITY in EPC/KM                                CUM                   CUM
MIDPOINT                                       FREQ    FREQ   PERCENT   PERCENT



  2    |****************************           4420    4420     56.20     56.20
  6    |*****                                   731    5151      9.29     65.49
 10    |***                                     517    5668      6.57     72.07
 14    |***                                     456    6124      5.80     77.86
 18    |**                                      354  [illegible]  4.50     82.36
 22    |**                                      262    6740      3.33     85.70
 26    |*                                       198    6938      2.52     88.21
 30    |*                                       146    7084      1.86     90.07
 34    |*                                       120    7204      1.53     91.60
 38    |*                                        85    7289      1.08     92.68
 42    |*                                       112    7401      1.42     94.10
 46    |                                         72    7473      0.92     95.02
 50    |                                         49    7522      0.62     95.64
 54    |                                         48    7570      0.61     96.25
 58    |                                         20    7590      0.25     96.50
 62    |                                         27    7617      0.34     96.85
 66    |                                         27    7644      0.34     97.19
 70    |                                         18    7662      0.23     97.42
 74    |                                         27    7689      0.34     97.76
 78    |                                         29    7718      0.37     98.13
 82    |                                         17    7735      0.22     98.35
 86    |                                         14    7749      0.18     98.53
 90    |                                         12    7761      0.15     98.68
 94    |                                          8    7769      0.10     98.78
 98    |                                          5    7774      0.06     98.84
102    |*                                        91    7865      1.16    100.00
       -----+----+----+----+----+---
           10   20   30   40   50

                PERCENTAGE
```

FIG. 5.1-3: 1987 BASE YEAR DEN DISTRIBUTIONS: GREATER MONTREAL AREA.

Trip link-density frequency distribution. All roads.

PERCENTAGE OF DEN

DEN MIDPOINT	DENSITY in EPC/KM	FREQ	CUM FREQ	PERCENT	CUM PERCENT
2	********************	989	989	40.63	40.63
6	******	289	1278	11.87	52.51
10	*****	227	1505	9.33	61.83
14	****	202	1707	8.30	70.13
18	**	118	1825	4.85	74.98
22	**	94	1919	3.86	78.84
26	*	56	1975	2.30	81.14
30	*	61	2036	2.51	83.65
34	*	54	2090	2.22	85.87
38	*	46	2136	1.89	87.76
42	*	26	2162	1.07	88.82
46	*	31	2193	1.27	90.10
50		22	2215	0.90	91.00
54		20	2235	0.82	91.82
58	*	40	2275	1.64	93.47
62		20	2295	0.82	94.29
66		14	2309	0.58	94.86
70		9	2318	0.37	95.23
74		10	2328	0.41	95.65
78		10	2338	0.41	96.06
82		7	2345	0.29	96.34
86		13	2358	0.53	96.88
90		10	2368	0.41	97.29
94		3	2371	0.12	97.41
98		6	2377	0.25	97.66
102	*	57	2434	2.34	100.00

```
-----+----+----+----+
    10   20   30   40
```

PERCENTAGE

FIG. 5.2-1: UPPER BOUND DEN DISTRIBUTIONS: SD1.

Trip link-density frequency distribution. All roads.

PERCENTAGE OF DEN

DEN MIDPOINT	DENSITY in EPC/KM	FREQ	CUM FREQ	PERCENT	CUM PERCENT
2	********************	1874	1874	39.92	39.92
6	******	526	2400	11.21	51.13
10	****	397	2797	8.46	59.59
14	****	329	3126	7.01	66.60
18	***	242	3368	5.16	71.75
22	**	182	3550	3.88	75.63
26	**	155	3705	3.30	78.93
30	*	124	3829	2.64	81.57
34	*	115	3944	2.45	84.02
38	*	92	4036	1.96	85.98
42	*	77	4113	1.64	87.62
46	*	61	4174	1.30	88.92
50	*	63	4237	1.34	90.26
54		45	4282	0.96	91.22
58	*	60	4342	1.28	92.50
62		40	4382	0.85	93.35
66		25	4407	0.53	93.89
70		27	4434	0.58	94.46
74		23	4457	0.49	94.95
78		18	4475	0.38	95.33
82		12	4487	0.26	95.59
86		19	4506	0.40	95.99
90		17	4523	0.36	96.36
94		8	4531	0.17	96.53
98		17	4548	0.36	96.89
102	**	146	4694	3.11	100.00

```
-----+----+----+----+
     10   20   30   40
```

PERCENTAGE

FIG. 5.2-2: UPPER BOUND DEN DISTRIBUTIONS: MONTREAL ISLAND.

Trip link-density frequency distribution. All roads.

PERCENTAGE OF DEN

```
DEN    DENSITY in EPC/KM                   CUM                CUM
MIDPOINT                          FREQ     FREQ   PERCENT  PERCENT


  2   |************************   3656     3656     47.21    47.21
  6   |*****                       724     4380      9.35    56.56
 10   |****                        578     4958      7.46    64.02
 14   |***                         469     5427      6.06    70.08
 18   |***                         399     5826      5.15    75.23
 22   |**                          289     6115      3.73    78.96
 26   |**                          250     6365      3.23    82.19
 30   |*                           185     6550      2.39    84.58
 34   |*                           164     6714      2.12    86.70
 38   |*                           132     6846      1.70    88.40
 42   |*                           103     6949      1.33    89.73
 46   |*                            86     7035      1.11    90.84
 50   |*                            90     7125      1.16    92.01
 54   |                             51     7176      0.66    92.67
 58   |                             69     7245      0.89    93.56
 62   |                             53     7298      0.68    94.24
 66   |                             41     7339      0.53    94.77
 70   |                             37     7376      0.48    95.25
 74   |                             26     7402      0.34    95.58
 78   |                             26     7428      0.34    95.92
 82   |                             22     7450      0.28    96.20
 86   |                             26     7476      0.34    96.54
 90   |                             21     7497      0.27    96.81
 94   |                             16     7513      0.21    97.02
 98   |                             19     7532      0.25    97.26
102   |*                           212     7744      2.74   100.00
      -----+----+----+----+----
          10   20   30   40


             PERCENTAGE
```

FIG. 5.2-3: UPPER BOUND DEN DISTRIBUTIONS: GREATER MONTREAL AREA.

Trip link-density frequency distribution. All roads.

5. CROSS-SECTIONAL ANALYSES

Cross-sectional analyses are presented in this section. It is an analysis of the spatial distribution of the supply and demand variables in the Greater Montreal Area, and their variations across the GMA at a given moment in time: the 7-8 AM peak of the 1987 base year.

The cross-sectional analyses also define the most suitable variables to enter the SDLM. In addition to that, the effect of including the zero-traffic links on modelling is analyzed.

5.1 Preliminary Analyses

The GMA road network, initiated in colonial times 300-400 years ago, is built around a central ridge on Montreal Island, and on the islands of Jesus, Bizard and Perrot.

At present, both the North and South shores, encompassing the islands, is developed in a way that boundaries are fused between suburban settings and exurbia. Further, the South Shore, linked by five river crossings to Montreal Island, is practically a city in and of itself with relatively high population and EMP densities in Longueuil. Thus, it is treated as one unit.

In the following sub-sections, a cross-sectional demand model is developed and presented using Method C described in Section 3 above, while the SDLM is developed and presented in Sub-section 6, using Method A, also described in section 3. Both models relate the basic supply-demand measures in the GMA.

Multivariate analyses are carried out, using the dependent variables presented in Sub-section 5.2 below, by using SAS multivariate statistical analyses from SAS/STAT User's Guide 1988, Release 6.03 Edition and its 1992 revision. The models used are of the form:

$$Y = B0 + B1 * X + B2 * X2 + \ldots \qquad \text{Eq. 5.2}$$

$$Y = B0 + B1 * X * X \qquad \text{Eq. 5.3}$$

$$Y = B1 * X \qquad \text{Eq. 5.4}$$

$$Y = B1 * X * X \qquad \text{Eq. 5.5}$$

Where;
Y = dependent variable
X = independent variable
X*X = independent variable squared
B0 = Y-intercept
B1, B2 = slope of the curve

Equations 5.2 and 5.3 are the least square regression curves minimizing the sum of errors; both linear and quadratic; while, equations 5.4 and 5.5 are the NO-INT (no intercept) curves, forced to pass through the origin (i.e., B0=0). SAS multivariate analyses procedure, 'Proc reg', is used to do regression analyses of the independent variable, usually the demand (DEM).

5.2 Supply-Demand Variables

The supply-demand measures were retrieved from the calibrated EMME/2 model. The demand matrix is in EPC trips for all motorized surface vehicles.

Z	Pr	At	IZ	Z	Pr	At	IZ
1	2693	32385	578	26	10813	4982	3668
2	2184	14640	253	27	4190	1406	605
3	2214	5486	216	28	9733	4514	1483
4	2534	5258	168	29	13251	9531	2974
5	8951	16085	183	30	7956	2483	848
6	7137	9861	1307	31	6692	2534	859
7	8615	6387	2356	32	9924	6118	3089
8	7333	4478	1627	33	6705	4710	1505
9	8002	6120	1431	34	12714	11178	4503
10	4063	10086	878	35	14611	7856	3993
11	8486	17846	2259	36	9006	4077	2889
12	10900	16454	2120	37	5803	3661	2135
13	7141	8949	1144	38	4679	2365	1551
14	9000	6719	1869	222	1109	2309	1
15	13733	10555	2426	223	183	1181	1
16	10211	11706	1756	224	6167	5533	1
17	9051	5861	1566	225	620	1862	1
18	7900	6390	1081	226	695	1639	1
19	5830	5374	1706	232	349	777	1
20	15936	6153	2967	233	559	3239	1
21	10202	11095	2420	234	312	2543	1
22	6342	2184	1492	235	40	1508	1
23	6674	3130	1826	236	671	921	1
24	9821	5863	3230	237	410	706	1
25	8748	3870	2600	238	647	976	1

TABLE 5.5: 1987 TOTAL At and Pr: 7-8 AM PEAK HOUR.

Zonal productions (Pr), attractions (At) and intra-zonal (IZ) EPC trips.

Table 5.5 presents the productions, attractions and intra-zonal EPC trips (aggregated at the zonal level). These trips represent the independent variable (DEM) to enter the model, a selected measure of demand. The 12 external zone values are presented for the sake of data completion, but they are not used.

The independent variable DEM is computed from the following equations:

DEMz = Pr + At - IZ	**Eq. 5.6**
DEMd = Pr + At - ID	**Eq. 5.7**
DEMs = Pr + At - IS	**Eq. 5.8**
DEM2 = Pr + At	**Eq. 5.9**

Where;
IZ = intra-zonal EPC trips; used for zonal aggregations
ID = intra-district EPC trips; used for district "
IS = intra-super district EPC trips; used for SD "
DEMz = demand using IZ
DEMd = demand using ID
DEMs = demand using SD
DEM2 = demand including internal trips

Table 5.6 presents the zonal statistics: number of observations (N) or links, sum, mean and standard deviation for the variables ZLL, and DEN. The variables DEN and ZLL are computed from Eq. 5.1.

Z	N	LINK SUM	LANE-KM: MEAN	ZLL STD DEV	TRAFFIC SUM	DENSITY: MEAN	DEN STD DEV
1	379	256.71	0.68	0.54	3328.3	8.78	17.53
2	265	141.96	0.54	0.44	2970.9	11.21	20.78
3	199	129.13	0.65	0.60	3902.2	19.61	30.89
4	156	106.53	0.68	0.42	2609.4	16.73	22.58
5	272	268.62	0.99	0.94	4156.0	15.28	20.68
6	297	236.75	0.80	0.66	3083.9	10.38	17.02
7	257	306.27	1.19	1.75	1623.4	6.32	15.41
8	227	186.27	0.82	0.69	916.90	4.04	14.95
9	220	229.92	1.05	0.82	2944.7	13.38	27.93
10	221	286.54	1.30	1.13	1980.8	8.96	19.98
11	237	380.85	1.61	1.35	3810.5	16.08	38.70
12	277	291.56	1.05	0.79	6305.1	22.76	32.41
13	162	178.95	1.10	0.70	3308.2	20.42	20.78
14	94	110.00	1.17	0.96	1890.6	20.11	31.62
15	179	278.05	1.55	1.13	2616.4	14.62	20.37
16	193	239.36	1.24	0.76	2414.6	12.51	13.18
17	152	213.34	1.40	1.08	1930.6	12.70	14.41
18	172	187.04	1.09	0.85	2008.9	11.68	24.59
19	163	297.34	1.82	1.43	1443.7	8.86	15.95
20	246	306.00	1.24	1.05	5994.9	24.37	67.58
21	299	463.18	1.55	1.52	3699.4	12.37	27.17
22	77	377.03	4.90	8.63	319.74	4.15	8.68
23	61	234.52	3.84	3.54	218.48	3.58	8.52
24	131	451.35	3.45	4.38	1220.3	9.32	15.45
25	134	504.15	3.76	5.87	530.20	3.96	11.73
26	105	358.02	3.41	4.52	1754.3	16.71	41.58
27	97	135.13	1.39	1.12	1243.1	12.82	41.41
28	163	194.15	1.19	1.04	2603.8	15.97	39.09
29	256	278.12	1.09	0.69	4867.1	19.01	50.56
30	96	162.13	1.69	1.63	588.77	6.13	12.06
31	194	301.60	1.55	1.77	2400.9	12.38	34.82
32	250	581.50	2.32	3.97	3658.9	14.64	105.68
33	179	273.73	1.53	1.36	952.58	5.32	8.51
34	534	373.73	0.79	0.86	6055.4	11.34	48.10
35	496	502.98	1.01	1.06	3419.2	6.89	16.09
36	197	848.00	4.30	4.88	636.33	3.23	9.20
37	93	456.64	4.91	6.09	239.31	2.57	5.77
38	135	656.70	4.86	7.60	575.37	4.26	10.41

TABLE 5.6: 1987 BASE YEAR; DEPENDENT VARIABLES: DEN & ZLL.

Footnote #2[2].

Other variable parameters and their aggregations into 38 zones and twelve districts (D) are presented in Appendix E1.

---

(2) A = area per zone in km-sq.
NB: Centroidal links excluded. Zero volume links included.

Z	N	A	ZLL	ZLLA	ZLLF	DEN	DENA	DENF	TAU	VAU
1	379	7.5	0.68	0.62	1.06	8.78	7.17	19.16	0.51	664
2	265	4.5	0.54	0.50	1.15	11.21	10.11	32.49	0.44	721
3	199	5.6	0.65	0.60	1.21	19.61	19.63	19.39	0.59	1085
4	156	5.2	0.68	0.68	0	16.73	16.73	0	0.76	751
5	272	24.3	0.99	0.91	1.84	15.28	11.13	58.14	0.93	1033
6	297	13.2	0.80	0.71	1.54	10.38	7.51	35.93	0.68	847
7	257	19.8	1.19	1.07	2.16	6.32	4.07	24.01	0.95	537
8	277	16.0	0.82	0.79	2.38	4.04	3.50	34.16	0.70	208
9	220	22.6	1.05	0.90	1.98	13.38	9.07	40.69	1.00	897
10	221	36.9	1.30	1.07	2.03	8.96	4.09	24.80	1.24	811
11	237	35.0	1.61	1.45	2.38	16.08	13.99	26.38	1.30	982
12	277	20.2	1.05	1.00	2.13	22.76	21.21	54.34	1.15	1037
13	162	9.2	1.10	1.07	1.42	20.42	16.63	54.97	0.97	1388
14	94	13.1	1.17	1.16	1.34	20.11	17.64	95.06	1.33	973
15	179	22.5	1.55	1.47	2.73	14.62	12.32	46.64	1.28	1045
16	193	18.4	1.24	1.24	0	12.51	12.51	0	1.07	783
17	152	18.5	1.40	1.32	5.39	12.70	12.02	46.67	1.13	923
18	172	27.9	1.09	1.03	1.61	11.68	5.27	66.48	1.29	763
19	163	40.4	1.82	1.60	4.66	8.86	6.97	32.60	1.73	678
20	246	69.2	1.24	1.23	1.57	24.37	21.93	96.90	1.58	932
21	299	63.6	1.55	1.17	3.29	12.37	9.17	26.89	1.31	777
22	77	207.2	4.90	4.56	5.64	4.15	1.29	10.48	5.61	431
23	61	200.4	3.84	3.42	6.28	3.58	1.91	13.25	3.79	330
24	131	105.5	3.45	2.59	6.08	9.32	6.45	18.17	2.43	867
25	134	357.6	3.76	3.04	7.06	3.96	0.90	17.95	3.78	382
26	105	297.4	3.41	2.57	8.44	16.71	11.68	46.86	4.03	648
27	97	36.4	1.39	1.23	3.16	12.82	6.31	85.19	1.88	673
28	163	30.9	1.19	0.89	2.92	15.97	12.57	35.71	1.18	905
29	256	34.8	1.09	0.95	1.92	19.01	14.19	49.48	1.17	628
30	96	43.3	1.69	1.42	5.10	6.13	3.86	35.03	1.72	500
31	194	98.6	1.55	1.33	3.08	12.38	6.07	55.00	1.88	728
32	250	334.2	2.32	1.78	4.57	14.64	11.55	27.30	2.33	550
33	179	72.4	1.53	1.36	2.30	5.32	2.72	17.26	1.51	471
34	534	45.0	0.79	0.63	2.04	11.34	9.74	23.94	0.90	505
35	496	78.1	1.01	0.84	1.94	6.89	3.84	23.02	0.90	623
36	197	527.9	4.30	4.38	3.91	3.23	2.01	9.76	4.00	253
37	93	226.7	4.91	4.53	8.08	2.57	1.43	12.04	3.60	327
38	135	326.2	4.86	5.01	2.26	4.26	2.93	28.60	4.36	293

TABLE 5.7: 1987 BASE YEAR, ADDITIONAL DEPENDENT VARIABLES.

Variables ZLL, ZLLA, ZLLF, DEN, DENA, DENF, TAU, VAU

Figures represent statistical mean values. Footnote #2.

Table 5.7 presents additional dependent variables used in the cross-sectional analyses (TAU and VAU). Furthermore, the variables DEN and ZLL are disaggregated by facility type.

It is of interest to note that the classification of data by facility type included infrastructure data and a supply measure: the traffic density (DEN) and the corresponding infrastructure lane-links (ZLLA and ZLLF). Other data by facility type were found to be of minor relevance and though retrieved, are not presented.

5.3 Cross-Sectional Travel Demand Models

The main research objective is to model the supply-demand measures into a Supply Demand Linkage Model (SDLM) relating travel demand to infrastructure supply at the sketch planning level i.e., how many more traffic lanes are needed, of what type, and where are they needed in order to balance an increase in demand (in POP or EMP), while maintaining the 1987 aggregate LOS of the network constant.
The modelling process starts at the cross-sectional level for the base year of 1987. This is done for the GMA and its several divisions in the following sub-sections.

It is of interest to note that each zone constitutes an observation entering the model; thus for example, the GMA has 38 observations, MTL has 21 observations, SD1 has 10 observations, and so on. The aggregation at the district level is not possible to model due to the low number of observations per district.

Several trials made to obtain a travel demand model at the cross-sectional level were fruitless, yet they are presented to:

1. better understand their relationships;
2. select suitable supply-demand measures to model;
3. select convenient zonal aggregations.

This is in conformity with the findings of Hutchinson (1990), as presented in Chapter 2.

The analyses is divided into two parts:

1. Basic models; and
2. Other models.

This division is done based on the choice of the dependent variables entering the models. Single basic variables are used in the basic models; while, 'Other models' may comprise composite, or and higher order independent variables.

The supply and demand variables were retrieved for the base year of 1987 and are modelled using Eq. 5.2 and SAS (Proc reg) multivariate regression analyses. The results are grouped by the dependent variable.

5.3.1 Basic models

Basic cross-sectional travel demand models are developed using the total road network (freeways, expressways and arterials), including links having zero traffic but excluding centroidal links.

Basically, the independent variable, demand, is tested as computed from equations 5.6 to 5.9, against two basic supply variables DEN, computed using Eq. 5.1, and ZLL, the zonal lane-links obtained from EMME/2; and their grouping by facility type; DENA, DENF, ZLLA, ZLLF.

The multivariate analyses comprised the six super districts (SD), the Montreal Island (SD1, SD2, and SD3), MTLin, MTLot, and a grouping of North Shore plus Laval (NL). The North Shore and Laval traffic, when MTL bound, uses the same congested river crossings to Montreal Island, thus they have a cumulative effect on the river crossings (they go through two bottle-necks); while, river crossings between the NS and Laval have a singular effect, when MTL bound. Consequently, Laval (SD4) and NS (SD5) are presented separately and grouped.

Table 5.8 presents the regression results of the independent variable DEMz (demand in EPC in 1000s) against the dependent variable ZLL, the zonal mean of lane-kms. DEMz was used because it provided a common base for all aggregations; other forms of DEM are presented later on.

The results shown with an asterix are not meaningful; (a) logically when B1 coefficient is negative and (b) statistically when the adjusted R-square [R2(ADJ)] figure is negative; they are presented for the sake of model completion.

LOC.		B0	B1	R2	R2(ADJ)
SD1		137.6	0.00432	0.3020	0.2147
SD2	*	195.8	0.00867	0.2268	-0.1601
SD3	*	209.6	0.00058	0.0030	-0.1960
SD4	*	1039	-0.0524	0.3414	0.1218
SD5		207.1	0.0204	0.1407	0.2890
SD6	*	990.9	-0.0296	0.3617	0.2341
NL	*			0.0344	-0.1035
MTLin		0.6269	0.0254	0.3004	0.1225
MTLot	*			0.0108	-0.0653
MTL		152.1	0.00524	0.1650	0.1211
GMA	*	549.8	-0.0130	0.1023	0.0773

TABLE 5.8: CROSS SECTIONAL MODEL: DEMZ Vs. ZLL.

* Results are not meaningful, shown to complete the table.

The model in Table 5.8, DEMz Vs. ZLL, shows that in the GMA as a whole and in SD4 and SD6, B1 has a negative coefficient. This is not meaningful in transportation. It probably implies an over-saturation condition i.e., more EPC demand does not require more road network (infrastructure) supply, as demand increases, supply decreases. This is absurd, consequently is not considered further.

Furthermore, a few of the adjusted R-squared figures are also negative, and the demand has no explanatory powers on the supply. Consequently, it is ignored statistically. This leaves only two significant regression lines in Table 5.8, MTL and SD5 (North Shore), yet they have low explanatory powers.

LOC.	B0	B1	R2	R2 (ADJ)
SD6	0.6351	0.5213	0.4047	0.3055
NL	2.8684	0.7550	0.3076	0.2087
MTLin*	17.331	-0.1392	0.0721	-0.1599
MTLot*			0.0329	-0.0415
MTL *			0.0096	-0.0425
GMA	6.8972	0.3386	0.1368	0.1128

TABLE 5.9: CROSS SECTIONAL MODEL: DEMz Vs. DEN

* Results are not meaningful, shown to complete the table.

Table 5.9 is similar to Table 5.8, except that it presents the independent variable DEMz against the dependent variable DEN, the mean of zonal traffic density in EPC per km, a direct measure of the average LOS per zone.

The regression analyses results in Table 5.9 show that the independent variable DEMz has low explanatory powers on the dependent variable DEN. Outstanding is the South Shore (SD6) where DEM has 30.55% explanatory power over DEN.

Further, when comparing results between tables 5.8 and 5.9, it is of interest to note that in the GMA, the explanatory power of DEMz is higher over DEN than over ZLL; the R2-ADJ has increased from 7.73% to 11.28% which is still insignificant.

Furthermore, a new DEM2 concept was introduced in Eq. 5.9 which includes the intra-zonal trips. The new regression results showed marginal differences and are not presented.

Another finding in the trip link-density frequency distributions is the variation in traffic densities between arterial and freeway roads. To capture such a difference, the ZLL (lane-km) were segregated by facility type into ZLLA (arterials) and ZLLF (freeways). The corresponding traffic densities are DENA and DENF.

Table 5.10 presents the regression results for the independent variable DEM, the regressor, against the dependent variables; ZLLA, ZLLF, DENA, and DENF.

LOC.		D.VAR	B0	B1	R2	R2(ADJ)
NL		DENA	-1.5235	0.7916	0.4866	0.4132
SD6		DENA	-0.8969	0.4702	0.3859	0.2836
MTLin		ZLLA	0.6024	0.02246	0.2528	0.0660
MTLin		ZLLF	-0.0388	0.1029	0.5463	0.4328
MTLin		DENF	3.9432	2.2469	0.4795	0.3493
GMA	*	ZLLA	2.8655	-0.0873	0.2096	0.1876
GMA	*	ZLLF	4.8895	-0.1291	0.1542	0.1307
GMA		DENA	3.9802	0.3564	0.1519	0.1284
GMA	*	DENF			0.0133	-.0141

TABLE 5.10: DEMAND MODEL: DEMz Vs. ZLLA, ZLLF, DENA, DENF.

* Results are not meaningful, shown to complete the table.

Although twenty-four regression analyses were estimated, four dependent variables for each of the six locations (GMA, MTL, MTLin, MTLot, SD6, NL), only a few results are presented; it is those having positive B1 and R2-ADJ coefficients. The GMA results are presented to complete the model, although they are not meaningful.

Results in Table 5.10 show that in the GMA, the DEMz variable, at 95% confidence, can explain only 12.84% of the variations in DENA; this is low.

An interesting higher explanatory power, in Table 5.10, of DEMz of 41.32% on DENA is registered for the North Shore and Laval group (NL) i.e., 41.32% of the variations in traffic density of arterial roads are explained by DEMz variations at 95% confidence level. This confirms the potential of the NL grouping.

LOC.	D.VAR	B0	B1	R2	R2(ADJ)
GMA	ZLL*	5.1435	-0.0757	0.7643	0.7407
GMA	ZLLA*	4.5183	-0.0661	0.7049	0.6754
GMA	ZLLF*	7.7664	-0.1050	0.6968	0.6664
GMA	DEN	3.3186	0.1975	0.5050	0.4555
GMA	DENA	0.5052	0.2040	0.5555	0.5510
GMA	DENF	11.879	0.5222	0.2856	0.2141

TABLE 5.11: GMA DEMAND MODEL: DEMd Vs. ZLL,A,F; DEN,A,F; VKT. District level aggregations. 12 observations per regression.

* Results are not meaningful, shown to complete the table.

A further scrutiny of the arterials, ZLLA and DENA, and freeways, ZLLF and DENF, variables in the trip frequency distributions, prompted their modelling against DEMd (Eq. 5.7) using intra-district (ID) EPC trip DEM.

The regression results of zonal aggregations at the district level for the GMA are presented in Table 5.11. There are twelve districts, and consequently twelve observations per regression analysis where, I.var is the independent variable and D.var is the dependent variable.

The results of the regression analyses of DEMd Vs. DEN, DENA, and DENF i.e., traffic densities, presented in Table 5.11 are significant. Further, testing demand as DEMs (Eq. 5.8) showed marginal variations, and it is not presented.

The above is a logical outcome; the more demand in EPC per district, the more the traffic densities or the lower the level-of-service (LOS).

5.3.2 Other models

Other variables are now to enter in the modelling process, and previously presented variables are transformed and analyzed at the zonal level and their GMA regression results are presented in Table 5.12 for the 7-8 AM peak hour. They are defined hereunder in two parts:

<u>A. Independent variables (I.var);</u>

1. Zonal car ownership = Z-CAR; obtained from Chapter 3.
2. DEMz/ZLL and DEM2/ZLL i.e, EPC trips per lane-km; this is another form of DEN aggregated at the zonal level.
3. DEMz/A i.e., aggregate zonal DEM density.

B. Dependent variables (D.var);

1. VKT; the vehicle kilometre of travel, it is much used in transportation analyses. VKT is obtained from:

$$VKT = VAU * LEN * LAN \qquad \text{Eq. 5.10}$$

2. VAU; the average lane traffic volumes in EPC.

3. ZLL/A; the road network density in lane-km per km-sq.

4. ZLL*[A/(sum of A)] = ZAA; ZLL multiplied by the weighted zonal areas.

I.VAR	D.VAR		B0	B1	R2	R2(ADJ)
DEMz/ZLL	DEN		7.144	0.08166	0.2160	0.1942
DEM2/ZLL	DEN				0.2272	0.2160
Z-CAR	DEN	*	410	-0.0014	0.0362	0.0094
DEMz/A	DEN	*			0.0447	
DEMz	VAU	*			0.0030	
DEMz/A	VAU	*			0.0365	
DEM2	VKT	*	139.01	-2.2480	0.7242	0.6967
DEMz	ZLL/A	*			0.0621	0.0360
DEMz	ZAA	*	35.27	-0.0015	0.1145	0.0890

TABLE 5.12: GMA: OTHER DEMAND MODEL.

For zonal observations and weighted variables.

* Results are not meaningful, shown to complete the table.

The regression results, shown in Table 5.12, show one important variation in the DEMz variable, the inclusion of the intra-zonal trips and using ZLL as weight has marginally improved the model; the adjusted R-squared has increased as compared with the previous travel demand model in the previous sub-section.

The DEMz variable has no explanatory powers on the newly introduced dependent variable VKT. Furthermore, the newly introduced variable, the zonal auto-ownership (total number of autos owned per zone), has no explanatory powers on DEN.

Table 5.13 presents a final set of regression analyses at the cross-sectional scale for MTL, the GMA and the City Centre (SD1) where the links having zero traffic volumes are excluded from the analyses.

The City Centre (SD1) is added at the MTL and GMA aggregation level as it represents the focus of the research that is, the impact of the decentralization process, the main objective of the research.

LOC.	I.VAR.		D.VAR	B0	B1	R2	R2(ADJ)
GMA	DEMz	*	ZAA	16.39	-0.0006	0.0703	0.0445
MTL	DEMz		ZAA	3.749	0.00036	0.0692	0.0202
SD1	DEMz	*	ZAA				

TABLE 5.13: DEMAND MODEL: ZERO VOLUME LINKS EXCLUDED.

* Results are not meaningful, shown to complete the table.

The results in Table 5.13 shows that deleting the zero volume links does not improve the model. The additional regression analyses of DEMz Vs. DEN and ZLL for the GMA, MTL, and SD1 are not meaningful and are not presented.

5.4 Synthesis of Models

It may be concluded that the cross-sectional regression analysis at 95% confidence level showed that DEM, the independent variable, has a low level of explanatory power on the dependent variables, ZLL, DEN... and their variations [sections 5.3.1 and 5.3.2].
Normalizing the variables did not improve the model (Section 5.3.2). The adjusted R-squared values are still quite low.

The **B1** component of the model (its value and coefficient), the slope of the regression line (Eq. 5.1), was found to be negative in the GMA in general and more so at some locations like, Laval and the South Shore. This probably implies an over-supply of infrastructure (road network) at the aggregate level, as discussed earlier.

The zonal aggregational groups at different levels (districts, super districts, MTLin, MTLot, NL,...) show no major basic preference between them as far as supply-demand modelling outcome though, they constitute distinct groups.

As expected, the DEMz variable in Table 5.13, where zero volume links are excluded, has even lower explanatory powers on the dependent variables. Thus, the exclusion of the links with zero traffic volumes does not improve the model.

It may be interpreted that, although many links in the peripheral zones have zero traffic volumes, such missing traffic is diverted to other links, thereby increasing their DEN artificially. Thus zero traffic volume links should be included in computations of average densities.

The results, as expected, show a higher concentration of traffic on the higher order network components, like freeways and expressways due to their higher attractiveness. This was captured by smaller coefficients in the volume delay functions.

In the sparsely inhabited metropolitan areas like, NS, SS, and Laval, there is more infrastructure available than it is actually warranted by demand; while, the reverse is true in the City Centre.

The cross-sectional analyses presented the problem of linking the supply-demand measures of an existing network at a range of scales. It would have been a pleasant surprise if the analyses had shown a better correspondence between existing supply and demand. This was also the case for Hutchinson (1990).

The outstanding outcome of the cross-sectional demand modelling is that there is no absolute best variables or groupings to enter the SDLM model, yet important guides are obtained:

1. The demand is best represented by: DEMz, DEMs, or DEM2.
2. The supply measures are best represented by: DEN; including zero traffic volume links.
3. Modelling cross-sectional demand variations is not successful. It does not capture adequately the dynamic variations in demand [Hutchinson, 1990].

Consequently, the 'incremental' or 'quasi-experimental' approach (Method A) is implemented in the next section to model the supply-demand measures and relate their variations both spatially and over time.

6. SUPPLY-DEMAND LINKAGE MODEL: SDLM

The main objective of the research is the development of the Supply-Demand Linkage Model (SDLM). It is achieved using the 'quasi-experimental' Method A, an incremental approach briefly described in Section 3.

The modelling process is implemented in two parts, using a process similar to the one used in the cross-sectional analyses. They are presented in this section in two parts:

1. Base SDLM model.
2. SDLM Sub-model.

The Base model captures uniform demand variations across the GMA, while the Sub-model is designed to capture the differential variations in growth between the GMA and any super district. For this research, since it deals with employment decentralization from the City Centre, the obvious super district to use is the City Centre or SD1.

The cross-sectional analyses could not capture the increase over time in the congestion level due to demand increase, but they did relate their spatial variations. This is due to the fact that modelling was limited to cross-sectional variations at a given point in time (1987 base year).

6.1 Preliminary Analyses

The SDLM model is developed using the multivariate regression analyses package SAS. The 1987 base year demand data (considered as the lower bound for DEM) and the upper bound data were retrieved from the calibrated EMME/2 travel demand model i.e., we already have two observations; the lower and upper bound figures (assuming uniform demand growth) for the SDLM Base model.

To obtain other observations for the multivariate regression analyses, the demand (zonal attractions and productions) is augmented uniformly by 4% at a time in all the 38 zones, and it is assigned to the road network. Between 35 and 40 iterations per assignment were needed, using the assignment stage of the Calibrated EMME/2 model.

The incremental demand process is repeated five times, to cover the 20% total growth (the established upper bound for demand growth), thus six cases (observations) are available for modelling. DEMs data are presented in Table 5.14.

LOC.		1.00	1.04	1.08	1.12	1.16	1.20
SD1	Pr	56806	59078	61350	63622	65895	68167
	At	109649	114035	118421	122807	127193	131579
	IS	35347	36761	38175	39589	41003	42417
SD2	Pr	38687	40234	41782	43329	44877	46424
	At	45180	46987	48794	50601	52408	54216
	IS	19697	20485	21273	22061	22848	23636
SD3	Pr	66626	69291	71956	74621	77286	79951
	At	63058	65581	68103	70625	73148	75670
	IS	31364	32619	33874	35128	36383	37637
SD4	Pr	41823	43496	45169	46842	48515	50188
	At	20469	21287	22106	22925	23744	24562
	IS	11994	12474	12954	13433	13913	14393
SD5	Pr	36056	37498	38940	40383	41825	43267
	At	17844	18558	19272	19986	20700	21413
	IS	13123	13648	14172	14697	15222	15747
SD6	Pr	69785	72577	75368	78159	80951	83742
	At	42150	43836	45522	47208	48894	50580
	IS	33773	35124	36475	37826	39177	40528
MTL	Pr	162119	168604	175089	181573	188058	194543
	At	217887	226602	235318	244033	252749	261464
	IS	86358	89812	93267	96721	100175	103630
GMA	Pr	321544	334405	347267	360129	372991	385852
	AT	321544	334405	347267	360129	372991	385852
	IS	145298	151111	156923	162734	168546	174358

TABLE 5.14: INCREMENTAL DEMAND MATRICES; SDS, MTL, GMA.

Productions, attractions, and intra-super district (IS) in EPC trips.

In this section, DEM is obtained using Eq. 5.8 and both terms DEM and DEMs are used interchangeably.

The variable DEN, is computed from Eq. 5.1, and its mean, standard deviation, and other statistics are obtained using SAS. The average zonal level-of-service (LOS), is obtained from Table 1.1 for a given mean zonal DEN, where the mean is the statistical average of DEN in any one zone. Table 5.15 presents the results for the base year and the five incremental assignments.

It is important to note that the results in Table 5.15 are aggregated figures and there is no implication whatsoever that some link-capacities are not exceeded even in the base year of 1987, this is the case for all traffic densities exceeding 40 EPC/km, as seen in Table 5.2.

DEMs		SD1	SD2	SD3	SD4	SD5	SD6	MTL	GMA
Base	DEN	11.85	15.44	15.14	14.52	8.64	8.23	13.49	12.02
	LOS	B	C	C	C	B	B	C	B
1.04	DEN	12.93	17.02	16.59	16.59	9.67	9.04	14.78	13.29
	LOS	C	C	C	C	B	B	C	C
1.08	DEN	13.91	18.65	18.14	18.61	10.63	9.66	16.05	14.47
	LOS	C	C	C	C	B	B	C	C
1.12	DEN	15.02	20.33	19.49	21.03	11.72	10.28	17.34	15.70
	LOS	C	D	D	D	B	B	C	C
1.16	DEN	16.06	21.70	21.01	23.68	13.05	11.27	18.58	17.03
	LOS	C	D	D	D	C	B	D	C
1.20	DEN	17.29	23.94	22.39	26.68	14.09	12.50	20.18	18.66
	LOS	C	D	D	D	C	C	D	C

TABLE 5.15: INCREMENTAL DEMAND: DEN and LOS for SDS, MTL, GMA.

The results in Table 5.15 confirms that even if DEM increases by twenty percent, the aggregate LOS in all super districts does not exceed LOS D, though a few zonal LOS reaches LOS E, as seen in Table 5.1.

Figure 5.2 (upper bound) shows that 87.76% of SD1 links have traffic flow below capacity; while the figures for MTL are: 85.98%, and the GMA are: 88.40%. The corresponding figures for the other GMA divisions are obtained from Table 5.2 e.g., SD3 (MTL East) has 16.6% (100-83.4) of links exceeding capacity, the highest at the upper bound scenario.

Thus, the mobility in the GMA as a whole is within 'tolerable' limits at present and it would be so in the year 2001; except for the river crossings and some localized bottle necks.

Furthermore, the overall growth in the GMA is far less than 20% in any SD for the 1997 forecasting year (to be presented in Chapter 6).

6.2 SDLM Base Model

The cross-sectional analyses have defined the suitable supply and demand measures to enter the multivariate analyses for the base SDLM model. They are:

1. the total demand (DEM) as the independent variable.
2. the traffic density mean (DEN) as the dependent variable.

The DEM data are obtained from Table 5.14 while, the DEN data are obtained from Table 5.15. These variables are modelled using the multivariate regression analyses of the SAS statistics software and the results are presented in Tables 5.16 and 5.17.

The statistics and regression analysis details for the GMA Base model are presented in Appendix E3. The SDLM Base model is to be used within the DEM (in 1000s EPC) range, by SD, obtained from Table 5.14 and presented in Table 5.16. Additional statistics are presented in Appendix E-E4.

LOC.	B0	B1	R2	R2(ADJ)	DEM-RANGE
SD1	-15.1119	0.205396	0.9991	0.9988	131-157
SD2	-26.2302	0.648049	0.9964	0.9955	64-77
SD3	-22.1512	0.378214	0.9988	0.9985	98-118
SD4	-46.2350	1.200669	0.9942	0.9928	50-60
SD5	-18.9298	0.673938	0.9976	0.9970	41-49
SD6	-12.3560	0.261920	0.9818	0.9773	78-94
MTL	-19.5164	0.112234	0.9985	0.9981	294-352
GMA	-20.6729	0.065504	0.9969	0.9961	498-597

TABLE 5.16: SDLM BASE MODEL; DEMs Vs. DEN. REGRESSION with INT.
DEM figures in 1000s. DEN in EPC/KM.

The negative intercept in all rows in Table 5.16 are a hard reality in transportation engineering; and models with negative intercepts are quite common. Furthermore, this is of no consequence due to the fact that the model is only valid in the DEM range shown where all the results, obtained by applying the model, are positive.

The multivariate analyses are repeated and a no-intercept regression model is forced, using Eq. 5.4. The results are shown in Table 5.17. The no-intercept model, shows a very small drop in explanatory power of the independent variable which is considered to be marginal.

The DEM range presented in Table 5.16 or Table 5.17, should not be exceeded. It represents the upper bound for DEM. Furthermore, the mobility on the road network, beyond 20% DEM variation, is also compromised as it falls below the proposed limit of 95% mobility.

LOC.	B0	B1	R2	R2(ADJ)	DEM-RANGE
SD1	NO-INT	0.101014	0.9959	0.9951	131-157
SD2	"	0.277873	0.9931	0.9918	64-77
SD3	"	0.171485	0.9947	0.9937	98-118
SD4	"	0.368219	0.9804	0.9765	50-60
SD5	"	0.253542	0.9894	0.9873	41-49
SD6	"	0.118760	0.9941	0.9929	78-94
MTL	"	0.052046	0.9948	0.9938	294-352
GMA	"	0.027895	0.9930	0.9916	498-597

TABLE 5.17: SDLM BASE MODEL; DEMs Vs. DEN. REGRESSIONS NO-INT.

DEM figures in 1000s. DEN in EPC/KM.

The GMA and MTL models in Table 5.16 shows that the variations of the dependent variable DEN are explained more than 99%, except for SD #6, by the variations in the independent variable DEMs at 95% level of confidence.

The B1 coefficient i.e., the slope of the SDLM curves, is a measure of the elasticity of supply (DEN) as related to demand (DEM); the higher the coefficient, the greater the responsiveness of supply to the additional demand.

Table 5.16 shows that the highest coefficients of B1 occurs in SD4, SD2, and SD5; where, a small variation in DEMs requires a relatively large variation in supply. This is in conformity with the cross-sectional analyses results, where SD4 has the smallest supply (ZLL) followed by SD2 and SD5, as seen from the following tabulation obtained from Table 5.4:

SD4; ZLL = 1072KM (1.33 * 806) lane-km
SD2; ZLL = 1434KM (1.43 * 1003) "
SD5; ZLL = 1547KM (3.59 * 431) "

Consequently, SDs having proportionally low infrastructure lane-km (ZLL), as weighted by DEMs, are more 'sensitive' to changes in DEM as it would be expected. The ratios ZLL/DEM are tabulated below for the upper and lower bound of DEM (Table 5.16):

SD4: 1072/50= 21.44; 1072/60= 17.87

SD2: 1434/64= 22.41; 1434/77= 18.62

SD5: 1547/41= 37.73; 1547/49= 31.57

Thus, the higher the B1 coefficient (SD4 highest), the lower the proportion of ZLL/DEM which is expected. This result is in conformity with the findings of Cervero (1989), presented in Chapter 2. This may be explained as the need to improve the infrastructure skeleton (additional lane-kms) in developing areas, like MTL-West, Laval and the North Shore.

The 'SAS Proc reg' output for the two models for the GMA, without intercept (Model M1) and with intercept (Model M2) are shown in Appendix E3. Further, the plots of the observation points ('o' for M2, 'x' for M1), and the residual values ('r' for M2) are also given in Appendix E3.

Furthermore, the 95% upper and lower bound confidence interval figures (shown by '-'), are also plotted for M1 and are superimposed on the observed points. The NO-INT solution, within the range of applicability of the SDLM, shows larger differences at the upper and lower boundaries (Appendix E3), as would be expected.

When actual figures are compared, the variation between the models M1 and M2 (tables 5.16 and 5.17), is found to be relatively small as can be seen from the following tabulation obtained from Appendix E3. The better match is obtained near the middle of the range while maximum differences are obtained at the extremes, indicating a higher degree curve potential, as seen from the following tabulation:

Dep. Var.		**Predicted Value**	
SD#	**DEN**	**NO-INT**	**with INT**
1	12.02	13.8859	11.9344
2	13.29	14.4412	13.2385
3	14.47	14.9967	14.5428
4	15.70	15.5522	15.8472
5	17.03	16.1076	17.1515
6	18.66	16.6630	18.4557

The residual plots for the regressions, shown in Appendix E-E3 for the GMA (Table 5.16) confirmed a second degree or higher curve possibilities, in spite of the high R2(adj) figures. Further analyses using the DEM-squared, equations 5.3 and 5.5, for the GMA are presented in Table 5.18.

LOC.	**B0**	**B1**	**R2**	**R2(ADJ)**
GMA	-2.818	5.985E-11	0.9987	0.9984
GMA	NO-INT	5.063E-11	0.9995	0.9994

TABLE 5.18: SDLM BASE MODEL. QUADRATIC REGRESSION.

DEM-squared: NO-INT and with INT.

DEM figures in EPC*E6. DEN in EPC/KM.

The quadratic regression curves, with and without intercept, show minor improvement on the linear regression results. The improvement is judged to be marginal and the linear regression, with intercept, is recommended for easy use in the sketch planning process.

The GMA SDLM Base model, the elasticity-based travel demand model, may be interpreted as follows: with 95% confidence, the independent variable DEMs has 99.61% explanatory powers on the dependent variable DEN, the mean of traffic density, and consequently the LOS. This is an excellent outcome.

The SDLM application should be limited to the maximum DEM increase of 20%. Model extrapolations should not be permitted and are not expected. Figures 5.3-1 to 5.3-8 present both linear regressions and the six observation points for the SDLM Base model in graphical form, and are listed hereunder:

The graphical presentation is a plot of equations 5.2 and 5.4 using B0 and B1 coefficients from tables 5.16 and 5.17; that is:

DEN = B0 + B1 * DEM; and

DEN = B1 * DEM

Where;
DEN = Average traffic density in EPC/KM per SD
DEM = Pr+At-IS in EPC in 1000s.

These are linear regression lines, with and without intercepts. Consequently, only their upper and lower bound coordinates are plotted. It should be noted that in all figures 5.3, the close fit between the observation points and the linear regression curves with intercepts results in the fusion of their symbols at the boundary points.

The linear regression lines recommended to use as the SDLM Base model, in Table 5.16 and represented graphically in Figures 5.3, are an excellent fit for all SDs.

The six observations per regression curve are super-imposed on the plots. They are retrieved from tables 5.14 (DEM) and 5.15 (DEN). The plots of the observed 'o' and predicted 'p' graphs for the GMA are also shown in Appendix E-E3 (obtained from SAS output).

The developed SDLM Base model is a uniform growth model, and does not capture the differential variations in demand between super districts, in order to assess the impact of EMP decentralization i.e., the variations in DEM between the City Centre and the GMA as a whole, which is the main objective of the research.

To evaluate the decentralization effect on the City Centre of the case study, it is necessary to develop another SDLM model, named SD1 or Sub-model, to assess the singular effect of the City Centre demand variations on supply. The Sub-model for Montreal City Centre (SD1) is developed in section 6.3.

The results obtained by applying the SDLM Base model and Sub-model, are superimposed by super district to obtain the impact of EMP decentralization. This superposition of results is scrutinized and validated in the sensitivity analysis in Section 7.

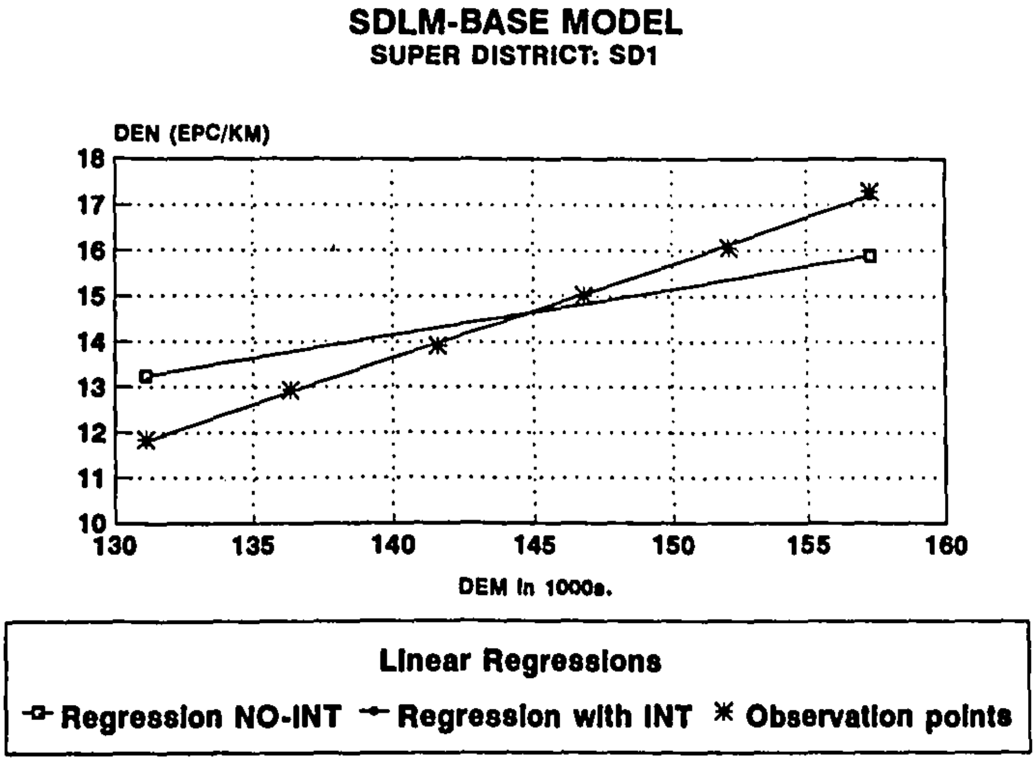


Fig. 5.3-1: SDLM Base model; City Centre

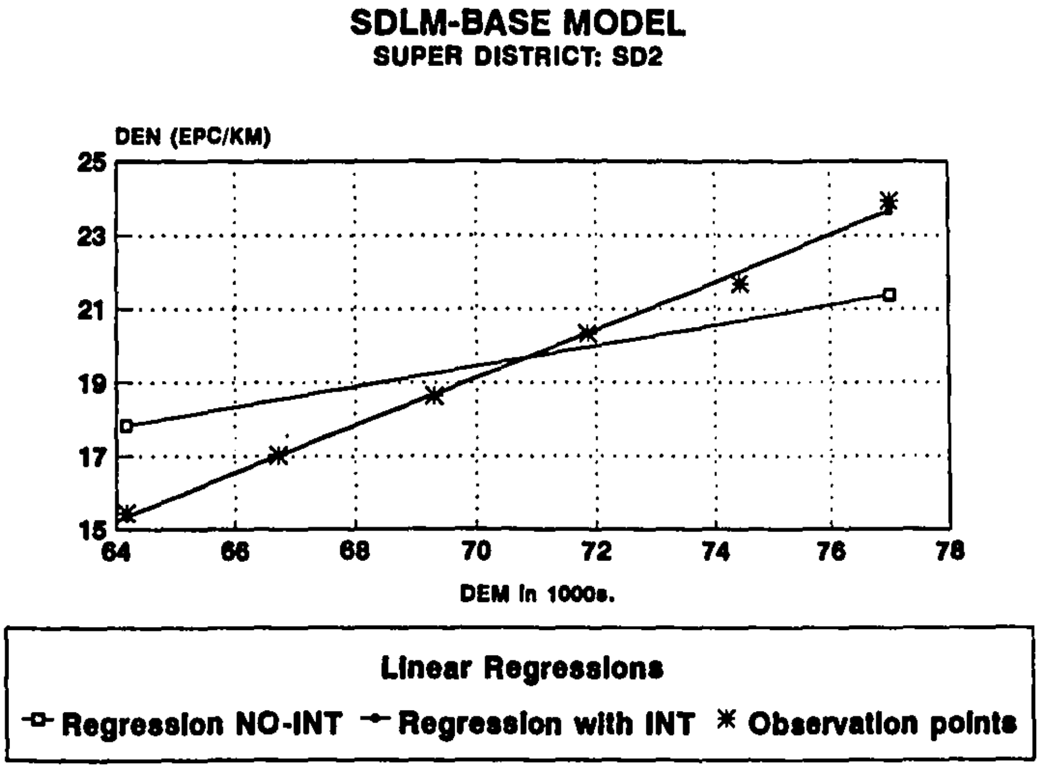


Fig. 5.3-2: SDLM Base model; MTL West

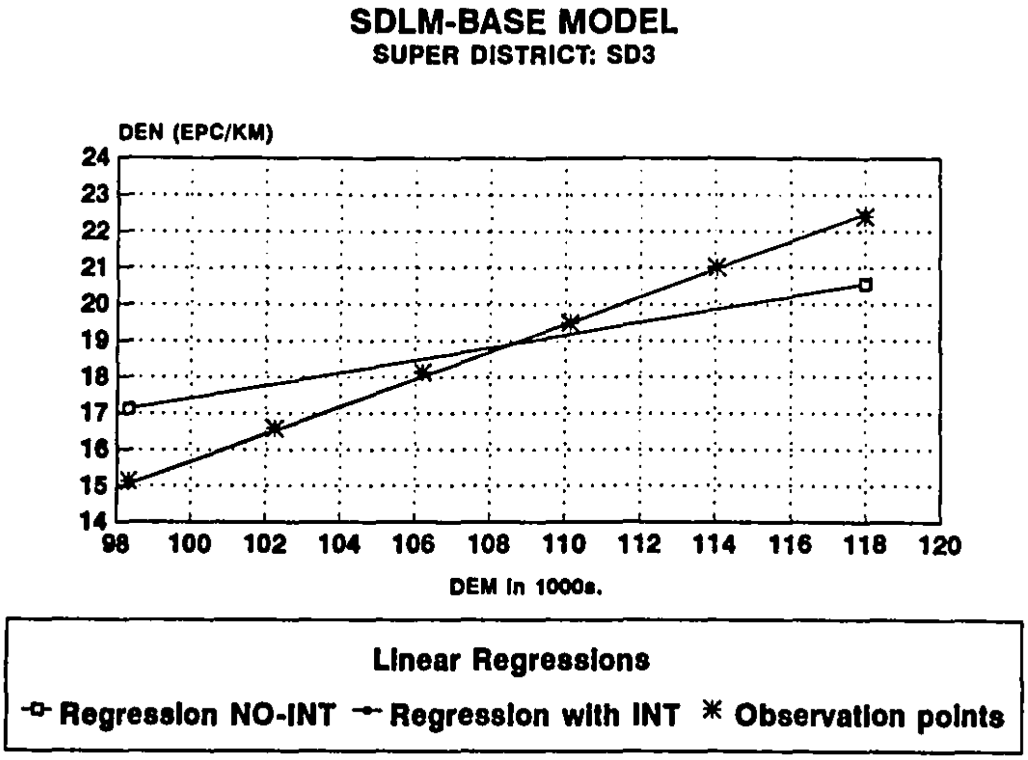


Fig. 5.3-3 SDLM Base; MTL East

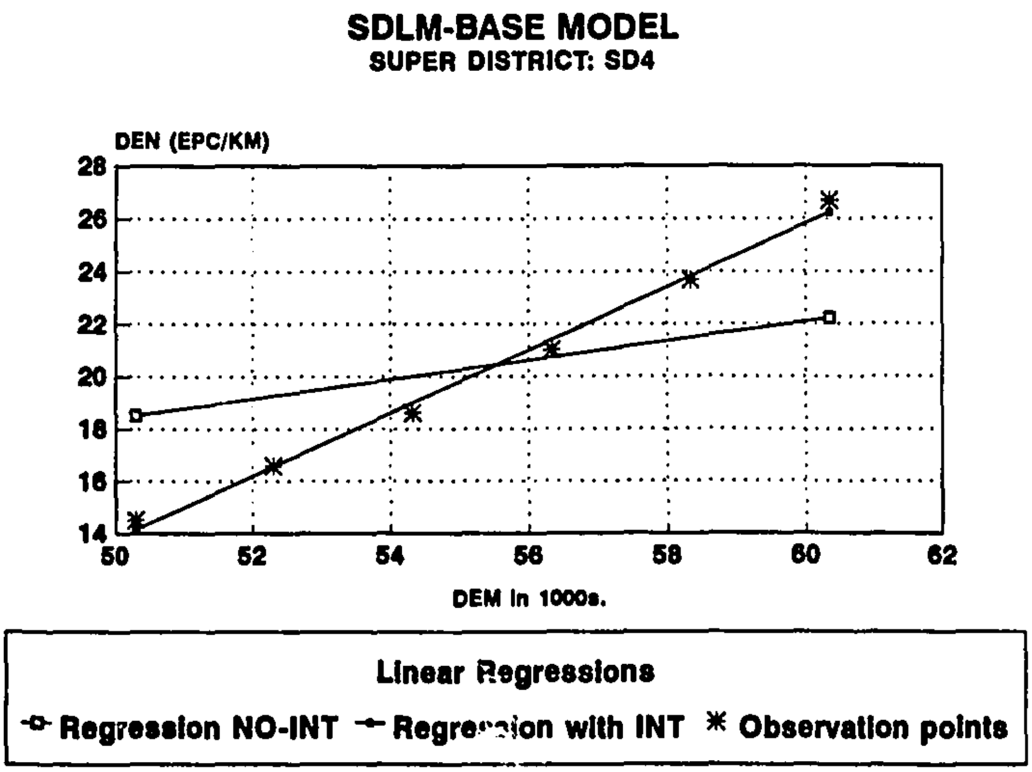


Fig. 5.3-4: SDLM Base; Laval

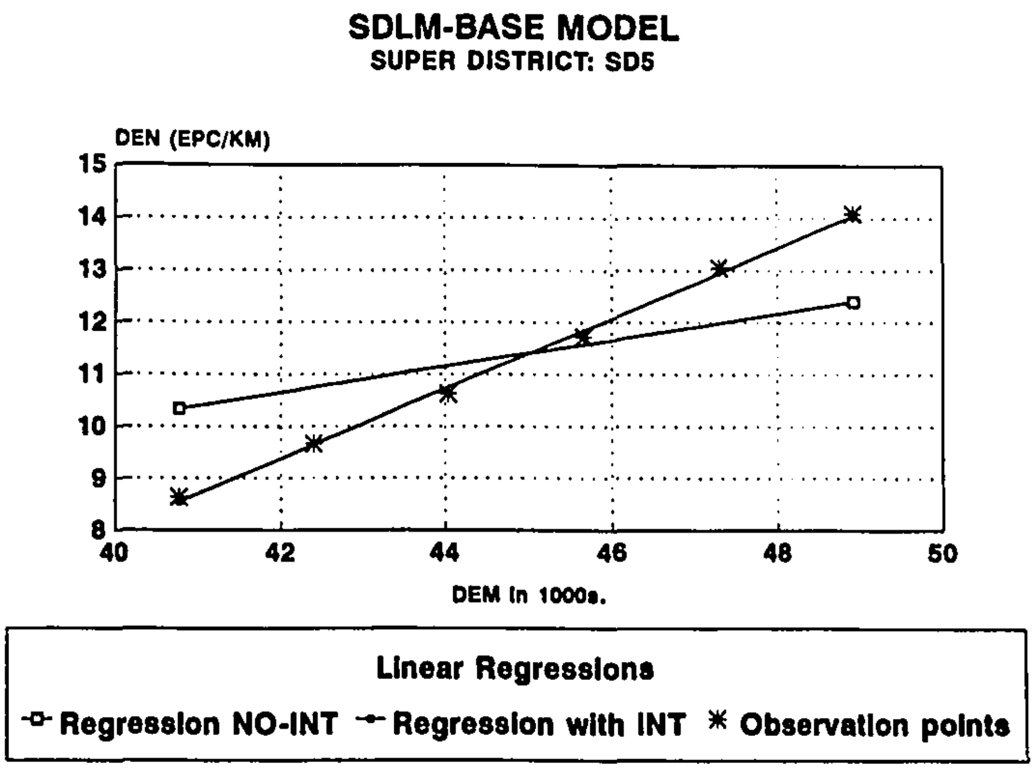


Fig. 5.3-5 SDLM Base model; North Shore

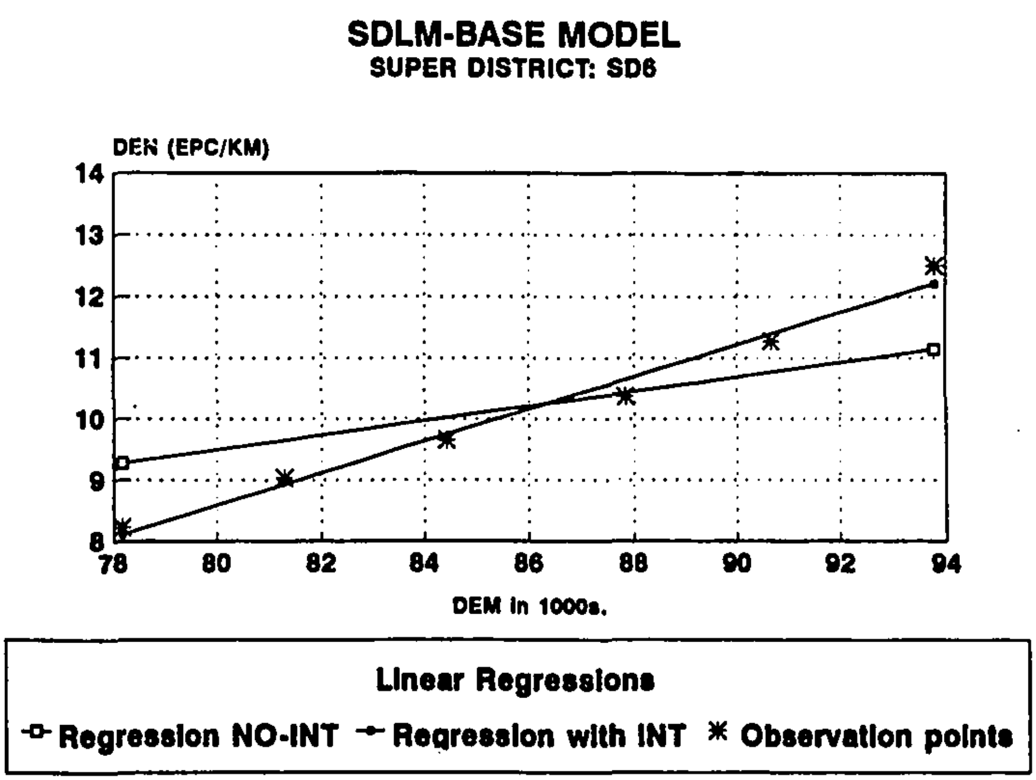


Fig. 5.3-6: SDLM Base model; South Shore

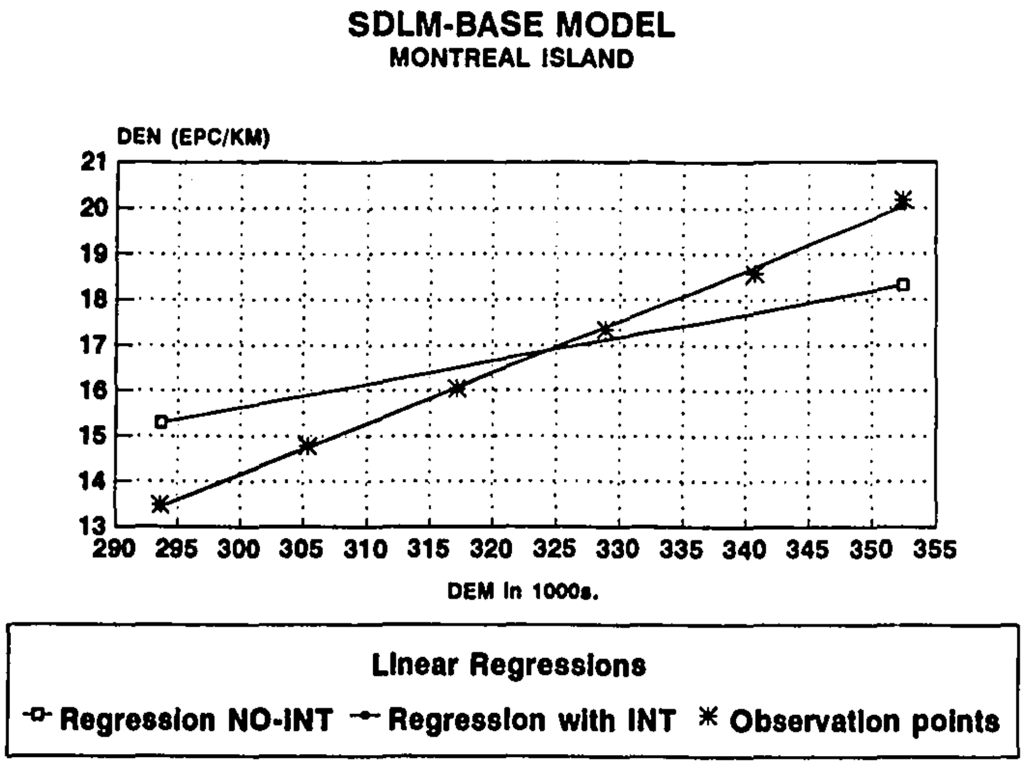


Fig. 5.3-7: SDLM Base model; Montreal Is

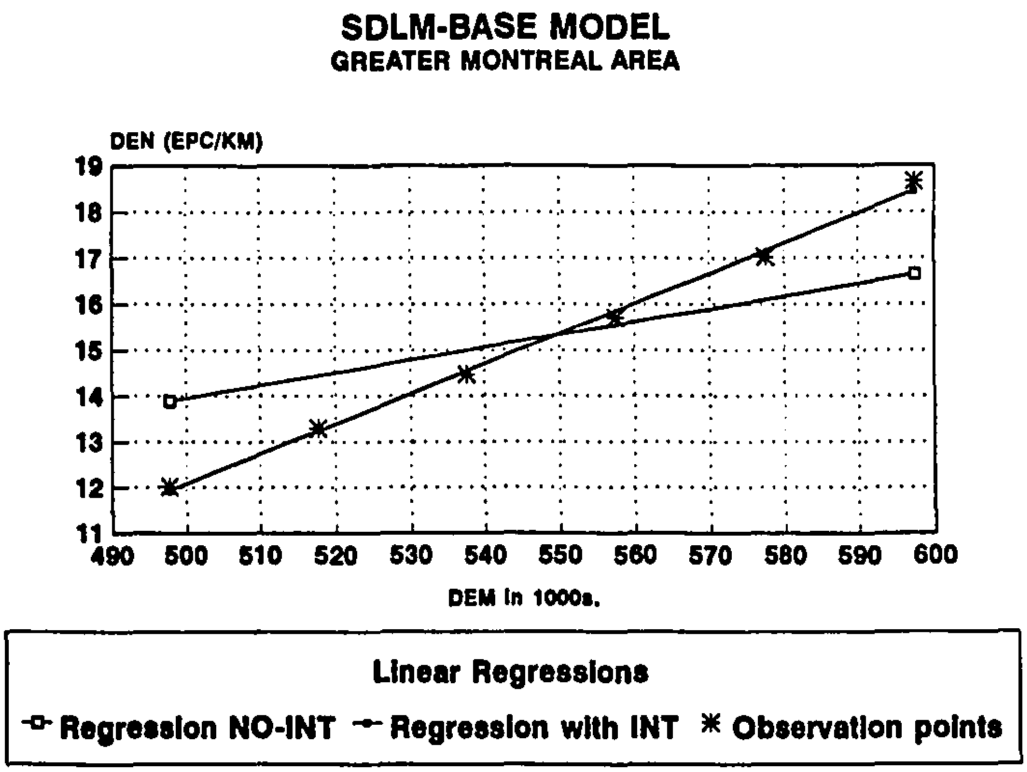


Fig. 5.3-8: SDLM Base model; GMA

6.3 SDLM Sub-model

The SDLM Base model captures the variations in population growth across the GMA, and both positive and negative activity variations by SD. This is confirmed in the sensitivity analyses, in next section. Further, the population variations were related to EMP variations in Chapter 3; consequently, variations in EMP levels across the GMA are also captured by the SDLM Base model.

The City Centre EMP decentralization was presented in Chapter 2 and demonstrated in Chapter 3. The research has not addressed the main topic; the differential EMP variations, over time, between the GMA and the City Centre.

The SDLM Base model does not capture the above mentioned spatial differentiation in DEM due to EMP decentralization. To do this, it is necessary to develop the SDLM Sub-model for the City Centre.

The SDLM Sub-model is developed using the same procedure as for the SDLM Base model. The DEM is incrementally increased, **in the City Centre only and as related to base year DEM**, while it is kept constant (at the base year level) in all other SDs, as it is not expected to have negative growth in SD1. Furthermore, an increase in DEM in SD1 produces higher traffic densities and leads to more conservative results as compared to a decrease in DEM.

Thus, increments of 4% are applied to productions and attractions of the ten zones constituting the City Centre, using EMME/2 matrix module. It is of interest to note that the net DEM (POP) variation in SD1 is positive over time.

The DEM increments (DEM and DEMs are used interchangeably), applied on total productions and total attractions for the ten zones in SD1, are also affecting the attractions and productions in the other super districts as expected. Because the increase in Pr in SD1 is balanced by attractions in all other SDs and likewise the increase in At in SD1 is balanced by productions in all other SDs too. This is presented in Table 5.19.

The corresponding DEN variations are obtained using the same procedure as for the SDLM Base model. The process is to assign the demand and its 4% incremental demand matrix to the road network iteratively using the Calibrated EMME/2. This is repeated for each demand increment; five assignments in total are made, in addition to the base year assignment; thus, there are also six observations to use in the multivariate analyses.

LOC.	1.00	1.04	1.08	1.12	1.16	1.20
SD1 Pr	56806	59078	61350	63622	65895	68167
At	109649	114035	118421	122807	127193	31579
IS	35347	36761	38175	39589	41003	42417
SD2 Pr	38687	39187	39688	40188	40689	41189
At	45180	45458	45736	46014	46292	46571
IS	19697	19697	19697	19697	19697	19697
SD3 Pr	66626	67488	68350	69212	70074	70936
At	63058	63354	63649	63944	64293	64534
IS	31364	31364	31364	31364	31364	31364
SD4 Pr	41823	42202	42581	42960	43339	43718
At	20469	20526	20583	20640	20697	20754
IS	11994	11994	11994	11994	11994	11994
SD5 Pr	36056	36310	36564	36818	37073	37327
At	17844	17868	17891	17914	17937	17961
IS	13123	13123	13123	13123	13123	13123
SD6 Pr	69785	70593	71401	72209	73017	73825
At	42150	42247	42344	42440	42537	42634
IS	33773	33773	33773	33773	33773	33773
MTL Pr	162119	165753	169388	173022	176658	180292
At	217887	222846	227806	232765	237724	242684
IS	86358	87882	89236	90650	92064	93478
GMA Pr	321544	326788	332032	337277	342521	347765
AT	321544	326788	332032	337277	342521	347765
IS	145298	146855	148209	149623	151037	152451

TABLE 5.19: INCREMENTAL DEM MATRICES for SD1 (only).

Productions, attractions, and intra-super district (IS) in EPC.

The mean DEN per assignment and per SD is computed using SAS and Eq. 5.1 and it is repeated per DEM increment. The aggregate LOS is obtained using Table 1.1, and the results are presented in Table 5.20.

DEMs		SD1	SD2	SD3	SD4	SD5	SD6	MTL	GMA
Base	DEN:	11.85	15.44	15.14	14.52	8.64	8.23	13.50	12.02
	LOS:	B	C	C	C	B	B	C	B
1.04	DEN:	12.61	16.13	15.82	15.18	8.61	8.36	14.23	12.56
	LOS:	C	C	C	C	B	B	C	C
1.08	DEN:	13.42	16.56	16.51	15.92	8.77	8.66	14.92	13.13
	LOS:	C	C	C	C	B	B	C	C
1.12	DEN:	14.26	17.21	17.02	16.39	9.04	8.96	15.63	13.69
	LOS:	C	C	C	C	B	B	C	C
1.16	DEN:	15.01	17.65	17.69	17.35	9.38	9.21	16.29	14.27
	LOS:	C	C	C	C	B	B	C	C
1.20	DEN:	15.89	18.32	18.36	17.95	9.58	9.65	17.07	14.92
	LOS:	C	C	C	C	B	B	C	C

TABLE 5.20: SD1 INCREMENTAL DEMAND: DEN and LOS for SDS, MTL, GMA.

Incremental DEMs in SD1 only, other SDs have base DEM.

The multivariate regression analyses results, for the Sub-model, are presented in Table 5.21. The procedure is long and time consuming and identical to the one used to obtain the Base model. Additional statistics are presented in App. E-E4.

LOC.	B0	B1	R2	R2(ADJ)	DEM-RANGE
SD1	-8.3489	0.153856	0.9996	0.9995	131-157
SD2	-30.6923	0.719602	0.9963	0.9954	
SD3	-38.5464	0.546432	0.9984	0.9980	
SD4	-65.0394	1.581258	0.9949	0.9937	
SD5	-22.0802	0.749526	0.9268	0.9085	
SD6	-16.4256	0.314217	0.9807	0.9759	
MTL	-15.4054	0.098473	0.9996	0.9995	
GMA	-19.6747	0.063618	0.9992	0.9990	

TABLE 5.21: SDLM SUB-MODEL for SD1; DEMs Vs. DEN. REGRESSION with INT.

DEMs variations in SD1 only.

DEM figures in 1000s.

The negative intercept (B0), as discussed earlier, is a hard reality in transportation engineering, and consequently a no-intercept regression is forced to evaluate their variations, using Eq. 5.4, and the results are presented in Table 5.22.

LOC.	B0	B1	R2	R2(ADJ)	DEM-RANGE
SD1	NO-INT	0.096188	0.9986	0.9983	131-157
SD2	"	0.255572	0.9987	0.9984	
SD3	"	0.165690	0.9980	0.9976	
SD4	"	0.315871	0.9966	0.9959	
SD5	"	0.217170	0.9991	0.9989	
SD6	"	0.110055	0.9987	0.9984	
MTL	"	0.049101	0.9984	0.9981	
GMA	"	0.025844	0.9981	0.9977	

TABLE 5.22: SDLM SUB-MODEL for SD1; DEMs Vs. DEN. REGRESSION NO-INT.

DEMs variations in SD1 only.
DEM in 1000s.

The difference between models with and without intercept is again considered to be marginal and the model with INT presented in Table 5.21 is recommended as it is a better fit for the base year figures.

Figures 5.4-1 to 5.4-8 present the Sub-model graphically. These figures are in conformity with those for the Base model. The B0 and B1 coefficients are obtained from tables 5.21 and 5.22; while the six observations per regression line are obtained from tables 5.19 (DEM) and 5.20 (DEN).
A comparison between B1 coefficients for the Base model (Table 5.16) and the Sub-model (Table 5.21) shows that the tangents of the curves in the Base model are bigger, as expected.

Similarly, only two points are plotted, the upper and lower bounds for DEM. These bounds are the outcome of applying the Sub-model for SD1 DEM variations and, consequently; they constitute the range for DEM. The range for the variation of DEM is dependent on the 20% increment of SD1 only.

It is of interest to note the relatively lower explanatory powers of the Sub model SD5 (North Shore) in Table 5.21 and presented graphically in Fig. 5.4-5, showing distinctly a higher order curve potential. But, this is of minor importance to this research as it focuses on the City Centre (SD1). This is further scrutinized in forecasting, in Chapter 6.

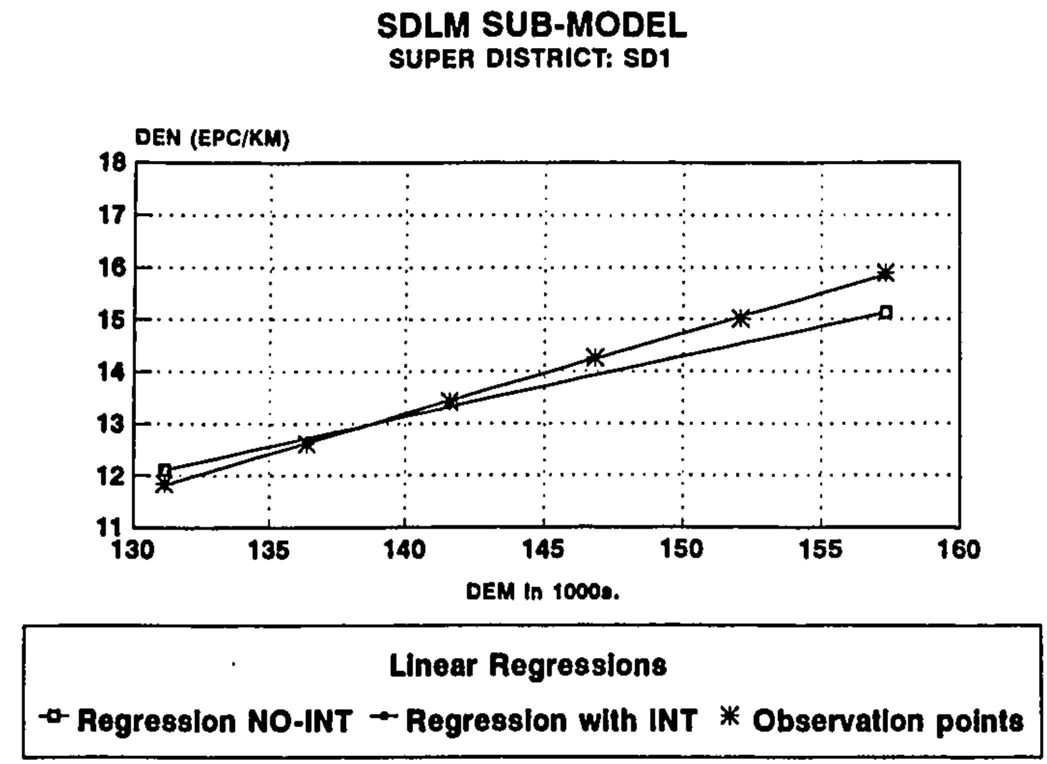


Fig. 5.4-1: SDLM Sub-model; City Centre

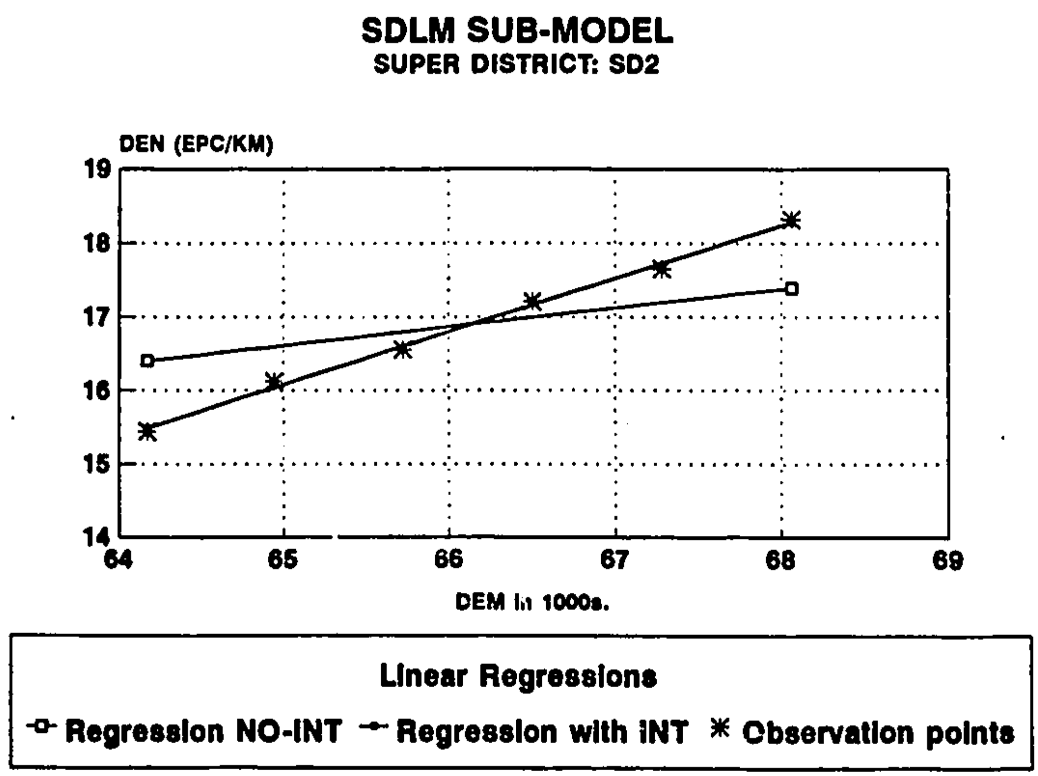


Fig. 5.4-2 SDLM Sub-model; MTL West

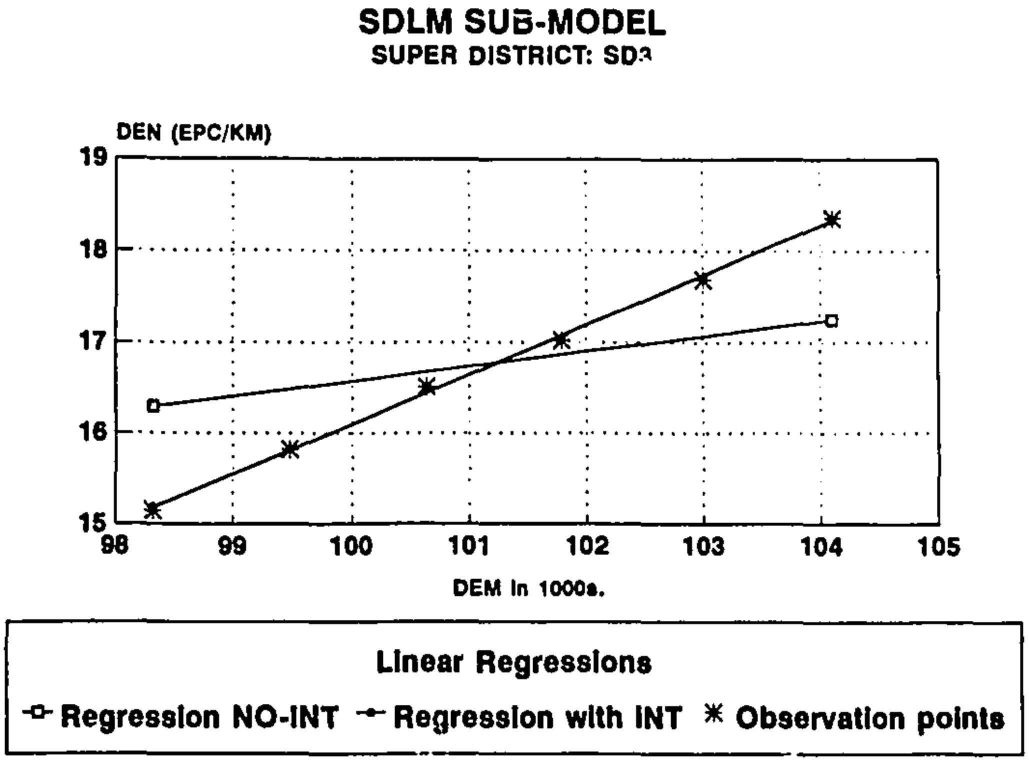


Fig. 5.4-3: SDLM Sub-model; MTL East

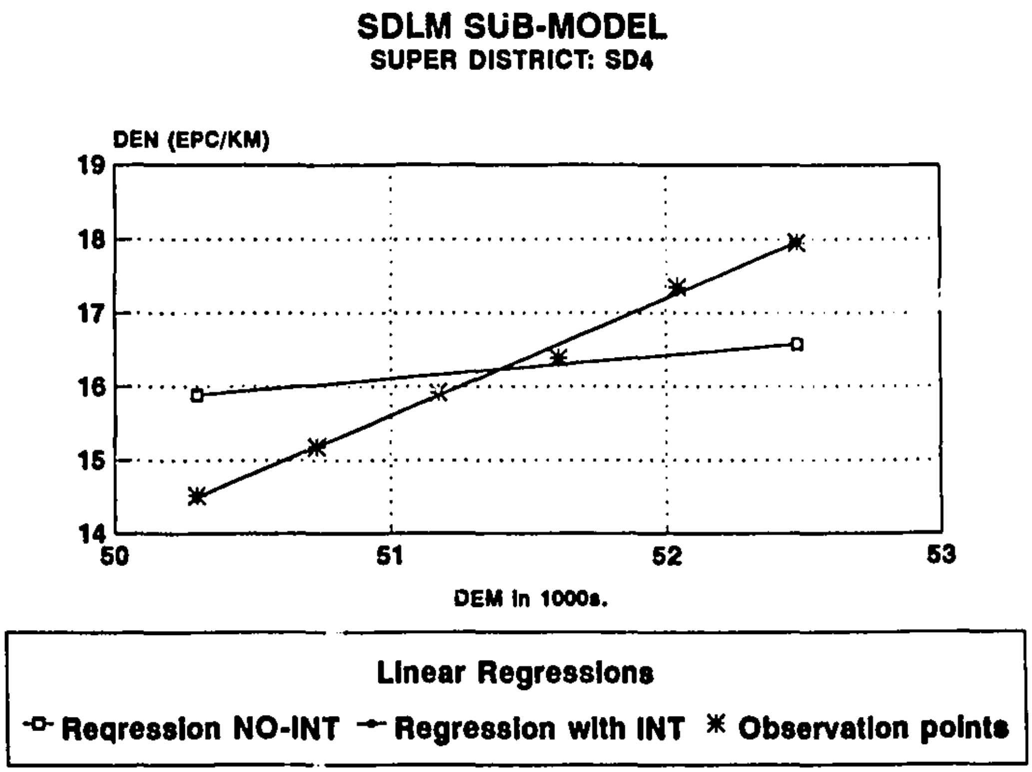


Fig. 5.4-4: SDLM Sub-model; Laval

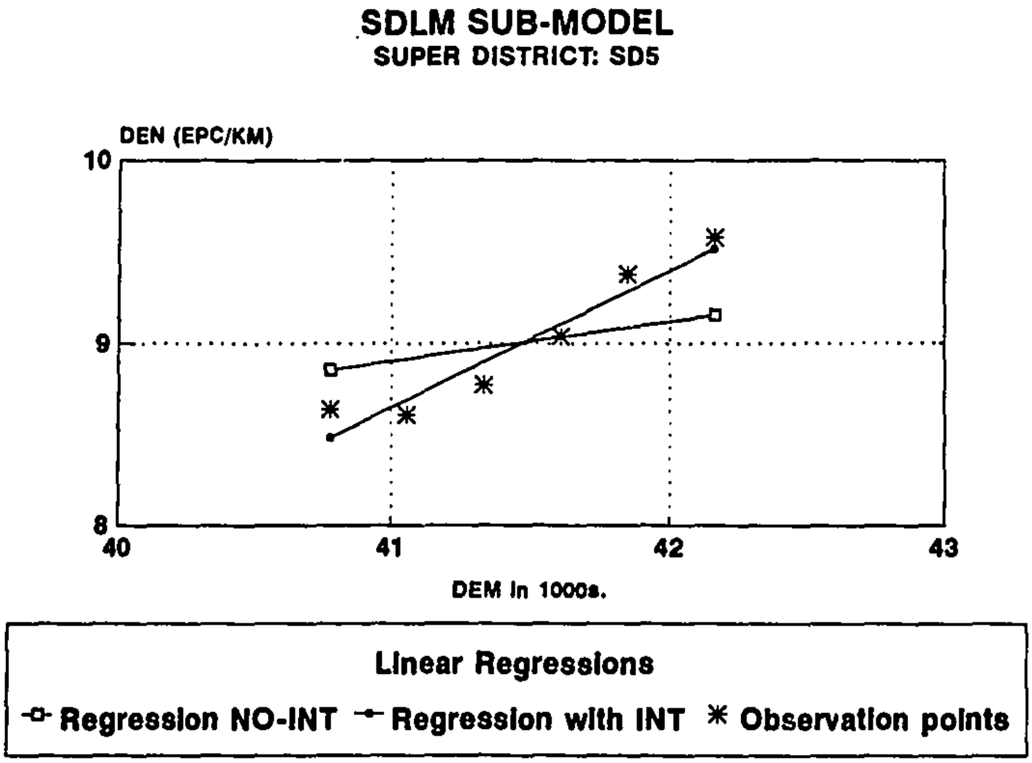


Fig. 5.4-5: SDLM Sub-model; North Shore

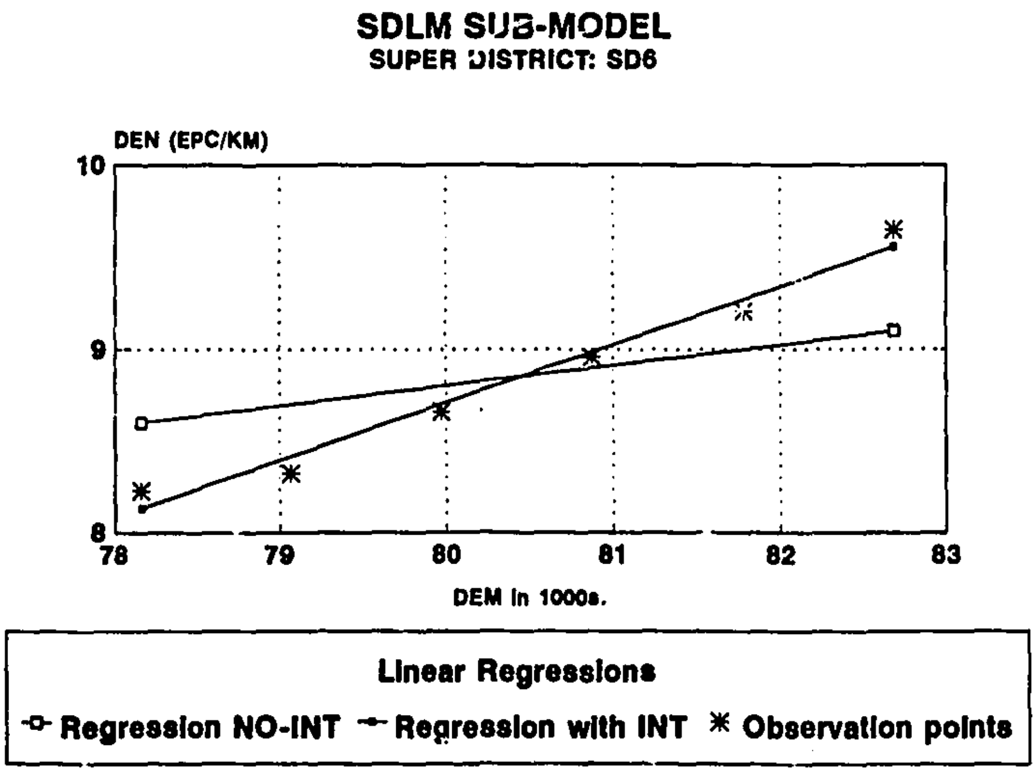


Fig. 5.4-6: SDLM Sub-model; South Shore

SDLM SUB-MODEL
MONTREAL ISLAND

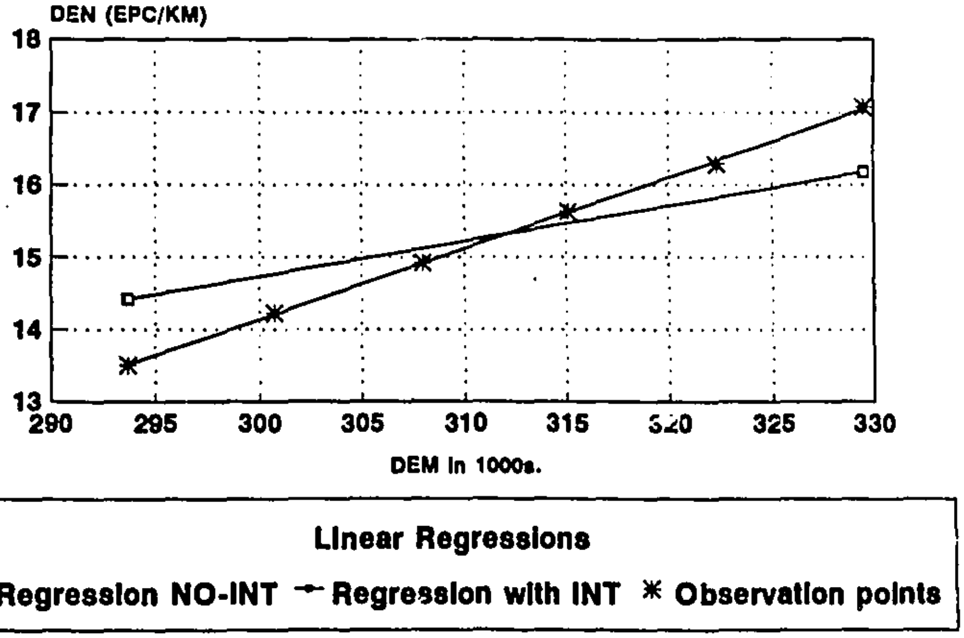


Fig. 5.4-7: SDLM Sub-model; Montreal Is

SDLM SUB-MODEL
GREATER MONTREAL AREA

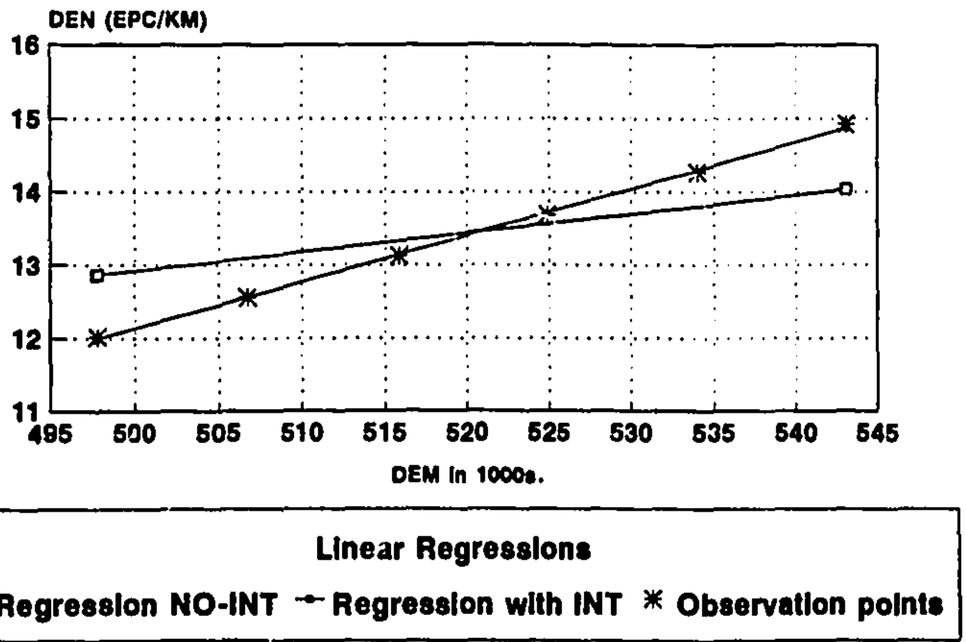


Fig. 5.4-8: SDLM Sub-model; GMA

The SDLM model, both Base and Sub-model, are applied to growth scenarios and are presented in Section 7. The results are superimposed and compared to those obtained using the calibrated EMME/2 travel demand model. The error between results determines the sensitivity of the SDLM.

7. SENSITIVITY ANALYSES

The developed SDLM model, both Base and Sub-model, shall be tested by carrying out a sensitivity analysis. This is accomplished through hypothetical scenarios of growth and decentralization for the GMA and the City Centre (SD1).

The sensitivity analysis tests the City Centre upper bound using growth scenarios (growth DEM scenarios) while its lower bound is tested using DEM reductions in the City Centre (decentralization scenarios). Further, a cross-sectional sensitivity analysis shall test the cross-sectional data at a pivot point scenario, which is defined as the mid-growth point between the upper and lower bounds of DEM (DEM and DEMs are used interchangeably) in the GMA, i.e., it is taken to be the base year demand augmented by ten percent.

Different sensitivity results might be obtained if a different pivot point is adopted; this would be of minor importance at the sketch planning level. The choice of the DEM plus 10% as pivot point will result in conservative estimates as presented later on.

The decentralization lower bound is defined as the maximum probable decentralization between the City Centre and the rest of the GMA. It is obtained assuming minimum-growth in the City Centre while a total POP differential growth of 4%, (this is equivalent to a differential compounded constant growth rate of 0.15% per year) for ten years, is applied to the rest of the GMA. This is in conformity with the BSQ (1984) POP scenario figures (to be presented in Chapter 6).
Furthermore, two additional hypothetical lower bound scenarios are applied to study the differential variations in results over a wider range.

The upper bound, the maximum probable differential growth between the City Centre and the rest of the GMA, is not expected to materialize. It is expected that the growth rate in SD1 will always be less than the GMA. This was demonstrated in Chapter 3; because a decentralization of EMP in SD1 is in progress and the 'Gentrification' of the City Centre is of minor impact. Yet, an upper bound of 4% is assumed, symmetric with the lower bound, base figure.

The sensitivity analysis consists in comparing boundary condition results obtained by applying the EMME/2 (assignment stage results) and the SDLM models: both Base and Sub-model for the upper and lower bound differential growth scenarios. Similarly, the cross-sectional sensitivity analysis (GMA cross-sectional growth scenario i.e., the pivot point scenario in this case) data compare results obtained by applying EMME/2 and SDLM Base model.

Table 5.23 presents the DEM matrices summarized by super district, MTL, and the GMA.

LOC.	**UBM**	**PPM**	**LOWER**	**BOUND**	**MATRICES**
	14,10	**10,10**	**6,10**	**4,10**	**0,10**
SD1	149.463	144.218	138.974	136.352	131.108
SD2	71.365	70.586	69.807	69.417	68.639
SD3	109.308	108.151	106.994	106.415	105.258
SD4	55.763	55.328	54.891	54.673	54.237
SD5	45.133	44.856	44.578	44.439	44.162
SD6	86.883	85.978	85.073	84.621	83.716
MTL	330.136	323.955	315.775	312.1[illegible]4	305.005
GMA*	556.548	547.474	538.307	533.861	524.787

TABLE 5.23: SENSITIVITY ANALYSES DEM SCENARIOS.

DEM figures in 1000s.

NB: GMA* DEM includes external trips which were utilized in developing SDLM.

Where;
DEM= At + Pr - IS
UBM= DEM upper bound matrix, SD1 at 14% of Base Year, others at 10%.
PPM= DEM pivot point matrix, all SDs are at 10% of Base Year.
LBM= DEM Lower Bound Matrices, are:
6,10: SD1 growth=6%, GMA growth=10%
4,10: SD1 growth=4%, GMA growth=10%
0,10: SD1 growth=0% (base year), GMA growth=10%

Matrices (scenarios) in Table 5.23 are obtained as follows:

1. The PPM (pivot point demand matrix) scenario is computed by augmenting by 10% the 1987 base year total demand matrix.
2. The UBM (upper bound demand matrix) scenario is computed by augmenting the City Centre (SD1) PPM by an additional 4%.
3. The lower bound matrices are obtained from the PPM scenario and reducing the DEM in the City Centre as follows: (a) by 4% (6,10); (b) by 6% (4,10); and (c) by 10% (0,10).

The DEM in the other SDs are also affected, as they balance the variations of DEM in SD1, as demonstrated earlier.

7.1 Data and Relationships Among Variables

The base year data variables are constants used in SDLM applications in the sensitivity analysis (in the following sub-sections) and in the impact analysis in Chapter 6. Next, several equations are derived to relate such variables. Furthermore, the derived equations may be used in any given scenario or to relate two scenarios. First the data are presented, and then the equations.

7.1.1 Data aggregation

The data are aggregated by facility type and super district. Table 5.24 presents the number of observations i.e., the number of links (LF=freeway links, LA=arterial links) categorized by facility type (as numbers and percentages), and their corresponding road network infrastructure data for the 1987 base year by super district. The Montreal Island and GMA aggregations are also presented.

Table 5.24 shows the dominance of the arterials as a facility type, both as numbers and more significantly as lane-kilometres. The arterial lane-kms constitute more than 80% of the infrastructure of the road network in Montreal Island. The lowest proportion of freeways is observed in SD3 (MTL East), while the highest is observed in SD5 (N. Shore).

LOC.	N.Obs	LF	LA	LF%	LA%	ZLL	ZLLF	ZLLA	ZLLF%	ZLLA%
SD1	2434	213	2221	8.75	91.25	2041	333	1708	31.99	68.01
SD2	1003	154	849	15.35	84.65	1437	391	1046	27.21	72.79
SD3	1259	61	1198	4.85	95.15	1617	166	1451	10.27	89.73
SD4	806	99	707	12.28	87.72	1071	275	796	25.68	74.32
SD5	449	82	367	18.26	81.74	1548	547	1001	35.34	64.66
SD6	1935	299	1636	15.45	84.55	4118	926	3192	22.49	77.51
MTL	4696	428	4268	9.11	90.89	5094	890	4204	17.63	82.37
GMA	7886	908	6978	11.51	88.49	11832	2639	9193	22.30	77.70

TABLE 5.24: LINKS CATEGORIZED by FACILITY TYPE and SUPER DISTRICT.

NB: It is of interest to note that ZLL, ZLLF, and ZLLA are constants in the research as they represent the 1987 infrastructure.

Where;
LOC. = location
N.Obs = number of observations (number of links)
LF = numbers of freeway links
LA = " " arterial "
LF%, LA% = percentages of LF and LA
ZLLF%, ZLLA% = percentages of ZLLF and ZLLA out of ZLL
ZLL, ZLLF, ZLLA = defined earlier (footnote #1) in lane-km.

The SDLM results, both Base and Sub-model, give density variations for the total road network i.e., arterials and freeways combined. To further refine the results, the disaggregation of the road network by facility type into ZLLA and ZLLF shall be tested against the EMME/2 figures.

7.1.2 Equations

The computation equations needed to disaggregate data into DENA and DENF are derived and presented below. A simple traffic volume (DEN*ZLL) proportionality to obtain dEPCA from dEPC is used:

dEPCA = dEPC * (DENA * ZLLA) / (DENb * ZLL)

Replacing dEPC = dDEN * ZLL in the above equation, we have:

dEPCA = dDEN * F2 **Eq. 5.11**

NB:
1. Variables label ending with 'b' relate to base year data.
2. Variables label ending with 'e' relate to EMME/2 estimated data.
3. Variables label ending with 's' relate to SDLM estimated data.

where;
DENb = DEN for base year (1987)
F2 = (ZLLA / DENb) * DENAb, is a constant per SD
dEPC = variation in EPC between base year and a given scenario
EPCA = DENAb * ZLLA, EPC for arterial trips
dEPCA = variation in EPCA between base year and a given scenario
EPCF = DENFb * ZLLF, EPC for freeway trips
dEPCF = variation in EPCF between a base year and a given scenario.

The additional arterial lane kilometres required to maintain DENA at the base year aggregate average value i.e., to keep the aggregate LOS constant at the base year level, is obtained as follows:

dZLLA = dEPCA / DENAb

Replacing dEPCA by its equation, we have:

dZLLA = dDEN * F1 Eq. 5.12

where;

F1 = ZLLA / DENb Eq. 5.13 and,

F2 = F1 * DENAb Eq. 5.14

The variations of EPC trip density in arterials is given by:

dDENA = dEPCA / ZLLA Eq. 5.15

Similarly, freeway and expressway equations are obtained by replacing DENA, EPCA,... by DENF, EPCF,... as follows:

dEPCF = dDEN * F4 Eq. 5.16

dZLLF = dDEN * F3 Eq. 5.17 and,

dDENF = dEPCF / ZLLF Eq. 5.18

where;

F3 = ZLLF / DENb Eq. 5.19

F4 = F3 * DENFb Eq. 5.20

The following simple equations are derived (by definition) by facility type as an alternative to equations 5.12 and 5.17.

dZLLA = dEPCA / DENA Eq. 5.21 and,

dZLLF = dEPCF / DENF Eq. 5.22

Factors F1, F2, F3, and F4 are obtained from EMME/2 base year data and are consequently constant per GMA super district and form a part of the SDLM.

The SDLM constants are computed and presented in Table 5.25.

LOC.	DENb	DENAb	DENFb	F1	F2	F3	F4
SD1	11.85	9.78	33.41	144.1	1410	28.1	939
SD2	15.44	12.85	29.69	67.7	871	25.3	751
SD3	15.14	13.11	53.76	95.8	1256	11.0	591
SD4	14.52	9.64	49.40	54.8	528	18.9	934
SD5	8.64	5.38	22.93	115.9	623	63.3	1451
SD6	8.23	5.89	20.61	387.8	2284	112.5	2319
MTL	13.49	11.32	34.97	311.6	3527	66.0	2308
GMA	12.02	9.58	30.82	764.8	7327	219.6	6768

TABLE 5.25: SDLM MODEL CONSTANTS.

DEN and (F) factors by SD and facility type.

7.2 Upper Boundary Analysis

The upper bound travel demand matrix (UBM, Table 5.23) in EPC is assigned to the road network using the assignment stage of EMME/2, and the relevant results (DEN, ME2) are presented in Table 5.26. The computations are explained by notes in Table 5.26.

The SDLM Base model is always applied to the PPM scenario in the sensitivity analysis and the Sub-model is applied to the differential growth scenarios between the City Centre (SD1) and the PPM scenario.

Table 5.26 presents the upper bound sensitivity analysis results. A comparison between the differences in results is also presented, using the SDLM models (both Base and Sub-model results super-imposed) and the calibrated EMME/2, the highly complex and time consuming, travel demand sequential model. The differences may be attributed in part to data aggregational effect, rounding up of figures, and the re-routing of EPC trips in the EMME/2 assignment stage which are not captured by the SDLM models.

LOC.	DEM (PPM)	B1 Base	DENbm	dDEM	B1' Sub.	dDEN	DENs SDLM	DENe ME2	PCT
SD1	144.22	0.205396	14.51	5.245	0.153856	0.81	15.32	15.14	+1.19
SD2	70.59	0.648049	19.51	0.779	0.719602	0.56	20.07	19.90	+0.85
SD3	108.15	0.378214	18.75	1.157	0.546432	0.63	19.39	19.24	+0.78
SD4	55.33	1.200669	20.20	0.435	1.581258	0.69	20.88	20.46	+2.05
SD5	44.86	0.673938	11.30	0.277	0.749526	0.21	11.51	10.97	+4.92
SD6	85.98	0.261920	10.16	0.905	0.314217	0.28	10.45	10.20	+2.45
MTL	322.96	0.112234	16.73	7.181	0.098473	0.71	17.44	17.26	+1.04
GMA*	547.47	0.065504	15.19	9.074	0.063618	0.58	15.77	15.49	-1.81

TABLE 5.26: DEN COMPARISONS: UPPER BOUND SENSITIVITY ANALYSIS.

NB: GMA* DEM includes external trips which were utilized in developing SDLM. DEM figures in 1000s.

Where;

DEM	= pivot point demand, PPM
B1, B1'	= Base SDLM and Sub-model coefficients respectively
B0, B0'	= Base SDLM and Sub-model INT coefficients respectively
DENbm	= B0 + B1 * DEM (Base model applied)
dDEM	= delta DEM= DEM difference =UBM - PPM
dDEN	= dDEM * B1' (Sub-model applied)
DENs (SDLM)	= DENbm + dDEN = DENs (DEN obtained using SDLM models)
DENe (ME2)	= DEN (upper bound) retrieved from EMME/2 assignment stage
PCT	= error%; (DENs - DENe) * 100 / DENe.
ME2	= EMME/2 assignment results.

Furthermore, the PCT error term, in Table 5.26, is constantly positive in all aggregations i.e., the SDLM is over estimating

DEN by a maximum of 5% (SD5) which is quite tolerable at the planning level, while it is below 2% in MTL and its SDs i.e., SD1, SD2, and SD3.

This is a good outcome and shows the reliability of the SDLM models at the upper boundary of DEM.

7.3 Lower Boundary Analysis

The lower boundary matrix is computed also using PPM, defined in 7.1 above, and by reducing the City Centre productions and attractions by 4%.

Furthermore, two additional lowest bound matrices are tested as the research is concerned with decentralization in the City Centre.

Thus, Table 5.27 presents a comparison of results for three lower bound matrices (scenarios): four, six and ten percent, representing decentralization in the City Centre.

Each lower bound matrix is assigned to the road network using the assignment stage of EMME/2 and the relevant results are presented in Table 5.27.

LOC.	LBM: 6% SD1, 10% GMA			LBM: 4% SD1, 10% GMA			LBM 0% SD1 10% GMA		
	SDLM	ME2	PCT	SDLM	ME2	PCT	SDLM	ME2	PCT
SD1	13.70	13.59	+0.81	13.30	13.19	+0.83	12.49	12.41	+0.64
SD2	18.95	18.26	+3.78	18.34	18.12	+1.21	18.11	17.55	+3.19
SD3	18.12	17.85	+1.51	17.80	17.58	+1.25	17.17	16.96	+1.24
SD4	19.50	18.89	+3.23	19.10	18.54	+3.02	18.47	17.87	+3.36
SD5	11.09	10.19	+8.83	10.99	10.12	+8.60	10.78	10.01	+7.69
SD6	9.88	9.55	+3.46	9.74	9.49	+2.63	9.45	8.92	+5.94
MTL	16.02	15.73	+1.84	15.67	15.51	+1.03	14.96	14.73	+1.56
GMA	14.61	14.22	+2.74	14.32	14.03	+2.07	13.75	13.36	+1.05

TABLE 5.27: DEN COMPARISONS: LOWER BOUND SENSITIVITY ANALYSIS.

DEM figures in 1000s. Variables defined previously.

The SDLM Base and Sub-models are applied in a similar way to the upper boundary analysis, and the results are also presented in Table 5.27.

The percentage error, in all scenarios of Table 5.27 are positive, meaning that the SDLM models (Base and Sub-model) are over-estimating the aggregate mean of traffic densities due to decentralization and it is less than 4% for LBM (6,10) and LBM (4,10), except for SD5. The maximum variation occurs in SD5 (N. Shore) in both tables 5.26 and 5.27.

The error in estimating the impact of decentralization (LBM scenarios, Table 5.27) is larger than the error in POP over-growth (UBM scenarios, Table 5.26) of the City Centre.
This confirms the statement of the previous sub-section: the re-routing of traffic due to decentralization, in the assignment stage, is of importance and is being partly

captured by the Sub-model (the SDLM is developed based on fixed infrastructure) and is probably the main source of error.

Thus, the SDLM should not be used where there is mobility reductions below the 95% limit (corresponding to a maximum DEM uniform increment of 20%) set when the upper DEM boundary was established earlier in this chapter.

Further scrutiny of results show that, generally speaking, the larger decentralization percentage has minor bearing on the error percentage between SDLM and EMME/2 results.

The lower bound for decentralization is 4% (6% increase over base year DEM for SD1 and 10% for the GMA) of total demand, while the expected percentage error is less than 4% except for SD5 (first 3 columns in Table 5.27). This is well within sketch planning tolerance.
The expected error in the GMA as a whole is less than 3% and in the MTL is less than 2%, and they represent an over-estimation.

7.4 Cross-Sectional Analysis

The pivot point matrix (PPM, Table 5.23) which represents a uniform demand growth of 10% in EPC trips is assigned to the road network using EMME/2 and the results are presented in Table 5.28.

Table 5.28 presents a comparison between traffic densities obtained from EMME/2 and SDLM base for a cross-sectional growth in DEM of 10% (PPM scenario). As expected, all results are well within sketch planning design tolerance limit and have negative errors i.e., the SDLM Base model is consistently over-estimating the aggregate mean traffic densities by less than 3% except for SD5.

LOC.	DENb	DENe	dDEN	DENs	PCT
SD1	11.85	14.24	-0.27	14.51	-1.89
SD2	15.44	19.02	-0.49	19.51	-2.58
SD3	15.14	18.57	-0.18	18.75	-0.97
SD4	14.52	19.65	-0.55	20.20	-2.80
SD5	8.64	10.72	-0.56	11.30	-5.41
SD6	8.23	9.91	-0.25	10.16	-2.52
MTL	13.49	16.42	-0.31	16.73	-1.89
GMA	12.02	14.83	-0.36	15.19	-2.43

TABLE 5.28: DEN COMPARISONS: CROSS-SECTIONAL SENSITIVITY ANALYSIS.

Where;
DENe = DEN for PPM (110%*DEM), obtained from EMME/2 (assignment)
DENb = DEN for base year, " " " "
dDEN = DEN difference (DENe-DENs) " " " "
DENs = DEN for PPM, obtained using SDLM base
PCT = percentage error between SDLM and EMME/2.

Tables 5.29 and 5.30 present a disaggregation of DEN into DENA and DENF obtained from EMME/2 (one assignment per spatial aggregation) and the results are compared to DENA and DENF obtained using the previously derived equations and the SDLM model constants in Table 5.25.

The following computations gave the results in Table 5.29:

1. dDENs = DENs - DENb by definition

2. dEPCA = dDENs * F2 from Eq. 5.11 (SDLM figures)

3. dDENA = dDENs * F2 / ZLLA from Eq. 5.15 (SDLM figures)

4. DENAs = dDENA + DENAb by definition

5. PCT = (DENAe - DENAs) / (100 * DENAe) by definition

Other columns are obtained from Table 5.25, from EMME/2 assignments, and by applying the SDLM Base model regression equations (with intercept, Table 5.16).

LOC.	DENs	DENb	dDENs	dEPCA	dDENA SDLM	DENAs SDLM	DENAe ME2	PCT
SD1	14.51	11.85	2.66	3751	2.20	11.98	11.96	-1.67
SD2	19.51	15.44	4.07	3545	3.39	16.24	15.96	-1.72
SD3	18.75	15.14	3.61	4534	3.12	16.23	16.32	+0.55
SD4	20.20	14.52	5.68	2999	3.77	13.41	13.34	-0.52
SD5	11.30	8.64	2.66	1657	1.66	7.04	7.01	-0.43
SD6	10.16	8.23	1.93	4408	1.38	7.27	7.37	+1.38
MTL	16.73	13.49	3.24	11427	2.72	14.04	13.98	-0.43
GMA	15.19	12.02	3.17	23227	2.53	12.11	12.00	-0.91

TABLE 5.29: DENA COMPARISONS: CROSS-SECTIONAL SENSITIVITY ANALYSES.

Where;
DENAe,ME2 = DENA for PPM (110%*DEM), obtained from EMME/2 (assignment)
DENAb = DENA for base year obtained from EMME/2 (assignment)
DENb = DEN for base year.

The results in Table 5.29 show that the disaggregated DENA figures differ less than two percent when obtained through the SDLM Base model as compared to the results from the more sophisticated EMME/2 model. This is an excellent outcome.

It is of interest to note that the signs of the error percentage in Table 5.29 have no apparent pattern i.e., the differences in DENA results when applying the SDLM Base model and when using the EMME/2 complex model are small (less than 2%) and may be considered random errors.

Table 5.30 presents the comparisons between DENF as obtained from EMME/2 and as computed using the SDLM Base model. Computations are identical to those used in Table 5.29 except that all arterial (e.g. DENA) variables are replaced by freeway (e.g. DENF) variables, and F2 is replaced by F4.

LOC.	DENs	DENb	dDENs	dEPCF	dDENF SDLM	DENFs SDLM	DENFe ME2	PCT
SD1	14.51	11.85	2.66	2498	7.50	40.91	38.03	-7.04
SD2	19.51	15.44	4.07	3057	7.82	37.51	35.90	-4.29
SD3	18.75	15.14	3.61	2134	12.85	66.61	62.64	-5.96
SD4	20.20	14.52	5.68	5305	19.29	68.69	64.69	-5.82
SD5	11.30	8.64	2.66	3860	7.06	29.99	27.33	-8.87
SD6	10.16	8.23	1.93	4476	4.83	25.44	23.82	-6.37
MTL	16.73	13.49	3.24	7478	8.40	43.37	40.77	-5.99
GMA	15.19	12.02	3.17	21455	8.13	38.95	36.59	-6.06

TABLE 5.30: DENF COMPARISONS: CROSS-SECTIONAL SENSITIVITY ANALYSES.

Where;
DENFe, ME2= DENF for PPM (110%*DEM), obtained from EMME/2 (assignment)
DENFb = DENF for base year obtained from EMME/2 (assignment)
DENFs, SDLM = dDENF + DENFb
DENb = DEN for base year
dDENs = DEN difference (DENs-DENb).

The error PCT in Table 5.30 are relatively significant and are all negative. The EPC trips are slightly over-estimated when computing DENF. Consequently, when using the SDLM Base model to estimate freeway and expressway requirements, the results should be factored down if a more accurate outcome is needed which is doubtful at the sketch planning level of analysis. This may be explained by the fact, as discussed earlier, freeways and expressways tend to attract traffic due to drivers perception of improving their disutility (time wise). This is captured by the volume delay functions in EMME/2.

The error PCT in Table 5.30 are well within sketch planning requirements and furthermore, the 10% cross-sectional DEM growth represent more than twenty years of growth.

7.4 Simple Example

Complete SDLM computation procedures are presented in Chapter 6, using the expected population growth and EMP decentralization as a pivot scenario which serves as a prototype procedural solution to the forecasting scenarios, namely: upper and lower EMP decentralization, in SD1; and upper and lower population growth, within the most likely growth range of the GMA.

At this point, a missing part in the previous analyses is presented through an example, namely: how to find the additional lane-km by facility type needed to balance the incremental growth in order to maintain the aggregate LOS at its 1987 base year level. This is established through a simple example as a continuation of the pivot point analyses.

PROBLEM

Find the additional road network requirements, by facility type and by GMA super district, needed to balance an overall uniform growth in the GMA of 10% while keeping the aggregate LOS by SD constant at the 1987 base year values.

SOLUTION

To solve this problem using the EMME/2 travel demand model would take three days of computer work; while when using the SDLM Base model, it becomes a simple computation, as follows:

1. Apply an overall growth of 10%, as a first step,
2. Find the DEM matrix of attractions, productions and intra-super district EPC trips;
3. Use the SDLM Base model to estimate the variations in DEN as compared to base year figures and translate them into lane-km. The available cross-sectional data from the sensitivity analyses are used to solve the example.

Steps 1 and 2 are needed in either model, EMME/2 or SDLM. The demand matrix, for this example, is the pivot point matrix or PPM.

The above, simply put, consists of the transformation of the available changes of EPC trips of freeways or dEPCF, and arterials or dEPCA (between the base year and the pivot point scenario, by super district), into their equivalent lane-km.

Values of dEPCA, dDENA, and DENA are obtained from Table 5.29 and those of dEPCF, dDENF, and DENF are retrieved from Table 5.30. Table 5.31 presents the results of computations for dZLLA, dZLLF, and dZLL (computed using equations 5.21 and 5.22).

LOC.	**dEPCA**	**DENA**	**dZLLA**	**dEPCF**	**DENF**	**dZLLF**	**dZLL**
SD1	3751	11.98	313	2498	40.91	61	374
SD2	3545	16.24	218	3057	37.51	81	299
SD3	4534	16.23	279	2134	66.61	32	311
SD4	2999	13.41	224	5305	68.69	77	301
SD5	1657	7.04	235	3860	29.99	129	364
SD6	4408	7.27	606	4476	25.44	176	782
MTL	11427	14.04	814	7478	43.37	172	986
GMA	23227	12.11	1918	21455	38.95	551	2469

TABLE 5.31: LANE-KM REQUIREMENTS by FACILITY TYPE and by SD.

Where;
dZLLA = additional required arterial lane-kilometres
dZLLF = " " freeways and expressways lane-km
dZLL = " " total lane-kilometres.

The results in Table 5.31 show how simple it is to obtain quick results using the SDLM Base model; the needed lane-km are significant; this is a hypothetical cross-sectional growth scenario of 10% (more than a 20 year growth period).

Important data manipulations are required to transform the EMP variations into growth population scenarios and afterwards into EPC trips. This is done using Production-Attraction relationships from Chapter 3. The data processing is detailed in Chapter 6.

To answer the question 'where to locate the additional facilities in the super districts?'; the results would be further disaggregated into their zonal components by proportion, similar to what was done for SDs disaggregations in EMME/2 model.

The answer to the question: where to locate the additional facilities within the zones; is that this is a zonal analysis and such details are beyond the sketch planning level of analysis.

8. CHAPTER SUMMARY and CONCLUSIONS

The SDLM models were developed in this Chapter using a quasi-experimental approach as recommended by authorities on the subject.

The SDLM models have important explanatory powers. The DEM variable has more than 98% explanatory powers on DEN, the aggregate average traffic density of the road network by super district.

The cross-sectional analysis improved the research understanding of the case study and its spatial components, but has lead to no concrete modelling results in spite of the significant work involved.

It may be concluded from the cross-sectional analyses that the road network construction in the GMA, as is typical in most metropolises, does not strictly relate to the increase in demand.

This is especially so in exurban and suburban settings where the increase in infrastructure is needed to improve mobility and to shorten time travel providing a minimal infrastructure grid to allow for suburban development.

The cross-sectional analyses presented the problem of linking the supply-demand measures of an existing network and has defined the working scope for the SDLM Base model and Sub-model.

The base year data may be considered to be the lower bound for the case study due to the fact that no dramatic decrease in overall demand is expected in the Greater Montreal Area; i.e., the total demand is not expected to decrease below the 1987 base year figures. This is evidenced in the growth forecasting scenarios in Chapter 6.

The cross-sectional analyses has helped to define the two variables to enter the SDLM model. They are: (a) the demand (DEM) as the independent variable, and (b) the average traffic density (DEN) as the dependent variable.

Table 5.16 presented the Base SDLM and together with the Sub-model in Table 5.21, they represent the main contribution of the research. These models have high explanatory powers i.e., they have an excellent simulation of reality. It appears to be a successful aggregate model.

The sensitivity analyses tested and compared results obtained using the highly sophisticated and state-of-the-art EMME/2 travel demand model and the developed model in this research. The SDLM results were found to be reliable and show some variations from EMME/2, as follows:

1. Upper bound results at the GMA aggregate level are within 2% and a maximum difference (less than 5%) was registered in SD5.

2. Lower bound (decentralization in SD1) at the GMA aggregate level are within 3% and a maximum difference (less than 9%) was also registered in SD5.

3. Cross-sectional (uniform DEM growth) analysis are at the GMA aggregation level as follows: (a) for DEN below 2.5%, (b) for DENA below 1%, and (c) for DENF below 6%; while at the SD level they are: (a) for DEN 5.5%, (b) for DENA 2%, and for DENF 9%.

There is apparently no pattern characterizing the differences (errors) except for SD5. The linear regression for Sub-model SD5, as seen from Fig. 5.4-5, does not provide a good fit with the observation points in general and with the base year point in particular.
Furthermore, DEM has the lowest explanatory powers on DEN (Table 5.21) relative to the other SDs. A higher order regression curve is indicated yet it was not adopted because of the low impact of SD5 on the analyses (maximum expected errors below 10% and mostly in SD5) due to the research concentration on SD1 and GMA; and in order to keep the Sub-model curves in standard format.

Thus, it is safe to conclude that errors in using the SDLM models in general are well below 10% generally speaking which are well within sketch planning tolerance limits.

Furthermore, the sensitivity analysis was carried out at the pivot point scenario (PPM) of 10% uniform growth, which represents more than 20 years of uniform growth, well beyond the research forecast period, thus rendering the analysis a conservative one.

A lower PPM would probably improve the reliability of SDLM, as the most probable cause for errors are the re-assignment of trips to different routes due to congestion, a non linear effect (depicted by the volume delay functions in EMME/2, as mentioned earlier).

The super district groupings, relating to local research data availability as seen in Chapter 3 Part C and confirmed in the cross-sectional analysis, are used to present modelling results for the research. And it is recommended to use for sub-model spatial aggregations: MTL Centre, MTL suburbs, South Shore, and the group of North Shore and Laval.

In order to capture the **Impact of employment decentralization on metropolitan road network**, in the EMP decentralization analyses, the two sketch planning levels of aggregation used have produced good results; the GMA and SD1 i.e., the SDLM Base model and its Sub-model.

The SDLM models, both Base and Sub-model, are used in forecasting scenarios in Chapter 6: for the upper and lower bounds for the most likely EMP decentralization; the upper and lower bounds for the population growth; and the pivot scenario or the most expected population growth and EMP decentralization.

Furthermore, the more complete and complex scenarios are solved using the SDLM models, showing data transformations and detailed step by step solutions.

The SDLM applications should be limited to a maximum DEM increase of 20%. This limit was imposed by the loss of 5% in mobility and constitutes the upper bound for DEM. Model extrapolations should not be permitted and are not expected.

The adopted linear relationships between supply and demand measures in the SDLM models has simplified their use as a sketch planning tool. A higher degree curve was shown to give marginally better but more complex results.

CHAPTER 6

FORECASTING SCENARIOS:

IMPACT OF EMPLOYMENT DECENTRALIZATION ON METROPOLITAN ROAD NETWORKS

1. INTRODUCTION

The previous chapters presented the several stages of the research, culminating in Chapter 5, the main research product: the Supply-Demand Linkage Model or 'SDLM'.

The sensitivity analyses in Chapter 5, proved the dependability of the SDLM results as compared to the EMME/2 results, the complex state-of-the-art travel demand model. A simple example was presented as a continuation of the sensitivity analysis.

The second main objective of the research is to obtain the **"Impact of Employment Decentralization on Metropolitan Road Networks"**, using the developed SDLM models, at the sketch planning level. This is achieved through forecasting scenarios for the two independent variables: population (POP) and employment (EMP).

The forecasting scenarios for the two temporal periods 1986-96 and 1986-2001 (defined in Chapter 3) are developed and tested in this chapter. Each forecasting period has a pivot scenario relating the POP and EMP variables. The pivot scenario is defined as having equivalent EMP and POP data, thus it acts as a pivot for other scenarios, for data translation between EMP and POP.

The scenarios present, generally speaking, upper and lower bounds i.e., control totals. Scenarios are categorized into POP growth and EMP decentralization (DCTZN). These represent the most probable POP growth range and the high and low EMP Decentralization. POP and EMP scenarios may be related, using the pivot scenario (P).

The required zonal lane-kilometres (ZLL) per scenario by super district (SD) are computed using the SDLM models as outlined briefly in the simple example in Chapter 5. The sequential computations, presented in this chapter, define the procedure for the translation of variables and the application of the SDLM models to obtain the impact of EMP decentralization, or other future regional activity pattern changes, on major road requirements.

To achieve the above mentioned objectives, a preliminary search is done to define the forecasting data and to relate the DEM, the independent variable used in the SDLM models which become the dependent variable in forecasting, as it is obtained from POP and EMP scenarios (POP and EMP become the independent variable in forecasting), to readily available forecasting data at the base year.

This is achieved as follows:

1. Obtain the zonal variables from Chapters 3 and 5 by zone.
2. Aggregate the variables by SD, based on findings in Chapter 5.
3. Model the DEM, as dependent variable, against the other variables or factor them up and as per findings in Chapter 5. This is a continuation of the calibration work by zone in Chapter 3.

The STCUM survey, the source for the research demand data, was carried out in the autumn of 1987 and the surveyed population sample was expanded using 1986 StatsCan POP figures. Thus the base year data, defined as the 1987 base year data by STCUM and used in the research as such in Chapters 3, 4 and 5, are actually 1986 base year data. Consequently, the 1987 base data term is used interchangeably with the 1986 base year data in this chapter.

2. RELATIONSHIPS AMONG VARIABLES

The relationships between DEM, the dependent variable in forecasting, and several independent variables are presented herein at the super district level of aggregation. They are obtained mostly from chapters 3 and 5.

The zonal cross-sectional calibrations were done in Chapter 3, Part D, and the results are presented in tables 3.44 and 3.45 for the variables presented in Table 3.43.

The calibration of a model, for use in scenarios, is a plus over the simple use of factors, yet it is not strictly required for the analyses. Factors may be used whenever such models have low explanatory powers.

Furthermore, model calibration is done to improve the research understanding of the spatial relationships among relevant variables at the SD level and to obtain, whenever possible, more reliable (calibrated model) relationships between them for forecasting purposes.

The DEM scenarios, used in the SDLM models, are obtained from available forecasting scenarios for other variables like POP, EMP, and DU which are translated into DEM scenarios in Section 4.

2.1 Data Aggregations by SD

The zonal data for the 1986 (previously 1987) base year were obtained from the STCUM and MOTQ and are presented in Table 3.43 in Chapter 3. The variables were defined in the corresponding chapters.

Table 6.1 presents the zonal data, both dependent and independent variables, from Chapter 3, Table 3.43, aggregated by SD. The IS matrix (intra super district EPC trips) is computed using the EMME/2 model and comprises the inter-zonal trips for zones within each SD.

SD	CAR	DU	POP	TW**	PHW*	Pr*	At*	IS*	DEM*
1	260254	361176	797641	348881	48178	56806	109649	35347	131108
2	127446	96992	273004	119270	32007	38687	45180	19697	64170
3	259435	280569	681613	290034	57197	66626	63058	31364	98320
4	139143	102327	284312	121753	32045	41823	20469	11994	50298
5	139120	93787	282746	109133	29315	36056	17844	13123	40777
6	282803	206626	400818	277490	60608	69785	42150	33773	78162
GMA	1.21E6	1.14E6	2.72E6	1.27E6	259350	309783	298350	145298	462835

TABLE 6.1: SD VARIABLES; CAR, DU, POP, TW, PHW, Pr, At, IS, DEM.

<u>NB:</u>
* Variables PHW, Pr, At, IS, DEM figures are for the AM peak hour.
** Variable TW figures are for an average day.
Other variables are by SD.
Variables defined for Table 3.43 in Chapter 3.

The multivariate analyses for the variables in Table 6.1 are done next to obtain the calibrated models.

2.2 DEM Model Calibrations by SD: Trip Generation

Multivariate analyses are implemented to calibrate the dependent variable DEM, and its components Pr, At, and IS against the independent variables CAR, DU, POP, TW, PHW attempting to produce cross-sectional models at the SD level which are in conformity with the aggregation levels of the SDLM models. The results are presented in Table 6.2.

DEP. VAR	I.VAR	B0	B1	R2	R2(ADJ)
DEM	POP	14465	0.138244	0.9039	0.8799
DEM	CAR	6323	0.351679	0.5921	0.4902
DEM	PHW	8587	1.585935	0.4361	0.2951
DEM	TW	15524	0.291887	0.8627	0.8284
DEM	DU	22409	0.287681	0.9411	0.9264
DEM	Pr	564.5	1.483128	0.4292	0.2865
DEM	At	29123	0.963832	0.9533	0.9416
DEM	IS	9930	2.775352	0.7728	0.7160
Pr	POP	32884	0.041351	0.4145	0.2681
Pr	TW	26364	0.119695	0.7435	0.6793
Pr	PHW	5901	1.057934	0.9944	0.9930
At	POP	-10945	0.133825	0.8255	0.7818
At	TW	-6712	0.267354	0.7053	0.6317
At	PHW	-2747	1.213929	0.2490	0.0612
IS	POP	7473	0.036932	0.6430	0.5537
IS	TW	4128	0.095162	0.9139	0.8924
IS	PHW	-5433	0.685929	0.8130	0.7662

TABLE 6.2: GMA MODELS BY SD; 6 OBSERVATIONS PER MODEL.

The results in Table 6.2 are grouped by the dependent variable. The variable DEM (Pr+At-IS) is presented first; then their components Pr, At, and IS. The modelling of the components are presented for flexibility purposes; to be able to relate to EMP which is basically an (At) variable.

The results in Table 6.2 show that the dependent variable DEM is best modelled by: At (94.16%), DU (92.64%), POP (87.99%), and TW (82.84%). The POP and At (related to EMP, defined later in this chapter) variables may be used to translate POP and EMP scenarios into DEM (DEM is used in SDLM to obtain DEN) because they represent the two parameters of the forecasting scenarios.

The implemented multivariate analyses relate all independent variables to each dependent variable, in Table 6.1, using SAS step regression analyses, at 0.1500 significance level. The independent variables are: POP, CAR, PHW, TW, and DU. The results are presented in Table 6.3 and show that only one independent variable out of the five is retained. The zonal multivariate results are presented in Chapter 3, Table 3.45.

DEP. VAR	I.VAR 1,2,3	B0	B1	B2	B3	R2
DEM	DU,--	22408.97	0.287681	---	---	0.9411
At	DU,--	-2491.71	13201.07	---	---	0.8348
Pr	PHW,--	5901.28	1.057934	---	---	0.9944
IS	TW,--	4128.22	0.095162	---	---	0.9139

TABLE 6.3: GMA STEP REGRESSION MODELS by SD; 6 OBSERVATIONS per MODEL.

NB:
Step-regression results for all independent variables in Table 6.1. The table shows the retained variables only.

The results in Table 6.3 emphasize the independent variable with the highest explanatory powers on the corresponding dependent variable. In spite of that, the previously selected variables are used; POP and At, because the DU forecasting data are less reliable, as explained later on.

It is good to note the increase in the coefficient of determination in modelling results at the SD aggregation level as compared with zonal modelling results in Chapter 3, Part D. This shows that the choice of the research of the SD aggregation level was a reasonable one.
Whenever a coefficient of determination for a model is low; then the use of factors would be appropriate and are preferable.

3. FORECASTING SCENARIOS

The forecasting scenarios were briefly defined in the introduction to this chapter and in Chapter 5. There are two independent variables to be considered; POP and EMP control totals. They are presented in the following sub-sections. The POP and EMP variations over time and spatial distribution into aggregational groups of concern to the research at this stage, are presented herein, namely: GMA, MTL, and SD1.

How to correlate POP and EMP variables and how to relate them to DEM, are the concern of this section. This is needed in order to be able to use the SDLM models to obtain the impact of POP growth and EMP decentralization on metropolitan road requirements.

3.1 Control Totals

The research data were defined in the sensitivity analyses by two variables: DEM, the independent variable and DEN, the dependent variable. The maximum DEM range is limited, by road network mobility considerations, to 120% of base year DEM, this represents a loss in mobility of 5%, as demonstrated in Chapter 5.

The temporal variations of POP are obtained from BSQ (1984), BSQ (1990), and those of EMP are obtained from Lamonde et al. (1989) for the research forecasting years of 1996 and 2001. The forecasting period of 1986-2001, was chosen in Chapter 3, in order to be able to assume, at the sketch planning level, constancy of relevant variables like POP age and gender, car ownership in particular and modal split behaviour in general.

The BSQ (1984) data are used because of their completeness and their compatibility with EMP forecast data obtained from Lamonde et al. Furthermore, GMA data forecasts are not available from BSQ (1990); the GMA is split in two spatial aggregations, Laval and MTL, while the North and South shores are excluded.

The road network by facility type is also assumed constant during the forecasting period i.e, there are no important infrastructure changes implemented during the forecasting period. This is an important assumption as it forms the base out of which the SDLM is developed.

As a matter of fact; the research is seeking the additional infrastructure needed to balance the increase in demand in order to keep the 1986 LOS constant throughout the GMA; thus, the additional road network requirements are the product of the model and do not violate the SDLM applicability.
To do so, the upper and lower bounds for POP and EMP scenarios have to be assessed first.

Table 3.12 (Chapter 3) presents the spatial POP control totals for the forecasting period while, Table 3.14 presents the corresponding spatial EMP totals segregated into manufacturing and service EMP.

3.2 Population Growth and Data Compatibility

The POP growth scenarios are obtained from three main sources: (a) BSQ (1984); (b) BSQ (1990); and (c) Lamonde et al. The upper and lower bounds present the most expected POP variations under normal forecasting conditions and constitute the POP control totals.

The data from these sources have different spatial boundaries and need to be related in a way that at least one common denominator exists between them. This is the Montreal Island (MTL) data whose spatial boundaries are the rivers.

The BSQ (1984) forecasts provide data for the GMA, MTL, Laval, NS, and SS; while the BSQ (1990) forecasts provide data for MTL and Laval only. Furthermore, though the data from Lamonde et al. (data based on BSQ, 1984) have compatible aggregations with BSQ (1984) data, they have different spatial boundaries.

Thus, only MTL data have continuous compatibility over time and fixed spatial boundaries (the rivers) and are used as the common denominator for the scenarios.

Furthermore, the research external boundaries for the GMA are different from both the StatsCan and BSQ (1984), as presented in Chapter 3. The research boundaries had to conform to STCUM boundaries to obtain the demand OD matrices, in compatible form with the supply data to calibrate the EMME/2 travel demand model.

The POP growth forecasts are presented in Tables 6.4 to 6.8 in three scenarios: high (H), most expected (M), and low (L) and the corresponding household (DU) data. The DU forecasts (numbers and size) were introduced for the first time in BSQ (1990) and are presented herein for the period 1986-2001. The independent variable dwelling units (DU) had important significant relationship with DEM, as seen earlier in this chapter, in tables 6.2 and 6.3. The POP forecasting data are grouped by source and presented next.

3.2.1 POP Data from BSQ (1990)

Table 6.4 presents Quebec population and household data forecasts for scenario M ('scenario de reference R'), the scenario for the most expected population growth. They are based on the 1986 StatsCan census survey and are obtained from BSQ (1990) tables.

The province of Quebec data are presented to assess the population growth of MTL in its regional context, as presented in Table 6.5.

The three scenarios (L, M, H) for MTL are presented in Table 6.5 for the forecasting period 1986-2001. Scenario M data are obtained from scenario R and the PCT figures for scenarios L and H are obtained from scenarios E and D; the other figures were computed.

YEAR	Sc	POPULATION (POP) No.	N'L	M'Y	TOT	PCT	HOUSEHOLD* No.	PCT	SIZE
1986		6539					2361		2.77
1991	M	6785	189.6	56.1	245.7	3.76	2610	10.5	2.60
1996	M	6991	158.5	47.8	206.3	6.91	2819	19.4	2.48
2001	M	7141	101.5	48.9	150.4	9.21	2988	26.6	2.39

TABLE 6.4: PROVINCE of QUEBEC POP and DU FORECASTS.

Scenario M; 1986-2001.

Figures in 1000s. Legend in footnote #1[1]
* Household size obtained from BSQ (1990), No. and PCT computed.

Source: BSQ (1990) tables.

The 1986 population data base for all scenarios, except scenario R, are not compatible with StatsCan data. Their POP data were retrieved from FIB (fichiers de l'inscription des beneficiaires) of the RAMK (Regie de l'assurance de maladie du Quebec) and are considered by the BSQ to be more accurate. The research has adopted scenario R based on StatsCan data, and the other scenarios were computed using BSQ percentages.

(1) Legend for tables:

N'L	= estimated natural population growth (birth and death)
M'Y	= estimated migratory balance, regional, and provincial
Tot	= estimated total population growth balance per year
PCT	= percentage total growth relative to 1986
Sc	= scenario
L	= five years period: low growth rate
M	= " " " medium growth rate
H	= " " " high growth rate
P	= " " " pivot scenario ('scenario de reference')

YEAR	SC	MONTREAL Is. POPULATION					MONTREAL Is. (DU)*		
		POP	N'L	M'Y	TOT	PCT	No.	PCT	SIZE
1986		1753					722		2.43
1991	L	1770			17.0	0.97	770	6.65	2.30
	M	1778	30.2	-4.6	25.6	1.43	770	6.65	2.31
	H	1810			56.6	3.25	784	8.52	2.31
1996	L	1726			-27.5	-1.54	788	9.14	2.19
	M	1802	21.8	2.2	24.0	2.80	808	11.9	2.23
	H	1908			97.7	8.84	848	17.5	2.25
2001	L	1726			-27.5	-1.54	814	12.7	2.12
	M	1821	5.8	12.8	18.6	3.88	835	15.7	2.18
	H	1994			85.7	17.75	894	23.8	2.23

TABLE 6.5: MTL POP and DU FORECASTS.

Scenarios: L, M, H; 1986-2001.

Figures in 1000s. Legend in footnote #1.
* DU size obtained from BSQ (1990), their No. and PCT computed.

Source: BSQ (1990) tables.

The DU forecast rates in Table 6.5 are greater than the POP rates, due to DU down-sizing over time; consequently, the use of DU variable would increase demand at a faster rate. This is taken care of by the different coefficients in the models in Table 6.2.

A comparison between Tables 6.4 and 6.5, i.e. between Quebec province figures and Montreal Island figures, shows that:

1. MTL household size is below the provincial average and is expected to down-size at a slower rate.
2. MTL population growth is below the provincial level.
3. The population migratory (M'Y) balance is lower in MTL.

4. As a matter of fact, the migratory balance, is negative in MTL in the first five-year forecast period: reflecting clearly anglophone out migrations.

The household size trends are plotted (data from tables 6.4 and 6.5) in Fig. 6.1 and show clearly that the household size difference between MTL and the provincial average is expected to decrease over time.

3.2.2 POP Data from BSQ (1984)

Table 6.6 presents the POP forecast figures and their corresponding percent (PCT) growth for the GMA and MTL, obtained from BSQ (1984). POP figures were computed by proportions between 1986 StatsCan figures (StatsCan survey figures with '*', for the CMA spatial boundaries) and POP1 figures obtained from several tables from BSQ (1984). The POP1 data are forecast data; the POP data are computed from POP1 data.

The 1986 forecast data [BSQ, 1984] in Table 6.6 are overestimates when compared with the StatsCan survey and consequently all BSQ (1984) forecasts are factored down. The computations in Table 6.6 proceeds as follows:
e.g. PCT=100*(3736-3697)/3697=**1.05**; POP=1.05*2892=**2922.**

YEAR	Sc	GREATER MONTREAL			MONTREAL ISLAND		
		POP	POP1	PCT	POP	POP1	PCT
1986	L	2892*	3697		1753*	1705	
	M		3720			1704	
	H		3726			1709	
1991	L	2922	3736	1.05	1696	1650	-3.23
	M	2980	3833	3.04	1704	1656	-2.82
	H	3003	3869	3.84	1720	1677	-1.87
1996	L	2937	3755	1.57	1648	1603	-5.98
	M	3057	3932	5.70	1672	1625	-4.64
	H	3123	4023	7.97	1716	1673	-2.11
2001	L	2933	3749	1.41	1605	1561	-8.45
	M	3110	4001	7.55	1605	1560	-8.45
	H	3222	4151	11.41	1719	1676	-1.93

TABLE 6.6: GMA and MTL POP FORECASTS.

Scenarios L, M, H; 1986-2001.

POP1 from BSQ (1984) and POP computed from POP1.
Figures in 1000s. Footnote #1. * StatsCan figures.

Source: BSQ (1984) tables and StatsCan 1986 survey.

The results in Table 6.6 show that MTL POP projections are negative in all scenarios while the GMA projections are all positive i.e., the population is decentralizing from MTL, and population aging is an important component in the process. The GMA POP growth scenarios can not be obtained from MTL POP data by factors, because MTL population is declining while the GMA is not.

3.2.3 POP Data from Lamonde et al. (1989)

Due to the fact that neither BSQ (1984) nor BSQ (1990) has statistical data for the Montreal City Centre (SD1), such data had to be obtained from Lamonde et al. The City Centre, MTL, and GMA data are presented in Table 6.7.

YEAR	GREATER MONT.*		MONTREAL Is.*		CITY CENTRE*	
	POP	PCT	POP	PCT	POP	PCT
1971	2743		1959		1259	
1981	2836		1760		1006	
1986	2892**		1753**		982**	
1991	2954	2.14	1747	-0.34	958	-2.44
1996	3023	4.53	1742	-0.63	935	-4.79
2001	3099	7.16	1740	-0.74	913	-7.03

TABLE 6.7: GMA, MTL & CITY CENTRE; POP FORECASTS.

Scenario P; 1986-2001.

Figures in 1000s. Footnote #1. 1991-2001 are forecast figures.
* Lamonde et al. spatial boundaries.
** Base year for PCT computations.

Data source: Lamonde et al. (1989), Table 2.1

Table 6.7 presents the population growth pivot (P) scenario defined by extrapolating 1981-1986 statistics by Lamonde et al. (p.13). It is one of four scenarios relating to different levels of POP growth projections.

Furthermore, this POP scenario P has its POP data equivalence of EMP and thus, it serves as a pivot in comparing POP and EMP results as presented later on.

It is of interest to note that the Montreal City Centre, in Table 6.7, has lost 12% of its population between 1971 and 1986; this trend is slowed down in the forecast to 4.4% for the period 1986-2001 and its share of the metropolitan population has dropped from 33.9% to 29.5% [Lamonde et al. p.12].

Furthermore, the two districts in MTL located south-west of the City Centre: Lachine and Lasalle, have similar growth trends as the City Centre. These districts were spatially incorporated in the City Centre (SD1) boundaries in this research as defined in Chapter 3. The balance of POP control total is achieved by gains in the other MTL districts [Lamonde et al. p.12] i.e., in SD2 and SD3.

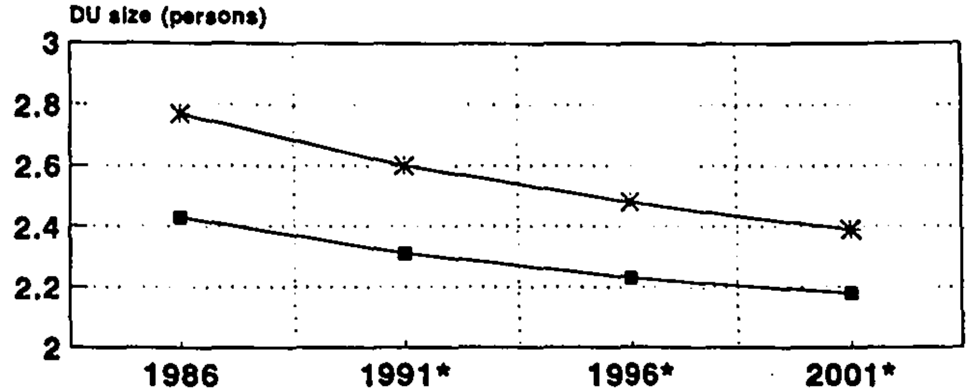
The trend lines for POP pivot scenario, in Table 6.7, are plotted in Fig. 6.2 and show that both SD1 and MTL are expected to lose population over time at decreasing rates while the GMA POP is growing.

3.2.4 POP data summary

A comparison between BSQ (1984) and BSQ (1990) scenarios shows an optimistic forecasting trend over time for MTL; while the forecasts of Lamonde et al. in Table 6.7 are based on BSQ (1984) pessimistic scenarios but optimistically revised. This is a middle ground forecast.

HOUSEHOLD SIZE TRENDS

Montreal Is and Quebec Province



	1986	1991*	1996*	2001*
PQ	2.77	2.6	2.48	2.39
MTL	2.43	2.31	2.23	2.18

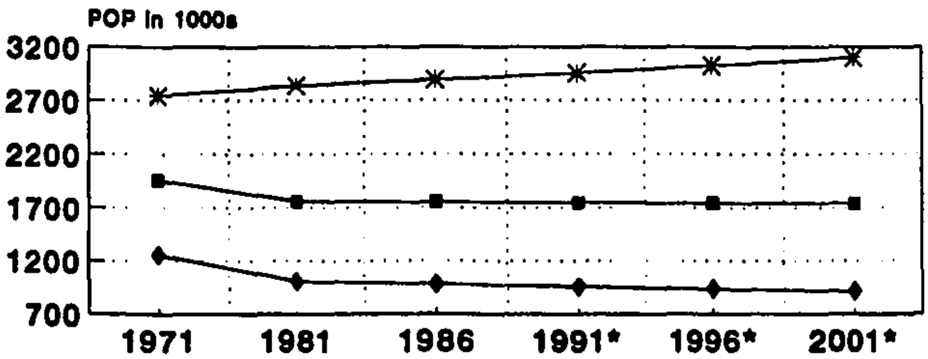
YEARS

PQ   MTL

Fig. 6.1: DU trends; MTL and PQ

POPULATION DATA and TRENDS

Pivot Scenario (P)



	1971	1981	1986	1991*	1996*	2001*
GMA	2743	2836	2892	2954	3023	3099
MTL	1959	1760	1753	1747	1742	1740
SD1	1259	1006	982	958	935	913

YEARS

GMA   MTL   SD1

Fig. 6.2: POP trends; GMA, MTL, SD1

* Forecast years

There are boundary differences between the boundaries of this research, based on 1986 Census Tracts, and the three POP data sources which are based on 1971 Census Tracts. Thus the percentage of population growth represent for the research, area growth trends i.e., uniform POP densities are assumed at spatial boundaries.

A comparison between MTL population growth forecast figures in Tables 6.4, 6.5, and 6.7 shows that:

1. The forecasts are different in the three tables.
2. The City Centre forecasts are only available in Table 6.7.
3. BSQ forecasts have become more optimistic over time.
4. Lamonde et al. forecast PCT growth figures are in between those of the BSQ (1984) and BSQ (1990) figures.

The GMA population in this research is in conformity with STCUM boundaries, and was 2720143 persons in 1986 (2.72E6 in Table 6.1) and thus all GMA data shall be scaled down proportionally. Furthermore, the population of SD1 (research boundaries) in 1986 was 797641 persons (Table 6.1) and SD1 data should also be scaled down proportionally.

The above points lead to the adoption of the population growth scenarios which are presented in Table 6.8. Several computation procedures and assumptions were used to obtain the figures in Table 6.8 and these are defined below:

1. Forecasts in Table 6.7 are chosen as scenario (P) for data compatibility reasons between POP and EMP scenarios; POP1 GMA figures are obtained from Table 6.7 scaled down by the proportion 2720/2892.

2. The POP1 figures of GMA, for scenarios [H, M, and L], are computed from Table 6.6 also by the proportion 2720/2892.

3. The POP2 figures for SD1, for scenario (P), are computed by the proportion 798/982 from Table 6.7.

4. The POP2 figures for SD1, for scenarios [H, M, and L], are computed by proportions from MTL scenarios [H, M, and L] in Table 6.6. The proportions are obtained from scenario (P) for SD1 and MTL: (a) 1991, 778/1747; (b) 1996, 760/1742; and (c) 2001 742/1740.

5. The POP3 figures for SD1, for scenarios [H, M, and L], are computed by proportions from MTL scenarios [H, M, and L] in Table 6.5 per forecast. The proportions are obtained from scenario (P) between SD1 and MTL: (a) 1991, 778/1747; (b) 1996, 760/1742; and (c) 2001 742/1740.

6. DU figures are computed by assuming a constant household size all over the GMA per scenario at the appropriate point in time. Furthermore, the (P) and (M) scenarios have assumed the same DU size.

7. POP1 and POP2 figures were obtained using BSQ (1984) forecasts, while POP3 figures were obtained from BSQ (1990) forecasts.

YEAR	Sc	GREATER MONTREAL AREA			CITY CENTRE (SD1)			
		POP1*	DU_SIZE**	DU#1*	POP2*	POP3*	DU#2*	DU#3*
1986		2720			798	798		
1991	L	2749	2.30	1195	755	788	328	343
	M	2812	2.31	1217	759	792	329	343
	H	2824	2.31	1223	766	806	332	349
	P	2778	2.31	1203	778		337	
1996	L	2762	2.19	1261	719	753	328	344
	M	2875	2.23	1289	729	786	314	356
	H	2937	2.25	1305	749	832	329	381
	P	2843	2.23	1275	760		341	
2001	L	2759	2.12	1301	685	736	323	347
	M	2925	2.18	1342	684	777	314	356
	H	3030	2.23	1359	733	850	329	381
	P	2915	2.18	1337	742		340	

TABLE 6.8: GMA and SD1; POP and DU FORECASTS.

Scenarios L, M, H; 1986-2001.

NB:
Figures in 1000s and persons per DU.
POP1 and POP2 figures from BSQ (1984); POP3 figures from BSQ (1990).
* POP and DU figures as per research boundaries.
** Persons per DU.

Data source: Tables 6.5, 6.6, and 6.7.

The POP forecasts for SD1 data in Table 6.8, show a large difference between POP2 and POP3 figures, reflecting BSQ growing optimism as mentioned earlier. The corresponding GMA POP3 figures, are not published and may not be extrapolated from MTL figures.

The DU data in Table 6.8, are less reliable than the POP data; consequently, their use should be carefully considered. This is due to the many assumptions used, like a constant household size throughout the GMA.

The population aging phenomena is in progress in the GMA and MTL in general and more so in SD1. This was discussed in Chapter 3, [Bussiere, 1989] and [BSQ, 1990].

The level of patronization of public transit systems varies by age and gender. The increase of females in the working force has a tendency to increase the patronization of public transport modes while an aging population tend to favour other modes. Lamonde et al. (p.61) rightly concluded that aging, null growth, and spatial population decentralization have an adverse effect on the use of public transport.

Furthermore, Lamonde et al. (p.65) asserts that mobility during the morning peak traffic becomes less critical for the older population as their trip purpose is other (shopping and recreational) than work and education which are the main components of the morning congestion.

It was demonstrated in Chapter 3, that the overall impact of all surface public transit on road network traffic was in the order of 3% which were the EPC trips for the surface transit mode used in Chapter 4. Thus the impact of aging and gender variations on road network congestion are marginal in this research and will tend to decongest traffic.

3.3 Employment and Data Compatibility

The Impact of employment decentralization on metropolitan road networks is assessed using EMP forecasting scenarios for the City Centre and by the application of the SDLM Base and Sub-model. This is achieved by comparing the different scenarios to the pivot scenario figures for EMP.

The EMP data are obtained from Chapter 3 and the work of Lamonde et al.; EMP by industry is categorized into manufacturing and service and each of these is segregated into several EMP sub-groups. EMP by occupation forecast data are not available.

3.3.1 Manufacturing EMP

Three manufacturing EMP scenarios were considered by Lamonde et al. (p.16), relating to 3 alternative methods of developing forecasts: scenario (a), periodic average temporal extrapolation of EMP figures from 1971-81 and 1981-86 periods; scenario (b), yearly average temporal extrapolation of EMP figures between 1971 and 1986 years; and scenario (c), regional economic trends in Quebec and the proportional share of its sub-regions.
The scenario (c) approach was established by BSQ. It implements EMP forecasts based on economic trends and was

retained as the 'scenario de reference' by Lamonde et al. i.e., the pivot scenario. It takes into consideration, among other factors, the population aging effect on economic growth.

AREA	Sc	1986	1991	1996	2001	PCT VARIATION 86-91	91-96	96-01
CEN.*	a	116	100	86	75	-3.0	-2.9	-2.8
	b	116	101	89	78	-2.7	-2.6	-2.5
	c	116	96	82	68	-3.8	-3.2	-3.7
MTL	a	223	216	211	208	-0.6	-0.5	-0.3
	b	223	220	220	222	-0.2	0.0	0.1
	c	223	209	203	192	-1.3	-0.5	-1.1
GMA*	a	282	279	279	279	-0.2	-0.1	0.1
	b	282	286	292	300	0.3	0.4	0.5
	c	282	271	269	259	-0.8	-0.1	-0.7

TABLE 6.9: MANUFACTURING EMP FORECASTS.

1986-2001. Scenarios a, b, c; 1986-2001.

NB:
Figures in 1000s and percent.
1991-2001 are forecast data.
* City Centre and GMA boundaries as per Lamonde et al.

Source: Lamonde et al. (1989), Table 2.3.

Table 6.9 presents the three manufacturing EMP scenarios for the case study. The results in Table 6.9 show a high 5-year periodical sequential decentralization of manufacturing EMP in the City Centre of -3.8%, -3.2%, and -3.7% between 1986 and 2001 in scenario (c) while the figures for MTL are lower i.e., there is a lower rate of decrease for the manufacturing EMP in Montreal Island, less decentralization in MTL than in SD1.

Around 65% of EMP decentralization in the City Centre between 1986 and 2001 are re-locating in other MTL districts [Lamonde et al, p.21]. This shows that the outbound emigration of EMP from MTL is expected to be of minor importance.

The research has also adopted scenario (c) and presented its general statistics in Chapter 3, tables 3.13 and 3.14. Results in Chapter 3 are partially re-presented and are augmented by data from Lamonde et al. tables 4.3 to 4.5. This establishes the EMP scenarios.

3.3.2 Service EMP

The service EMP in the City Centre is thriving on the structure of the evaporating manufacturing EMP. There is a transformation of the manufacturing sector into an active sector of services. This is a common phenomenon in metropolitan areas of industrialized countries in general and in North American metropolises in particular. This was presented in Chapter 2.

The forecasting data for service EMP by industry are also obtained from Lamonde et al. The same approach is applied as for manufacturing EMP and the 'scenario de reference' is adopted. Other scenarios were hard to develop due to 'la plus grande pauvrete des statistiques' Lamonde et al. (p.24) i.e., not enough data were available.

Table 6.10 presents service EMP by industry for the period 1971-86 and for the period 1986-2001. EMP are categorized into three groups: consumption (CONSP) services, production (PRODN) services, and public (PUBLC) services.

YEAR	1971	1981	1986	1991	1996	2001	71-81	81-86	86-91	91-96	96-01
CONSP	227	360	422	483	511	526	4.7	3.2	2.7	1.1	0.6
PRODN	184	277	285	309	317	322	4.2	0.6	1.6	0.6	0.3
PUBLC	174	262	282	308	337	367	4.2	1.5	1.8	1.8	1.7
TOTAL	585	899	989	1099	1165	1215	4.4	1.9	2.1	1.2	0.8

TABLE 6.10: GMA SERVICE EMP FORECASTS by INDUSTRY.

Reference scenario. Consumption, production, and public. 1971-2001.

Figures in 1000s and percent for time periods.
1991-2001 figures are forecast data.
GMA boundaries as per Lamonde et al.

Source: Lamonde et al. (1989), Table 2.5.

Table 6.11 presents service EMP for the period 1971-86 and forecasting for the period 1986-01; for the City Centre (CEN.), MTL and GMA.

YEAR	1971	1981	1986	1991	1996	2001	71-81	81-86	86-91	91-96	96-01
CEN.*	385	445	465	488	491	486	1.5	0.9	1.0	0.1	-0.2
MTL	499	653	706	770	801	819	2.7	1.6	1.7	0.8	0.4
GMA*	585	899	989	1099	1165	1215	4.4	1.9	2.1	1.2	0.8

TABLE 6.11: CITY CENTRE, MTL, GMA; SERVICE EMP FORECASTS.

Reference scenario; 1971-2001.

NB:
Figures in 1000s and percent for time periods. 1991-2001 figures are forecast data. * City Centre and GMA boundaries as per Lamonde et al.

Data source: Lamonde et al., Table 2.7.

A comparison between Tables 6.10 and 6.11 shows that although all service EMP categories in Table 6.11 have increased over time, the City Centre forecast shows a net decrease between 1991 and 2001.

The overall service EMP trend in the GMA in the three categories in Table 6.10, are positive over time. Thus, the EMP in the City Centre is decentralizing over time in both EMP categories; manufacturing and services.

Forecasts for service EMP were developed by Lamonde et al. in two parts: (a) 'Part constante' or normal growth; and (b) 'etalement' or dispersion (Decentralization) effect. These two scenarios provide the time variations of EMP for the impact analyses and are presented in Table 6.12.

AREA	Sc	1986	1991	1996	2001
CEN.*	a	465	503	522	534
	b	465	488	491	486
MTL	a	706	778	819	848
	b	706	770	801	819
GMA*		989	1099	1165	1215

TABLE 6.12: SERVICE EMP SCENARIOS.

EMP growth (a), EMP decentralization (b).

Figures in 1000s.
* City Centre and GMA boundaries as per Lamonde et al.

Data source: Lamonde et al., Table 2.9.

The GMA figures in both scenarios have one control total in Table 6.12 (i.e., one GMA forecast figure) in order to permit the assessment of the impact of EMP decentralization forecasts on traffic congestion in metropolitan areas.

3.3.3 EMP totals

Table 6.13 presents the EMP variations by industry for the GMA, MTL, and City Centre for the period 1971-86 and forecasts for the period 1986-2001.

The forecasting figures are based on the hypothesis of constant zonal share i.e., normal cross-sectional population dispersion is considered in addition to manufacturing EMP decentralization [Lamonde et al, p.86]. This is the low decentralization scenario L i.e, higher EMP in SD1.

Incorporating the service EMP decentralization effect from scenario (b) in Table 6.12, the upper bound control total for EMP decentralization is obtained and re-named scenario (H) i.e, high EMP decentralization or lower EMP figures in SD1. The results are summarized for both service and manufacturing industries in Table 6.13.
The EMP data and forecast scenarios by industry in Table 6.13 need to have their boundaries translated into boundaries for this research.

YEAR	Sc	GREATER MONTREAL*			MONTREAL ISLAND			CITY CENTRE*		
		M	S	T	M	S	T	M	S	T
1971		284	585	869	248	499	747	185	385	570
1981		305	899	1205	247	653	899	139	445	584
1986		282	989	1271	223	706	929	116	465	581
1991	L	271	1099	1370	209	778	987	96	503	599
	H	271	1099	1370	209	770	979	96	488	584
1996	L	269	1165	1434	203	819	1022	82	522	603
	H	269	1165	1434	203	801	1004	82	491	573
2001	L	259	1215	1474	192	848	1040	68	534	601
	H	259	1215	1474	192	819	1011	68	486	554

TABLE 6.13: EMP FORECASTS by INDUSTRY.

High (H) & Low (L) decentralization scenarios; 1971-2001.

Figures in 1000s. Footnote #2[2].
* City Centre and GMA boundaries as per Lamonde et al.
Data sources: Lamonde et al., Table 4.3; and research Table 6.12.

Figure 6.3 presents the EMP trends in the three regions of SD1, MTL, and GMA obtained using data from Table 6.13 (data still needs to be translated into research boundaries). It presents the decentralization scenarios (H and L); it is of interest to note the highest decentralization rate of SD1 and the control total of EMP in GMA. Certainly, the higher the decentralization, the lower the EMP figures.

Figure 6.4 presents the EMP trends by industry also, for the 3 spatial aggregations, and using data from Table 6.13. It is evident that the manufacturing industry is disappearing from the GMA and its divisions, while the service industry is thriving in them at different rates and EMP is almost constant over time in SD1.

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(2) Legend for tables:
M = manufacturing industry EMP
S = service industry EMP
T = total industry EMP
NB: City Centre boundaries are different from SD1 boundaries.

EMPLOYMENT SCENARIOS
City Centre, Montreal, Greater Montreal

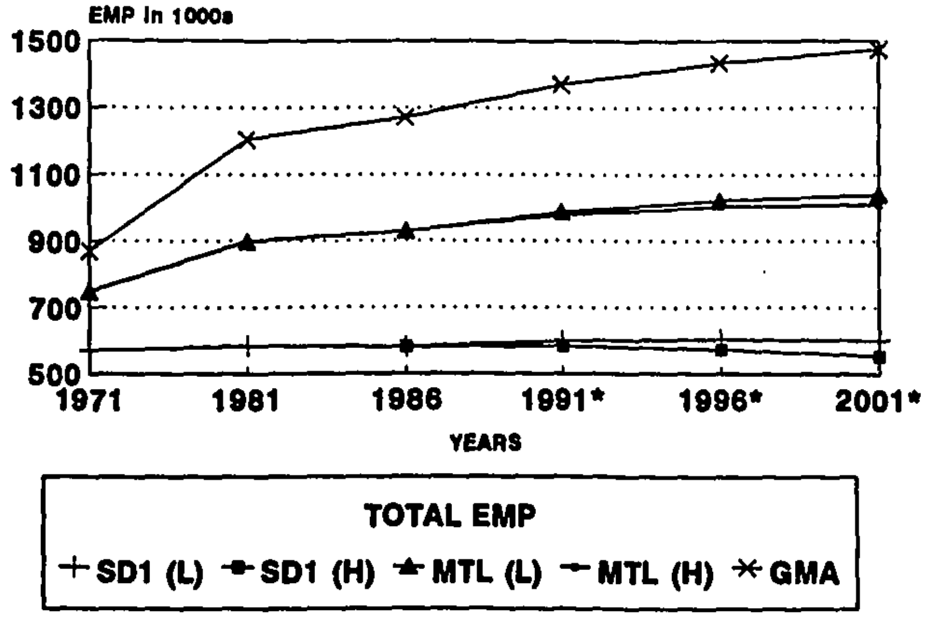

Fig. 6.3: EMP trends; GMA, MTL, SD1
* Forecast years; L & H EMP scenarios

EMPLOYMENT SCENARIOS by INDUSTRY
High Decentralization; GMA, MTL, SD1

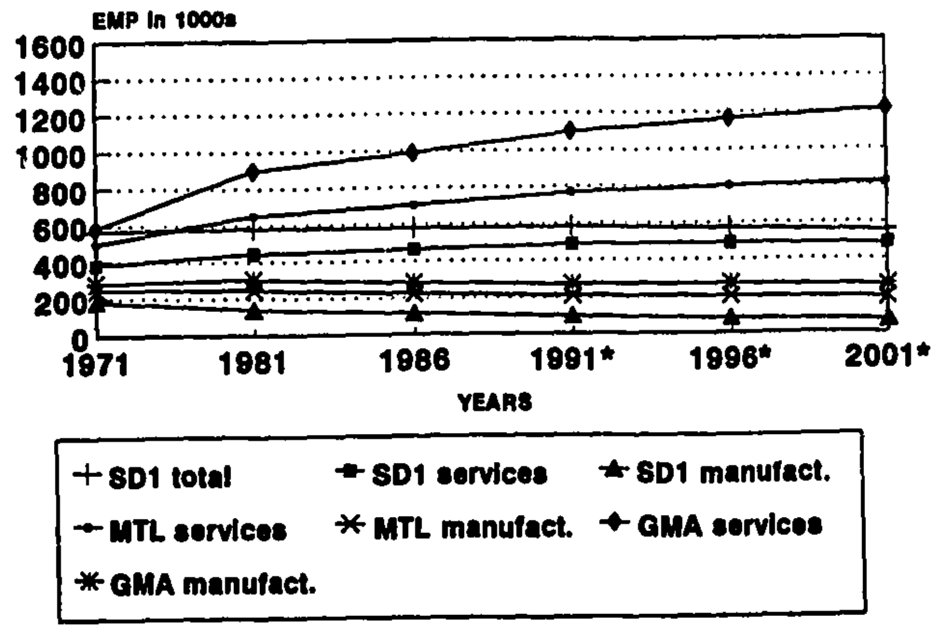

Fig. 6.4: EMP trends; GMA, MTL, SD1
* Forecast years; H scenario

Although the research EMP and POP densities in Montreal City Centre in particular and in the GMA in general, may have minor differences at their spatial boundaries than those defined by [Lamonde et al], yet they are assumed to be compatible. Thus, the research EMP data forecasts by industry for SD1 and GMA are computed by proportions from their counterparts [Lamonde et al.] in Table 6.13 and the results are presented in Table 6.14.

The data in Table 6.14 show that the temporal variations of total EMP in SD1, scenario (H), are marginal during the period 1986-96 i.e., a 0.64% decrease is expected while a more important decentralization of 4.66% is expected for the period 1986-2001.

YEAR	Sc	GREATER MONTREAL AREA			CITY CENTRE (SD1)		
		M	S	T	M	S	T
1986		265	930	1195	94	378	472
1991	L	255	1034	1289	78	409	487
	H	255	1034	1289	78	398	475
1996	L	253	1096	1349	67	424	490
	H	253	1096	1349	67	399	466
2001	L	244	1143	1386	55	434	488
	H	244	1143	1386	55	395	450

TABLE 6.14: SD1 and GMA EMP FORECASTS by INDUSTRY.

Scenarios L, H; 1986-2001.

Research boundary limits. Figures in 1000s. Footnote #2.

Source: Tables 6.12, 6.13.

Scenario L forecasts for SD1 show minor total EMP increase over time of 3.81% for 1986-1996 period and a lesser growth of 3.39% for 1986-2001 period i.e., a net decentralization of 0.41% between 1996 and 2001. The manufacturing EMP forecasts are expected to decentralize constantly in SD1 at the rate of 28.72% for 1986-96 period; and at the rate of 41.49% for 1986-01 period.

Furthermore, as presented in Table 6.14, the GMA manufacturing EMP is forecast to decrease by 4.53% (ten year period) by 1996 and by 7.92 % by 2001 i.e., a decrease rate of 3.39% for the period 1996-2001.

The GMA service EMP are forecast to increase by 17.85% by 1996 and 22.90% by 2001 i.e., the rate of increase tapers off in the period 1996-2001. The forecasts were made during the 1988-1989 period and had assumed an early economic recovery which did not materialize.

The above decrease of EMP in Montreal City Centre explains partly its relatively low temporal congestion level variations as compared to similar metropolises in North America. It was shown in Chapter 3 that the work trips represent around 70% of all morning peak hour trips and they mostly use the auto mode of transport, thus EMP decrease reduces the peak hour trips considerably.

Therefore, there is a transformation and a decentralization process in progress and it continues into the future. The manufacturing industry is not only diminishing in the City Centre (SD1) but in the GMA as whole. The service industry is increasing at a faster rate in the GMA, due to its decentralization from the City Centre which is compensating for the lost manufacturing jobs. Thus, the total EMP growth over time for the GMA is positive.

3.4 Synthesis of Scenarios

In this sub-section, a synthesis of scenarios is produced prior to impact analysis in Section 5. The POP and EMP variables and their control totals are presented separately.

3.4.1 POP scenarios

The POP scenarios, presented earlier, have different control totals i.e., different spatial boundaries, depending on the forecasting source. The research is set to establish a range for the most likely POP growth i.e., generally speaking POP growth upper and lower bound forecasts.

It was seen in Table 6.8 that scenario (P) forecasts greater growth rates than scenario (M) of [BSQ, 1984] but less than that of [BSQ, 1990]. Thus, scenarios (P) and (M) are kept.

A comparison between POP2 and POP3 forecast figures in SD1, in Table 6.8, show that the upper bound for POP growth are obtained from [BSQ, 1990] and the lower bound are obtained from [BSQ, 1984] which would represent the minimum and maximum expected POP growth range. These are presented in Table 6.15.

The compatible GMA and SD1 POP forecast scenarios were obtained as follows:

1. Scenarios [L, M, H, and P] in Table 6.8 are kept unchanged since they are compatible.

2. The next two steps are done to obtain GMA and SD1 figures for [BSQ, 1990] from their equivalent [BSQ, 1984] figures; because the BSQ has stopped providing forecast statistics for the GMA.

a. The upper bound POP scenario (UB) for the GMA is computed by proportions from Tables 6.5, 6.7 and 6.8 using MTL data as a pivot: (1908/1742)*2843 and (1994/1740)*2915.

b. The corresponding SD1 figures are obtained by proportions from Tables 6.5, 6.7, 6.8: (1908/1742)*832 and (1994/1740)*850.

Scenario UB data transformation assumes that MTL and the GMA have proportional growth rates. It was seen earlier in this chapter that they have different POP growth rates and there are strong out migration forces in MTL [BSQ, 1984] thus, scenario UB should be cautiously used.

YEAR	Sc	DU_SIZE	GREATER MONTREAL		CITY CENTRE (SD1)	
			POP	DU	POP	DU
1996	L	2.19	2762	1261	719	344
	M	2.23	2875	1289	729	352
	H	2.25	2937	1305	749	370
	P	2.23	2843	1275	760	341
	UB	2.25	3114	1384	911	405
2001	L	2.12	2759	1301	685	347
	M	2.18	2925	1342	684	356
	H	2.23	3030	1359	733	381
	P	2.18	2915	1337	742	340
	UB	2.23	3341	1498	974	437

TABLE 6.15: POP and DU FORECASTS for GMA and SD1.

Scenarios L,M,H,P,UB for 1996 and 2001.

Figures in 1000s. Research boundaries.
Scenarios [L, M, and H] from [BSQ, 1984].
Scenario (P) from [Lamonde et al].
Scenario (UB) from [BSQ, 1990].

Source: Table 6.8.

Table 6.15 presents scenarios [L, M, H, P, and UB] for SD1 and GMA for the forecasting years 1996 and 2001. The household size in scenario H was adopted in scenario UB. The POP scenarios shall be translated into their equivalent DEM figures, in Section 4, to be used in the SDLM models.

3.4.2 EMP scenarios

The EMP scenarios have as a main purpose the assessment of the impact of EMP decentralization (in the City Centre) on road networks. The EMP forecasting range was presented in Table 6.14. The POP scenario P and its equivalent EMP data are obtained from [Lamonde et al] by scrutinizing their Tables 2.1, 4.1, 4.3, and 4.5.

The EMP scenario H is equivalent to the POP scenario P as far as DEM is concerned i.e., they have compatible spatial distributions of EMP and POP. Consequently, scenario H is a copy of scenario P which is also kept. They represent the most expected total EMP growth with and without decentralization of the service EMP sector.

YEAR	Sc	GREATER MONTREAL AREA			CITY CENTRE (SD1)		
		M	S	T	M	S	T
1986*		265	930	1195	94	378	472
1996	L	253	1096	1349	67	424	490
	H	253	1096	1349	67	399	466
	P	253	1096	1349	67	399	466
2001	L	244	1143	1386	55	434	488
	H	244	1143	1386	55	395	450
	P	244	1143	1386	55	395	450

TABLE 6.16: EMP FORECASTS by INDUSTRY; GMA and SD1.

Scenarios L, H, P; 1986-2001.

Figures in 1000s. Research boundary limits.
* Statistical figures. Footnote #2.

Source: Table 6.13.

The manufacturing EMP dispersion component is included in the three scenarios [L, H, P] in Table 6.16. These scenarios shall be translated into their equivalent DEM scenarios in Section 4, to be used in the impact analyses.

It is of interest to note that, at the sketch planning level, there is a marginal difference in DEM due to modal split variations between manufacturing and service EMP. A larger variation, would be expected in EMP aggregations by occupation, like professional and blue collar workers. These topics were discussed in chapter 3.

POP and EMP scenarios data from tables 6.15 and 6.16 are plotted in figures 6.5 and 6.6 for SD1 and GMA. As presented earlier, the GMA has one control total for EMP to differentiate the effect of EMP decentralization from EMP variations related to spatial variations.

POP in the City Centre is decentralizing in all scenarios as seen in Fig.6.5 while EMP, scenario L, show stabilized EMP levels; this is an EMP level excluding decentralization effects. Scenario H or the expected decentralization of EMP, is in line with the POP scenarios.

All POP forecasts are positive in the GMA. scenario P (pivot from Lamonde et al.) is trailing scenario M (BSQ, 1984) in Fig. 6.6.

POP and EMP SCENARIOS
City Centre

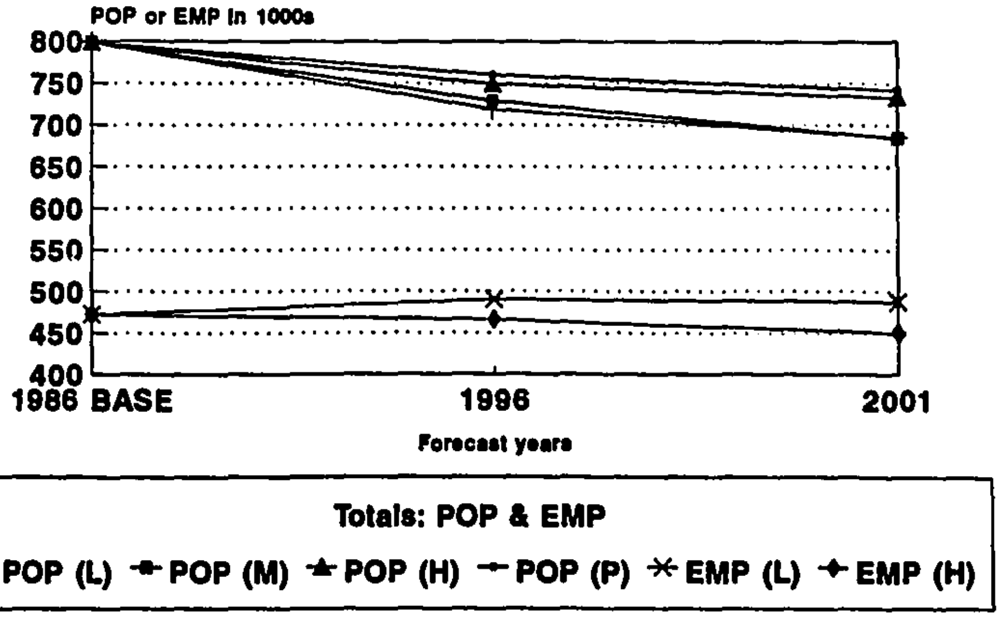

Fig. 6.5: SD1; POP & EMP SCENARIOS
L, M, H, P scenarios

POP SCENARIOS
Greater Montreal Area

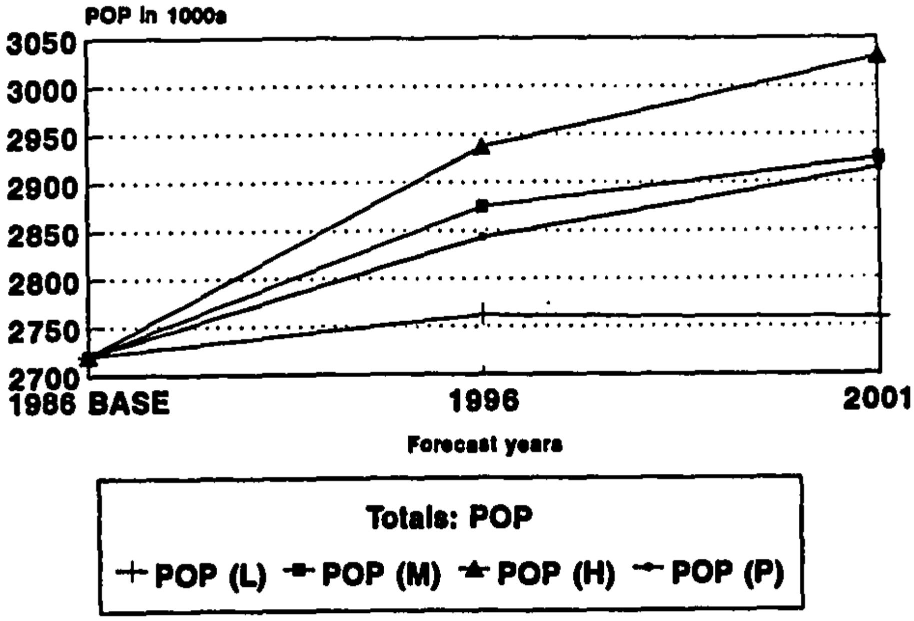

Fig. 6.6: GMA; POP SCENARIOS
L, M, H, P scenarios

4. FORECASTING DEM SCENARIOS

The POP and EMP scenarios are translated into equivalent DEM scenarios in this section. This is achieved in two parts; data translation procedures and scenario translations or transformations.

4.1 Data Translation Procedures

Two procedures are presented next, to translate; (1) POP and (2) EMP data, into their equivalent DEM data.

4.1.1 DEM from POP, trip generation data

The POP and DU data were found to have, in the multivariate analysis in Section 2, the biggest explanatory powers on the dependent variable DEM. This is interpreted as follows:

1. POP has 87.99% explanatory powers on DEM at 95% confidence level.
2. DU has 92.64% explanatory powers on DEM at 95% confidence level.
3. The multivariate analyses results in Table 6.3 showed that although all five independent variables entered the stepwise regression analyses, the DU was the only variable retained.
4. The DU variable forecast scenarios are less reliable than

those of the POP variable as seen in the commentary on Table 6.8.

It may be concluded that DEM, the dependent variable in forecasting, may be computed using Eq. 6.1 below which was obtained from the multivariate analyses in Table 6.2.

$$DEM = 14465 + 0.138244 * POP \qquad \text{Eq. } 6.1$$

Where, DEM is the morning peak hour EPC (equivalent passenger car) trips per super district; and POP is the total population per super district.

4.1.2 DEM from EMP, trip attraction data

Two possible procedures for the EMP data translation into their equivalent DEM are presented:

1. To convert EMP into work trips; total trips; or peak hour trips and then into DEM.
2. To convert EMP into DEM by proportions using the pivot scenario.

Procedure (2) is more direct and reduces data translation computations and potential inaccuracies yet it has to be justified first. Consequently, procedure (1) is pursued to establish the linear relationship between EMP and DEM first, and then procedure (2) is used.

Procedure (1).

The independent variable EMP, in forecasting scenarios, represent the total employment attractions per analyzed area This does not account for absenteeism, sick leaves, vacations, unemployment and the like. These are taken care of in the 'no-trip done the previous day' code in the STCUM survey.

RTAC [1988, p.9] provides the following statistics to translate home-to-work linkages into production and attraction trips:

1. 7% to 8% of ELF report sick.
2. 5% to 15% of ELF do not report to work.

Three factors, relating EMP to attractions (At), are available as default figures in sequential models (like TMODEL/2 and QRS II), may be combined theoretically into one equation to translate EMP into equivalent At (then use At to compute DEM from Eq. 6.3), are presented in Eq. 6.2:

$$\mathbf{At = A * B * C * EMP} \qquad \textbf{Eq. 6.2}$$

The factors in Eq. 6.2 are presented hereunder:

1. Translate EMP into daily home based work trip attractions

to account for employment absenteeism and the like. This is factor (A), which may be obtained from [RTAC, 1988, p.9].

2. Translate daily trip attractions into their equivalent 7-8 AM peak hour figures, using factors from Chapter 3, Part C. This is factor B.

3. Translate 7-8 AM work trip attractions into 7-8 AM total trip attractions, using factored data from Chapter 3, Part C. This is factor C.

4. Factors [A, B, and C] may also be obtained from the NCHRP Special Report #187.

Equation 6.2 has assumed constancy over time of the relationships between EMP, attractions, peak hour to daily trip ratios, etc... This is possible only for short range forecasting periods and preferably for one factor at a time. As a matter of fact, modelling procedures are needed to obtain each of these factors [RTAC 1989, p13-20]. This is beyond the scope of this research.

To relate variables At and DEM, the multivariate analyses results in Table 6.2 are used. The independent variable At has 94.16% explanatory powers on the dependent variable DEM at 95% confidence level and the model is expressed by Eq. 6.3 below:

$$\mathbf{DEM = 29213 + 0.963832 * At} \qquad \textbf{Eq. 6.3}$$

Where, DEM and At are the morning peak hour EPC trips in any super district. The many factors involved in equations 6.2 and 6.3 would lead to erroneous results due to the cumulation of assumptions that are hard to interpret without independent data control.

Procedure (2).

Procedure (1) shows linear relationships between EMP and At in Eq. 6.2 and also between At and DEM in Eq. 6.3. Consequently, a linear relationship is expected (RTAC 1989) between EMP and DEM and the use of procedure (2) in sketch planning is justifiable.

4.2 POP and EMP Scenario Translations into DEM

The POP and EMP scenarios, for the GMA and SD1, are summarized and their data projected proportionally over the other GMA five super districts first, and then translated into equivalent DEM data.

Data projections from SD1 and GMA onto SD2 to SD6 are computed by simple proportions i.e., the differential data are assumed constant in the other SDs (other than SD1) and their distribution is unchanged from base year distributions.

Only the variations in DEM (POP or EMP), between base year data and a given scenario, are used in the SDLM models; e.g., a given scenario estimates a uniform constant rate of growth of 5% from base year figures for all SDs, except for SD1 where the rate is 4% i.e., a decentralization of 1%.

The SDLM Sub-model is used to assess the decentralization effect of 1%; and the SDLM Base model is used for the growth rate of 5%. Then the results from both SDLM models are added algebraically (super-imposed) as presented in the simple example in Chapter 5. This serves the research purpose of isolating the impact of EMP decentralization.

4.2.1 POP scenarios

The POP scenarios, in Table 6.15, are translated into SD data. The POP data difference between the GMA and SD1 is distributed to other super districts (SD2 to SD6) in proportion to their 1986 base year population difference and are presented in column R5 in Table 6.17.
This implies that the cross-sectional analyses results for the base year hold over short forecasting periods of 10 to 15 years as discussed at length in chapters 3 and 5 i.e., the assumption of constancy, for short forecast periods, among variable's relationships.

In addition, the above is further justified, since DEM data were computed using Eq. 6.1 which establishes linear relationship between DEM and POP. Furthermore, the SD data distribution is not used directly in the SDLM models, as shall be seen in Section 5 and are presented for the sake of table completion.

YEAR	Sc	GMA*	SD1*	R5	SD2	SD3	SD4	SD5	SD6
1986*		2720	798		273	682	284	283	400
1996	L	2762	719	1.0630	290	725	302	301	425
	M	2875	729	1.1165	305	761	317	316	447
	H	2937	749	1.1384	311	776	323	322	455
	UB	3114	911	1.1462	313	782	326	324	458
	P	2843	760	1.0838	296	739	308	307	433
2001	L	2759	685	1.0791	295	736	306	305	432
	M	2925	684	1.1660	318	795	331	330	466
	H	3030	733	1.1951	326	815	339	338	478
	UB	3341	974	1.2315	336	840	350	349	493
	P	2915	742	1.1306	309	771	321	320	452

TABLE 6.17: GMA and SD1 POP FORECASTS by SD.

Scenarios for 1996 and 2001.

Figures in 1000s. * Statistical figures.

Source: Tables 6.15 and 6.1.

The ratios R5 in Table 6.17 represent the DEM variation in each scenario as compared with 1986 base DEM for the GMA excluding SD1 i.e., for SD2 to SD6. A DEM increase is forecast for 1996 varying from 6.30% to 14.62% (sc. UB). The figures for the year 2001 are: 7.91% and 23.15%.

The variations in scenario (UB) for the GMA are 14.49% for 1996, and 22.83% for 2001; they exceed the mobility upper bound limit of 20%. Although scenario (UB) forecast for 1996 is within the DEM range, its DEM exceeds 20% in the year 2001. Furthermore, the extrapolation process used to compute scenario (UB) was not recommended, due to the multiple assumptions, as discussed earlier. Consequently, scenario (UB) will be considered no more.

It is of further interest to note that in developing the optimistic (UB) scenario, [BSQ, 1990] assumed an economic recovery in Quebec at the time of publication which has not materialized to date. This also renders the POP scenario (UB) non achievable.

The POP scenarios presented above in Table 6.17, should have their data translated into DEM data equivalents. Two approaches are possible to use; Eq. 6.1 and ratios based on Eq. 6.1, as obtained from Table 6.17.

The results are presented in Table 6.18 using POP growth ratios and subdividing the table into three parts: (a) column Roth, growth ratio for all SDs except SD1; (b) SDoth, sum of all SDs except SD1, from Table 6.17; (c) column R1, SD1 growth ratios; and (d) column Rg, GMA growth ratios.

The ratios R1 in Table 6.18 show decentralization forecasts for the City Centre in all POP scenarios (R1 < 1), thus the decentralization process in SD1 is not limited to EMP but it includes POP decentralization where POP aging is an important component.

The GMA population as a whole is also expected to grow in absolute figures (Rg > 1). This outweighs the POP loss in the City Centre.

YEAR	Sc	GMA	Rg	SD1	R1	SDoth	Roth
1986*		462.8	1.0000	131.1	1.0000	331.7	1.0000
1996	L	469.9	1.0154	118.1	0.9010	352.6	1.0630
	M	489.2	1.0570	119.8	0.9135	370.4	1.1165
	H	499.7	1.0798	123.0	0.9386	377.6	1.1384
	P	483.7	1.0452	124.9	0.9524	359.5	1.0838
2001	L	469.4	1.0143	112.5	0.8584	357.9	1.0791
	M	497.7	1.0754	112.4	0.8571	386.8	1.1660
	H	515.5	1.1140	120.4	0.9185	396.4	1.1951
	P	496.0	1.0717	121.9	0.9298	375.0	1.1306

TABLE 6.18: GMA and SD1, POP DEM FORECASTS RATIOS.

Scenarios for 1996 and 2001.

* Statistical figures. EPC trips in 1000s.

Source: Table 6.17.

4.2.2 EMP scenarios

The EMP scenarios data in Table 6.19 are expanded into SD data first. The EMP data difference between the GMA and SD1 is distributed to other SDs in proportion to their 1986 base year total attractions (At).

This is justified because DEM is linearly related to EMP as seen from Equations 6.2 and 6.3. They are presented in Table 6.19. The ratios were computed using a similar procedure as the one for the POP variable in Table 6.17.

The GMA total EMP and total DEM data have one control total. This is done in order to obtain the impact of EMP decentralization in SD1 while the control total is fixed as discussed earlier.

YEAR	Sc	GMA	Ratio	SD1	SD2	SD3	SD4	SD5	SD6
1986*	At	298		110	45	63	20	18	42
1986	EMP	1195*	3.8457	472*	173	242	77	69	162
1996	L	1349	4.5691	490	206	288	91	82	192
	H	1349	4.6968	466	212	297	95	85	195
	P	1349	4.6968	466	212	297	95	85	195
2001	L	1386	4.7766	488	215	300	96	86	201
	H	1386	4.9787	450	224	314	99	90	209
	P	1386	4.9787	450	224	314	99	90	209

TABLE 6.19: GMA and SD1, EMP FORECASTS by SD Scenarios for 1996 and 2001.

Figures in 1000s. * Statistical figures. (At) figures from Table 6.1.
Source: Tables 6.1 and 6.16.

The EMP scenarios presented in Table 6.19 are translated into DEM (similar to POP translations in Table 6.18) by proportions between scenario P and scenario L. The results are presented in Tables 6.20. The ratios are based on 1986 DEM data and computed using the DEM figures in the table; e.g. [(490/466)*124.9=131.3, (488/450)*121.9=132.2].

YEAR	Sc	GMA	Rg	SD1	R1	SDoth	Roth
1986*		462.8	1.0000	131.1	1.0000	331.7	1.0000
1996	L	483.7	1.0452	131.3	1.0015	352.4	1.0624
	H*	483.7	1.0452	124.9	0.9524	358.8	1.0838
	P	483.7	1.0452	124.9	0.9524	358.8	1.0838
2001	L	496.0	1.0717	132.2	1.0084	363.8	1.0968
	H*	496.0	1.0717	121.9	0.9298	374.1	1.1306
	P	496.0	1.0717	121.9	0.9298	374.1	1.1306

TABLE 6.20: GMA and SDs EMP DEM FORECAST RATIOS.

Scenarios for 1996 and 2001.

Figures in 1000s.
* DEM figures and ratios obtained from scenario P, Table 6.18.

Source: Tables 6.18 and 6.19.

Scenario L forecasts for 1996 an EMP increase of 0.15% for SD1, in Table 6.20, while scenario H forecast an EMP decrease of 4.76% in SD1 and an EMP increase of 4.52% is forecast for the GMA in both scenarios. Thus decentralization is forecast in both scenarios L and H because (Rg > R1) in both. The same applies to the year 2001 EMP forecast scenarios.

5. IMPACT ANALYSIS

The Impact of employment decentralization on metropolitan road networks shall be assessed in this section grouped in two: (a) the 1996 and (b) 2001; forecasting scenarios. This is the second main objective of the research.

For easy reference, the results in tables 6.18 and 6.20 are summarized in Table 6.21, thus grouping POP and EMP scenarios in one table. The suffix PG (POP growth) and ED (EMP decentralization) are added to their abbreviations for easy reference e.g., high POP growth scenario (HPG), and high EMP decentralization scenario (HED).

YEAR	Sc	GMA	Rg	SD1	R1	SDoth	Roth
1986*		462.8	1.0000	131.1	1.0000	331.7	1.0000
1996	LPG	469.9	1.0154	118.1	0.9010	352.6	1.0630
	MPG	489.2	1.0570	119.8	0.9135	370.4	1.1165
	HPG	499.7	1.0798	123.0	0.9386	377.6	1.1384
	P	483.7	1.0452	124.9	0.9524	359.5	1.0838
	HED	483.7	1.0452	124.9	0.9524	359.5	1.0838
	LED	483.7	1.0452	131.3	1.0015	352.4	1.0624
2001	LPG	469.4	1.0143	112.5	0.8584	357.9	1.0791
	MPG	497.7	1.0754	112.4	0.8571	386.8	1.1660
	HPG	515.5	1.1140	120.4	0.9185	396.4	1.1951
	P	496.0	1.0717	121.9	0.9298	375.0	1.1306
	HED	496.0	1.0717	121.9	0.9298	375.0	1.1306
	LED	496.0	1.0717	132.2	1.0084	363.8	1.0968

TABLE 6.21: DEM FORECASTS from POP and EMP GMA and SD1 scenarios; 1996 and 2001.

EPC trips in 1000s.

Source: Tables 6.18 and 6.20.

Scenario P is kept in Table 6.21, though a repetition, in order to have a POP growth total for the GMA as a whole without the effect of the City Centre decentralization.

5.1 Traffic Densities in GMA

The Base SDLM model developed in Chapter 5, Table 5.16, by super district is presented below in equations 6.4 to 6.11. To be noted the 6-decimal places used for the coefficients of variables (the slope of the curve), as recommended in statistical packages (SAS).

SD1: DEN = -15.11 + 0.205396 * DEM **Eq. 6.4**

SD2: DEN = -26.23 + 0.648049 * DEM **Eq. 6.5**

SD3: DEN = -22.15 + 0.378214 * DEM **Eq. 6.6**

SD4: DEN = -46.24 + 1.200669 * DEM **Eq. 6.7**

SD5: DEN = -18.93 + 0.673938 * DEM **Eq. 6.8**

SD6: DEN = -12.36 + 0.261920 * DEM **Eq. 6.9**

MTL: DEN = -19.52 + 0.112234 * DEM **Eq. 6.10**

GMA: DEN = -20.67 + 0.065504 * DEM **Eq. 6.11**

Where;

DEN is in EPC/km, and DEM is in 1000s.

Similarly, the SDLM Sub-model by SD is obtained from Table 5.21, is presented in Equations 6.12 to 6.18.

SD1: DEN = -8.35 + 0.153856 * DEM **Eq. 6.12**

SD2: DEN = -30.69 + 0.719602 * DEM **Eq. 6.13**

SD3: DEN = -38.55 + 0.546432 * DEM **Eq. 6.14**

SD4: DEN = -65.04 + 1.581258 * DEM **Eq. 6.15**

SD5: DEN = -22.08 + 0.749526 * DEM **Eq. 6.16**

SD6: DEN = -16.43 + 0.314217 * DEM **Eq. 6.17**

MTL: DEN = -15.41 + 0.098473 * DEM **Eq. 6.18**

GMA: DEN = -19.67 + 0.063618 * DEM **Eq. 6.19**

Equations 6.4 to 6.11 compute traffic densities (DEN) or their variation (dDEN) by SD due to a cross-sectional uniform DEM change in the GMA; while, Equations 6.12 to 6.19 compute DEN by SD due to a differential change in DEM in the City Centre (SD1), the results are super-imposed to obtain the impact of DEM variations in the City Centre. This was tested in the sensitivity analyses in Chapter 5.

Comparing B1 coefficients between the SDLM models, we have:

1. SD1, B1 coefficient is bigger in the Base model.
2. SD2-SD6, B1 coefficients are smaller in the Base model.
3. MTL and GMA, B1 coefficient are bigger in the Base model.

The above is of importance as it shows clearly a higher sensitivity between supply-demand in the Base model for SD1 as compared with other SDs. Furthermore, as expected and demonstrated in Chapter 5, the Base model shows higher sensitivity than its Sub-model, in MTL and the GMA.

5.1.1 1996 forecast scenarios

As presented in Chapter 5, the difference in DEM (dDEM), between a scenario and the base year, produces a difference in DEN (dDEN) that is used to obtain the difference in infrastructure lane-km (dZLL) and a difference in EPC (dEPC) vehicular trips by facility type. DEN variations by SD are presented in Table 6.22 for the 1996 forecast scenarios for both POP and EMP.

The following computations were done:

1. Apply equations 6.4 to 6.9, using GMA percent DEM growth by scenario i.e., (Rg - 1.00) from Table 6.21, to obtain the dDEN between the base year and the scenario in question due to a uniform cross-sectional DEM variation across the GMA. This is applied on all scenarios.
2. Apply equations 6.12 to 6.17, using SD1 scenario ratio difference (Rg - R1) from Table 6.21, to obtain the dDEN due to a differential DEM between the GMA and SD1. In the research, this is applied only to EMP scenarios.
3. Super-impose (algebraic addition) the results from (1) and (2) to obtain the impact of EMP decentralization i.e., the relative City Centre DEN variations due to EMP DEM variations per scenario, and by super district and by facility type.

The computed DEN forecast results are an over-estimate of their true values. This was established in the sensitivity analyses when the SDLM model results were compared with the highly sophisticated and state-of-the-art EMME/2 model results (see Chapter 5, Sensitivity Analysis).

A scrutiny of the ratios (Rg-R1), in Table 6.22, and when compared to Table 5.27 (Chapter 5), DEN compensatory reduction factors (to balance DEN over-estimation) are recommended and used (applied to the end results of DEN) as follows: -1.0% for SD1, SD2, and SD3; -3% for SD4 and SD6; and -8% for SD5. The results are presented in Table 6.22 as dDEN over-estimations. And they are constants for the scenarios.

The difference in ratios (Rg - R1), part (B) in Table 6.22, are positive for both EMP scenarios, this means that the GMA variations are larger than those of SD1 i.e., part (B) dDEN figures are deducted from part (A) figures in Table 6.22 and presented in part (C).

It is of interest to note that the POP scenarios, including scenario P, were treated as uniform growth throughout the GMA in order to obtain the impact between high and low POP growth scenarios on 'Metropolitan Road Networks'; while the impact of differential DEM variations (decentralization) in SD1 on the

GMA (both EMP and POP) are assessed from scenario P results because scenario P is identical in both cases.

The EMP scenarios [HED and LED], in Table 6.22 part (C), show higher dDEN figures for the low EMP decentralization (LED), while dDEN figures for the high EMP decentralization (HED) are negative.

LOCATION	Rg-R1	SD1	SD2	SD3	SD4	SD5	SD6
Base year DEM*		131.1	64.2	98.3	50.3	40.8	78.2
Base year DEN**		11.85	15.44	15.14	14.52	8.64	8.23
A. Base SDLM: dDEN variations							
HPG	.0798	2.148	3.319	2.966	4.818	2.194	1.634
MPG	.0570	1.534	2.371	2.119	3.442	1.567	1.167
LPG	.0154	0.416	0.642	0.574	0.933	0.425	0.316
P	.0452	1.217	1.881	1.681	2.731	1.243	0.926
HED	.0452	1.217	1.881	1.681	2.731	1.243	0.926
LED	.0452	1.217	1.881	1.681	2.731	1.243	0.926
B. Sub-model: dDEN variations							
HED	.0928	1.873	4.289	4.987	7.384	2.839	2.281
LED	.0437	0.881	2.019	2.347	3.475	1.336	1.074
Over-estimation		0.119	0.119	0.119	0.436	0.691	0.247
Net HED		1.754	4.170	4.868	6.948	2.178	2.034
Net LED		0.762	1.900	2.228	3.039	0.645	0.827
C. Net dDEN variations							
HPG		2.148	3.319	2.966	4.818	2.194	1.634
MPG		1.534	2.371	2.119	3.442	1.567	1.167
LPG		0.416	0.642	0.574	0.933	0.425	0.316
P		1.217	1.881	1.681	2.731	1.243	0.926
HED		-.537	-2.35	-3.19	-4.22	-.935	-1.11
LED		0.455	-.089	-.547	-.308	0.598	0.099

TABLE 6.22: 1996 FORECASTS; dDEN variations by SD.

* DEM figures from Table 6.1 in 1000s.
** DEN in EPC/km from Table 5.15.

Montreal East (SD3), Montreal West (SD2), and Laval (SD4) have negative dDEN which means that the impact of even low SD1 EMP decentralization scenario (LED) is traffic de-congestion in SD4, SD2, and SD3. This may be explained by the fact that SD1 is an important EMP attraction hub for the three super districts and others (as seen in Chapter 3) and consequently, the SD1 morning bound work trips from SD2, SD3 and SD4, are expected to decrease.

This decrease is related to the level of EMP decentralization, represented by the ratio difference [Rg - R1], and is resulting in traffic de-congestion for HED scenario forecasts.

The super district of Montreal West area (SD2) has more balanced supply-demand EMP relationships (as seen in Chapter 3) and consequently, it will not have the same degree of de-congestion due to EMP decentralization in SD1. This also applies to the South Shore super district.

The base year DEN are obtained from Table 5.15 and added to part (C) in Table 6.23. It presents DEN by SD per scenario and the corresponding aggregated level-of-service (LOS) are obtained from Table 1.1.

LOCATION		SD1	SD2	SD3	SD4	SD5	SD6
Base year DEN*		11.85	15.44	15.14	14.52	8.64	8.23
Base year LOS*		B	C	C	C	B	B
DEN and LOS							
HPG	DEN	14.00	18.76	18.11	19.34	10.83	9.86
	LOS	C	D	C	D	B	B
MPG	DEN	13.38	17.81	17.26	17.96	10.21	9.40
	LOS	C	C	C	C	B	B
LPG	DEN	12.27	16.08	15.71	15.45	9.07	8.55
	LOS	B	C	C	C	B	B
P	DEN	13.07	17.32	16.82	17.25	9.88	9.16
	LOS	C	C	C	C	B	B
HED	DEN	11.31	13.09	11.95	10.30	7.71	7.12
	LOS	B	C	B	C	B	A
LED	DEN	12.31	15.35	14.59	14.21	9.24	8.33
	LOS	B	C	C	C	B	B

TABLE 6.23: 1996 FORECASTS; DEN and LOS by SD.

* DEN in EPC/km from Table 5.15 and LOS from Table 1.1.

As discussed in Chapter 1, the LOS is a complex issue and meaningful for a highway segment or for an intersection at grade. Thus, the aggregate LOS is more indicative of the change in SD traffic congestion status rather than actually defining the SD LOS, because a mobility parameter is also needed as presented in Chapter 5 (when defining the upper bound for DEM).

The SD congestion status is more properly described by the operational parameter DEN, its mean and variance, as discussed in Chapter 5 under cross-sectional analysis. This is based on [HCM, 1985] as discussed in Chapter 1 (this relates to mobility). All reference hereunder to LOS is of an indicative nature and relates to an aggregate LOS, defined by the DEN range in Table 1.1.

The aggregate LOS forecasts for the year 1996 by SD, for all scenarios in Table 6.23, show that the LOS would have dropped one level in SD1 scenarios HPG, MPG and P; further LOS drops are registered in SD2 and SD4 for the HPG scenario; this would have been the case if there are no EMP and POP decentralizations in SD1. Furthermore, the aggregate LOS has improved one level in SD3 for scenario HED, due to decentralization of EMP.

LOS variations, on a link and zone basis, have definitely changed in all super districts and traffic is denser in many links. The impact of EMP decentralization has produced de-congestion in SD1 as seen in scenario (HED) where traffic density has decreased from 11.85 to 11.31 EPC per kilometre.

As a matter of fact all SDs have their LOS improved one level due to the high decentralization of EMP (scenario HED, Table 6.23). This is presented graphically in Fig. 6.7 (in next sub-section).

The trip link frequency distributions, over time, have a larger mean DEN in all SDs and all scenarios, except SD2,3,4 in scenarios LED and HED. Consequently their distribution curves are more skewed due to the additional link-capacities exceeded as discussed in the cross-sectional analyses in Chapter 5.

5.1.2 2001 forecast scenarios

Table 6.24 presents dDEN results for the year 2001 forecast scenarios for both POP and EMP. The computations needed are done in three parts [A, B, and C], similar to those for the 1996 forecasts and using the same Equations 6.4 to 6.19.

LOCATION	Rg|Rg-R1	SD1	SD2	SD3	SD4	SD5	SD6
Base year DEM*		131.1	64.2	98.3	50.3	40.8	78.2
Base year DEN**		11.85	15.44	15.14	14.52	8.64	8.23
A. Base SDLM: dDEN variations							
HPG	.1140	3.068	4.742	4.237	6.883	3.134	2.334
MPG	.0754	2.029	3.136	2.802	4.552	2.072	1.543
LPG	.0143	0.386	0.597	0.533	0.866	0.394	0.294
P	.0717	1.930	2.983	2.665	4.330	1.971	1.468
HED	.0717	1.930	2.983	2.665	4.330	1.971	1.468
LED	.0717	1.930	2.983	2.665	4.330	1.971	1.468
B. Sub-model: dDEN variations							
HED	.1419	2.862	6.554	7.620	11.28	4.338	3.486
LED	.0633	1.277	2.924	3.400	5.035	1.936	1.555
Over-estimation		0.119	0.119	0.119	0.436	0.691	0.247
Net HED		2.743	6.435	7.501	10.84	3.647	3.239
Net LED		1.158	2.805	3.281	4.599	1.245	1.308
C. Net dDEN variations							
HPG		3.068	4.742	4.237	6.883	3.134	2.334
MPG		2.029	3.136	2.802	4.552	2.072	1.543
LPG		0.386	0.597	0.533	0.866	0.394	0.294
P		1.930	2.983	2.665	4.330	1.971	1.468
HED		-.813	-3.45	-4.84	-6.51	-1.68	-1.77
LED		0.772	0.178	-.616	-.269	0.726	0.160

TABLE 6.24: 2001 FORECASTS, dDEN variations by SD.

* DEM figures from Table 6.1 in 1000s.
**DEN in EPC/km and LOS from tables 1.1 and 5.15.

The variations of EMP dDEN between the base year and 2001, in Table 6.24, are expected and are in conformity with the previously presented 1996 figures.

The base year DEN are added to part (C) in Table 6.24 to obtain DEN by super district per scenario and the corresponding LOS are obtained from Table 1.1. The results are presented in Table 6.25.

LOCATION		SD1	SD2	SD3	SD4	SD5	SD6
Base year DEN*		11.85	15.44	15.14	14.52	3.64	8.23
Base year LOS*		B	C	C	C	B	B
DEN and LOS							
HPG	DEN	14.92	20.18	19.38	21.40	11.77	10.56
	LOS	C	D	D	D	B	B
MPG	DEN	13.88	18.58	17.94	19.07	10.71	9.77
	LOS	C	D	C	D	B	B
LPG	DEN	12.24	16.04	15.67	15.39	9.03	8.52
	LOS	B	C	C	C	B	B
P	DEN	13.78	18.42	17.81	18.85	10.61	9.70
	LOS	C	C	C	D	B	B
HED	DEN	11.04	11.99	10.30	8.01	6.96	6.46
	LOS	B	C	B	B	A	A
LED	DEN	12.62	15.62	14.52	14.25	9.37	8.39
	LOS	C	C	C	C	B	B

TABLE 6.25: 2001 FORECASTS; DEN and LOS by SD.

* DEN in EPC/km and LOS from Tables 1.1 and 5.15.

The aggregate LOS variations are as expected; the DEN increases as DEM increases. It is of interest to note that only the percentage change in DEM for the GMA was used in dDEN computations, in both 1996 and 2001 scenarios. This makes the SDLM efficient and a time saver. The drop in LOS is noted mainly in SD1 POP scenarios, where SD1 decentralization impact was not incorporated.

A comparison between scenarios P and HED i.e., POP growth with and without City Centre decentralization (for both EMP and POP) shows that the average SD1 DEN drops from 13.78 to 11.04 EPC/km (19.88%); **thus, the aggregate de-congestion impact of decentralization is quantified.**

This does not, by any means, imply that there will be no localized traffic bottle necks in SD1, where link capacities are exceeded due to an increase in the more complex travel pattern type of many-to-many. This topic was further discussed in Chapter 5, and in Chapter 2.

Figure 6.8 presents the results in bar chart format and together with Fig. 6.7 present the distributional aggregate LOS (DEN). These figures present the distributional LOS for 1996 and 2001 forecasts: (a) all scenarios show a relative reduction in DEN in SD1 for 1996 and 2001; (b) DEN from HED scenario are lowest in both 1996 and 2001 forecast periods. Thus, the decentralization process is a good solution to City Centre traffic congestion; (c) DEN variations range has increased in 2001 i.e., DEN min. and DEN max. occur in 2001 forecasts, more decongestion in 2001 is expected than in 1996 for the HED scenario.

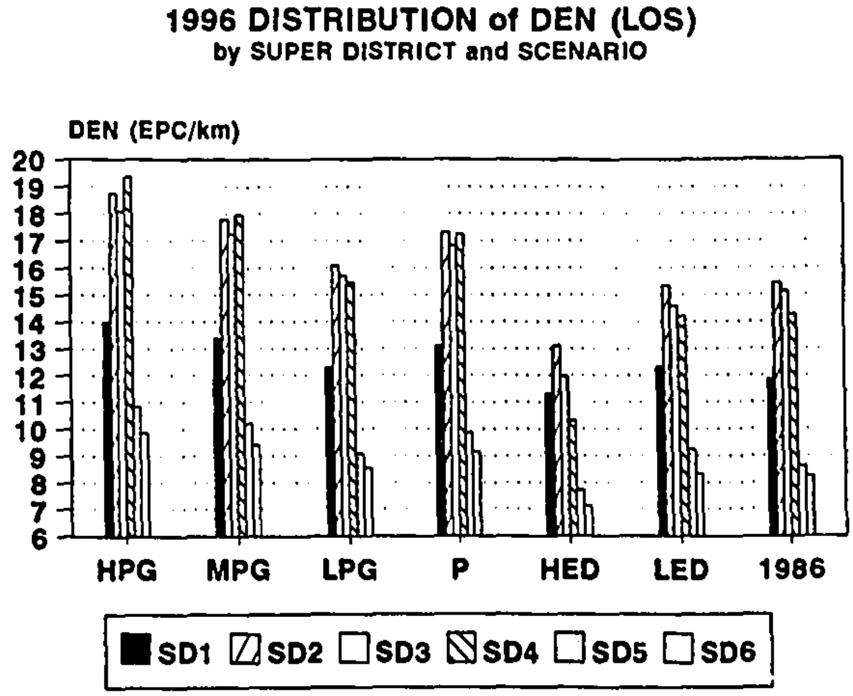

Fig. 6.7: 1996; DISTRIBUTIONAL DEN (LOS)
Source: Table 6.23

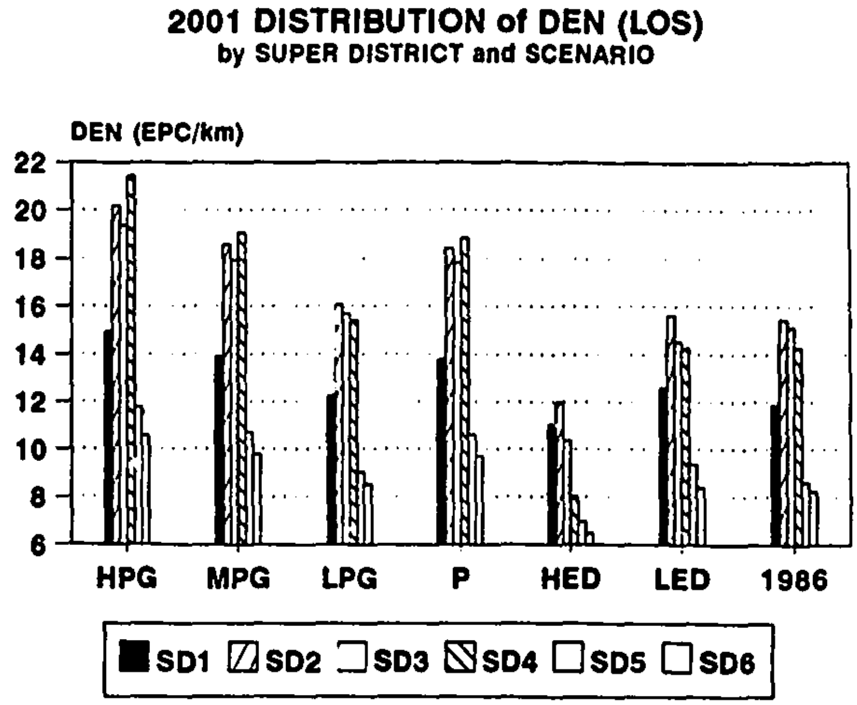

Fig. 6.8: 2001; DISTRIBUTIONAL DEN (LOS)
Source: Table 6.25

5.2 Infrastructure Lane-km Requirements

The additional lane-km requirements (dZLL) by facility type (dZLLA and dZLLF) to balance the variations in DEN (dDEN) by SD are computed in this section for both forecasting periods. This permits to maintain constant, the aggregate mean of LOS in links, at its base year level.

It is of relevance to note that the base year DEN distributions by super district (Chapter 5, Cross-sectional Analyses) may differ from the new distributions even if DEN is maintained constant, because the additional ZLL (computed in this sub-section) would not necessarily provide the same distribution as the 1986 one.
As a matter of fact, they should not keep the 1986 distribution constant, as they shall be implemented to relieve traffic congestion i.e., to reduce the skewness of the distribution, and thus to improve the 1986 distribution by improving mobility (theoretically) i.e., reduce the number of links having DEN>40.

The lane-km (ZLL) by super district and by facility type (ZLLA for arterial and ZLLF for freeways and expressways), are obtained for the base year from Table 5.24 in Chapter 5. The dZLLA and dZLLF and their corresponding dEPC (variation in equivalent passenger car trips) are computed using factors

[F1, F2, F3 and F4], computed in Chapter 5 which are constants for the GMA and are obtained from Table 5.25. These constants are used in computations in next sub-section.

5.2.1 1996 forecast scenarios

Equations 5.11 and 5.16 (Chapter 5) are used to compute dEPCA and dEPCF by super district. And equations 5.12 and 5.17 are used to compute dZLLA and dZLLF by super district.

The dDEN figures are multiplied by the corresponding factors F1 to F4 to obtain dZLL and dEPC by SD and facility type. The dZLL supply requirements resulting from the corresponding dEPC (demand variations) are presented in tables 6.26 and 6.27 for POP scenarios and in tables 6.28 and 6.29 for EMP scenarios.

LOC	F2	F4	dDEN VARIATIONS			dEPCA BALANCE			dEPCF BALANCE		
			HPG	MPG	LPG	HPG	MPG	LPG	HPG	MPG	LPG
SD1	1410	939	2.148	1.534	0.416	3029	2163	587	2017	1440	391
SD2	871	751	3.319	2.371	0.642	2891	2065	559	2493	1781	482
SD3	1256	591	2.966	2.119	0.574	3725	2861	721	1753	1252	339
SD4	528	934	4.818	3.442	0.933	2544	1817	493	4500	3215	871
SD5	623	1451	2.194	1.567	0.425	1367	976	265	3183	2274	617
SD6	2284	2319	1.634	1.167	0.316	3732	2665	722	3789	2706	733

TABLE 6.26: 1996 POP FORECASTS; DEM VARIATIONS (dEPC).

EPC trips by SD and facility type.

Source: Tables 6.22 and 5.25.

The dDEN variations (a supply measure, the difference in the mean DEN in links by SD and facility type) are computed using the SDLM models in the previous section 5.1. These are used to compute dEPC and dZLL by SD. Thus, it translates DEM variations (dEPC trips), into their equivalent supply variations (dZLL) in lane-kms.

This is the impact of POP growth variations on road network congestion. This relates directly the additional DEM (dEPC) to the additional balancing supply (dZLL); the main objective of the research.

LOC.	F1	F3	dDEN VARIATIONS			dZLLA BALANCE			dZLLF BALANCE		
			HPG	MPG	LPG	HPG	MPG	LPG	HPG	MPG	LPG
SD1	144.1	28.1	2.148	1.534	0.416	306	221	60	60	43	12
SD2	67.7	25.3	3.319	2.371	0.642	225	161	43	84	60	16
SD3	95.8	11.0	2.966	2.119	0.574	284	203	55	33	23	6
SD4	54.8	18.9	4.818	3.442	0.933	230	189	51	91	65	18
SD5	115.9	63.3	2.194	1.567	0.425	254	182	49	139	99	27
SD6	387.8	112.5	1.634	1.167	0.316	634	453	123	184	131	36

TABLE 6.27: 1996 POP FORECASTS; SUPPLY VARIATIONS (dZLL).

Supply-Demand balance, ZLL in lane-km, by SD and facility type.

dEPC in EPC trips and dZLL in lane-kms.

Source: Tables 6.22 and 5.25.

The results in Table 6.27 show that the highest lane-km requirements are in the South Shore (SD6) for the high POP growth scenario (HPG): 905 lane-km of arterial and 263 lane-km of freeways and expressways; while, the same figures for (LPG) scenario are 114 and 33 lane-km.

The second highest lane-km requirements are in SD1 and they vary between 86 and 442 lane-km for arterial streets and 11 to 56 lane-km for expressways and freeways. This is the range for the most expected POP growth [BSQ, 1984]. The third highest lane-km requirements are in (SD3).

It is important to note that in the process of elimination of local and collector-distributor supply links in the GMA (EMME/2 model calibration, Chapter 4), the City Centre has lost the highest proportion of link lane-km, due to their high density level. This resulted, among other effects, in relatively higher cross-boundary traffic DEN in arterial due to traffic re-assignment in EMME/2.

Consequently, the high requirements in arterial lane-km (POP scenario HPG) may be satisfied, using relatively economical solutions, by transforming several collector-distributor links into arterial. This is a de-facto situation at present since collector streets are functioning as arterial streets in SD1.

It is of further interest to note again that the POP scenarios are applied as uniform cross-sectional growth over the case study while the EMP and (P) scenarios had a common control total and a differential variation in DEM levels in the City Centre in order to study the impact of employment decentralization on metropolitan road networks.

It should be emphasized that the computed lane-km requirements (dZLLA and dZLLF) are needed to maintain the base year aggregate LOS by SD constant over time, expressed as the mean DEN. This goal may be waved as of necessity. For instance, there will be minor pressure on transportation officials to maintain an LOS B in the South Shore (SD6) while there are pressing needs to improve the capacities of all South Shore water crossings into MTL.

Table 6.28 presents the dEPC DEM that produced the dDEN for the EMP scenarios.

LOC.	F2	F4	dDEN VARIATIONS			dEPCA BALANCE			dEPCF BALANCE		
			HED	LED	P	HED	LED	P	HED	LED	P
SD1	1410	939	-.537	0.455	1.217	-757	642	1716	-504	427	1143
SD2	871	751	-2.35	-.089	1.881	-2047	-78	1638	-1765	-67	1413
SD3	1256	591	-3.19	-.547	1.681	-4007	-687	2111	-1885	-323	993
SD4	528	934	-4.22	-.308	2.731	-2228	-163	1442	-3941	-288	2551
SD5	623	1451	-.935	0.598	1.243	-582	373	774	-1357	868	1804
SD6	2284	2319	-1.11	0.099	0.926	-2535	226	2115	-2574	230	2147

TABLE 6.28: 1996 EMP FORECASTS; DEM VARIATIONS (dEPC).

EPC trips by SD and facility type.

Source: Tables 6.22 and 5.25.

LOC.	F1	F3	DDEN VARIATIONS			dZLLA BALANCE			dZLLF BALANCE		
			HED	LED	P	HED	LED	P	HED	LED	P
SD1	144.1	28.1	-.537	0.455	1.217	-77	66	175	-15	13	34
SD2	67.7	25.3	-2.35	-.089	1.881	-159	-6	127	-59	-2	48
SD3	95.8	11.0	-3.19	-.547	1.681	-306	-52	161	-35	-6	18
SD4	54.8	18.9	-4.22	-.308	2.731	-231	-17	150	-80	-6	52
SD5	115.9	63.3	-.935	0.598	1.243	-108	69	144	-59	38	79
SD6	387.8	112.5	-1.11	0.099	0.926	-430	38	359	-125	11	104

TABLE 6.29: 1996 EMP FORECASTS; SUPPLY VARIATIONS (DZLL).

Supply-Demand balance, ZLL in lane-km, by SD and facility type.

dEPC in EPC trips and dZLL in lane-kms.

Source: Tables 6.22 and 5.25.

Table 6.29 presents the supply requirements in lane-km to balance the additional DEM in EPC trips (dEPC).
Tables 6.28 and 6.29 present the impact of decentralization in SD1; the additional trips produced and the requirements in lane-km to balance them, thus maintaining the aggregate base year LOS constant. This is done by super district and by facility type.

A comparison between the three EMP scenarios, presented in Figures 6.9 and 6.10 (tables 6.28 and 6.29), the 1996 supply-demand linkages in SD1, gives the decentralization impact by facility type for the City Centre. For instance:

1. Scenario P has no decentralization in SD1 (uniform POP growth in the GMA of 4.52%); it shows that a change in DEM of 1716 EPCA trips in SD1 are balanced by a change in supply of 175 lane-km of arterial while, a dDEM of 1143 EPCF requires 34 lane-km of freeways.

2. Scenario LED has manufacturing EMP decentralization in SD1 (the low EMP and POP decentralizations are super-imposed onto uniform POP growth in the GMA); it shows that for a dDEM of 642 EPCA crips a supply of 66 lane-km of arterial is required while, a dDEM of 427 EPCF requires 13 lane-km of freeways.

3. Scenario HED has both manufacturing and service EMP

decentralization in SD1 super-imposed on uniform POP growth in the GMA. This scenario shows that both DEM and supply figures are negative i.e., an EMP decentralization is expected to decrease dDEM (negative) and consequently there are no additional supply requirements in SD1.

Thus, a decentralization in SD1, results in traffic de-congestion; this is true for both scenarios LED and HED depicted in Fig. 6.9 for EMP forecasts.

Therefore, the **"Impact of employment decentralization on metropolitan road networks"** in the case study is traffic de-congestion in the City Centre in particular, where decentralization occurs, and at the cross-sectional level in general depending upon the relationships between the overall growth and the strength of decentralization.

This may have far reaching consequences, as discussed at length by Cervero, in several publications from 1986 to 1989, [Pisarski (1989), and others]; and it is quantified by the SDLM models now. **To allow decentralization in city centres as a solution to urban traffic congestion problems**; basically it means to bring the place-of-work and the place-of-residence together and out-of-cities, thus making the work trip shorter; and this relieves the AM work trip congestion. <u>Thus, the suburbs are transforming into small cities or extended towns.</u>

1996 DEMAND-SUPPLY LINKAGES in SD1
DEM variations from 1986 base figs.
by FACILITY TYPE and SCENARIO

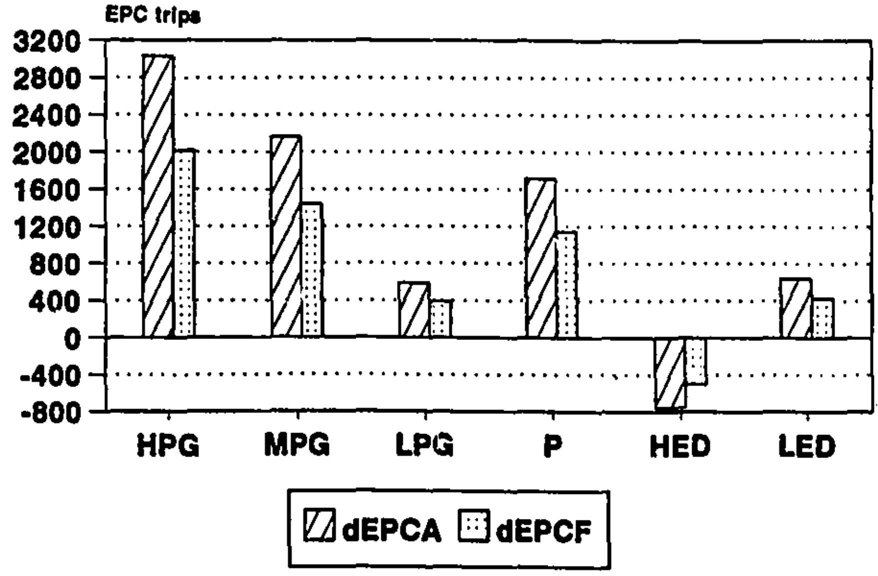

Fig. 6.9-1: 1996; DEM variations in SD1
Source: Tables; 6.26 to 6.29

1996 DEMAND-SUPPLY LINKAGES in SD1
Supply variations from 1986 base figs.
by FACILITY TYPE and SCENARIO

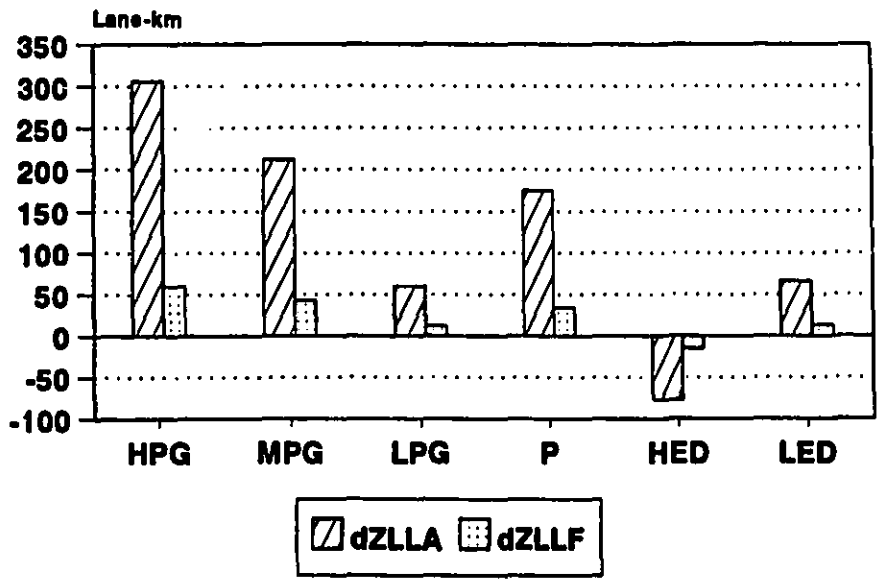

Fig. 6.9-2: 1996; Sup. variations in SD1
Source: Tables; 6.26 to 6.29

5.2.2 2001 forecast

Table 6.30 presents the 2001 POP scenarios, similar to Table 6.26. The higher level of demand forecasts are within the 20% growth relative to the base year, thus the SDLM models are applicable. The computations are similar to those used in developing Tables 6.26 to 6.29 and are not repeated.

LOC.	F2	F4	DDEN VARIATIONS			dEPCA BALANCE			dEPCF BALANCE		
			HPG	MPG	LPG	HPG	MPG	LPG	HPG	MPG	LPG
SD1	1410	939	3.068	2.029	0.386	4326	2861	544	2881	1905	362
SD2	871	751	4.742	3.136	0.597	4130	2731	520	3561	2355	448
SD3	1256	591	4.237	2.802	0.533	5322	3519	669	2504	1656	315
SD4	528	934	6.883	4.552	0.866	3634	2403	457	6429	4252	809
SD5	623	1451	3.134	2.072	0.394	1952	1291	245	4547	3006	572
SD6	2284	2319	2.334	1.543	0.294	5331	3524	671	5413	3578	682

TABLE 6.30: 2001 POP FORECASTS; DEM VARIATIONS (dEPC).

EPC trips by SD and facility type.

Source: Tables 6.24 and 5.25.

LOC.	F1	F3	DDEN VARIATIONS			dZLLA BALANCE			dZLLF BALANCE		
			HPG	MPG	LPG	HPG	MPG	LPG	HPG	MPG	LPG
SD1	144.1	28.1	3.068	2.029	0.386	442	292	56	86	57	11
SD2	67.7	25.3	4.742	3.136	0.597	321	212	40	120	79	15
SD3	95.8	11.0	4.237	2.802	0.533	406	268	51	47	31	6
SD4	54.9	18.9	6.883	4.552	0.866	377	249	47	130	86	16
SD5	115.9	63.3	3.134	2.072	0.394	363	240	46	198	131	25
SD6	387.8	112.5	2.334	1.543	0.294	905	598	114	263	174	33

TABLE 6.31: 2001 POP FORECASTS; SUPPLY VARIATIONS (dZLL).

Supply-Demand balance, ZLL in lane-km, by SD and facility type.

dEPC in EPC trips and dZLL in lane-kms.

Source: Tables 6.24 and 5.25.

Table 6.31 presents the supply requirements in lane-km to balance the additional DEM in EPC trips, similar to Table 6.27 for 1996 POP scenarios.

The EMP scenarios for the year 2001, show decentralization in SD1 and are presented in Table 6.32 for the DEM variations; while Table 6.33 presents the corresponding lane-km requirements by facility type and by super district.

LOC.	F2	F4	DDEM VARIATIONS			dEPCA BALANCE			dEPCF BALANCE		
			HED	LED	P	HED	LED	P	HED	LED	P
SD1	1410	939	-.813	0.772	1.930	-1146	1089	2721	-763	725	1812
SD2	871	751	-3.45	0.178	2.983	-3005	155	2598	-2591	134	2240
SD3	1256	591	-4.84	-.616	2.665	-6079	-774	3347	-2860	-364	1575
SD4	528	934	-6.51	-.269	4.330	-3437	-142	2286	-6080	-251	4044
SD5	623	1451	-1.68	0.726	1.971	-1047	452	1228	-2438	1053	2860
SD6	2284	2319	-1.77	0.160	1.468	-4043	365	3353	-4145	371	3404

TABLE 6.32: 2001 EMP FORECASTS; DEM VARIATIONS (dEPC).

EPC trips by SD and facility type.

Source: Tables 6.24 and 5.25.

Scenario HED results show a decrease in net traffic EPC trips in all SDs, except the North Shore (SD5). This may be explained by the fact that the exurban regions north of the case study are important contributors of labour force to Laval as well as to SD1; thus, they are relatively less affected by a strong EMP decentralization in the City Centre.

Tables 6.32 and 6.33 present the impact of decentralization in SD1 for the year 2001 forecasts, similar to tables 6.28 and

6.29 for 1996. It is of further interest to note that scenario P (without the effect of SD1 dDEM), has the highest lane-km requirements by facility type in all super districts.

LOC.	F1	F3	DDEN VARIATIONS			dZLLA BALANCE			dZLLF BALANCE		
			HED	LED	P	HED	LED	P	HED	LED	P
SD1	144.1	28.1	-.813	0.772	1.930	-117	111	278	-23	22	54
SD2	67.7	25.3	-3.45	0.178	2.983	-234	12	202	-87	5	75
SD3	95.8	11.0	-4.84	-.616	2.665	-464	-59	255	-53	-7	29
SD4	54.8	18.9	-6.51	-.269	4.330	-357	-15	237	-123	-5	82
SD5	115.9	63.3	-1.68	0.726	1.971	-195	84	228	-106	46	125
SD6	387.8	112.5	-1.77	0.160	1.468	-686	62	569	-199	18	165

TABLE 6.33: 2001 EMP FORECASTS; SUPPLY VARIATIONS (DZLL).

Supply-Demand balance, ZLL in lane-km, by SD and facility type.

dEPC in EPC trips and dZLL in lane-kms.

Source: Tables 6.24 and 5.25.

A comparison between the three EMP scenarios (P, HED, LED), shown in Fig. 6.10, gives the decentralization impact by facility type for the City Centre. For instance:

1. <u>Scenario P</u> has no decentralization in SD1 (uniform POP growth in the GMA of 4.52%); it shows that a change in DEM in SD1 of 4533 (2721+1812) EPC trips is balanced by a change in supply of 332 (278+54) lane-km.

2. <u>Scenario LED</u> has manufacturing EMP decentralization in SD1 (low EMP and POP decentralization super-imposed on uniform POP

growth in the GMA); a change in DEM of 1814 (1089+725) EPC trips is balanced by a change in supply of 133 (111+22) lane-km.

3. Scenario HED has both manufacturing and service EMP (total EMP) decentralization in SD1 super-imposed on uniform POP growth in the GMA. It shows that both DEM and supply figures are negative i.e., an EMP decentralization is expected to decrease the DEM and consequently there is no additional supply requirements in SD1.

Thus, the previously presented paragraphs show that the decentralization of employment in the City Centre results in traffic de-congestion in conformity with 1996 forecasts. Therefore, the **"Impact of employment decentralization on metropolitan road networks"** in the case study is as a matter of fact a **traffic de-congestion in the City Centre and in other super districts** as well; and true for both forecasting periods.

2001 DEMAND-SUPPLY LINKAGES in SD1
DEM variations from 1986 base figs.
by FACILITY TYPE and SCENARIO

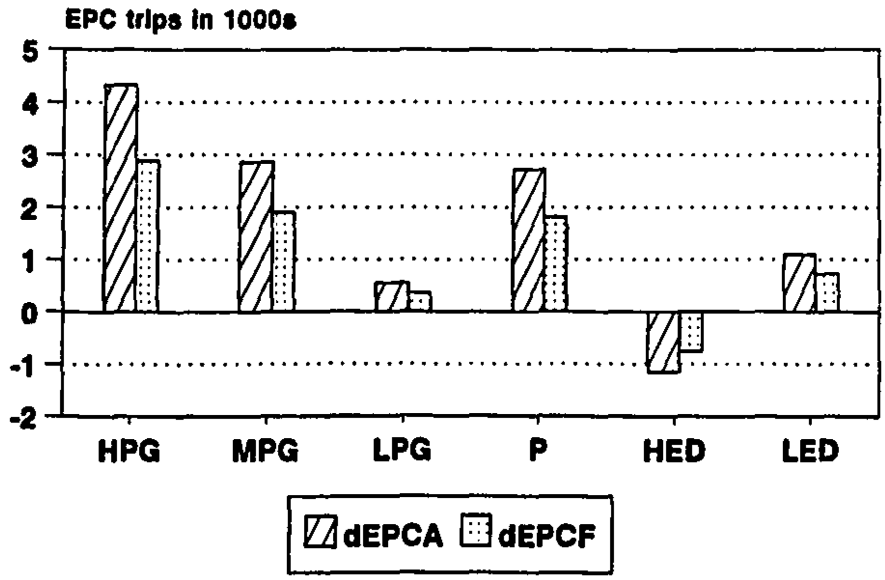

Fig. 6.10-1: 2001; DEM VARIATIONS in SD1
Source: Tables; 6.30 to 6.33

2001 DEMAND-SUPPLY LINKAGES in SD1
Supply variations from 1986 base figs.
by FACILITY TYPE and SCENARIO

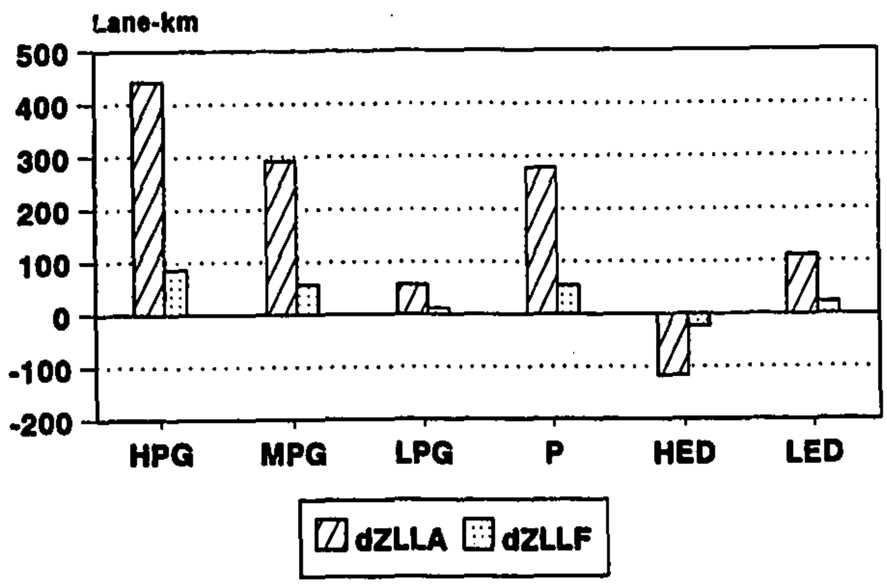

Fig. 6.10-2: 2001; SUP. VARIATIONS in SD1
Source: Tables; 6.30 to 6.33

The differential trends in EMP demand and supply are presented in figures 6.11, in two parts: DEM and SUPPLY variations. The 1986 base year is the reference line. The EMP scenarios [P, LED, and HED] are presented by facility type: (A) arterial roads and (F) freeways and expressways. There are no 1991 figures presented.

The DEM and SUPPLY variation trends are negative for the high decentralization scenario HED while the trend curve for scenario LED has a flatter slope than the one for scenario P. In comparing EMP and POP forecasts, it is evident (Fig. 6.11) that traffic congestion considerations are not solely dependent on demographic (POP) variables or trip generation, they did not show traffic decongestion in SD1. The more reliably demonstrated EMP forecasts or trip attractions should be used and are recommended.

Certainly, POP and EMP, forecasts may be obtained from land use considerations and the traffic congestion is monitored using SDLM models. Especially so, if a land use sketch planning model, is developed, relating land use and trip generations and attractions i.e., a sketch land use planning model, short circuiting land use models as presented in ISGLUTI (1988), and based upon the SDLM approach.

DEMNAND-SUPPLY EMP TRENDS In SD1

DEM variations from 1986 base year

EMP scenarios by facility type

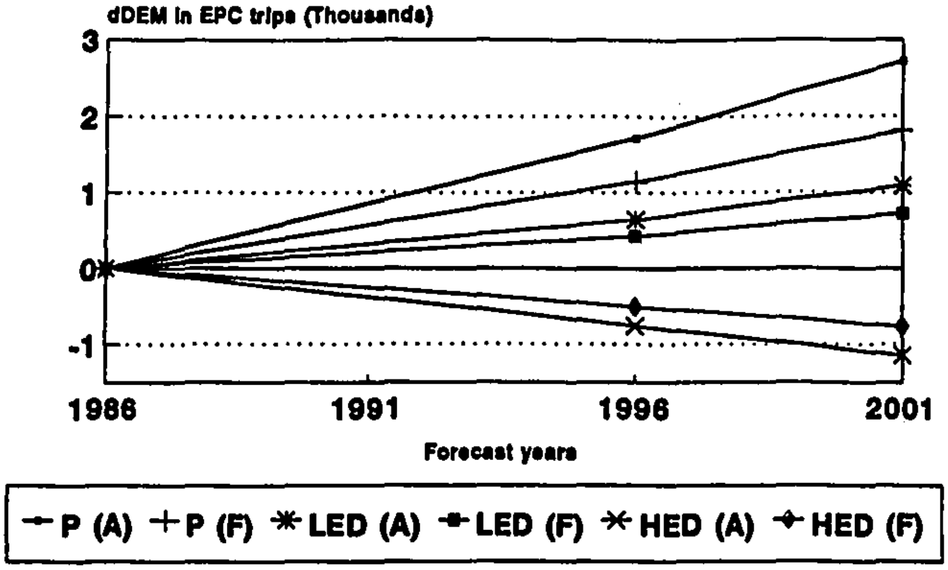

Fig. 6.11-1: DEM EMP TRENDS In SD1
Source: Tables; 6.28, 6.32

DEMNAND-SUPPLY EMP TRENDS In SD1

Supply variations from 1986 base year

EMP scenarios by facility type

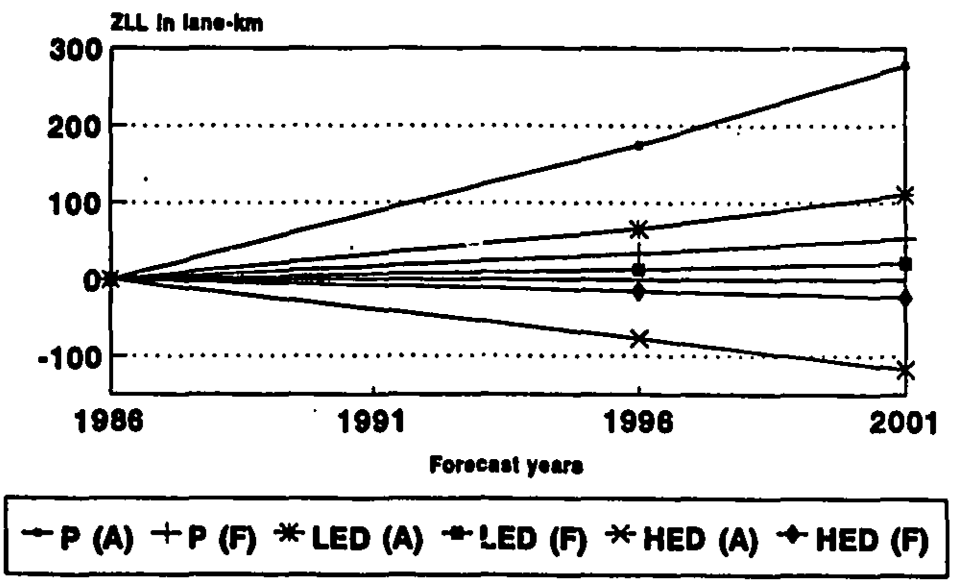

Fig. 6.11-2: LANE-KM TRENDS In SD1
Source: Tables; 6.29, 6.33

6. CHAPTER SUMMARY and CONCLUSIONS

This chapter applied the SDLM models successfully to the case study and concluded that the 'Impact of Employment Decentralization on Metropolitan Road Network' has resulted in a convoluted many-to-many travel pattern de-congesting the road network.

To achieve the above, cross-sectional models were calibrated at the super district aggregation level, relating statistically available independent variables, to DEM, the independent variable in the SDLM models.

The above mentioned modelling process at some point was not very reliable to translate EMP into DEM due to the many assumptions used to compute the needed factors. This lead to the use of proportionality factors between scenarios based upon demonstrated linear relationships.

The zonal efficiency concept is worth following through to quantify descriptive analyses, and to compare quantitatively the spatial relationships between the place-of-work and the place-of-residence in a case study or to relate attractions and productions by SD and to expand the concept that if at all possible. This is a secondary research contribution.

The decentralization process was quantified by modelling the supply-demand relationships into the SDLM Base model and Sub-model for the City Centre in terms of DEM and DEN variables.

The result of the application of the SDLM models to POP and EMP scenarios established the impact of decentralization in the City Centre quantitatively by translating DEM and DEN into equivalent passenger car trip (EPC) variations as the demand and the resulting requirements in infrastructure in lane-km (ZLL) as the supply by super district and by facility type.

The variations in traffic densities (dDEN), at the super district aggregate level or macro-level, are minimal and usually well below lowering the LOS one level, and thus keeping the super districts LOS relatively unchanged. It was found that an increase in demand of 20% (Chapter 5) would bring the LOS down one level and consequently, it is suggested that such a change be considered as an upper bound for demand and a mobility boundary. This boundary corresponds to an increase in the number of links having their capacity exceeded (DEN>40 EPC/km) by 5%.

The above is rather misleading, because one would think that there are no traffic congestion problems. As a matter of fact, traffic build ups are not uncommon and at the micro-level, the capacity of a few links are exceeded. This is evident from the cross-sectional analyses in Chapter 5.

Comparing DEN results between base year figures and scenario HED in Tables 6.23 and 6.25, show that the **Impact of employment decentralization on metropolitan road networks** is again congestion relief in the City Centre, and all over the GMA and it depends on how strong a decentralization is conceived as related to the cross-sectional POP growth distribution in a case study.

The de-congestion in super districts, other than SD1, may be explained by the fact that the travel pattern in today's metropolises has evolved in the last three decades from the traditional 'many-to-one' pattern, to the more complex 'many-to-many' pattern.

Chapter 2 dwelt on the above at length, it may be further added that the many-to-many pattern has become more convoluted or disorderly in general and it is confirmed in Canada [Bourne, 1989]. The research case study analyses have demonstrated that this has resulted in de-congestion in several super districts as well as in the City Centre where EMP decentralization was applied, and that is due to improved zonal efficiencies i.e., the place-of residence is getting nearer to the place-of-work.

The zonal (zonal refers to super district efficiencies in this case) efficiencies, were introduced in this research in Chapter 3, in response to literature review findings, and they refer to the imbalance between supply and demand in a certain area under study.

The zonal efficiencies are improved by the decentralization process in SD1 resulting in de-congestion. Most probably the decentralization of EMP has brought the place-of-work nearer to the place-of-residence. This would explain the de-congestion in other super districts than the City Centre.

The aggregate LOS (level-of-service) of the super districts has improved (lower DEN) as a result of decentralization in the peak morning rush hour. This is explained by a more balanced super district supply and demand of labour force i.e., 'more efficient super districts' which is quantified by the research and it is a research secondary contribution.

CHAPTER 7

CONCLUSIONS and FUTURE RESEARCH

1. INTRODUCTION

In the last four decades, major socio-economic changes have dramatically transformed urban growth patterns in North America, resulting in increased traffic congestion and dramatically-altered travel patterns. This congestion has, in turn, resulted in further employment decentralization and the shift of the place-of-work to the suburbs. This has, in some cases, brought about the creation of large suburban activity centres in the vicinity of large cities.

Increasing employment decentralization has essentially transformed the commuter trip from a many-to-one to a many-to-many pattern, thus decreasing public transit effectiveness and ridership, and increasing suburban road traffic congestion. This is due to the increasing predominance of the auto mode of transport.

Furthermore, decentralization has brought about an increase in housing demand for most income groups in the suburbs, so that the suburbs are no longer the exclusive habitat of white collar workers.

The development of supply-demand linkages and the modelling of such linkages was undertaken in this research to by-pass the assignment stage of the complex four-stage, UTMS travel demand model, and to compliment such models at the sketch planning level of analyses without network representation. Thus, the developed supply-demand linkage model, eliminates the need to code the infrastructure with its thousands of nodes and links.

Understanding the case study was of prime concern to the research and this was described in the cross-sectional analyses in Chapter 5. The analysis of the distributional frequencies of traffic density at its upper and lower demand boundaries was of interest and it completed the analyses of local data in Chapter 3.

The research analyzed, using SAS multivariate analyses software package, the relationships among dependent and independent variables using a summary of demand matrices retrieved from STCUM. The supply data, presented in Chapter 4, were obtained from the MOTQ, using EMME/2 software. The demand data, retrieved from the STCUM data bank.

2. REVIEW

The literature review for employment decentralization in North America and the relevant modelling techniques, in addition to the demographic trends, and a comparison between Canadian and U.S. metropolises were covered at length in chapters 2 and 3.

The work of other researchers was discussed at some length in Chapter 2. More specific procedures relating to quick response modelling systems and the development of a set of transport parameters, as described in the NCHRP Reports #186 and #187 (1978), were developed into a software package QRS II.

Chapter 3 presented a descriptive analysis of the Greater Montreal Area in four parts:

Part A presented the review of local data as obtained from publications in two parts relating the case study to: (a) its Canadian context; and (b) its North American context. The criteria for the choice of the case study was presented and the spatial aggregations were defined.

Part B presented detailed data analyses for the case study at one point in time, namely the 1981 StatsCan data. It was scrutinized in depth to show EMP spatial distribution by purpose.

Part C presented detailed demand data, to be used in the travel demand model and the SDLM. The data were obtained from STCUM, using SAS software.

Part D presented the research multivariate analyses and calibrated the relationships among demand and supply measures at the zonal aggregation level. The calibrations at the super district aggregational level were implemented in Chapter 6. Statistical factors were computed using the research data base, which were useful in scenario transformations.

Chapter 4 presented the calibration and validation of a travel demand model, the EMME/2 sequential, state-of-the-art model. Main congestion problems were experienced at all inbound river crossings where lane capacities are exceeded. All base year demand matrices, used in this chapter, represent information for an average autumn day in 1987 for the 7-8 AM peak traffic and are given in equivalent passenger car trips (EPC) for all surface motorized vehicles.

The supply data, in the form of a road network of the GMA are used by the EMME/2 model. A complex network, comprising thousands of nodes and links, was coded for use in EMME/2.

Chapter 5 presented the development of the Supply-Demand Linkage Model or SDLM mogels for the case study, the Greater Montreal Area. The output supply-demand measures from the calibrated-validated model were modelled into the 'Supply-Demand Linkage Model'.

The SDLM was developed in two parts: (a) by varying the demand incrementally and uniformly across the GMA to obtain the supply and demand measures: the variations of DEN resulting from incremental variations of DEM; and (b) by varying DEM incrementally in the City Centre and holding DEM constant in all other SDs, to obtain the effect of spatial demand variations on the mean of the road network DEN i.e., an indication of the aggregate LOS variation.

The sensitivity analysis was carried out, in Chapter 5, at three levels; upper bound, lower bound and cross-sectional at the pivot scenario. It proved the reliability of the developed SDLM models. The differences obtained in applying the highly complex, state-of-the-art EMME/2 model and the SDLM models to the Greater Montreal Area were in the order of 5%. This is a good result, and thus verifying the developed SDLM model.

The forecasting scenarios for the two temporal periods 1986-1996 and 1986-2001 are developed and tested in Chapter 6. Each forecasting period has a pivot scenario relating the POP and EMP variables. The scenarios represent, generally speaking, upper and lower bounds i.e., control totals.

The supply-demand linkages computed using the SDLM models in the impact analyses, provided supply requirements in lane-kilometres per scenario by super district and facility type. These supply requirements are needed to balance the additional demand in order to maintain the aggregate LOS or the traffic densities of the base year. It is also possible to compute the supply requirements needed to achieve a pre-set aggregate LOS.

3. RESEARCH FINDINGS and LIMITATIONS

It was demonstrated in Chapter 3D that as the auto-ownership per household increases, the transit ridership decreases. This is observed to be true over time, i.e there is a strong correlation between auto ownership per household and transit ridership. It was also demonstrated that home-based person-trips variations over time (Fig. 3.5), for work and shopping purposes are increasing at similar rates.

The educational trips, highly dependent on population growth and aging, are barely increasing, while the single most important component in other trip categories is recreation, and it is booming. This is in conformity with U.S. findings; people are making more recreational trips, strongly influenced by the higher auto-availability per person.

Analyses of the four main demand variables; population, household size, auto person-trips, and transit person-trips (Fig. 3.6), and their temporal variations, show that population growth rate is very low, and the household size is decreasing over time. This is in conformity with U.S. findings.

The number and percentage of the intra-zonal trips represent a measure of zonal efficiency, and these are quantified as a result of the application of the SDLM models (Chapter 6), and thus become a minor research contribution. Zonal efficiencies are measured by a balance in supply-demand between the POR and the POW, yet this is not entirely satisfactory unless people elect to have both of their home and work addresses in the same district. Otherwise, there is a mismatch between zonal POR and POW and traffic congestion is not relieved. Thus zonal efficiency implies a balance of attractions and productions by zone, and this is needed to call a certain zone efficient.

The time consuming cross-sectional analyses improved the research understanding of the case study and its spatial components, but has lead to no concrete results. It may be concluded that the road network construction rationale in the GMA, which is expected to be typical in most metropolises, does not strictly relate to the increase in demand. This is especially so in exurban and suburban settings where the provision of a minimum level of infrastructure is needed to improve mobility and to shorten time travel.

The sensitivity analyses allow for the testing and comparing of results obtained using the highly sophisticated and state-of-the-art EMME/2 travel demand model and the SDLM models. The SDLM results were demonstrated to be reliable. Thus, it is safe to conclude that errors in using the SDLM models in general are in the order of 5%.

Furthermore, the sensitivity analysis was carried out at the pivot point scenario of 10% uniform growth, which represents almost 20 years of uniform growth.

The decentralization process was quantified by modelling the supply-demand relationships into the SDLM Base model and Sub-model for the City Centre in terms of demand (DEM) and the mean of the traffic density (DEN) variables.
The SDLM models were successfully applied (Chapter 6) to the case study and concluded that the **impact of employment decentralization on metropolitan road networks** has resulted in a dispersed many-to-many travel pattern de-congesting the road network in the City Centre, and all over the GMA. The degree of decentralization determines the level of decongestion in the City Centre.
The above may very well be due to improved zonal efficiencies i.e., the place-of residence is getting nearer to the place-of-work, which would explain the de-congestion in other super districts than the City Centre.

The aggregate level-of-service of the super districts has improved as a result of decentralization. This is explained by a more balanced super district supply and demand of labour force i.e., **'more efficient super districts'**. Thus, the research has simplified and added to the UTMS models an important component at the sketch planning level.

Furthermore, this new developed and verified tool, the SDLM models, by-passes the assignment stage of UTMS models, thereby saving considerable analysis time. Thus, a comparison between (a) the classical solution to the urban transportation planning forecast process, using UTMS models, and (b) the research results from the SDLM models, is worthy of consideration.

To put both the UTMS models and the SDLM models on equal footings for comparison, a short listing of the advantages and disadvantages in using the SDLM models as compared to the UTMS models is presented below:

<u>1. Advantages of SDLM models:</u>

a. UTMS models require two independent demand data sets to calibrate and validate. This is done by experienced professionals and needs about six months. The SDLM model calibration and verification require about two months work of a qualified engineer per model, using a calibrated and validated UTMS model, and using the methodology developed in this research.

b. UTMS models require the use of sophisticated software.

c. UTMS models require a complex coded network, consisting of thousands of nodes and links. This is done by qualified technicians and requires about six months.

d. UTMS models require complex calibrated volume delay functions (VDF). This is done by technicians and qualified professionals and would need months of work depending on the level of detailed calibration required.

e. UTMS models require the use of high-tech computer hardware which must have a math-coprocessor.

f. UTMS models need to be assisted by complex statistical packages, like SAS.

g. SDLM models **do not** need the above requirements (b) to (f). SDLM models require a simple calculator.

h. SDLM models compute directly aggregated results by SD and facility type.

2. Disadvantages:

a. SDLM models do not provide link data information, like traffic volume, speed, density, ...

b. SDLM models are not applicable at the micro-analyses level.

c. SDLM models are applied to a case study, where the variations in demand must be within the range used in its development; in this research, it is the base year demand augmented by 20%. UTMS models are restricted by the 'mobility concept', and consequently, in this particular case, they are also limited by a 20% demand increase.

The above advantages and disadvantages are best demonstrated in the following example elaborating on relative time requirements, highlighting the advantages of the SDLM models.

Example: given a demand forecast scenario to be tested, with ten variations; it is required to compute the additional lane-km requirements by SD and facility type, and by scenario.

For the SDLM models, on average, per alternative, it is necessary:

a. To compute the additional lane-km requirements to balance a variation in demand by super district (SD), facility type and scenario: a simple calculator and two hours of engineering time per alternative.

Thus, an estimated total of three working days for the ten alternatives are required.

For the UTMS models, on average, per alternative, it is necessary

a. To compute trip productions and trip attractions, using other models (assuming models are available). One day is needed per model and per alternative. A total of two working days are needed per alternative.

b. To do trip distribution, using a calibrated-validated UTMS model (assuming such a model is available and up-dated). One day is needed per alternative.

c. To do assignment, verify results, and compute link-traffic densities. Three days are needed per alternative.

d. To compute additional lane-km requirements by SD and facility type, using SAS programming and comparing to base year figures. Four days are needed per alternative.

Thus, the calibrated and validated UTMS model would require 100 working days, as compared to the three days for SDLM models, to compute the additional lane-km requirements by facility type and super district for the ten alternatives.

Furthermore, the SDLM models do not need detailed forecasting data matrices, they use variations in demand from the base year, starting with the same premise in each alternative.

Thus, the main disadvantage in using the SDLM models is the lack of detailed link data. This is largely irrelevant in sketch planning.

4. RESEARCH CONTRIBUTIONS

4.1 Secondary Research Contributions

The research HAS improved the understanding of the changing travel patterns from a many-to-one traditional trip pattern to the more complex many-to-many type and has quantified the changes (in the City Centre of the case study) resulting from activity decentralization using the SDLM models.

The SDLM models may not be transportable to other Canadian CMAs, but it is expected that the established procedure is transportable, since the structural relationships established are strong and reasonable ones.

A sequential, four stage (EMME/2) model, and several cross-sectional models were calibrated, relating measures of trip production and trip attraction, both at the zonal and super district aggregation levels.

The 'zonal efficiency concept' is quantified using the SDLM models. The zonal efficiency and mobility concepts are worth following through to quantify descriptive analyses. Furthermore, the SDLM models permit to compare quantitatively the relationships between the place-of-work and the place-of-residence in a case study.

The 'mobility concept' was quantified and related to the percentage of lane-links having traffic levels exceeding capacity, as obtained from the trip-link frequency distributions. It is of interest to follow such a concept as an adjunct, or additional qualifier, to the 'aggregate level-of-service concept'.

4.2 Primary Research Contribution

The research has two main contributions:

The first main contribution of the research was the development and validation of the **Supply-Demand Linkage Model or SDLM models, both Base and Sub-model, relating transport**

supply and demand measures; the demand in person-trip and the road network traffic density in EPC/km. The SDLM replaces the complex and time consuming assignment stage of the UTMS model, and compliments the UTMS models at the sketch planning level.

The second main contribution of the research was to quantify the **"Impact of employment decentralization on metropolitan road networks"**, using the developed SDLM models. Thus, the changes in travel demand patterns resulting from activity dispersion were quantified using the SDLM models. This simplified, quick response procedure, transforms the SDLM models into a powerful tool.

5. COMMENTS and CONCLUSIONS

The research conclusions were presented on chapter by chapter basis. At this junction, a few comments leading to the next section defining the need for future research are presented.

5.1 SDLM Simulation

The developed and recommended SDLM Base model for the case study has 99.61% explanatory powers of the independent variable demand (DEM) on the dependent variable, the mean traffic density (DEN) in the GMA, and 99.88% in SD1; at 95%

confidence level. The SDLM Sub-model has 99.92% explanatory powers in the GMA and 99.96% in SD1; also at 95% confidence level. This is an excellent simulation based on the EMME/2 application which was within 3% of true values (Chapter 4).

The SDLM models were presented in Figures 5.3 and 5.4 which are a plot of Equations 6.4 to 6.19, obtained from Tables 5.16 and 5.21. The constants in Table 5.25 also form a part of the SDLM models.

5.2 Research

There was a need first to understand the phenomena in progress and to identify the forces behind it at the micro and macro-scale levels. This lead to the conclusion that the suburban infrastructure was not designed to cope with the changing trip pattern.

The relaxed urban construction standards, at the local and regional levels, was an important basic driving force behind traffic congestion (Cervero 1989). There is a need to control land use activity dynamics in new developments, based on quick estimates of the impact of variations on demand. This is possible to achieve using models like the SDLM.
Although denser suburban work environments may increase congestion in the near term, yet in the long run, they

concentrate activities so as to result into viable alternatives to the dominant auto mode of travel.

The automobile has dominated the commuting pattern for several decades and all attempts to boost public transit riderships has yield limited results. The auto mode of transportation outweighs all other modes combined and is the main cause of traffic congestion.

The traditional solution to improve the capacity of existing road networks or to add new links to them to achieve a balance between supply and demand requires large financial resources. Increasing the network infrastructure, the supply-side solution, may be short lived as such improvements may generate new traffic ending in a vicious circle of attrition of funds unless a final balance of supply and demand is achieved theoretically.

Though the supply-demand balance is difficult to achieve, yet not impossible to control if it is protected by a long range planning that would keep further developments within limits set forth in standards which are easy to implement and be revised over time to maintain a selected LOS in the overall facility compatible with objectives. The research has supplied the tools to implement goals and objectives by establishing the Supply-Demand Linkage Model or SDLM.

5.3 SDLM Models

The development of the SDLM models in this research was based on data availability and its compatibility. The several steps implemented, and the data aggregations made this research achieve its objectives. Next presented, are a critique and the the limitations on the use of the SDLM models.

5.3.1 Critique

The spatial aggregations of the case study has probably deprived the research of the possibility to obtain more refined results. Thus it is recommended that there should be more than 38 zones in future research and aggregate the results in the modelling procedure.

The cross-sectional analyses were extensive time-consumers and the results do not fully justify the time spent. But it was necessary to establish relationships between demand-supply measures at the cross-sectional level to establish the methodology.

The spatial compatibilities between data are of prime concern and should be more carefully selected at the start of the research. This research adopted StatsCan Census Tract units, and then had to switch to STCUM zone units. The extensive time spent was necessary to relate employment data from different sources.

The aggregation of the network data and the forced cancellation of thousands of nodes and links was also time consuming and had problematic results in Chapter 4. It would have been of interest to do full network tests before and after aggregations.

The development process of the SDLM models and the sensitivity analysis test were found to be satisfactory.

The forecasting scenarios are acceptable in themselves, but the problem of data compatibility lead to lengthy data translations.

5.3.2 Limitations

The development of the SDLM models in Chapter 5 and their application in Chapter 6 defined their applicability and limitations, three main issues are presented below:

1. The range of demand forecasts should not exceed the upper bound of demand. This is a 120% of the base year demand. This limit also defines tentatively a mobility limit.
2. The SDLM models are applicable to the Greater Montreal Area. Any other use must be proven a priori.

3. The supply-demand balance as quantified by the SDLM models, is applicable at the macro-scale only. The additional lane-km requirements redresses the frequency distribution curve, but they are not intended to and are not expected to be applicable at the micro-level of analyses.

6. Future Research Needed

A "variety of research designs will be needed, ... comparative **case studies** of small sets of cities in both countries (Canada and the U.S.) by locally based researchers **following a common method**; and continued research at the macro scale drawing on census and other secondary sources", [Goldberg et al. 1986, p256].

Future work is necessary to expand and extend the works done by Pisarski, Bourne, Cervero and others through "case studies of (other) selected cities to provide detailed trip pattern data to corroborate and extend the present understanding of commuting trends... Facility-based analysis are required... Traffic operations studies are needed to examine opportunities for enhanced use of available facility capacity responsive to changed pattern of demand... New research data is needed to overcome present weaknesses and gaps in our knowledge" [Pisarski, 1987, p65].

Pisarski (1987, p10) defines the future research work as: "...detailed case studies of a number of metropolitan areas to gain the detailed understanding of trends not possible at the national scale; analyses of changes in traffic demand patterns looking at facility volumes by direction and time relative to available capacity; and development of better data to support a more comprehensive understanding of perceived trends."

The zonal efficiency, mobility, and aggregate LOS concepts are worth following up to quantify descriptive analyses and to improve the development of future SDLM models. This is recommended on a case by case basis, to establish changing travel patterns, and **it is implemented by developing SDLM models for other case studies, using a common method.**

The results of several case studies are needed to attempt to obtain universal relationships, if at all possible, between supply and demand measures.

The simplified travel demand model developed in this research, those that have been developed in the past, and those expected to be developed in the future from new approaches outlined above, aimed at simplified sketch planning, will eventually free planners and engineers to concentrate their efforts on ideas with real promise in getting those improvements into the urban transportation planning system for the benefit of all.

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APPENDIX A

Supplemental to Chapter 3, Part B

APPENDIX A1: MVS-SAS PROGRAM.

Sample program aggregating CTs into 38 zones and 12 districts; also aggregating trips by purpose and by industry. The Proc format presents the equivalence between CTs, zones and districts.

This program retrieves OD matrices from the 1981 special magnetic tapes of StatsCan.

```
/INFO MVS TI(200) PA(200) CL(60) R(MUSIC) N(GHAN-M)
// EXEC SETUP,PARM='T6=7380NT(RO,SL,SLOT=D27)'
// EXEC SAS606
//WORK DD UNIT=WORK,SPACE=(CYL,(25,25),,,ROUND),
//        DCB=(RECFM=FS,DSORG=PS,LRECL=6144,BLKSIZE=6144)
//*LABOUR DD DSN=MA74.EMPL81.ZONE,DISP=OLD
//IN1 DD DSN=NSM.CTD81B50.ZONE,UNIT=TAPE6,VOL=SER=7380NT,
//     DISP=OLD,LABEL=(1,SL)
//SYSIN    DD *
LIBNAME    LABOUR    'MA74.EMPL81.ZONE4'    DISP=(NEW,CATLG)
SPACE=(CYL,(25,25));
DATA LABOUR.INDGRP81;
   INFILE IN1;
INPUT CA 1-3 @;
    IF CA=462;


 INPUT CT_A 4-8  CT_B 9-13  CODE 14  @ 53 (V7-V33) (9.) @;
   T=V7;
   M=V10+V13;
   S=V16+V19;
   L=V22;
   F=V25+V28;
```

```
   P=V31;
   orig=ct_a;
   dest=ct_b;
 label orig='TRIP ORIGIN'  dest='TRIP DESTINATION' ;
KEEP ORIG DEST CODE T M S L F P;


  proc format;
    value fzone                                       99999='EXTZ'
                 6200-7000,7700,7800,12800-13100='ZONE 1'
               5100-6100,13200-13700,14200-14400='ZONE 2'
         3200-3900,4100-5000,14500,14900,15000='ZONE 3'
           13800-14100,14600-14800,15100-17800='ZONE 4'
11100-11300,11600-12700,22000-22400,
                  36000-37000,38500,40000-40400='ZONE 5'
7900-8400,9500,10600-11000,11400-<11600,35000-35600='ZONE 6'
                 7100-7600,8500-9300,30000-31700='ZONE 7'
                                     32000-32900='ZONE 8'
     9400,9600-10500,33000,34000,38000-<38400='ZONE 9'
                         39000-39700,43000-44000='ZONE 10'
                         28500-28800,41000-42100='ZONE 11'
                         26400-27200,27700-28400='ZONE 12'
                   17900,20500-21900,22500-24900='ZONE 13'
                         27300-27600,61000-61900='ZONE 14'
                        25000-26300,60000-<60600='ZONE 15'
               1400-3100,18000-18900,19600-20400='ZONE 16'
                     100-1300,19000-<19600,56000='ZONE 17'
                       29000-<29100,59000-<59500='ZONE 18'
                               29100,57000-58500='ZONE 19'
                                     51000-55000='ZONE 20'
                                     45000-50000='ZONE 21'
                                     75000-75800='ZONE 22'
                                     72500-73200='ZONE 23'
                                     70100-71000='ZONE 24'
                       68400-<68800,68900-<70100='ZONE 25'
                         67500-67700,68100-68300='ZONE 26'
                                     65200-65600='ZONE 27'
                                     64000-65100='ZONE 28'
                                     62800-63900='ZONE 29'
                                    65700-<66200='ZONE 30'
                               62500-62700,66200='ZONE 31'
        85400-<85600,88700-<89000,90302-90400='ZONE 32'
                       85600-<85900,86700-<86900='ZONE 33'
                                4000,86900-88600='ZONE 34'
                        82500-<82700,85900-86600='ZONE 35'
        85000-<85400,90000-90301,92900-<93100='ZONE 36'
                              82700-<83200,83300='ZONE 37'
                               77500,80000-80700='ZONE 38';
run;
```

```
proc format;
    value fcode    1,2='INSIDE CMA BY Census Tract'
                     3='REST OF CMA'
                     4='REST OF CANADA'
                     5='NO USUAL POW IN CANADA'
                     6='OUTSIDE CMA'
                     7='OUTSIDE CANADA'
                     8='NOT STATED'     ;      RUN   ;
  PROC SORT;      BY CODE;

PROC FREQ DATA=LABOUR.INDGRP81  FORMCHAR(1,2,7)='    '
         ORDER=FORMATTED;
        TITLE 'TOTAL TRIPS    INDUSTRY';
  TABLES ORIG*DEST / NOROW NOCOL NOPERCENT NOCUM
            OUT=LABOUR.TOTAL;
     WEIGHT T;       BY CODE;
     FORMAT ORIG DEST  FZONE.  ;
     FORMAT CODE FCODE.  ;

PROC FREQ DATA=LABOUR.INDGRP81  FORMCHAR(1,2,7)='    '
        ORDER=FORMATTED;
       TITLE 'MANUFACTURING AND PRIMARY  INDUSTRY'   ;
  TABLES ORIG*DEST / NOROW NOCOL NOPERCENT NOCUM
            OUT=LABOUR.MANUFPR   ;
     WEIGHT M;       BY CODE;
     FORMAT ORIG  DEST  FZONE.  ;
     FORMAT CODE FCODE.  ;

PROC FREQ DATA=LABOUR.INDGRP81  FORMCHAR(1,2,7)='    '
        ORDER=FORMATTED;
       TITLE 'CONSTRUCTION AND TRANSP-COMM  INDUSTRY' ;
  TABLES ORIG*DEST / NOROW NOCOL NOPERCENT NOCUM
           OUT=LABOUR.CONSTRAN   ;
     WEIGHT S;       BY CODE;
     FORMAT ORIG  DEST  FZONE.  ;
     FORMAT CODE FCODE.  ;

PROC FREQ DATA=LABOUR.INDGRP81  FORMCHAR(1,2,7)='    '
         ORDER=FORMATTED;
       TITLE 'TRADE    INDUSTRY'  ;
  TABLES ORIG*DEST / NOROW NOCOL NOPERCENT NOCUM
           OUT=LABOUR.TRADE  ;
      WEIGHT L;       BY CODE;
      FORMAT ORIG  DEST  FZONE.  ;
```

```
      FORMAT CODE FCODE.  ;


PROC FREQ DATA=LABOUR.INDGRP81  FORMCHAR(1,2,7)='   '
         ORDER=FORMATTED;
    TITLE ' FIRE, COMMUNITY AND P.SERVICE  INDUSTRY' ;
  TABLES ORIG*DEST /NOROW NOCOL NOPERCENT NOCUM
         OUT=LABOUR.FIRECOM;
      WEIGHT F;    BY CODE;
      FORMAT ORIG DEST FZONE. ;
      FORMAT CODE FCODE.  ;


PROC FREQ DATA=LABOUR.INDGRP81 FORMCHAR(1,2,7)='   '
         ORDER=FORMATTED;
      TITLE 'PUBLIC ADMIN. AND DEFENCE  INDUSTRY'  ;
  TABLES ORIG*DEST /NOCOL NOCUM NOPERCENT NOROW
       OUT=LABOUR.PUBDEF;
      WEIGHT P;  BY CODE;
      FORMAT ORIG DEST FZONE. ;
      FORMAT CODE FCODE. ;      RUN;


proc format;
    value fzon
                        99999='EXTD'
             6200-7000,7700,7800,12800-13100,
           5100-6100,13200-13700,14200-14400,
  4000,3200-3900,4100-5000,14500,14900,15000='D1'
         13800-14100,14600-14800,15100-17800,
11100-11300,11600-12700,22000-22400,
                36000-37000,38500,40000-40400,
                17900,20500-21900,22500-24900='D2'
7900-8400,9500-9600,10400-11000,11400-<11600,35000-35600,
               7100-7600,8500-9300,30000-31700,
                                   32000-32900,
     9400,9700-10300,33000,34000,38000-<38400='D3'
                      26400-27200,27700-28400,
                      27300-27600,61000-61900,
                     25000-26300,60000-<60600='D4'
                      39000-39700,43000-44000,
                      28500-28800,41000-42100,
                                   51000-55000,
                                   45000-50000='D5'
            1400-3100,18000-18900,19600-20400,
                  100-1300,19000-<19600,56000,
                    29000-<29100,59000-<59500,
                           29100,57000-58500='D6'
                                   75000-75800,
```

```
                                      72500-73200,
                                      70100-71000='D9'
                          68400-68800,68900-<70100,
                           67500-67700,68100-68300='D8'
                                      65200-65600,
                                      64000-65100,
                                      62800-63900,
                                     65700-<66200,
                                 62500-62700,66200='D7'
                         85600-<85900,86700-<86900,
                                      86900-88600,
                          82500-<82700,85900-86600='D10'
               85400-<85600,88700-<89000,90300-90400,
          85000-<85400,90000-<90300,92600,92900-<93100='D11'
                                 82700-83200,83300,
                                 77500,80000-80700='D12' ;run;


proc format;
    value fcod  1,2='INSIDE CMA BY CENSUS TRACTS'
                  3='REST OF CMA'
                  4='AT HOME'
                  5='NO USUAL POW IN CMA'
                  6='OUTSIDE CMA'
                  7='OUTSIDE CANADA'
                  8='NOT STATED'    ;  RUN ;
  PROC SORT;       BY CODE;


PROC FREQ DATA=LABOUR.INDGRP81  FORMCHAR(1,2,7)='    '
         ORDER=FORMATTED;
       TITLE 'TOTAL TRIPS    INDUSTRY';
  TABLES ORIG*DEST / NOROW NOCOL NOPERCENT NOCUM
            OUT=LABOUR.TOTAL2;
     WEIGHT T;       BY CODE;
     FORMAT ORIG DEST  FZON.  ;
     FORMAT CODE FCOD.  ;


PROC FREQ DATA=LABOUR.INDGRP81  FORMCHAR(1,2,7)='    '
        ORDER=FORMATTED;
      TITLE 'MANUFACTURING AND PRIMARY  INDUSTRY'  ;
  TABLES ORIG*DEST / NOROW NOCOL NOPERCENT NOCUM
            OUT=LABOUR.MANUFPR2  ;
     WEIGHT M;       BY CODE;
     FORMAT ORIG  DEST  FZON.  ;
     FORMAT CODE FCOD.  ;
```

```
PROC FREQ DATA=LABOUR.INDGRP81  FORMCHAR(1,2,7)='    '
        ORDER=FORMATTED;
      TITLE 'CONSTRUCION AND TRANSP-COMM  INDUSTRY' ;
  TABLES ORIG*DEST / NOROW NOCOL NOPERCENT NOCUM
         OUT=LABOUR.CONSTRN2  ;
     WEIGHT S;      BY CODE;
     FORMAT ORIG  DEST  FZON.  ;
     FORMAT CODE FCOD.  ;


PROC FREQ DATA=LABOUR.INDGRP81  FORMCHAR(1,2,7)='    '
         ORDER=FORMATTED;
      TITLE 'TRADE    INDUSTRY'  ;
  TABLES ORIG*DEST / NOROW NOCOL NOPERCENT NOCUM
         OUT=LABOUR.TRADE2  ;
      WEIGHT L;      BY CODE;
      FORMAT ORIG  DEST  FZON.  ;
      FORMAT CODE FCOD.  ;


PROC FREQ DATA=LABOUR.INDGRP81  FORMCHAR(1,2,7)='    '
         ORDER=FORMATTED;
    TITLE ' FIRE, COMMUNITY AND P.SERVICE  INDUSTRY' ;
  TABLES ORIG*DEST /NOROW NOCOL NOPERCENT NOCUM
         OUT=LABOUR.FIRECOM2;
      WEIGHT F;    BY CODE;
      FORMAT ORIG DEST FZON. ;
      FORMAT CODE FCOD.  ;


PROC FREQ DATA=LABOUR.INDGRP81 FORMCHAR(1,2,7)='    '
         ORDER=FORMATTED;
      TITLE 'PUBLIC ADMIN. AND DEFENCE  INDUSTRY'  ;
  TABLES ORIG*DEST /NOCOL NOCUM NOPERCENT NOROW
       OUT=LABOUR.PUBDEF2;
      WEIGHT P;  BY CODE;
      FORMAT ORIG DEST FZON. ;
      FORMAT CODE FCOD. ; RUN; ENDSAS;
/*
//
```

APPENDIX A2: IML-SAS PROGRAM.

Sample program for matrix handling: 1981 StatsCan OD matrix by industry.

```
PROC IML;

A={1370 65 0 140 105 120 40 155 35 ,
2975 2900 60 300 585 180 185 550 75 ,
1500 725 330 200 280 125 90 445 25 ,
530 85 0 35 330 15 60 45 10 ,
3050 135 10 1160 355 460 270 495 105 ,
1940 150 5 260 1950 140 375 230 50 ,
3025 190 0 945 360 1520 335 735 260 ,
1050 45 5 210 360 115 2130 190 75 ,
4235 205 15 850 485 565 385 2340 140 ,
1630 85 0 645 215 670 585 390 2340 ,
945 15 5 235 140 300 80 480 220 ,
585 25 0 200 110 175 440 85 280 ,
1235 210 25 185 285 215 305 260 115 };


AX={295,640,260,80,740,650,775,350,1140,575,225,260,440};
B=1185/6430;
C=935/6430;
D=600/6430;
D8=ROUND(AX*B);
D9=ROUND(AX*C);
D12=ROUND(AX*D);

PRINT D8 D9 D12;
C8=ROUND(.58*AX);
C3={60,250,835,630,240,130,195,135,220,375,990,1345,480};
C5={70,160,60,25,255,215,265,110,265,195,45,45,60};
C6={125,360,370,130,230,280,205,290,295,305,195,355,.};
C=C8+C3+C5;
T=A[,+];
U=1.000;
F2=C/T+U;
R1=A[1,]*F2[1,];
R2=A[2,]*F2[2,];
R3=A[3,]*F2[3,];
R4=A[4,]*F2[4,];
R5=A[5,]*F2[5,];
```

```
R6=A[6,]*F2[6,];
R7=A[7,]*F2[7,];
R8=A[8,]*F2[8,];
R9=A[9,]*F2[9,];
R10=A[10,]*F2[10,];
R11=A[11,]*F2[11,];
R12=A[12,]*F2[12,];
R13=A[13,]*F2[13,];
A2=ROUND(R1//R2//R3//R4//R5//R6//R7//R8//R9//R10//R11//R12//
R13);
A3=A2||D8||D9||D12||C6;
A4=A3[,+];
A5=A3||A4;
A6=A5[+,];
ODA=A5//A6;
RO={D1 D10 D11 D2 D3 D4 D5 D6 D7 D8 D9 D12 EXT TOTAL};
CO={D1 D10 D11 D2 D3 D4 D5 D6 D7 D8 D9 D12 EXT TOTAL};
CO2={D6 D7 D8 D9 D12 EXT TOTAL};
ODA1=ODA[,1:7];
ODA2=ODA[,8:14];

PRINT 'ORIGIN-DESTINATION HBW TRIPS. PUBLIC ADM. & DEFENCE
INDUSTRY',
     ODA[ROWNAME=RO COLNAME=CO FORMAT=6.];

PRINT 'ORIGIN-DESTINATION HBW TRIPS. PUBLIC ADM. & DEFENCE
INDUSTRY',
     ODA1[ROWNAME=RO COLNAME=CO FORMAT=6.];

PRINT 'ORIGIN-DESTINATION HBW TRIPS. PUBLIC ADM. & DEFENCE
INDUSTRY',
     ODA2[ROWNAME=RO COLNAME=CO2 FORMAT=6.];
/*
//
```

APPENDIX A3: 1981 ELF OD MATRICES by INDUSTRY.

These matrices were retrieved from StatsCan special magnetic tapes for ELF for 1981 aggregated by district (D), they are complimentary to Tables 3.26 to 3.31. The program in Appendix A1 was used.

OD1	D1	D10	D11	D2	D3	D4	D5
D1	3374	373	95	1659	835	779	1008
D10	4537	9899	1797	2347	2218	1303	2330
D11	1940	3069	1835	804	934	787	1047
D12	1563	858	178	624	4009	316	2883
D2	5136	667	198	14691	2155	6618	5009
D3	6529	668	160	3866	11997	1795	6943
D4	3962	875	226	8579	2025	16739	5404
D5	3457	402	98	4097	2659	2512	19351
D6	4362	832	367	4865	2080	4832	2676
D7	2189	412	80	4355	1263	3926	5612
D8	830	193	81	1168	459	1941	1176
D9	1483	225	41	2199	1033	1371	8184
EXT	1827	1367	522	1536	1743	1512	3839
TL	41189	19840	5678	50790	33410	44431	65462

OD2	D6	D7	D8	D9	D12	EXT	TOTAL
D1	947	61	147	186	146	160	9770
D10	2499	230	226	285	225	960	28856
D11	2314	170	85	107	84	1405	14581
D12	389	73	53	67	53	540	11606
D2	3323	667	499	629	496	610	40698
D3	1442	331	357	450	354	760	35652
D4	5635	1068	490	619	487	530	46639
D5	1454	510	222	280	220	660	35922
D6	15669	547	395	499	393	600	38117
D7	1795	5841	284	358	282	430	26827
D8	4510	660	65	82	65	600	11830
D9	951	1995	73	92	73	685	18405
EXT	2910	722	149	187	148	.	16462
TL	43838	12875	3045	3841	3026	7940	335365

TABLE A1: 1981 CMA ELF; OD MATRIX by DISTRICT.

Manufacturing industry; HBW person-trips.

Source: 1981 StatsCan customers service magnetic tapes.

OD1	D1	D10	D11	D2	D3	D4	D5
D1	1573	75	0	161	121	138	46
D10	3273	3190	66	330	644	198	204
D11	1922	929	423	256	359	160	115
D12	865	139	0	57	538	24	98
D2	3517	156	12	1337	409	530	311
D3	2215	171	6	297	2226	160	428
D4	3399	213	0	1062	404	1708	376
D5	1163	50	6	233	399	127	2358
D6	4761	230	17	956	545	635	433
D7	1855	97	0	734	245	762	666
D8	1400	22	7	348	207	445	119
D9	1059	45	0	362	199	317	797
EXT	1581	269	32	237	365	275	391
TL	28583	5586	569	6370	6661	5479	6342

OD2	D6	D7	D8	D9	D12	EXT	TOTAL
D1	178	40	54	43	28	125	2582
D10	605	83	118	93	60	360	9224
D11	570	32	48	38	24	370	5246
D12	73	16	15	12	7	130	1974
D2	571	121	136	108	69	230	7507
D3	263	57	120	95	61	280	6379
D4	826	292	143	113	72	205	8813
D5	210	83	65	51	33	290	5068
D6	2631	157	210	166	106	295	11142
D7	444	2662	106	84	54	305	8014
D8	711	326	41	33	21	195	3875
D9	154	507	48	38	24	355	3905
EXT	333	147	81	64	41	.	3816
TL	7569	4523	1185	938	600	3140	77545

TABLE A2: 1981 CMA ELF; OD MATRIX by DISTRICT.

Public administration and defence by industry; HBW person-trips.

Source: 1981 StatsCan customers service magnetic tapes.

OD1	D1	D10	D11	D2	D3	D4	D5
D1	3535	70	6	337	512	140	471
D10	7029	4643	481	1104	1716	540	1692
D11	3786	930	1055	461	732	439	674
D12	1858	397	44	309	1660	125	1734
D2	5446	258	76	3660	1569	1025	2366
D3	7326	225	51	1014	5873	327	3914
D4	5821	321	127	2320	1490	4737	3319
D5	5228	159	5	885	1374	341	11137
D6	5952	401	302	1934	1614	1591	2613
D7	3936	211	78	2098	1133	1399	3948
D8	1493	144	96	714	409	1164	1108
D9	2405	66	16	749	684	651	4587
EXT	3365	704	197	852	1429	803	3069
TL	57180	8529	2534	16437	20195	13282	40632

OD2	D6	D7	D8	D9	D12	EXT	TOTAL
D1	297	52	78	120	84	150	5852
D10	1193	184	153	236	165	845	19981
D11	798	81	62	95	66	755	9934
D12	286	66	28	43	30	410	6990
D2	1095	345	194	299	209	545	17087
D3	873	191	218	336	235	650	21233
D4	2102	884	223	343	240	800	22727
D5	418	253	147	226	158	845	21176
D6	4593	441	219	337	236	965	21198
D7	1218	5492	211	325	227	970	21246
D8	1324	546	46	71	49	590	7754
D9	404	1244	61	94	66	1365	12392
EXT	894	619	130	200	140	.	12402
TL	15495	10398	1770	2725	1905	8890	199972

TABLE A3: 1981 CMA ELF; OD MATRIX by DISTRICT

Construction, transport, and community by industry; HBW person-trips.

Source: 1981 StatsCan customers service magnetic tapes.

OD1	D1	D10	D11	D2	D3	D4	D5
D1	3069	90	22	916	382	337	500
D10	3198	10727	1239	1488	1212	664	1090
D11	1457	1804	3234	668	408	841	685
D12	971	1230	129	507	1499	280	1284
D2	4907	384	55	9754	1754	2593	2791
D3	6163	314	88	3115	10690	1180	3804
D4	3292	373	110	4400	911	10414	2787
D5	2565	199	70	2743	1789	1444	18127
D6	3178	371	174	2562	867	3406	1264
D7	1746	337	67	2751	932	2880	3863
D8	601	150	50	1032	271	2355	822
D9	698	142	61	1042	486	1173	5442
EXT	1015	634	187	886	785	979	1858
TL	32860	16755	5486	31864	21986	28546	44317

OD2	D6	D7	D8	D9	D12	EXT	TOTAL
D1	472	101	99	129	65	80	6262
D10	1090	138	207	269	136	675	22133
D11	1604	69	66	85	43	670	11634
D12	345	162	21	28	14	200	6670
D2	1798	504	342	444	224	355	25905
D3	904	182	332	431	217	405	27825
D4	3621	1032	318	413	208	320	28199
D5	555	458	210	273	138	440	29011
D6	10699	491	267	347	175	295	24096
D7	1246	10825	258	335	169	585	25994
D8	2706	1022	59	77	39	195	9379
D9	435	2539	76	99	50	500	12743
EXT	1246	734	88	115	58	.	8585
TL	26721	18257	2343	3045	1536	4720	238436

TABLE A4: 1981 CMA ELF; OD MATRIX by DISTRICT.

Trade industry; HBW person-trips.

Source: 1981 StatsCan customers service, magnetic tapes.

OD1	D1	D10	D11	D2	D3	D4	D5
D1	19016	554	16	2279	1530	510	597
D10	17121	18947	648	2877	2904	796	1019
D11	7461	3862	4012	1276	991	812	485
D12	5200	1336	0	704	2537	253	957
D2	23802	1123	93	24282	4623	2759	3326
D3	25901	857	54	6357	23735	603	3679
D4	14208	714	60	7208	2001	14601	3157
D5	12821	473	27	4806	4483	1602	24890
D6	14806	731	131	5174	2249	3471	1484
D7	7917	405	39	4459	1574	4211	3958
D8	3248	121	43	1546	622	1874	484
D9	4947	232	50	2005	1159	1491	6086
EXT	5678	1296	156	1906	1547	923	1784
TL	162126	30651	5329	64879	49955	33906	51906

OD2	D6	D7	D8	D9	D12	EXT	TOTAL
D1	1330	141	331	434	274	610	27622
D10	2240	278	414	544	343	1300	49431
D11	2865	171	133	174	110	1650	24002
D12	506	81	52	68	43	640	12377
D2	4830	987	764	1003	632	1450	69674
D3	1815	490	632	830	524	1180	66657
D4	6968	1461	538	707	446	745	52814
D5	1516	871	375	492	310	955	53621
D6	21268	579	636	836	527	770	52662
D7	2671	16368	468	614	387	965	44036
D8	4535	1175	63	83	52	635	14481
D9	927	4212	104	136	86	1060	22495
EXT	2178	875	171	225	142	.	16881
TL	53649	27689	4681	6146	3876	11960	506753

TABLE A5: 1981 CMA ELF; OD MATRIX by DISTRICT.

FIRE, community, and public service industry; HBW person-trips.

Source: 1981 StatsCan customers service magnetic tapes.

OD1	D1	D10	D11	D2	D3	D4	D5
D1	30443	1113	138	5453	3316	1866	2535
D10	35101	47331	4136	8216	8490	3556	6338
D11	17085	10618	10362	3564	3361	2993	2827
D12	10277	3800	317	2110	10491	961	7214
D2	42856	2623	416	54064	10448	13648	13786
D3	48156	2194	346	14829	54699	3965	18558
D4	30492	2532	495	23575	6799	48442	14884
D5	25379	1261	189	12985	10587	6008	75868
D6	33017	2558	948	15510	7416	14171	8442
D7	17614	1495	263	14407	5263	13162	17900
D8	7731	663	246	4834	1954	7655	3789
D9	10924	689	175	6263	3602	4826	25275
EXT	13816	4231	1067	5404	5880	4423	10794
TL	322891	81108	19098	171214	132306	125676	208210

OD2	D6	D7	D8	D9	D12	EXT	TOTAL
D1	3272	426	710	910	599	1135	51916
D10	7726	875	1113	1426	939	4095	129342
D11	8174	549	391	501	330	4825	65580
D12	1638	335	174	222	146	1980	39665
D2	11718	2623	2067	2648	1744	3190	161831
D3	5193	1250	1670	2140	1409	3260	157669
D4	19246	4780	1720	2203	1451	2615	159234
D5	4211	2133	1023	1311	863	3125	144943
D6	54990	2178	1707	2187	1440	2885	147449
D7	7380	41194	1328	1702	1121	3250	126079
D8	13882	3653	272	348	229	2200	47456
D9	2787	10312	364	467	308	4015	70007
EXT	7480	3114	622	797	525	.	58153
TL	147697	73422	13161	16862	11104	36575	1.36E6

TABLE A6: 1981 CMA ELF; OD MATRIX by DISTRICT.

Total HBW person-trips (by industry).

Source: 1981 StatsCan customers service magnetic tapes.

APPENDIX B

Supplemental to Chapter 3, Part C

APPENDIX B1: SAMPLE PROGRAM SHOWING ZONES.

By purpose and time of day.

This program presents zonal equivalence between STCUM (1496 zones) and the research (38 zones), one of the 1496 zones is misplaced (located at the boundary, between Zs 9 and 10. This is of marginal consequence if any at all.

Furthermore, the selection of modal priorities in a multi-modal trip (a total of 13 priority order) are also presented.

```
DATA A1;
INFILE ENQ87;
  INPUT @13 PURP 1.
        @16 AUTO 1.
        @35 TM PIB2. @37 MODE PIB2.
        @39 XP PD3.2  ;
  ID+1;
DATA A2;
INFILE REFSPAT;
  INPUT   @27 ZO IB2.  @47 ZD IB2. ;
  ID+1;
DATA A3;
MERGE A1 A2 BY ID;
     LABEL ZO='TRIP ORIGINS' ZD='TRIP DESTINATIONS'  ;
     LABEL TM='AM TIME OF DEPARTURE' PURP='TRIP PURPOSE';
DATA A4;
SET A3;
IF      MODE='.... 1... .... ....' B THEN MOD=5 ;
ELSE IF MODE='.... ...1 .... ....' B THEN MOD=8 ;
```

```
ELSE IF MODE='.1.. .... .... ....' B THEN MOD=2 ;
ELSE IF MODE='..1. .... .... ....' B THEN MOD=3 ;
ELSE IF MODE='...1 .... .... ....' B THEN MOD=4 ;
ELSE IF MODE='.... .1.. .... ....' B THEN MOD=6 ;
ELSE IF MODE='.... ..1. .... ....' B THEN MOD=7 ;
ELSE IF MODE='.... .... .... 1...' B THEN MOD=13;
ELSE IF MODE='1... .... .... ....' B THEN MOD=1 ;
ELSE IF MODE='.... .... 1... ....' B THEN MOD=9 ;
ELSE IF MODE='.... .... ..1. ....' B THEN MOD=11;
ELSE IF MODE='.... .... ...1 ....' B THEN MOD=12;
ELSE IF MODE='.... .... .1.. ....' B THEN MOD=10;
ELSE MOD= 14;
DROP MODE;
   PROC FORMAT;
        VALUE FM            5,8   ='AUT'
                    2,3,4,6,7,13 ='SRFTR'
                            1,9   ='FXTR'
                            ALL   ='ALLMD'    ;
         VALUE FA      1     ='AUTP'
                       2     ='AUTD';       RUN;
   PROC FORMAT;
        VALUE FP       1   ='WK'
                       2   ='EDN'
                       3   ='HMR'
                   4,5,6   ='OTH'
                       7   ='NOWK'
                     1-6   ='ALL'  ;
RUN;
PROC FORMAT;
      VALUE FZ                             OTHER='EXT'
 1-9,11,12,18-41,44,56-78,462,463,559         ='Z1'
        10,13-17,42,43,45-55,79-93,799-802='Z2'
                    803-824,1018,1019,1136='Z3'
                   765-768,770,774,777-798='Z4
       375-397,400-445,453-455,461,687-712='Z5'
 398,399,446-452,456-460,470,471,477-483,
          489-504,507-509,512-524,542-550='Z6'
                  525-541,551-558,560-588='Z7'
                               336-373    ='Z8'
  279,281,289,290,292-301,304,306,308-335,
    464-469,472-476,484-488,505,506,510,511='Z9'

179-195,208,209,273-278,280,282-288,291,302,303,305,307='Z10
'
196-198,201-207,210-234,237-239,242-270,374,589-595,598,600=
'Z11'
235,236,240,241,271,272,596,597,599,601-625,628-644,649-671=
'Z12'
                713-764,769,771-773,775,776='Z13'
```

```
                    626-627,645-648,825-860='Z14'
                            672-686,861-911='Z15'
912-929,931-943,958-972,975-985,999-1008,1020-1026='Z16'
   930,944-957,973,974,986-998,1009-1017,1027-1042='Z17'
                        1043-1065,1071-1098='Z18'
                        1066-1070,1099-1135='Z19'
                104-123,144-158,178,199,200='Z20'
                     94-103,124-143,159-177='Z21'
                        1321-1329,1470,1478='Z22'
                        1427,1428,1431-1437='Z23'
                             1438-1442,1447='Z24'
                                  1448-1457='Z25'
                        1458-1469,1482,1483='Z26'
                                  1330-1342='Z27'
                                  1350-1365='Z28'
                        1369-1379,1385-1404='Z29'
              1343-1349,1366-1368,1380-1384='Z30'
                                  1405-1425='Z31'
          1251-1264,1274-1276,1278,1279,1472='Z32'
          1237-1241,1245,1247-1250,1265-1271='Z33'
                                  1137-1194='Z34'
                   1195-1236,1242-1244,1246='Z35'
          1272,1273,1277,1280-1289,1473,1474='Z36'
                        1290,1291,1296-1302='Z37'
                        1303-1314,1316-1319='Z38';
RUN;
  PROC FORMAT;
       VALUE FD             Z1,Z2,Z3           ='D1'
                            Z4,Z5,Z13          ='D2'
                            Z6,Z7,Z8,Z9        ='D3'
                            Z12,Z14,Z15        ='D4'
                            Z10,Z11,Z20,Z21    ='D5'
                            Z16,Z17,Z18,Z19    ='D6'
                         Z27,Z28,Z29,Z30,Z31   ='D7'
                           Z25,Z26             ='D8'
                           Z22,Z23,Z24         ='D9'
                            Z33,Z34,Z35        ='D10'
                            Z32,Z36            ='D11'
                            Z37,Z38            ='D12'
                                 OTHER         ='EXT';
RUN;
   PROC FORMAT; VALUE FSD
                              D1,D2,D3          ='SD1'
                              D5                ='SD2'
                              D4,D6             ='SD3'
                              D7                ='SD4'
                              D8,D9             ='SD5'
                              D10,D11,D12       ='SD6'
                                  OTHER        ='EXT' ;  RUN;
```

```
    PROC FORMAT; VALUE FTA
                        600-659  ='T6'
                        700-759  ='T7'
                        800-859  ='T8'
                        730-744  ='T73'
                        745-759  ='T74'
                        800-814  ='T81'
                        815-829  ='T82'
                        830-844  ='T83'
                        845-859  ='T84'
                        ALL      ='T24'   ;
                VALUE FTB
                        600-659  ='T6'
                        700-759  ='T7'
                        800-859  ='T8'
                        ALL      ='T24'   ;
                VALUE FTC
                        ALL      ='T24'   ;
RUN;
  PROC SORT;   BY PURP TM MOD AUTO ;
                 RUN;
DATA TRIP.WK;
        SET A4;
   PROC FREQ  DATA=TRIP.WK FORMCHAR(1,2,7)='   ';
            ORDER=FORMATTED;
        TITLE 'STCUM OD87, WORK TRIP ZONE MATRICES'  ;
  TABLES ZO*ZD/NOROW NOCOL NOPERCENT NOCUM  OUT=TRIP.WORK;
         WEIGHT XP;  BY PURP TM MOD AUTO ;
    FORMAT ZO ZD FZ. ;
    FORMAT PURP FP.  ;
    FORMAT MOD FM.  ;
    FORMAT AUTO FA.  ;
    FORMAT TM FTA. ;
RUN;
DATA TRIP.EDN;
       SET A4;
      PROC FREQ DATA=TRIP.EDN FORMCHAR(1,2,7)='   ';
           ORDER=FORMATTED;
       TITLE 'STCUM OD87, EDUCATION TRIP ZONE MATRICES'  ;
  TABLES ZO*ZD/NOROW NOCOL NOPERCENT NOCUM  OUT=TRIP.EDCTN;
        WEIGHT XP;  BY PURP TM MOD ;
      FORMAT ZO ZD FZ. ;
      FORMAT PURP FP.  ;
      FORMAT MOD FM.  ;
      FORMAT TM FTB. ;
RUN;
DATA TRIP.HMRET;
         SET A4;
     PROC FREQ  DATA=TRIP.HMRET FORMCHAR(1,2,7)='   ';
```

```
            ORDER=FORMATTED;
    TITLE 'STCUM OD87, RETURN HOME, TRIP ZONE MATRICES'  ;
 TABLES ZO*ZD/NOROW NOCOL NOPERCENT NOCUM  OUT=TRIP.HMRTN;
         WEIGHT XP;  BY PURP TM MOD ;
      FORMAT ZO ZD FZ. ;
      FORMAT PURP FP.  ;
      FORMAT MOD FM.  ;
      FORMAT TM FTC. ;
RUN;
DATA TRIP.OTHER;
         SET A4;
   PROC FREQ  DATA=TRIP.OTHER FORMCHAR(1,2,7)='   ';
          ORDER=FORMATTED;
    TITLE 'STCUM OD87, OTHER WORK TRIP ZONE MATRICES'  ;
       TITLE2 '(RECREATION, SHOPPING AND OTHERS)  ;
  TABLES ZO*ZD/NOROW NOCOL NOPERCENT NOCUM  OUT=TRIP.OTHERS;
       WEIGHT XP;  BY PURP TM MOD ;
      FORMAT ZO ZD FZ. ;
      FORMAT PURP FP.  ;
      FORMAT MOD FM.  ;
      FORMAT TM FTB. ;
RUN;
DATA TRIP.ALL;
       SET A4;
      PROC FREQ  DATA=TRIP.ALL FORMCHAR(1,2,7)='   ';
           ORDER=FORMATTED;
       TITLE 'STCUM OD87, WORK TRIP ZONE MATRICES'  ;
 TABLES ZO*ZD/NOROW NOCOL NOPERCENT NOCUM  OUT=TRIP.TOTAL;
       WEIGHT XP;  BY PURP TM MOD AUTO ;
      FORMAT ZO ZD FZ. ;
      FORMAT PURP FP.  ;
      FORMAT MOD FM.  ;
      FORMAT AUTO FA.  ;
      FORMAT TM FTB. ;
RUN;
DATA TRIP.NOWK;
      SET A4;
    PROC FREQ  DATA=TRIP.NOWK FORMCHAR(1,2,7)='   ';
          ORDER=FORMATTED;
     TITLE 'STCUM OD87, NO WORK REPORTED, ZONE MATRICES'  ;
  TABLES ZO*ZD/NOROW NOCOL NOPERCENT NOCUM  OUT=TRIP.NOWK;
          WEIGHT XP;
RUN;
 DATA TRIP.WK;
      SET A4;
   PROC FREQ  DATA=TRIP.WK FORMCHAR(1,2,7)='   ';
          ORDER=FORMATTED;
     TITLE 'STCUM OD87, WORK TRIP DISTRICT MATRICES'  ;
 TABLES ZO*ZD/NOROW NOCOL NOPERCENT NOCUM  OUT=TRIP.WORK;
```

```
     WEIGHT XP;  BY PURP TM MOD AUTO ;
      FORMAT ZO ZD FD. ;
      FORMAT PURP FP.  ;
      FORMAT MOD FM.  ;
      FORMAT AUTO FA.  ;
      FORMAT TM FTB. ;
RUN;
 DATA TRIP.EDN;
        SET A4;
   PROC FREQ DATA=TRIP.EDN FORMCHAR(1,2,7)='   ';
        ORDER=FORMATTED;
   TITLE 'STCUM OD87, EDUCATION TRIP DISTRICT MATRICES'  ;
 TABLES ZO*ZD/NOROW NOCOL NOPERCENT NOCUM  OUT=TRIP.EDCTN;
     WEIGHT XP;  BY PURP TM MOD ;
      FORMAT ZO ZD FD. ;
      FORMAT PURP FP.  ;
      FORMAT MOD FM.  ;
      FORMAT TM FTB. ;
RUN;
 DATA TRIP.HMRET;
        SET A4;
  PROC FREQ  DATA=TRIP.HMRET FORMCHAR(1,2,7)='   ';
           ORDER=FORMATTED;
    TITLE 'STCUM OD87, RETURN HOME, TRIP DISTRICT MATRICES';
  TABLES ZO*ZD/NOROW NOCOL NOPERCENT NOCUM  OUT=TRIP.HMRTN;
      WEIGHT XP;  BY PURP TM MOD ;
       FORMAT ZO ZD FD. ;
       FORMAT PURP FP.  ;
       FORMAT MOD FM.  ;
       FORMAT TM FTC. ;
RUN;
 DATA TRIP.OTHER;
        SET A4;
   PROC FREQ  DATA=TRIP.OTHER FORMCHAR(1,2,7)='   ';
        ORDER=FORMATTED;
    TITLE 'STCUM OD87, OTHER WORK TRIP DISTRICT MATRICES'  ;
    TITLE2 '(RECREATION, SHOPPING AND OTHERS)  ;
  TABLES ZO*ZD/NOROW NOCOL NOPERCENT NOCUM  OUT=TRIP.OTHERS;
    WEIGHT XP;  BY PURP TM MOD ;
      FORMAT ZO ZD FD. ;
      FORMAT PURP FP.  ;
      FORMAT MOD FM.  ;
      FORMAT TM FTB. ;
RUN;
 DATA TRIP.ALL;
        SET A4;
  PROC FREQ  DATA=TRIP.ALL FORMCHAR(1,2,7)='   ';
        ORDER=FORMATTED;
     TITLE 'STCUM OD87, WORK TRIP DISTRICT MATRICES'  ;
```

```
  TABLES ZO*ZD/NOROW NOCOL NOPERCENT NOCUM  OUT=TRIP.TOTAL;
     WEIGHT XP;  BY PURP TM MOD AUTO ;
      FORMAT ZO ZD FD. ;
      FORMAT PURP FP.  ;
      FORMAT MOD FM.  ;
      FORMAT AUTO FA.  ;
      FORMAT TM FTB. ;
RUN;
 DATA TRIP.NOWK;
       SET A4;
   PROC FREQ  DATA=TRIP.NOWK FORMCHAR(1,2,7)='    ';
         ORDER=FORMATTED;
    TITLE 'STCUM OD87, NO WORK REPORTED, DISTRICT MATRICES';
  TABLES ZO*ZD/NOROW NOCOL NOPERCENT NOCUM  OUT=TRIP.NOWK;
        WEIGHT XP;
RUN;
 DATA TRIP.WK;
       SET A4;
  PROC FREQ  DATA=TRIP.WK FORMCHAR(1,2,7)='    ';
         ORDER=FORMATTED;
   TITLE 'STCUM OD87, WORK TRIP SUPER-DISTRICT MATRICES';
 TABLES ZO*ZD/NOROW NOCOL NOPERCENT NOCUM  OUT=TRIP.WORK;
     WEIGHT XP;  BY PURP TM MOD ;
     FORMAT ZO ZD FSD. ;
     FORMAT PURP FP.  ;
     FORMAT MOD FM.  ;
     FORMAT TM FTB. ;
RUN;
 DATA TRIP.EDN;
        SET A4;
    PROC FREQ DATA=TRIP.EDN FORMCHAR(1,2,7)='    ';
        ORDER=FORMATTED;
   TITLE 'STCUM OD87, EDUCATION TRIP SUPER-DISTRICT MATRICES';
 TABLES ZO*ZD/NOROW NOCOL NOPERCENT NOCUM  OUT=TRIP.EDCTN;
     WEIGHT XP;  BY PURP TM MOD ;
      FORMAT ZO ZD FSD. ;
      FORMAT PURP FP.  ;
      FORMAT MOD FM.  ;
      FORMAT TM FTB. ;
RUN;
 DATA TRIP.HMRET;
       SET A4;
   PROC FREQ  DATA=TRIP.HMRET FORMCHAR(1,2,7)='    ';
          ORDER=FORMATTED;
  TITLE  'STCUM  OD87,  RETURN  HOME  TRIP,  SUPER-  DISTRICT
MATRICES';
 TABLES ZO*ZD/NOROW NOCOL NOPERCENT NOCUM  OUT=TRIP.HMRTN;
     WEIGHT XP;  BY PURP TM MOD ;
      FORMAT ZO ZD FSD. ;
```

```
      FORMAT PURP FP.  ;
      FORMAT MOD FM.  ;
      FORMAT TM FTC. ;
RUN;
 DATA TRIP.OTHER;
       SET A4;
   PROC FREQ  DATA=TRIP.OTHER FORMCHAR(1,2,7)='    ';
          ORDER=FORMATTED;
   TITLE 'STCUM OD87, OTHER WORK TRIP, SUPER- DISTRICT
MATRICES';
      TITLE2 '(RECREATION, SHOPPING AND OTHERS)  ;
  TABLES ZO*ZD/NOROW NOCOL NOPERCENT NOCUM  OUT=TRIP.OTHERS;
      WEIGHT XP;  BY PURP TM MOD ;
       FORMAT ZO ZD FSD. ;
       FORMAT PURP FP.  ;
       FORMAT MOD FM.  ;
      FORMAT TM FTB. ;
RUN;
 DATA TRIP.ALL;
       SET A4;
   PROC FREQ  DATA=TRIP.ALL FORMCHAR(1,2,7)='    ';
          ORDER=FORMATTED;
  TITLE 'STCUM OD87, WORK TRIP, SUPER-DISTRICT MATRICES'  ;
 TABLES ZO*ZD/NOROW NOCOL NOPERCENT NOCUM  OUT=TRIP.TOTAL;
      WEIGHT XP;  BY PURP TM MOD ;
       FORMAT ZO ZD FSD. ;
       FORMAT PURP FP.  ;
       FORMAT MOD FM.  ;
       FORMAT TM FTB. ;
RUN;
 DATA TRIP.NOWK;
        SET A4;
   PROC FREQ  DATA=TRIP.NOWK FORMCHAR(1,2,7)='    ';
          ORDER=FORMATTED;
   TITLE  'STCUM  OD87,  NO  WORK  REPORTED,  SUPER-DISTRICT
MATRICES';
  TABLES ZO*ZD/NOROW NOCOL NOPERCENT NOCUM  OUT=TRIP.NOWK;
      WEIGHT XP;
RUN; ENDSAS;
/*
//
```

APPENDIX B2: 1987 OD PERSON-TRIPS BY PURPOSE.

SAS listing of 1987 OD person-trips, retrieved from STCUM, by origin (OR) and destination (DES) for the 38 research zones and an external (EXT) zone by purpose; where;

OPT = other purpose trip
HMT = home return trips
WKT = work trips
EDNT= education purpose trips
TOT = total trips.

The listing was transformed into tables, marices, and so on.

OR	DES	OPT	HMT	WKT	EDNT	TOT
EXT	EXT	5998	6043	3297	1227	16565
EXT	Z1	1025	2318	573	120	4036
EXT	Z10	277	1697	280	0	2254
EXT	Z11	602	4016	420	0	5038
EXT	Z12	584	5392	231	105	6312
EXT	Z13	264	4535	186	12	4997
EXT	Z14	431	5698	143	0	6272
EXT	Z15	436	8467	117	20	9040
EXT	Z16	552	6057	316	0	6925
EXT	Z17	444	4595	71	18	5128
EXT	Z18	419	5018	83	0	5520
EXT	Z19	161	2291	154	0	2606
EXT	Z2	803	1605	357	178	2943
EXT	Z20	420	6404	126	42	6992
EXT	Z21	460	3333	154	41	3988
EXT	Z22	279	3971	31	40	4321
EXT	Z23	293	4342	58	19	4712
EXT	Z24	502	7075	21	17	7615
EXT	Z25	155	5358	25	0	5538
EXT	Z26	239	4765	96	0	5100
EXT	Z27	200	2199	0	0	2399
EXT	Z28	521	5071	0	0	5592
EXT	Z29	810	5876	178	0	6864
EXT	Z3	212	1704	94	0	2010
EXT	Z30	252	4792	24	16	5084
EXT	Z31	116	3214	19	0	3349
EXT	Z32	210	4402	119	22	4753
EXT	Z33	291	4405	43	0	4739
EXT	Z34	604	8269	188	0	9061
EXT	Z35	995	8035	198	19	9247
EXT	Z36	351	9878	119	37	10385
EXT	Z37	281	3540	408	179	4408
EXT	Z38	360	3868	178	126	4532
EXT	Z4	455	2900	108	20	3483
EXT	Z5	729	7197	360	121	8407

EXT	Z6	627	5081	250	85	6043
EXT	Z7	597	4651	241	0	5489
EXT	Z8	438	4139	237	21	4835
EXT	Z9	456	4828	176	25	5485
Z1	EXT	2645	183	1915	141	4884
Z1	Z1	24313	20476	12036	5077	61902
Z1	Z10	783	3195	302	0	4280
Z1	Z11	1084	7116	1124	228	9552
Z1	Z12	1126	10238	880	159	12403
Z1	Z13	1189	8962	673	22	10846
Z1	Z14	393	4683	81	86	5243
Z1	Z15	677	8892	251	47	9867
Z1	Z16	1068	11118	715	74	12975
Z1	Z17	872	7715	194	0	8781
Z1	Z18	219	4177	191	0	4587
Z1	Z19	79	2365	148	16	2608
Z1	Z2	6617	9576	3738	1003	20934
Z1	Z20	583	8012	277	0	8872
Z1	Z21	793	7326	256	0	8375
Z1	Z22	56	1585	21	0	1662
Z1	Z23	37	1801	40	0	1878
Z1	Z24	51	1472	40	0	1563
Z1	Z25	112	1320	46	0	1478
Z1	Z26	111	2155	0	0	2266
Z1	Z27	0	997	19	0	1016
Z1	Z28	415	3949	77	0	4441
Z1	Z29	483	3892	168	0	4543
Z1	Z3	1287	4604	532	111	6534
Z1	Z30	74	2259	0	0	2333
Z1	Z31	103	2037	17	0	2157
Z1	Z32	237	3644	65	0	3946
Z1	Z33	177	4668	56	51	4952
Z1	Z34	786	8691	346	48	9871
Z1	Z35	1312	15712	243	19	17286
Z1	Z36	180	2888	64	21	3153
Z1	Z37	106	2293	21	0	2420
Z1	Z38	251	2831	20	0	3102
Z1	Z4	1922	8457	719	272	11370
Z1	Z5	4275	21371	1236	1155	28037
Z1	Z6	6965	24229	1698	1269	34161
Z1	Z7	1360	15435	946	236	17977
Z1	Z8	1084	8482	197	45	9808
Z1	Z9	1307	12072	599	528	14506
Z10	EXT	983	57	1312	40	2392
Z10	Z1	1428	392	2256	603	4679
Z10	Z10	9155	14649	3749	4272	31825
Z10	Z11	822	858	1545	202	3427
Z10	Z12	166	823	236	80	1305
Z10	Z13	230	681	180	20	1111
Z10	Z14	62	529	40	0	631
Z10	Z15	103	1257	68	0	1428
Z10	Z16	134	579	122	101	936
Z10	Z17	182	284	80	20	566
Z10	Z18	20	376	40	0	436
Z10	Z19	101	206	40	0	347
Z10	Z2	255	284	485	120	1144
Z10	Z20	1062	5908	479	200	7649
Z10	Z21	2582	5197	1208	756	9743

Z10	Z22	258	2194	67	0	2519
Z10	Z23	98	728	0	0	826
Z10	Z24	80	578	20	20	698
Z10	Z25	0	227	0	0	227
Z10	Z26	18	320	20	0	358
Z10	Z27	37	525	0	0	562
Z10	Z28	269	1121	0	0	1390
Z10	Z29	125	731	140	0	996
Z10	Z3	157	98	200	22	477
Z10	Z30	25	507	0	0	532
Z10	Z31	0	273	0	0	273
Z10	Z32	0	263	0	0	263
Z10	Z33	20	207	0	0	227
Z10	Z34	52	643	78	0	773
Z10	Z35	85	936	82	0	1103
Z10	Z36	62	204	0	0	266
Z10	Z37	79	616	40	0	735
Z10	Z38	100	1547	40	0	1687
Z10	Z4	100	315	60	0	475
Z10	Z5	589	1374	435	142	2540
Z10	Z6	465	1048	620	199	2332
Z10	Z7	406	1672	362	0	2440
Z10	Z8	574	2272	520	180	3546
Z10	Z9	3910	4534	1654	1000	11098
Z11	EXT	1912	90	3755	168	5925
Z11	Z1	3124	965	4509	1673	10271
Z11	Z10	566	1856	1187	41	3650
Z11	Z11	17918	28765	8415	7661	62759
Z11	Z12	3565	9945	3061	2280	18851
Z11	Z13	793	2084	690	314	3881
Z11	Z14	367	2395	273	129	3164
Z11	Z15	207	3531	308	148	4194
Z11	Z16	388	1830	440	98	2756
Z11	Z17	227	923	164	0	1314
Z11	Z18	231	1344	311	81	1967
Z11	Z19	21	475	105	0	601
Z11	Z2	955	773	1128	413	3269
Z11	Z20	1097	6740	796	81	8714
Z11	Z21	1223	3268	680	95	5266
Z11	Z22	96	1689	84	12	1881
Z11	Z23	164	1913	61	0	2138
Z11	Z24	160	1711	41	0	1912
Z11	Z25	165	1217	42	0	1424
Z11	Z26	41	538	0	0	579
Z11	Z27	162	1865	49	0	2076
Z11	Z28	1386	4725	272	407	6790
Z11	Z29	667	2840	452	0	3959
Z11	Z3	90	336	160	21	607
Z11	Z30	230	2230	142	0	2602
Z11	Z31	16	973	157	21	1167
Z11	Z32	39	248	21	0	308
Z11	Z33	42	409	41	0	492
Z11	Z34	140	1042	183	36	1401
Z11	Z35	213	1704	68	21	2006
Z11	Z36	0	441	21	0	462
Z11	Z37	20	373	62	0	455
Z11	Z38	137	1086	20	0	1243
Z11	Z4	490	968	497	255	2210

Z11	Z5	2867	6304	3177	1723	14071
Z11	Z6	1165	2909	1052	782	5908
Z11	Z7	268	1868	298	21	2455
Z11	Z8	230	2001	85	41	2357
Z11	Z9	716	3533	628	267	5144
Z12	EXT	2781	18	3921	237	6957
Z12	Z1	3561	730	6927	1585	12803
Z12	Z10	221	340	928	0	1489
Z12	Z11	5161	6942	4939	1955	18997
Z12	Z12	18374	33045	8892	10860	71171
Z12	Z13	3724	5635	3011	686	13056
Z12	Z14	2178	8857	1123	415	12573
Z12	Z15	1870	6483	1246	346	9945
Z12	Z16	1312	2938	969	452	5671
Z12	Z17	429	1747	462	0	2638
Z12	Z18	735	2269	753	42	3799
Z12	Z19	38	580	290	0	908
Z12	Z2	1847	672	3684	1191	7394
Z12	Z20	392	2512	224	67	3195
Z12	Z21	240	576	494	79	1389
Z12	Z22	0	296	42	0	338
Z12	Z23	102	640	116	19	877
Z12	Z24	170	1441	408	44	2063
Z12	Z25	444	1975	111	0	2530
Z12	Z26	157	676	54	0	887
Z12	Z27	152	1154	76	0	1382
Z12	Z28	2386	2933	519	62	5900
Z12	Z29	1733	6330	1517	229	9809
Z12	Z3	390	981	611	195	2177
Z12	Z30	235	2479	117	0	2831
Z12	Z31	581	3025	199	61	3866
Z12	Z32	154	641	126	0	921
Z12	Z33	188	489	77	0	754
Z12	Z34	136	1042	196	21	1395
Z12	Z35	195	1438	180	39	1852
Z12	Z36	70	277	40	19	406
Z12	Z37	63	293	65	0	421
Z12	Z38	41	368	0	0	409
Z12	Z4	1304	1794	1300	319	4717
Z12	Z5	2563	4990	3384	1894	12831
Z12	Z6	687	1611	1095	470	3863
Z12	Z7	137	851	218	45	1251
Z12	Z8	154	682	302	36	1174
Z12	Z9	303	1323	389	95	2110
Z13	EXT	1823	0	3336	90	5249
Z13	Z1	3509	516	5486	1033	10544
Z13	Z10	122	200	592	0	914
Z13	Z11	673	1145	1457	553	3828
Z13	Z12	2331	6336	3661	1458	13786
Z13	Z13	21457	32771	6635	9441	70304
Z13	Z14	631	3387	779	218	5015
Z13	Z15	2823	6635	2265	711	12434
Z13	Z16	3532	7677	1555	1302	14066
Z13	Z17	856	1779	545	105	3285
Z13	Z18	1561	1991	592	49	4193
Z13	Z19	137	903	314	46	1400
Z13	Z2	3706	1266	4494	1780	11246
Z13	Z20	281	602	238	52	1173

Z13	Z21	17	393	311	0	721
Z13	Z22	0	190	21	0	211
Z13	Z23	310	298	41	0	649
Z13	Z24	112	640	65	19	836
Z13	Z25	242	1235	0	0	1477
Z13	Z26	224	816	67	0	1107
Z13	Z27	0	374	20	0	394
Z13	Z28	538	978	255	41	1812
Z13	Z29	501	1648	617	125	2891
Z13	Z3	1156	1205	989	317	3667
Z13	Z30	190	783	83	0	1056
Z13	Z31	187	1122	115	0	1424
Z13	Z32	61	596	128	22	807
Z13	Z33	39	615	40	26	720
Z13	Z34	393	1352	436	63	2244
Z13	Z35	256	997	155	20	1428
Z13	Z36	14	286	0	0	300
Z13	Z37	110	170	63	0	343
Z13	Z38	30	338	17	0	385
Z13	Z4	2915	2962	1951	634	8462
Z13	Z5	2139	4865	2846	1930	11780
Z13	Z6	551	836	970	197	2554
Z13	Z7	252	1080	409	24	1765
Z13	Z8	89	500	260	27	876
Z13	Z9	247	710	255	70	1282
Z14	EXT	1742	19	4141	284	6186
Z14	Z1	975	20	3795	713	5503
Z14	Z10	87	40	594	0	721
Z14	Z11	442	469	1993	469	3373
Z14	Z12	3452	48	3588	2570	12658
Z14	Z13	1279	1371	1985	380	5015
Z14	Z14	22793	41039	6624	16307	86763
Z14	Z15	3876	6018	3606	694	14194
Z14	Z16	1437	1741	2068	871	6117
Z14	Z17	755	1039	583	87	2464
Z14	Z18	2014	5225	2093	106	9438
Z14	Z19	177	641	542	22	1382
Z14	Z2	852	130	1818	970	3770
Z14	Z20	87	437	190	22	736
Z14	Z21	42	194	230	19	485
Z14	Z22	109	77	19	0	205
Z14	Z23	19	268	64	0	351
Z14	Z24	153	552	254	22	981
Z14	Z25	504	1814	212	0	2530
Z14	Z26	209	701	106	612	1628
Z14	Z27	65	337	108	0	510
Z14	Z28	694	464	191	44	1393
Z14	Z29	799	1864	1085	82	3830
Z14	Z3	554	341	582	44	1521
Z14	Z30	146	520	131	0	797
Z14	Z31	678	1817	390	62	2947
Z14	Z32	38	312	149	0	499
Z14	Z33	37	84	44	0	165
Z14	Z34	209	333	337	44	923
Z14	Z35	167	351	148	109	775
Z14	Z36	21	84	64	0	169
Z14	Z37	0	127	85	0	212
Z14	Z38	0	98	0	0	98

Z14	Z4	525	359	712	237	1833
Z14	Z5	572	304	1526	711	3113
Z14	Z6	348	337	437	128	1250
Z14	Z7	109	165	283	0	557
Z14	Z8	0	227	131	22	380
Z14	Z9	108	121	305	44	578
Z15	EXT	2716	0	6736	272	9724
Z15	Z1	2047	164	6235	1537	9983
Z15	Z10	374	60	996	29	1459
Z15	Z11	289	562	2775	754	4380
Z15	Z12	2340	2149	3768	1355	9612
Z15	Z13	2807	5172	3549	894	12422
Z15	Z14	3128	6886	2081	1644	13739
Z15	Z15	22886	43485	9044	15538	90953
Z15	Z16	4776	8045	3619	2119	18559
Z15	Z17	2005	3881	1361	586	7833
Z15	Z18	5626	4536	2294	204	12660
Z15	Z19	574	1652	637	101	2964
Z15	Z2	1077	390	3400	1069	5936
Z15	Z20	143	499	176	0	818
Z15	Z21	201	240	465	125	1031
Z15	Z22	51	94	17	97	259
Z15	Z23	293	200	117	24	634
Z15	Z24	20	426	145	28	619
Z15	Z25	423	1381	185	0	1989
Z15	Z26	265	1138	176	0	1579
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Z15	Z28	258	370	453	0	1081
Z15	Z29	387	1332	584	25	2328
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Z15	Z31	361	1288	363	51	2063
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Z15	Z33	152	608	147	0	907
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Z15	Z38	28	38	29	0	95
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Z16	Z24	80	675	135	0	890
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Z16	Z26	542	2400	181	0	3123
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Z16	Z32	218	1528	359	0	2105
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Z18	EXT	1881	0	3435	104	5420
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Z19	Z25	145	768	145	0	1058
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Z19	Z28	24	70	0	21	115
Z19	Z29	270	227	103	18	618
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Z19	Z9	123	130	103	21	377
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Z20	Z20	25394	43055	6304	17306	92059
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Z20	Z22	367	1442	246	0	2055
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Z20	Z27	22	407	21	0	450
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Z21	Z11	1256	957	2667	370	5250
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Z21	Z21	27805	40968	6865	13740	89378
Z21	Z22	1259	7097	304	46	8706
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Z22	EXT	2043	19	2182	201	4445
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Z22	Z13	128	21	35	0	184
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Z22	Z17	27	36	0	0	63
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Z22	Z19	0	0	44	0	44
Z22	Z2	143	0	355	115	613
Z22	Z20	628	78	758	246	2110
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Z22	Z22	14344	25698	4791	9262	54095
Z22	Z23	39	0	27	27	93
Z22	Z24	87	170	33	0	290
Z22	Z25	0	119	48	0	167
Z22	Z26	0	36	0	0	36
Z22	Z27	0	26	0	0	26
Z22	Z28	102	163	80	27	372
Z22	Z29	18	99	12	44	173
Z22	Z3	21	0	36	12	69
Z22	Z30	54	42	0	0	96
Z22	Z32	0	19	0	0	19
Z22	Z33	0	9	35	0	54
Z22	Z34	0	44	0	0	44
Z22	Z35	75	169	44	95	383
Z22	Z37	0	177	12	0	189

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Z22	Z7	71	143	133	31	378
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Z23	EXT	1577	0	3011	291	4879
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Z23	Z2	130	71	560	51	912
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Z23	Z6	38	0	230	38	306
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Z23	Z9	33	25	198	0	256
Z24	EXT	2317	0	4941	225	7483
Z24	Z1	288	0	1285	190	1763
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Z24	Z16	327	113	429	100	969
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Z24	Z19	25	0	99	0	124
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Z24	Z31	204	362	248	81	895
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Z24	Z37	0	22	25	0	47
Z24	Z38	0	100	60	0	160
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Z24	Z6	65	19	226	0	310
Z24	Z7	70	41	162	103	376
Z24	Z8	0	91	78	19	188
Z24	Z9	21	61	147	58	287
Z25	EXT	2037	0	3413	222	5672
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Z25	Z13	304	80	909	80	1373
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Z25	Z17	158	238	737	234	1367
Z25	Z18	236	169	863	0	1268
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Z25	Z20	162	40	19	0	221
Z25	Z21	62	70	101	44	277
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Z25	Z23	39	409	18	22	488
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Z25	Z26	1269	958	246	90	2563
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Z25	Z30	136	184	223	19	562
Z25	Z31	219	1092	1135	423	2869
Z25	Z32	0	20	180	0	200
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Z25	Z34	207	310	187	0	704
Z25	Z35	38	248	19	38	343
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Z25	Z7	0	123	147	131	401
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Z26	Z13	138	319	708	94	1259
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Z26	Z2	596	85	1510	429	2620
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Z26	Z26	26047	47417	8862	19085	101411
Z26	Z27	36	0	53	0	89
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Z26	Z29	72	88	318	75	553
Z26	Z3	173	52	608	629	1462
Z26	Z30	0	17	54	0	71
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Z27	Z22	0	63	26	0	89
Z27	Z23	1069	1047	316	325	2757
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Z27	Z26	0	71	0	0	71
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Z27	Z31	163	137	128	111	539
Z27	Z32	0	20	38	0	58
Z27	Z33	17	21	0	0	38
Z27	Z34	0	0	44	0	44
Z27	Z36	0	0	23	0	23
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Z27	Z7	38	96	96	0	230
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Z29	Z17	193	281	211	0	685
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Z29	Z30	1394	7713	706	1197	11010
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Z29	Z34	88	244	182	0	514
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Z30	Z36	21	0	0	0	21
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Z31	EXT	1107	0	2440	94	3641
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Z31	Z16	386	259	504	41	1190
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Z31	Z18	166	275	467	21	929
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Z31	Z2	261	68	743	435	1507
Z31	Z20	31	87	99	0	217
Z31	Z21	46	55	101	0	202
Z31	Z23	102	129	112	0	343
Z31	Z24	205	438	107	137	887
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Z34	Z27	0	24	0	0	24
Z34	Z28	22	127	0	22	171
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Z35	Z26	37	801	106	0	944
Z35	Z28	42	91	60	0	193
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Z35	Z37	1296	4571	1352	969	8188
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Z36	EXT	3634	0	5281	1913	10828
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Z36	Z12	43	117	194	40	394
Z36	Z13	73	0	249	0	322
Z36	Z14	95	44	134	18	291
Z36	Z15	84	128	236	44	492
Z36	Z16	426	173	488	105	1192
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Z36	Z29	43	20	59	0	122
Z36	Z3	230	23	595	0	848
Z36	Z31	0	0	74	0	74
Z36	Z32	473	779	1404	70	2726
Z36	Z33	2870	1340	1316	1482	7008
Z36	Z34	1584	732	1893	590	4799
Z36	Z35	1127	560	1171	368	3226
Z36	Z36	21591	40348	8667	14179	84785
Z36	Z37	241	306	357	143	1047
Z36	Z38	0	95	21	0	116
Z36	Z4	151	21	105	26	303
Z36	Z5	89	117	436	307	949
Z36	Z6	169	46	381	126	722
Z36	Z7	85	148	245	0	478

Z36	Z8	23	68	59	59	209
Z36	Z9	18	62	116	0	196
Z37	EXT	1165	654	2320	325	4464
Z37	Z1	602	0	1778	198	2578
Z37	Z10	50	80	513	17	660
Z37	Z11	102	82	351	36	571
Z37	Z12	97	103	154	134	488
Z37	Z13	92	173	156	0	421
Z37	Z14	87	63	42	20	212
Z37	Z15	55	80	138	0	273
Z37	Z16	171	77	77	91	416
Z37	Z17	52	19	132	40	243
Z37	Z18	40	62	116	79	297
Z37	Z19	33	21	17	40	111
Z37	Z2	213	0	869	219	1301
Z37	Z20	17	19	57	0	93
Z37	Z21	33	35	0	38	106
Z37	Z22	142	12	59	17	230
Z37	Z23	156	106	0	0	262
Z37	Z24	0	25	0	22	47
Z37	Z25	0	37	0	20	57
Z37	Z26	1170	1303	526	419	3418
Z37	Z28	0	0	71	0	71
Z37	Z29	20	0	73	0	93
Z37	Z3	135	26	276	39	476
Z37	Z30	0	40	20	0	60
Z37	Z31	19	19	0	0	38
Z37	Z32	33	112	158	0	303
Z37	Z33	99	207	148	38	492
Z37	Z34	458	687	660	204	2009
Z37	Z35	3274	2748	1183	626	7331
Z37	Z36	211	656	117	0	984
Z37	Z37	9488	22448	4886	10731	47553
Z37	Z38	270	335	238	0	843
Z37	Z4	58	0	109	0	167
Z37	Z5	127	0	328	173	628
Z37	Z6	139	111	404	134	788
Z37	Z7	547	195	495	0	1237
Z37	Z8	522	205	835	66	1628
Z37	Z9	102	157	474	38	771
Z38	EXT	1409	489	2428	254	4580
Z38	Z1	795	55	1889	406	3145
Z38	Z10	268	60	1285	133	1746
Z38	Z11	140	40	895	186	1261
Z38	Z12	78	41	271	59	449
Z38	Z13	151	17	220	20	408
Z38	Z14	60	0	40	18	118
Z38	Z15	0	57	40	0	97
Z38	Z16	100	125	178	138	541
Z38	Z17	0	103	20	20	143
Z38	Z18	78	0	115	35	228
Z38	Z19	20	83	20	0	123
Z38	Z2	260	91	607	175	1133
Z38	Z20	62	147	60	18	287
Z38	Z21	119	93	328	40	580
Z38	Z22	0	79	40	0	119
Z38	Z23	0	40	20	0	60
Z38	Z24	121	38	0	0	159

Z38	Z25	35	117	0	0	152
Z38	Z26	38	52	79	180	349
Z38	Z27	20	44	0	0	64
Z38	Z28	40	28	38	40	146
Z38	Z29	0	0	140	0	140
Z38	Z3	182	21	58	20	281
Z38	Z30	0	19	0	0	19
Z38	Z31	0	81	20	0	101
Z38	Z32	60	116	0	18	194
Z38	Z33	33	82	38	20	173
Z38	Z34	198	333	232	115	878
Z38	Z35	139	460	120	80	799
Z38	Z36	55	21	20	20	116
Z38	Z37	57	437	168	75	737
Z38	Z38	1553	30597	5716	10997	65863
Z38	Z4	135	150	80	17	332
Z38	Z5	80	78	452	277	887
Z38	Z6	286	77	525	293	1181
Z38	Z7	386	368	670	20	1444
Z38	Z8	552	569	1333	353	3807
Z38	Z9	280	434	979	321	2014
Z4	EXT	380	0	2210	120	3710
Z4	Z1	909	1021	4485	1888	11303
Z4	Z10	222	140	213	0	575
Z4	Z11	309	788	745	165	2007
Z4	Z12	649	2203	1311	423	4586
Z4	Z13	1956	4525	1512	564	8557
Z4	Z14	342	1486	294	24	2146
Z4	Z15	639	2645	606	51	3941
Z4	Z16	1787	4298	1185	419	7689
Z4	Z17	705	1539	352	70	2666
Z4	Z18	310	769	411	46	1536
Z4	Z19	0	498	240	0	738
Z4	Z2	4124	3596	3667	2074	13461
Z4	Z20	25	876	244	0	1145
Z4	Z21	42	135	71	0	248
Z4	Z22	0	0	44	23	67
Z4	Z23	21	145	80	0	246
Z4	Z24	23	448	21	25	517
Z4	Z25	74	614	166	0	854
Z4	Z26	36	567	21	0	624
Z4	Z27	60	261	0	0	321
Z4	Z28	156	992	21	0	1169
Z4	Z29	188	916	300	0	1404
Z4	Z3	1309	2690	1105	1205	6309
Z4	Z30	100	406	0	0	506
Z4	Z31	30	383	21	0	434
Z4	Z32	22	568	87	0	677
Z4	Z33	62	447	66	0	575
Z4	Z34	246	1929	359	0	2534
Z4	Z35	104	923	153	71	1251
Z4	Z36	48	169	0	0	217
Z4	Z37	25	129	44	0	198
Z4	Z38	134	155	0	60	349
Z4	Z4	12085	16118	3404	3384	34991
Z4	Z5	1959	5905	1963	2025	11852
Z4	Z6	595	1570	972	518	3655
Z4	Z7	178	952	407	0	1537

Z4	Z8	23	432	226	73	754
Z4	Z9	136	930	236	89	1391
Z5	EXT	4073	109	4777	491	9450
Z5	Z1	9011	2417	11967	4327	27722
Z5	Z10	618	838	902	2384	
Z5	Z11	2815	6061	3190	2153	14219
Z5	Z12	2125	6662	3246	1015	13048
Z5	Z13	2814	5831	2383	1048	12076
Z5	Z14	302	2543	299	19	3163
Z5	Z15	761	4617	736	45	6159
Z5	Z16	1000	3624	1194	593	6411
Z5	Z17	390	1942	247	52	2631
Z5	Z18	348	1525	319	109	2301
Z5	Z19	101	557	174	157	989
Z5	Z2	3242	2090	4283	1699	11314
Z5	Z20	431	3379	287	105	4202
Z5	Z21	376	1296	550	89	2311
Z5	Z22	22	437	42	21	522
Z5	Z23	38	1026	114	0	1178
Z5	Z24	81	1047	112	0	1240
Z5	Z25	197	742	22	89	1050
Z5	Z26	68	847	20	49	984
Z5	Z27	71	703	21	0	795
Z5	Z28	745	2524	220	77	3566
Z5	Z29	362	2291	584	27	3264
Z5	Z3	459	1220	805	141	2625
Z5	Z30	102	1253	108	0	1463
Z5	Z31	40	1110	71	0	1221
Z5	Z32	0	896	140	0	1036
Z5	Z33	157	726	19	19	921
Z5	Z34	295	2414	331	61	3101
Z5	Z35	255	2847	268	42	3412
Z5	Z36	91	781	55	45	972
Z5	Z37	0	606	0	0	606
Z5	Z38	75	731	21	0	827
Z5	Z4	3837	4714	2315	1277	12143
Z5	Z5	32643	53854	11305	19510	117312
Z5	Z6	6474	10605	3121	3886	24086
Z5	Z7	733	2422	779	123	4057
Z5	Z8	330	1774	256	33	2393
Z5	Z9	2677	6097	983	1115	10872
Z6	EXT	3523	94	2893	325	6835
Z6	Z1	11295	5343	13488	4601	34727
Z6	Z10	440	918	1038	0	2396
Z6	Z1	1301	2296	1860	676	6133
Z6	Z1	596	1654	1289	244	3783
Z6	Z1	533	1432	438	44	2447
Z6	Z1	116	765	104	74	1059
Z6	Z1	173	1680	231	18	2102
Z6	Z1	619	1895	587	123	3224
Z6	Z1	230	1073	99	20	1422
Z6	Z18	39	706	225	0	970
Z6	Z19	117	289	40	0	446
Z6	Z2	2481	1355	2495	1051	7382
Z6	Z20	286	1699	172	0	2157
Z6	Z21	539	1828	599	136	3102
Z6	Z22	89	331	103	0	523
Z6	Z23	21	324	19	0	364

Z6	Z24	0	272	18	19	309
Z6	Z25	91	110	18	0	219
Z6	Z26	84	464	42	0	590
Z6	Z27	46	135	59	0	240
Z6	Z28	245	1055	207	0	1507
Z6	Z29	233	529	215	0	977
Z6	Z3	255	652	458	143	1508
Z6	Z30	19	535	20	0	574
Z6	Z31	92	342	0	0	434
Z6	Z32	64	474	77	22	637
Z6	Z33	107	899	60	0	1066
Z6	Z34	249	1131	246	0	1626
Z6	Z35	468	2854	180	100	3602
Z6	Z36	43	770	27	21	861
Z6	Z37	103	540	104	0	747
Z6	Z38	0	973	18	0	991
Z6	Z4	1187	1849	565	302	3903
Z6	Z5	6043	10986	4333	2395	23757
Z6	Z6	22137	30594	5766	8922	67419
Z6	Z7	2420	6498	1247	351	10516
Z6	Z8	1404	2319	333	192	4248
Z6	Z9	4482	9648	1794	1617	17541
Z7	EXT	2466	91	3164	82	5803
Z7	Z1	5357	871	10820	1420	18468
Z7	Z10	374	440	1448	41	2303
Z7	Z11	245	306	1823	192	2566
Z7	Z12	350	283	668	129	1430
Z7	Z13	380	651	733	63	1827
Z7	Z14	20	392	120	24	556
Z7	Z15	272	477	345	520	1614
Z7	Z16	680	907	664	238	2489
Z7	Z17	174	485	366	39	1064
Z7	Z18	156	411	259	104	930
Z7	Z19	100	226	224	80	630
Z7	Z2	1691	556	2509	907	5663
Z7	Z20	84	543	181	40	848
Z7	Z21	196	382	501	61	1140
Z7	Z22	134	260	0	20	414
Z7	Z23	88	110	0	0	198
Z7	Z24	20	312	19	20	371
Z7	Z25	137	260	23	0	420
Z7	Z26	79	132	64	0	275
Z7	Z27	57	113	41	19	230
Z7	Z28	104	208	104	41	457
Z7	Z29	97	174	224	0	495
Z7	Z3	410	194	970	47	1621
Z7	Z30	54	177	19	0	250
Z7	Z31	0	160	18	0	178
Z7	Z32	20	299	129	0	448
Z7	Z33	105	521	80	179	885
Z7	Z34	334	931	372	40	1677
Z7	Z35	1028	2067	474	185	3754
Z7	Z36	85	286	82	0	453
Z7	Z37	139	1000	74	39	1252
Z7	Z38	308	878	198	0	1384
Z7	Z4	373	333	569	121	1396
Z7	Z5	691	1104	1591	698	4084
Z7	Z6	2846	3056	3177	1539	10618

Z7	Z7	26841	42978	8178	13698	91695
Z7	Z8	8203	6117	2645	1184	18149
Z7	Z9	527	895	1399	268	3089
Z8	EXT	1452	281	2910	273	4916
Z8	Z1	2333	206	6090	1381	10010
Z8	Z10	754	1119	1947	205	4025
Z8	Z11	114	168	1426	614	2322
Z8	Z12	159	332	498	159	1148
Z8	Z13	159	336	227	23	745
Z8	Z14	68	174	182	23	447
Z8	Z15	159	603	136	0	898
Z8	Z16	430	186	387	273	1276
Z8	Z17	65	283	114	0	462
Z8	Z18	21	104	136	0	261
Z8	Z19	0	104	112	0	216
Z8	Z2	648	107	1359	455	2569
Z8	Z20	152	967	250	68	1437
Z8	Z21	345	631	540	205	1721
Z8	Z22	50	150	0	0	200
Z8	Z23	87	204	23	0	314
Z8	Z24	108	118	68	0	294
Z8	Z25	41	58	23	0	122
Z8	Z26	56	221	20	0	297
Z8	Z27	0	80	0	0	80
Z8	Z28	63	187	45	23	318
Z8	Z29	23	229	114	0	366
Z8	Z3	137	164	409	114	824
Z8	Z30	23	69	0	0	92
Z8	Z31	23	22	23	0	68
Z8	Z32	23	109	91	0	223
Z8	Z33	43	292	91	0	426
Z8	Z34	45	377	227	23	672
Z8	Z35	232	1006	45	205	1488
Z8	Z36	88	117	68	0	273
Z8	Z37	91	1286	131	23	1531
Z8	Z38	468	2984	318	23	3793
Z8	Z4	201	257	250	45	753
Z8	Z5	432	538	1196	430	2596
Z8	Z6	546	1577	1685	296	4104
Z8	Z7	4414	10891	2520	599	18424
Z8	Z8	22449	35517	7174	12055	77195
Z8	Z9	1470	1854	2021	750	6095
Z9	EXT	2000	101	3047	141	5289
Z9	Z1	4287	865	6954	2573	14679
Z9	Z10	2321	5799	2479	620	11219
Z9	Z11	1230	1185	2024	698	5137
Z9	Z12	140	638	1064	225	2067
Z9	Z13	309	382	325	71	1087
Z9	Z14	41	370	79	0	490
Z9	Z15	154	845	215	0	1214
Z9	Z16	98	488	471	101	1158
Z9	Z17	162	358	80	0	600
Z9	Z18	76	415	115	0	606
Z9	Z19	0	227	113	0	340
Z9	Z2	651	207	1281	431	2570
Z9	Z20	261	1346	416	24	2047
Z9	Z21	606	1478	545	77	2706
Z9	Z22	45	348	65	0	458

Z9	Z23	20	196	25	0	241
Z9	Z24	0	185	0	0	185
Z9	Z25	200	58	35	20	313
Z9	Z26	20	107	20	0	147
Z9	Z27	17	308	20	0	345
Z9	Z28	333	1053	99	39	1524
Z9	Z29	84	268	122	0	474
Z9	Z3	92	256	141	43	532
Z9	Z30	79	164	0	0	243
Z9	Z31	0	293	46	0	339
Z9	Z32	0	54	20	0	74
Z9	Z33	0	227	45	0	272
Z9	Z34	111	289	181	0	581
Z9	Z35	224	849	185	0	1258
Z9	Z36	0	116	62	0	178
Z9	Z37	131	565	60	0	756
Z9	Z38	310	1435	160	205	2110
Z9	Z4	298	296	658	114	1366
Z9	Z5	3353	3527	2481	1226	10587
Z9	Z6	5811	6396	3110	2613	17930
Z9	Z7	615	1900	406	44	2965
Z9	Z8	1596	3593	850	352	6391
Z9	Z9	22408	30158	4973	8494	66033

APPENDIX B3: EQUIVALENCE AMONG ZONES.

The following list presents the zonal equivalence: (1) research 38 zones (Z38); (2) MOTQ 699 zones (Z7); and (3) STCUM 1496 zones (Z15)

Z15	Z7	Z38
1292	645	.
1293	645	.
1294	646	.
1295	646	.
1315	662	.
1475	662	.
1476	662	.
1477	662	.
1320	664	.
1426	669	.
1429	669	.
1481	669	.
1430	671	.
1443	679	.
1444	679	.
1445	679	.
1446	679	.
1471	689	.
1479	689	.
1480	689	.
1484	690	.
1485	691	.
1486	692	.
1487	693	.
1488	694	.
1489	695	.
1490	696	.
1497	696	.
1491	697	.
1492	698	.
1493	699	.
1494	700	.
1495	700	.
1496	700	.
1	1	1
2	2	1
4	2	1
3	3	1
5	3	1
6	4	1
9	4	1
7	5	1
8	5	1
11	7	1
12	8	1
18	12	1
19	13	1
21	13	1
22	13	1
23	13	1
20	14	1
24	15	1
25	16	1
26	16	1
27	16	1
28	17	1
29	17	1
30	17	1
31	18	1
32	18	1
33	18	1
36	18	1
37	18	1
34	19	1
35	19	1
38	20	1
41	20	1
71	20	1
72	20	1
39	21	1
40	21	1
44	21	1
56	27	1
57	28	1
58	29	1
59	30	1
60	31	1
61	31	1
62	31	1
63	32	1
64	32	1
65	32	1
66	32	1
67	33	1
68	33	1
69	33	1
70	34	1
73	35	1
74	35	1
75	35	1
76	35	1
77	36	1
78	37	1
462	195	1
463	196	1
559	242	1
10	6	2
13	6	2
14	9	2
15	10	2
16	10	2
43	10	2
49	10	2
17	11	2
50	11	2
42	22	2
45	23	2
46	24	2
47	24	2
48	24	2
79	24	2
51	25	2
53	25	2
54	25	2
52	26	2
55	26	2
80	38	2
81	38	2
82	38	2
83	38	2
84	38	2
85	39	2
86	39	2
87	40	2
88	41	2
89	41	2
90	41	2
91	42	2
92	42	2
93	42	2

799	340	2
800	341	2
801	341	2
802	342	2
803	343	3
804	343	3
805	343	3
806	344	3
811	344	3
812	344	3
807	345	3
808	345	3
809	345	3
810	345	3
813	346	3
814	346	3
815	347	3
823	347	3
816	348	3
817	348	3
818	349	3
821	349	3
822	349	3
819	350	3
820	350	3
824	351	3
1018	351	3
1019	351	3
1136	488	3
765	325	4
766	325	4
767	326	4
768	326	4
770	328	4
780	328	4
781	328	4
774	330	4
782	330	4
783	330	4
777	332	4
778	332	4
779	333	4
784	334	4
785	334	4
786	334	4
787	334	4
788	334	4
789	334	4
790	334	4
791	335	4
792	335	4
793	336	4
794	336	4
795	337	4
796	338	4
797	338	4
798	339	4
375	161	5
376	161	5
377	161	5
378	161	5
400	161	5
379	162	5
380	162	5
381	162	5
382	163	5
383	163	5
384	164	5
385	164	5
386	164	5
387	165	5
388	165	5
389	166	5
390	167	5
391	168	5
392	168	5
393	169	5
422	169	5
423	169	5
394	170	5
395	170	5
396	170	5
397	170	5
401	172	5
402	172	5
403	173	5
404	173	5
405	173	5
406	174	5
407	174	5
408	174	5
409	175	5
410	175	5
411	176	5
414	176	5
415	176	5
412	177	5
413	177	5
418	177	5
419	177	5
420	177	5
416	178	5
417	178	5
421	179	5
431	179	5
432	179	5
424	180	5
425	180	5
426	181	5
427	181	5
428	181	5
429	182	5
430	182	5
433	183	5
434	183	5
435	184	5
436	184	5
437	184	5
438	185	5
439	185	5
440	185	5
441	186	5
442	186	5
443	186	5
444	186	5
445	187	5
453	187	5
454	187	5
461	187	5
455	192	5
687	293	5
688	293	5
689	293	5
690	293	5
691	293	5
692	294	5
695	294	5
696	294	5
693	295	5
694	295	5
697	296	5
700	296	5
702	296	5
698	297	5
699	297	5
701	297	5
703	298	5
704	298	5
705	299	5
706	299	5
707	300	5
708	300	5
709	300	5
710	301	5
711	301	5
712	301	5
398	171	6
399	171	6
446	188	6
447	188	6
448	189	6
449	189	6
456	189	6
450	190	6
451	191	6
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1176	578	34
1177	579	34
1178	579	34
1183	580	34
1184	581	34
1185	582	34
1186	582	34
1190	582	34
1191	582	34
1187	583	34
1188	583	34
1189	583	34
1192	583	34
1193	584	34
1194	584	34
1195	585	35
1198	585	35
1199	585	35
1196	586	35
1201	586	35
1197	587	35
1246	587	35
1200	588	35
1204	588	35
1202	589	35
1203	589	35
1205	590	35
1206	590	35
1207	591	35
1208	592	35
1209	593	35
1212	593	35
1210	594	35
1211	594	35
1213	595	35
1214	596	35
1215	596	35
1216	596	35
1217	597	35
1218	598	35
1219	599	35
1220	600	35
1221	601	35
1222	601	35
1223	602	35
1224	603	35
1225	604	35
1226	605	35
1227	606	35
1228	606	35
1229	607	35
1230	608	35
1231	609	35
1232	609	35
1233	610	35
1234	611	35
1235	612	35
1236	613	35
1242	617	35
1243	618	35
1244	618	35
1272	630	36
1273	630	36
1285	630	36
1277	633	36
1280	633	36
1281	636	36
1282	637	36
1283	638	36
1284	639	36
1473	639	36
1474	639	36
1286	640	36
1289	640	36
1287	641	36
1288	642	36
1290	643	37
1291	644	37
1296	647	37
1297	647	37
1298	648	37
1302	648	37
1299	649	37
1300	650	37
1301	651	37
1303	652	38
1304	652	38
1305	653	38
1306	654	38
1307	655	38
1308	656	38
1311	656	38
1309	657	38
1310	658	38
1312	659	38
1313	660	38
1319	660	38
1314	661	38
1316	663	38
1317	663	38
1318	663	38

APPENDIX C

Supplemental to Chapter 3, Part D

APPENDIX C1: SAMPLE SAS OUTPUT.

Proc reg, step regression.

The following is SAS Proc Reg, step regression partial output, modelling the dependant variable TW against the independent variables: (1) CAR; (2) DU); and (3) POP.

A. Descriptive Statistics

Variables	Sum	Mean	Uncorrected SS
INTERCEP	38	1	38
CAR	1208201	31794.763158	43429253723
DU	1138477	29959.921053	40779093359
POP	2920134	76845.631579	258325944690
TW	1236561	32541.078947	46049537341

Variables	Variance	Std Deviation
INTERCEP	0	0
CAR	135534840.02	11641.943138
DU	180281414.02	13426.89145
POP	916929815.27	30280.848985
TW	157040762.62	12531.590586

B. Uncorrected Sums of squares and Crossproducts

USSCP	INTERCEP	CAR	DU	POP	TW
INTERCEP	38	1208201	1138477	2920134	1236561
CAR	1208201	43429253723	40255972710	104360677560	43820910408
DU	1138477	40255972710	40779093359	101705180889	42973495206
POP	2920134	104360677560	101705180889	258325944690	108670771843
TW	1236561	43820910408	42973495206	108670771843	46049537341

C. Correlation

CORR	CAR	DU	POP	TW
CAR	1.0000	0.7017	0.8829	0.8345
DU	0.7017	1.0000	0.9451	0.9519
POP	0.8829	0.9451	1.0000	0.9720
TW	0.8345	0.9519	0.9720	1.0000

D. Stepwise Procedure for Dependent Variable TW

D1. Step 1

Variable POP Entered R-square = 0.94468741 C(p) = 13.96208690

	DF	Sum of Squares	Mean Square	F	Prob>F
Reg	1	5489113944.4252	5489113944.4252	614.85	0.0001
Error	36	321394272.33800	8927618.6760556		
Total	37	5810508216.7632			

Var	Parameter Estimate	Standard Error	Type II Sum of Squares	F	Prob>F
INT	1630.90863464	1337.49177964	13274331.319451	1.49	0.2306
POP	0.40223718	0.01622179	5489113944.4252	614.85	0.0001

D2. Step 2

Variable DU Entered R-square = 0.95506264 C(p) = 6.96562134

	DF	Sum of Squares	Mean Square	F	Prob>F
Reg	2	5549399321.7070	2774699660.8535	371.93	0.0001
Error	35	261108895.05612	7460254.1444606		
Total	37	5810508216.7632			

Var	Parameter Estimate	Standard Error	Type II Sum of Squares	F	Prob>F
INT	2284.37188586	1244.36655209	25153591.763270	3.37	0.0748
DU	0.29103988	0.10238193	60285377.281879	8.08	0.0074
POP	0.28026545	0.04539738	284335594.99376	38.11	0.0001

Bounds on condition number: 9.37229, 37.48916

D3. Step 3

Variable CAR Entered R-square = 0.96078928 C(p) = 4.00000000

	DF	Sum of Squares	Mean Square	F	Prob>F
Reg	3	5582673984.2366	1860891328.0789	277.70	0.0001
Error	34	227834232.52657	6701006.8390168		
Total	37	5810508216.7632			

Var	Parameter Estimate	Standard Error	Type II Sum of Squares	F	Prob>F
INT	1146.12995827	1284.95187589	5331311.5782385	0.80	0.3787
CAR	0.34608953	0.15531080	33274662.529549	4.97	0.0326
DU	0.66437496	0.19360808	78907746.287460	11.78	0.0016
POP	0.00633078	0.13024255	15832.49300952	0.00	0.9615

Bounds on condition number: 85.88228, 423.7405

D4. Step 4

Variable POP Removed R-square = 0.96078655 C(p) = 2.00236270

	DF	Sum of Squares	Mean Square	F	Prob>F
Reg	2	5582658151.7436	2791329075.8718	428.78	0.0001
Error	35	227850065.01958	6510001.8577023		
Total	37	5810508216.7632			

Var	Parameter Estimate	Standard Error	Type II Sum of Squares	F	Prob>F
INT	1131.66632972	1232.07997129	5492121.1183221	0.84	0.3646
CAR	0.35321500	0.05057004	317594425.03030	48.79	0.0001
DU	0.67353400	0.04384734	1536079373.5829	235.96	0.0001

Bounds on condition number: 1.969963, 7.879852

NB: 1. All variables in the model are significant at the 0.1500 level.
2. No other variable met the 0.1500 significance level for entry into the model.

E. Summary of Stepwise Procedure for Dependent Variable TW

Step	Variable Ent'd	Variable Rem'd	No. In	Partial R**2	Model R**2	C(p)	F	Prob>F
1	POP		1	0.9447	0.9447	13.9621	614.8464	0.0001
2	DU		2	0.0104	0.9551	6.9656	8.0809	0.0074
3	CAR		3	0.0057	0.9608	4.0000	4.9656	0.0326
4		POP	2	0.0000	0.9608	2.0024	0.0024	0.9615

E1. Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	2	5582658151.7	2791329075.9	428.775	0.0001
Error	35	227850065.02	6510001.8577		
C Total	37	5810508216.8			

Root MSE	2551.47053	R-square	0.9608
Dep Mean	32541.07895	Adj R-sq	0.9585
C.V.	7.84077		

E2. Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	T for H0: Parameter=0	Prob > |T|
INTERCEP	1	1131.666330	1232.0799713	0.919	0.3646
CAR	1	0.353215	0.05057004	6.985	0.0001
DU	1	0.673534	0.04384734	15.361	0.0001

E3. Squared values

Variable	DF	Type I SS	Type II SS	Standardized Estimate	Semi-partial Corr Type I
INTERCEP	1	40239029124	5492121	0.00000000	.
CAR	1	4046578778	317594425	0.32813942	0.69642424
DU	1	1536079374	1536079374	0.72165364	0.26436231

Variable	DF	Squared Partial Corr Type I	Squared Semi-partial Corr Type II	Squared Partial Corr Type II	Tolerance
INTERCEP	1	.	.	.	.
CAR	1	0.94669462	0.05465863	0.58226718	0.50762375
DU	1	0.87082813	0.26436231	0.87082813	0.50762375

Variable	DF	Variance Inflation
INTERCEP	1	0.00000000
CAR	1	1.96996300
DU	1	1.96996300

E4. Covariance of Estimates

COVB	INTERCEP	CAR	DU
INTERCEP	1518021.0557	-34.69464902	-8.130764709
CAR	-34.69464902	0.0025573285	-0.001555912
DU	-8.130764709	-0.001555912	0.0019225892

E5. Correlation of Estimates

CORRB	INTERCEP	CAR	DU
INTERCEP	1.0000	-0.5568	-0.1505
CAR	-0.5568	1.0000	-0.7017
DU	-0.1505	-0.7017	1.0000

E6. 95% upper and lower bounds

Dep Var Obs	TW	Predict Value	Std Err Predict	Lower95% Mean	Upper95% Mean	Lower95% Predict	Upper95% Predict
1	29953.0	22951.0	911.560	21100.4	24801.5	17450.6	28451.3
2	24260.0	20700.85	964.020	18743.8	22657.9	15163.7	26238.0
3	17580.0	18842.1	920.000	16974.5	20709.8	13336.0	24348.3
4	27243.0	26669.2	853.392	24936.7	28401.62	21207.4	32130.9
5	56268.0	57111.0	1016.925	55046.6	59175.5	51535.05	62687.0
6	41468.0	42875.9	635.175	41586.5	44165.4	37538.1	48213.8
7	44274.0	44902.4	725.295	43429.96	46374.8	39517.4	50287.3
8	32856.0	31151.4	431.926	30274.6	32028.3	25898.0	36404.9
9	32973.0	37226.3	492.293	36226.9	38225.7	31951.1	42501.6
10	16178.0	16002.2	730.623	14519.0	17485.4	10614.3	21390.1
11	33432.0	29643.6	426.904	28776.9	30510.3	24391.9	34895.3
12	49005.0	47438.4	660.108	46098.3	48778.4	42088.1	52788.6
13	42006.0	44076.4	942.518	42163.0	45989.8	38554.5	49598.2
14	41215.0	42793.6	568.884	41638.7	43948.4	37486.64	48100.5
15	58573.0	53795.3	854.884	52059.8	55530.8	48332.6	59258.1
16	52803.0	57708.5	1160.478	55352.6	60064.3	52018.1	63398.8
17	38619.0	39271.1	482.022	38292.54	40249.6	33999.7	44542.4
18	29784.0	27619.3	450.775	26704.2	28534.4	22359.4	32879.3
19	20035.0	19904.6	602.773	18680.9	21128.3	14582.3	25226.9
20	42330.0	40382.4	875.919	38604.2	42160.6	34906.0	45858.9
21	27330.0	28841.7	578.825	27666.6	30016.7	23530.3	34153.0
22	18425.0	20584.0	613.080	19339.4	21828.6	15256.8	25911.1
23	21440.00	24430.0	556.318	23300.7	25559.43	19128.6	29731.5
24	29244.0	30080.4	612.780	28836.4	31324.4	24753.3	35407.4
25	28868.0	31512.0	593.606	30307.0	32717.1	26194.0	36830.1
26	29581.0	30812.2	609.178	29575.5	32048.9	25486.9	36137.5
27	12695.0	13626.2	768.628	12065.9	15186.6	8216.6	19035.9
28	26010.0	26706.2	493.120	25705.2	27707.3	21430.7	31981.8
29	39369.0	37961.0	588.747	36765.8	39156.2	32645.2	43276.9
30	24050.0	23186.0	595.113	21977.8	24394.1	17867.2	28504.7
31	19629.0	20226.4	601.899	19004.46	21448.3	14904.5	25548.3
32	28021.0	27043.0	602.474	25819.9	28266.1	21720.8	32365.2
33	24881.0	23278.8	560.020	22141.9	24415.7	17975.8	28581.9
34	55394.0	52693.1	888.970	50888.4	54497.8	47208.0	58178.2
35	54834.0	52395.0	1073.543	50215.6	54574.4	46775.4	58014.5
36	29032.0	31979.3	651.607	30656.5	33302.1	26633.3	37325.3
37	17780.00	18899.8	633.365	17614.0	20185.6	13562.8	24236.71
38	19123.0	21240.3	577.584	20067.7	22412.8	15929.5	26551.1

B7. Cook's coefficient

Obs	Residual	Std Err Residual	Student Residual	-2-1-0 1 2	Cook's D
1	7002.0	2383.078	2.938	*****	0.421
2	3559.1	2362.344	1.507	***	0.126
3	-1262.14	2379.832	-0.530	*	0.014
4	573.8	2404.522	0.239		0.002
5	-843.027	2340.057	-0.360		0.008
6	-1407.9	2471.144	-0.570	*	0.007
7	-628.376	2446.211	-0.257		0.002
8	1704.6	2514.646	0.678	*	0.005
9	-4253.3	2503.527	-1.699	***	0.037
10	175.8	2444.625	0.072		0.000
11	3788.401	2515.503	1.506	***	0.022
12	1566.6	2464.601	0.636	*	0.010
13	-2070.4	2371.004	-0.873	*	0.040
14	-1578.56	2487.242	-0.635	*	0.007
15	4777.7	2403.991	1.987	***	0.166
16	-4905.46	2272.288	-2.159	****	0.405
17	-652.095	2505.525	-0.260		0.001
18	2164.7	2511.335	0.862	*	0.008
19	130.4	2479.247	0.053		0.000
20	1947.6	2396.407	0.813	*	0.029
21	-1511.7	2484.947	-0.608	*	0.007
22	-2158.98	2476.719	-0.872	*	0.016
23	-2990.05	2490.083	-1.201	**	0.024
24	-836.4	2476.793	-0.338		0.002
25	-2644.0	2481.458	-1.066	**	0.022
26	-1231.2	2477.681	-0.497		0.005
27	-931.2	2432.943	-0.383		0.005
28	-696.2	2503.365	-0.278		0.001
29	1408.0	2482.615	0.567	*	0.006
30	864.0	2481.097	0.348		0.002
31	-597.4	2479.459	-0.241		0.001
32	978.0	2479.320	0.394		0.003
33	1602.2	2489.253	0.644	*	0.007
34	2700.9	2391.597	1.129	**	0.059
35	2439.0	2314.629	1.054	**	0.080
36	-2947.3	2466.863	-1.195	**	0.033
37	-1119.8	2471.609	-0.453		0.004
38	-2117.3	2485.236	-0.852	*	0.013

Sum of Residuals	3.092282E-11
Sum of Squared Residuals	227850065.02
Predicted Resid SS (Press)	286076133.46

APPENDIX D

Supplemental to Chapter 4.

APPENDIX D1: AREA and COORDINATES for RESEARCH ZONES.

The following table presents the area and centroidal xy coordinates for the research 38 zones. These were computed from MOTQ respective data for their 699 zones.

Zs	AREA	X-coor	Y-coor
Z1	7.50	6115.45	50388.98
Z2	4.50	6121.29	50409.73
Z3	5.60	6130.04	50426.90
Z4	5.20	6104.25	50424.06
Z5	24.30	6065.23	50398.44
Z6	13.20	6085.45	50369.11
Z7	19.80	6116.16	50350.47
Z8	16.00	6075.04	50316.47
Z9	22.60	6050.03	50344.35
Z10	36.90	5985.64	50347.33
Z11	35.00	6011.83	50395.68
Z12	20.20	6039.49	50440.26
Z13	9.20	6081.18	50437.49
Z14	13.10	6067.14	50500.95
Z15	22.50	6090.46	50480.86
Z16	18.36	6122.87	50456.17
Z17	18.50	6145.97	50492.81
Z18	27.90	6110.26	50531.32
Z19	40.40	6155.51	50564.92
Z20	69.20	5894.54	50373.03
Z21	63.60	5878.74	50319.29
Z22	207.20	5718.45	50287.99
Z23	200.40	5820.48	50432.75
Z24	105.50	5898.39	50559.56
Z25	357.60	6009.11	50662.13
Z26	297.40	6218.01	50736.39
Z27	36.40	5912.32	50436.95
Z28	30.90	5971.98	50443.68
Z29	34.80	6003.14	50480.94
Z30	43.30	5951.92	50502.07
Z31	98.60	6044.69	50569.22
Z32	334.20	6262.05	50589.50
Z33	72.40	6261.78	50402.53
Z34	45.00	6187.92	50440.84
Z35	78.10	6214.79	50363.34
Z36	527.90	6383.69	50455.03
Z37	226.70	6163.97	50250.78
Z38	326.20	5976.25	50202.04

APPENDIX D2: CALIBRATION MACRO

The macro applied using EMME/2 software package to calibrate-validate the gravity model is presented below. The macro is based on a draft of an old macro provided by INRO Inc., using escape language.

```
~/-------------------------------------
~/ calibration of entropy model:
~/ step 0    initialization
~/ -------------------------------------
~x=0         / to initialize iteration counter
3.21         / to call module 3.21
1            / matrix calculations
y            / to save results
ms12
y            / initialize matrix or change header info
teta%x%
theta value at iteration %x%
~?q=1         / register q=1, yes-no question, initialize
y            / yes, initialize data
0            / initial value=0
~/ enter starting theta = 1/ mean travel time
~*           / enter starting value of theta

2            / report results to printer
~/---------------------------------------
~: step 1
~/ iteration  %x%
~/---------------------------------------
1            / matrix calculations
y            / save results
mf6
y            / initialize matrix or change header info
entrop
entropy matrix at iteration %x%
~?q=1        / yes-no question
y
0
~/ matrix expression:
exp(0-ms12*mf61)

n            / no submatrix
2            / report results to printer
q
3.22         / to call module 3.22
```

```
1           / 2-d balancing
mf6         / matrix to be balanced
mo5         / prod. matrix from mf66
md5         / attraction matrix from mf66
n           / no submatrix

2           / to printer
1           / save balanced matrix
mf67
y
gpq%x%
demand matrix at iteration %x%
~?q=1
y
0
2           / to printer
q

3.21
1
y
ms13
y
t(%x%)
total time at iteration %x%
~?q=1
y
0
~/ matrix expression:
mf67*mf61


n
+           / aggregations for destinations
+           / aggregations for origin
2           / report result to printer
1           / mod 3.21, matrix calculation
n           / do not save results
~/ matrix expression:
(ms13-ms5)/ms5*100



1           / result to terminal
~/ this is the relative difference from total time to reproduce:
~/ hit "return" to perform another iteration or "q" to quit
~*          / to read a line from terminal and continue macro
~?m=0    / register m, to test the use of correct module
9     / the "9" is replaced with "q"
~/---------------------------------------------------
~/ computation of the new theta using Newton's method
~/---------------------------------------------------
1             /still using module 3.21
y
ms14
y
slop%x%
slope at iteration %x%
~?q=1
y
0
~/ matrix expression:
```

```
0-(mf67*mf61^2)

n           / no submatrix
+           / aggregations for destinations
+           / aggregations for origins
2           / report results to printer
~x+1
1           / mod 3.21, matrix calculation
y           / save results
ms12        / initialize or change header information
y
teta%x%
theta value at iteration %x%    / new computed theta to step 1 again
n
ms12-(ms13-ms5)/ms14

2           / report results to printer
~$ step 1
```

APPENDIX D3: 2-D BALANCE ITERATIONS.

First and last trials.

Using 'macro' from D2 above.

Several trials were made to obtain the best value of 'theta'. Up to 10 automatic iterations per balancing trial are performed. Optionally, as many trials as necessary can be made depending on 'theta' values. Reproduced here are the first and last trials (edited) giving the value of 'theta' which was presented in Chapter 4 (there are more than 90 pages in this file).

```
MATRIX CALCULATIONS

Expression: ms12 = .03487

Result matrix:   ms12: teta0     theta value at iteration 0

Constraint matrix:            none

Number of expression evaluations:          1
Minimum expression value:             0.034870
Maximum expression value:             0.034870
Average expression value:             0.034870
Sum of expression values:             0.034870
Result:                                 .03487
-------------------------------------------------

Expression: mf06 = exp(0 - ms12 * mf61)

Result matrix:   mf06: entrop    entropy matrix at iteration 0
Data matrices:     ms12: teta0     theta value at iteration 0
         mf61: autm10    auto time, from mf66, s25-a10
Constraint matrix:            none
Submatrix:      all origins    all destinations
Number of expression evaluations:       2500
Minimum expression value:             0.005073
Maximum expression value:             1.000000
Average expression value:             0.240788
Sum of expression values:           601.971130

--------------------------------------------------


Two-dimensional balancing:

matrix to be balanced: mf06;  no constraint matrix
maximum number of iterations for balancing =              10
maximum relative error on totals for balancing =        .0001
all  origins   all  destinations
productions on origins: mo05
total of productions on origins =                321544
attractions on destinations: md05
total of attractions on destinations =           321544
relative difference on totals =                   0

iteration   1     maximum current error on totals =  6.169
iteration   2     maximum current error on totals =  .2878
iteration   3     maximum current error on totals =  .0395
iteration   4     maximum current error on totals =  .0058
iteration   5     maximum current error on totals =  .0008
iteration   6     maximum current error on totals =  .0002
iteration   7     maximum current error on totals =   0
-----------------------------------------------------------
```

Two-dimensional balancing; balanced matrix saved on mf67

```
----------------------------------------------------------
```

MATRIX CALCULATIONS

```
Expression: ms13 = mf67 * mf61

Result matrix: ms13: t(0)      total time at iteration 0
Data matrices: mf67: gpq0      demand matrix at iteration 0
               mf61: autm10    auto time, from mf66, s25-a10

Constraint matrix:            none
Submatrix: all origins ,  all destinations
Aggregation over origins:                    +
Aggregation over destinations:               +
Number of expression evaluations:         2500
Minimum expression value:             0.000000
Maximum expression value:         82491.898438
Average expression value:          4425.191406
Sum of expression values:      11062979.000000
Result:                               11062980
```

MATRIX CALCULATIONS

```
Expression:  ms14 = 0 - (mf67 * mf61 ^ 2)

Result matrix: ms14: slop0     slope at iteration 0
Data matrices: mf67: gpq0      demand matrix at iteration 0
               mf61: autm10    auto time, from mf66, s25-a10

Constraint matrix:  none

Submatrix:   all origins    ; all destinations
Aggregation over origins:                    +
Aggregation over destinations:               +
Number of expression evaluations:         2500
Minimum expression value:      -5774846.000000
Maximum expression value:             0.000000
Average expression value:       -216641.312500
Sum of expression values:    -541603264.000000
Result:                               -*******
```

MATRIX CALCULATIONS

```
Expression:  ms12 = ms12 - (ms13 - ms05) / ms14

Result matrix: ms12: teta1     theta value at iteration 1
Data matrices: ms12: teta1     theta value at iteration 1
               ms13: t(0)      total time at iteration 0
               ms05: totim     total travel time from mf61
               ms14: slop0     slope at iteration 0

Constraint matrix:            none
Number of expression evaluations:            1
Minimum expression value:             0.038271
Maximum expression value:             0.038271
Average expression value:             0.038271
Sum of expression values:             0.038271
Result:                                .038271
```

End trial #1 (iteration #1)

Last trial start (iteration #15)

```
------------------------------
EMME/2 Module: 3.21      Date: 92 12 13
User: E938/INRODEMO..MGH     Page: 2705
Project:       IMPACT: GMA decentralization
-------------------------------------------
```

MATRIX CALCULATIONS

```
Expression:  mf06 = exp(0 - ms12 * mf61)

Result matrix: mf06: entrop    entropy matrix at iteration 15
Data matrices: ms12: teta15    theta value at iteration 15
               mf61: autm10    auto time, from mf66, s25-a10


Constraint matrix:             none

Submatrix:   all origins   ;   all destinations

Number of expression evaluations:          2500
Minimum expression value:              0.000332
Maximum expression value:              1.000000
Average expression value:              0.146345
Sum of expression values:            365.861359
```

Two-dimensional balancing:

```
matrix to be balanced: mf06

no constraint matrix

maximum number of iterations for balancing =              10
maximum relative error on totals for balancing =       .0001
all  origins   all  destinations
productions on origins: mo05
total of productions on origins =               321544
attractions on destinations: md05
total of attractions on destinations =          321544
relative difference on totals =                  0

iteration   1     maximum current error on totals =  5.7671
iteration   2     maximum current error on totals =  .4518
iteration   3     maximum current error on totals =  .1684
iteration   4     maximum current error on totals =  .0621
iteration   5     maximum current error on totals =  .0212
iteration   6     maximum current error on totals =  .0071
iteration   7     maximum current error on totals =  .0024
iteration   8     maximum current error on totals =  .0009
iteration   9     maximum current error on totals =  .0003
iteration  10     maximum current error on totals =  .0001
```

Two-dimensional balancing

balanced matrix saved on mf67

MATRIX CALCULATIONS

Expression: ms13 = mf67 * mf61

Result matrix: ms13: t(15)   total time at iteration 15

Data matrices: mf67: gpq15   demand matrix at iteration 15
   mf61: autm10   auto time, from mf66, s25-a10

Constraint matrix: none

Submatrix: all origins   ; all destinations

```
Aggregation over origins:                    +
Aggregation over destinations:               +
Number of expression evaluations:         2500
Minimum expression value:             0.000000
Maximum expression value:         68538.234375
Average expression value:          3707.607910
Sum of expression values:       9269020.000000
Result:                                9269020
```

The results of 'theta' are in matrix mf69 and is presented next.

APPENDIX D4: 2-D EXPONENTIAL CALIBRATION (T) 'theta'.

The exponential distributional matrix is obtained using the following equation (presented in the macro):

Cij = mf69 = exp (-0.052859 * mf61); where, theta = -0.052859

Thus, this appendix D4 is in three parts, presenting:

(a) D4-1: presents the total demand matrix including trucks.

(b) D4-2: presents the auto time, impedance (mf61), obtained from EPC trip assignment of total demand (mf66).

(c) D4-3: presents Cij, the exponential distributional coefficients (mf69).

D4-1: Total demand matrix (mf66) in EPC trips

```
-----------------------------------------------------------
EMME/2 Module: 3.12   User: E938/INRODEMO..mgh    Page: 4132
Project:        IMPACT: GMA decentralization
Matrix     mf66: totdem      total  demand,  from  mf20  rev.(auto,b,tr)
-----------------------------------------------------------
```

origin	dest:..value	dest:..value	dest:..value	dest:..value	dest:..value
1	1:577.594	2: 163.24	3: 1.166	4:117.342	5:184.652
1	6:113.208	7:140.344	8:127.412	9:163.028	10:45.6012
1	11:141.828	12:103.106	13:40.0468	14:31.1746	15:18.8256
1	16:87.6302	17: 32.065	18:63.2396	19:55.3956	20:56.1164
1	21:90.8526	22: 1	23:15.1474	24: 18.709	25: 1
1	26:37.4074	27: 1	28: 1	29:34.7362	30: 1
1	31: 1	32:22.2706	33: 1	34:60.9288	35: 1.007
1	36:21.3802	37: 1	38:17.8186		
2	1: 325.95	2:253.128	3:84.2912	4:81.3868	5: 77.327
2	6:42.6968	7:49.7776	8: 1	9:18.9952	10:115.752
2	11:20.6488	12:119.568	13:61.9252	14:48.9932	15:82.2772
2	16: 206.7	17: .954	18:31.1746	19: 1	20:12.4656
2	21: .689	22: 1	23: 18.709	24: 1	25: 1
2	26:16.0378	27:24.0514	28:37.4074	29:81.0582	30:31.1746
2	31: 1	32: 14.257	33: 21.041	34:100.043	35:94.4248
2	36: 1	37: 1	38: 1		
3	1:198.008	2:133.242	3:216.452	4:53.2226	5: 134.62
3	6:62.6566	7:57.0068	8: 1.219	9:57.1234	10:17.8186
3	11:115.964	12: 94.711	13:147.234	14:41.6262	15:80.9098
3	16:266.802	17:20.7972	18:81.6094	19:43.2056	20: 1
3	21:65.9108	22: 1	23: 1	24: 1	25:42.7604
3	26: 1	27: 1	28: 1	29:22.7052	30: 1
3	31:16.9282	32: 1	33:42.7604	34:25.3764	35:20.7124
3	36: 18.709	37: 1	38: 1		
4	1:163.558	2: 253.34	3:72.1436	4:168.434	5:182.638
4	6:101.103	7:71.4864	8:23.2988	9: 1.166	10:16.0378
4	11:111.618	12: 115.54	13:233.094	14: 1.431	15: 87.026
4	16:174.052	17: 18.709	18:121.158	19: 65.508	20:131.864
4	21:22.2706	22: 1	23:71.2638	24: 36.517	25: 1.325
4	26: 18.709	27: 1	28: 1	29: 2.491	30: 1
4	31: 1	32:33.8458	33: 18.709	34:21.3802	35: 1.749
4	36: 1	37:22.2706	38: 1		
5	1:1363.16	2:334.642	3: 118.19	4: 292.56	5:1916.48
5	6:936.298	7:82.7436	8:56.6782	9:268.922	10:222.282
5	11: 688.47	12:561.906	13:454.634	14: 1.007	15: 134.09
5	16: 251.75	17:63.4092	18: 26.553	19:15.1474	20:40.7782
5	21:127.094	22: 1	23:16.9282	24:39.1882	25:40.0892
5	26:17.8186	27: 1	28: 21.412	29:142.358	30: 87.291
5	31: 1	32: 1	33: 1	34:80.0194	35:23.2776

5	36: 1	37: 1	38: 18.709		
6	1: 1441.6	2:239.772	3:58.5226	4:153.594	5:796.378
6	6:1306.98	7:276.872	8:61.1196	9:294.574	10: 150.52
6	11:487.282	12:188.362	13: 73.034	14: 37.63	15:36.8456
6	16:272.102	17:51.6644	18:77.7192	19:16.0378	20:48.9932
6	21:234.896	22:35.6266	23: 18.709	24: 1	25: 1
6	26: 1	27: 36.517	28:61.4588	29:71.4864	30: 1
6	31: 1	32: 1	33:35.6266	34: 71.709	35:59.0632
6	36: 18.709	37:76.6062	38: 1		
7	1:1541.24	2:214.862	3:196.842	4:111.512	5:484.208
7	6:564.132	7:2356.38	8:500.214	9:392.412	10:166.844
7	11:303.054	12:114.162	13:42.4742	14:17.8186	15:54.3356
7	16:149.884	17:117.448	18:57.0068	19:54.3356	20:72.1542
7	21: 168.01	22: 1	23: 1	24:17.8186	25: 1
7	26:20.4898	27:16.9282	28:91.9126	29:59.8476	30:16.9282
7	31: 1	32:54.3356	33:52.5548	34:93.6934	35: 76.108
7	36: .954	37:32.9554	38:62.3492		
8	1: 925.38	2:267.332	3:105.152	4:44.9122	5:315.244
8	6:303.796	7:489.084	8: 1627.1	9:533.074	10:573.248
8	11:458.662	12:89.4852	13:105.152	14:40.0892	15:62.9534
8	16:95.5272	17: 1	18:40.0892	19:40.0892	20:42.4742
8	21: 204.05	22: 1	23:20.4898	24: 1	25:20.4898
8	26: 1	27: 1	28:60.5684	29:20.4898	30:17.8186
8	31: 1	32:20.4898	33:40.0892	34:60.5684	35:24.0938
8	36: 36.517	37:97.9864	38: 157.94		
9	1:1459.62	2:236.062	3:39.1882	4:172.144	5:773.588
9	6: 825.74	7:145.008	8: 113.42	9: 1431	10:623.068
9	11:439.264	12:261.714	13:71.0624	14:35.6266	15: 55.226
9	16:78.8958	17:18.8786	18:81.9486	19: 50.774	20:147.446
9	21:154.018	22:22.2706	23:22.2706	24: 1	25:16.0378
9	26: 1	27:17.8186	28:22.2706	29:44.5412	30: 1
9	31: 1	32:17.8186	33:58.7876	34: 65.455	35: 55.226
9	36:34.7362	37:53.4452	38:56.1164		
10	1: 316.94	2:57.6852	3:17.8186	4: 2.12	5:165.678
10	6:183.804	7:254.718	8:91.1918	9:460.252	10:878.422
10	11:381.176	12:90.1318	13:37.7466	14:35.6266	15: 1
10	16: 2.12	17:17.8186	18: 1	19:17.8186	20:218.042
10	21:458.874	22: 46.322	23:16.9282	24:17.8186	25: 1
10	26: 1	27: 1	28:24.9418	29:33.8458	30: 1
10	31: 1	32: 1	33: 1	34: 1	35:17.8186
10	36:16.0378	37:32.9554	38: 1		
11	1:767.228	2:218.784	3: 18.709	4:86.7398	5:876.408
11	6:431.102	7:35.6266	8: 37.63	9:117.236	10:354.464
11	11:2258.86	12:687.304	13:216.664	14: 95.188	15:235.956
11	16:184.758	17: 55.226	18:114.374	19: 18.709	20:239.348
11	21:290.652	22:32.9554	23: 36.517	24: 1	25:81.9486
11	26: 18.709	27: 36.517	28:89.2944	29:133.878	30:95.3152
11	31: 43.248	32: 1	33: 18.709	34:72.1542	35: 18.709
11	36: 18.709	37: 18.709	38: 46.64		
12	1:1217.94	2:389.232	3:221.752	4: 245.39	5:916.264
12	6:377.678	7:58.9148	8:75.9384	9: 113.42	10:148.082
12	11:1312.28	12: 2120	13:620.842	14:215.922	15:513.464
12	16:203.096	17:166.844	18:179.034	19:72.3238	20:39.9514
12	21:132.712	22: 1	23: 55.226	24:130.274	25:57.8972
12	26:17.8186	27:17.8186	28:154.124	29: 404.92	30:32.9554
12	31:32.3406	32:22.4402	33: 55.226	34: 75.048	35:34.8528
12	36:17.8186	37:19.5994	38:17.8186		
13	1:543.992	2: 501.38	3:137.906	4:392.094	5:460.888
13	6:103.223	7: 102.99	8:71.0306	9:20.3732	10:104.336
13	11:394.532	12:782.174	13:1143.74	14:333.794	15: 415.52
13	16:309.414	17:57.5156	18:98.3574	19:35.7856	20:21.0304
13	21:115.752	22: 1	23: 1	24:35.6266	25: 1
13	26: 1	27:17.8186	28:94.4248	29:196.948	30:16.9282
13	31: 41.87	32: 55.226	33:40.0892	34:103.795	35: 2.173
13	36: 1	37:24.0514	38:15.1474		
14	1:605.578	2:157.728	3:59.9536	4:70.3416	5:343.652
14	6:82.9026	7:21.8784	8:38.2978	9:79.8286	10: 36.517
14	11:495.444	12:1068.48	13:415.414	14:1868.78	15:837.612
14	16:529.046	17: 138.86	18:453.892	19:139.602	20:58.7876

14	21:129.108	22: 1	23: 36.517	24:16.9282	25:73.0446
14	26:35.6266	27:37.4074	28:58.7876	29:215.922	30:39.1882
14	31:157.092	32:39.1882	33:19.5994	34: 108.65	35:77.4966
14	36: 1	37: 1	38: 1		
15	1:901.954	2:633.562	3:207.124	4:485.056	5:757.158
15	6: 246.98	7:92.5062	8:95.7498	9:66.3772	10:216.452
15	11:587.982	12:1323.94	13:784.718	14:560.952	15:2426.34
15	16:1035.94	17:352.132	18:449.758	19:222.706	20:45.4316
15	21:169.282	22: 1	23:16.9282	24:21.3802	25:22.2706
15	26:81.0582	27: 1	28:22.2706	29:190.694	30:45.7602
15	31:108.226	32:67.7022	33:89.9622	34:71.5924	35:73.8608
15	36:22.2706	37:25.8322	38:25.8322		
16	1:693.558	2: 880.33	3:561.376	4:420.184	5:495.868
16	6:172.038	7:146.386	8:23.8924	9:61.6708	10:107.802
16	11:438.098	12:410.856	13: 864.96	14: 177.02	15:765.108
16	16:1756.42	17:340.154	18:377.572	19:209.032	20: 64.13
16	21:80.3374	22: 1	23:34.7362	24: 1	25: 1
16	26:99.7672	27: 1	28: 69.483	29:92.9196	30:21.3802
16	31:35.4464	32:74.8254	33:18.9316	34: 165.89	35: 94.022
16	36: 1	37: 14.257	38:32.9554		
17	1: 863.9	2:576.746	3:500.426	4:157.304	5:229.172
17	6: 176.49	7:61.2256	8:81.7684	9:21.8784	10:17.8186
17	11:179.458	12:343.652	13:164.618	14:162.286	15:529.894
17	16:1285.78	17:1565.62	18:473.502	19:441.384	20:20.4898
17	21:74.8254	22: 1	23:19.5994	24:61.4588	25:34.7362
17	26:37.4074	27: .954	28:70.3734	29:60.5684	30: 1
17	31:17.8186	32: 69.483	33:52.5548	34:205.746	35:40.2482
17	36:77.4966	37: 1	38: 1		
18	1:644.692	2:457.284	3: 223.66	4:96.8734	5:288.638
18	6:57.8972	7:55.3956	8: 19.769	9: 36.517	10:109.604
18	11:176.702	12:525.548	13: 562.86	14:428.134	15:861.144
18	16:453.574	17:450.288	18: 1081.2	19:296.164	20: 19.769
18	21:54.3356	22:17.8186	23: 1	24:37.4074	25: 1
18	26: 18.709	27: 1	28: 1.06	29:37.4074	30: 3.392
18	31:57.0068	32:73.0446	33:37.4074	34:129.108	35:21.1576
18	36: 18.709	37:32.9554	38: 1		
19	1: 232.67	2:464.068	3: 389.02	4: 19.822	5:147.022
19	6: 39.803	7:53.4452	8: 18.709	9:34.7362	10: 36.517
19	11: 18.709	12:112.678	13:171.296	14:110.452	15: 262.88
19	16:444.246	17:558.408	18:357.114	19:1705.54	20: 18.709
19	21: 18.709	22: 1	23: 1	24: 1	25: 73.935
19	26:95.2516	27: 1	28: 1	29: 55.226	30: 1
19	31: 36.517	32: 19.822	33: 18.709	34:38.2978	35: 36.517
19	36: 19.822	37: 1	38: 1		
20	1:1721.44	2:293.514	3: 70.596	4: 197.16	5: 1155.4
20	6: 361.46	7:177.232	8:125.186	9:284.928	10:1534.88
20	11:1840.16	12:583.106	13:106.848	14:71.2638	15:52.5548
20	16: 71.497	17:16.9282	18: 106	19:54.3356	20:2966.94
20	21:2898.04	22:158.576	23:35.6266	24:33.8458	25: 1
20	26: 1	27: 1	28:49.1098	29:208.396	30:35.6266
20	31: 18.709	32: 18.709	33: 1	34:16.9282	35:17.9352
20	36:37.4074	37:16.9282	38: 1		
21	1:1827.44	2:173.204	3:17.8822	4: 1	5:361.566
21	6:664.408	7:57.0068	8:217.512	9:234.366	10:1242.32
21	11:1099.22	12:249.948	13: 69.483	14:57.8972	15: 32.065
21	16: 50.774	17:19.5994	18: 1	19: 82.839	20:606.002
21	21:2429.52	22:165.254	23: 1	24:52.6714	25: 1
21	26: 1	27: 1	28:31.1746	29: 32.065	30: 1
21	31: 1	32:19.5994	33: 1	34:16.0378	35: 1
21	36:16.0378	37:16.0378	38: 1		
22	1:374.922	2: 125.61	3: .636	4: 27.613	5:138.966
22	6:86.6232	7: 27.613	8:57.0068	9: 105.11	10:687.622
22	11:487.282	12:87.3016	13: 1	14:31.1746	15:24.0514
22	16:16.0378	17: 1	18: 1	19:15.1474	20: 451.56
22	21:1656.78	22:1492.48	23: 1	24: 1	25:24.0514
22	26: 1	27: 1	28:37.4074	29:15.1474	30: 1
22	31: 1	32: 1	33:15.1474	34: 1	35:15.1474
22	36: 1	37:10.6848	38:44.4034		
23	1: 281.43	2:176.384	3:30.2842	4:63.2502	5:213.802

23	6: 60.685	7:34.7362	8:15.1474	9: 32.065	10:134.514
23	11:283.338	12: 209.35	13:29.3938	14:62.3492	15:99.7672
23	16:36.5382	17:16.9282	18:48.9932	19:31.1746	20: 50.774
23	21:157.622	22: 1	23:1826.38	24:670.768	25:81.9486
23	26:48.9932	27:140.238	28:266.378	29: 357.22	30: 50.774
23	31: 50.774	32:15.1474	33: 1	34: 1	35: 1
23	36: 3.869	37:16.0484	38: 1		
24	1:401.104	2:427.604	3:16.9282	4: 5.247	5:287.684
24	6: 108.65	7: 1	8:34.7362	9:52.5548	10:127.412
24	11:506.044	12:439.688	13:244.966	14:35.6266	15:131.122
24	16:159.424	17:34.7362	18:88.1814	19:52.5548	20:57.0068
24	21: 111.3	22:16.9282	23:250.266	24:3229.82	25:184.652
24	26: 1.113	27:39.1882	28: 135.15	29: 403.33	30:327.328
24	31:113.102	32: 1.06	33: 2.12	34: 1	35: 1
24	36: 1	37: 1	38:35.6266		
25	1:304.114	2:545.264	3:16.9282	4:194.192	5:224.508
25	6:63.2396	7:18.0942	8: 1	9:16.9282	10:16.9282
25	11:165.148	12: 466.93	13:193.344	14:306.552	15:173.734
25	16:167.692	17:168.646	18: 315.35	19: 187.09	20:16.9282
25	21:16.9282	22: 1	23:17.2038	24:337.822	25:2600.18
25	26:67.7022	27: 1	28:156.668	29:489.614	30:73.1612
25	31: 234.26	32:144.266	33: 1	34:35.6266	35:16.9282
25	36: 1	37: 1	38: 1		
26	1:744.014	2:600.914	3:259.382	4:143.524	5:120.416
26	6:48.1028	7:32.9554	8:51.6644	9:15.1474	10:47.2124
26	11:117.766	12:230.868	13:242.316	14:185.288	15:292.136
26	16:755.886	17:326.056	18:334.006	19:542.508	20:16.0378
26	21: 1	22: 32.065	23: 1	24:16.0378	25:121.158
26	26: 3667.6	27: 1	28:16.0378	29:53.4452	30:16.0378
26	31: 1	32:99.7672	33:98.8768	34: 78.387	35: 78.387
26	36: 1	37:140.768	38:15.1474		
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27	6: 1	7: 1.272	8: 1	9:89.1354	10:117.554
27	11:396.758	12:281.536	13:94.4884	14:31.1746	15:33.8458
27	16: 56.127	17: 1	18: 19.61	19:21.3802	20:30.2842
27	21:157.622	22: 1	23:124.444	24:54.3356	25:34.7362
27	26: 1	27:604.836	28:104.834	29:340.154	30: 150.52
27	31:44.1172	32: 18.709	33: 1	34: 1	35: 1
27	36: 1	37: 1	38: 1		
28	1:963.434	2:211.258	3:61.1196	4:131.334	5:543.462
28	6:239.984	7:15.1474	8:37.4074	9: 310.58	10:330.508
28	11:1045.16	12:647.978	13:189.316	14:148.718	15:140.768
28	16:177.444	17:37.4074	18:57.8972	19: 1	20:108.332
28	21:135.362	22: 2.385	23:57.8972	24:53.4452	25:40.0892
28	26: 1	27:153.594	28:1482.94	29:632.184	30:98.8026
28	31:75.0586	32: 1	33: 1	34: 1	35: 1
28	36: 23.161	37: 1	38: 1		
29	1:956.862	2:538.162	3: 80.719	4:190.164	5:627.308
29	6:97.4034	7:79.2774	8:35.6266	9:43.9794	10:203.096
29	11:576.746	12: 1558.2	13:288.744	14:493.112	15: 293.09
29	16:303.796	17:57.0068	18:83.9732	19: 24.539	20:159.424
29	21:147.022	22: 1	23:38.2978	24:356.266	25: 36.517
29	26:19.5994	27:95.5908	28:493.854	29:2974.36	30:234.048
29	31:359.234	32:63.2396	33: 1	34:22.5462	35:58.7876
29	36:17.8186	37: 1	38: 1		
30	1:506.998	2:200.764	3:68.6562	4:92.0292	5:244.224
30	6: 48.124	7:38.2978	8:15.1474	9:32.3936	10: 142.57
30	11:496.398	12:542.402	13:132.924	14:115.964	15:168.328
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30	21: 105.11	22: 1	23:89.0718	24:279.204	25: 1
30	26:15.1474	27: 19.557	28:421.562	29:1029.58	30: 848
30	31:103.551	32: 1	33: 1	34:35.6266	35:62.3492
30	36: 1	37: 18.709	38: 1		
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31	6:130.486	7:49.8836	8: 1	9:9.79864	10:96.2056
31	11:129.532	12:752.176	13:203.732	14:297.966	15:392.942
31	16: 98.898	17: 18.709	18:172.144	19: 67.204	20:58.7876
31	21: 18.709	22: 1	23:81.0582	24: 27.613	25:93.7994
31	26: 41.87	27:54.3356	28:168.222	29: 539.01	30: 107.59

31	31: 858.6	32: 1	33: 1	34:17.8186	35:17.8186
31	36: 1	37:16.9282	38: 18.709		
32	1:1304.86	2: 815.67	3:250.372	4: 98.156	5:213.272
32	6:106.106	7:66.9178	8:48.1028	9: 14.257	10:66.8118
32	11:17.9352	12:98.9934	13: 155.82	14:130.168	15:196.948
32	16:325.526	17:411.598	18: 153.17	19:156.774	20: 1
32	21: 1	22: 1	23: 1	24: 1	25: 1
32	26: 1	27: 1	28:51.6644	29:31.1746	30: 1
32	31: 14.257	32:3088.84	33:292.242	34:1020.25	35:239.136
32	36: 122.96	37:17.8186	38: 1		
33	1: 897.82	2:603.458	3:158.788	4: 146.81	5:113.738
33	6:180.518	7:56.1164	8:38.5204	9:16.9282	10: 19.822
33	11:70.3734	12:51.6644	13:41.1916	14:54.3356	15: 87.291
33	16:148.824	17: 106	18:70.3734	19: 18.709	20: 1.166
33	21:70.3734	22:16.9282	23: 1	24: 1	25: 1
33	26: 1	27: 18.709	28: 1	29: 1	30: 1
33	31: 1	32: 194.51	33: 1505.2	34:826.906	35:697.586
33	36:147.022	37:56.1164	38: 1		
34	1:1228.54	2:782.068	3: 280.9	4:109.498	5:237.864
34	6:83.9944	7:194.722	8:41.2552	9:23.1504	10:138.118
34	11:181.684	12:140.132	13:167.056	14: 62.01	15: 298.92
34	16:362.414	17: 120.84	18: 219.42	19:158.788	20:19.5994
34	21:19.5994	22: 1	23:19.5994	24:19.5994	25:20.7654
34	26:39.1882	27: 1	28: 1	29:79.2774	30: 1
34	31: 1	32:712.214	33:754.508	34:4502.88	35:543.356
34	36:210.728	37:138.118	38:41.5202		
35	1:2250.38	2:678.612	3:241.468	4:155.502	5:455.058
35	6: 738.29	7:413.188	8:98.7178	9:56.8902	10: 260.23
35	11:387.642	12: 169.6	13:143.418	14:89.9622	15:167.904
35	16:327.222	17:74.4862	18:109.604	19: 164.83	20: 1
35	21:54.3356	22: 1	23: 1	24:17.9882	25: 1
35	26:75.7158	27: 1	28:35.6266	29: 1.06	30:21.3802
35	31: 1	32:351.814	33:539.752	34:1418.28	35:3993.02
35	36:71.2638	37:345.242	38:36.6866		
36	1:832.418	2:625.612	3:151.474	4:146.068	5: 94.711
36	6: 67.946	7: .954	8: 37.471	9:16.0378	10:39.1882
36	11:65.9744	12: 73.935	13:48.1028	14:21.3802	15:61.4588
36	16:209.774	17: 150.52	18:52.5548	19: 32.065	20: 1.537
36	21:16.0378	22: 1	23: 18.709	24: 19.875	25: 1
36	26: .954	27: 1	28: 1	29: 1	30: 1
36	31: .954	32:504.772	33:593.388	34:877.362	35:471.382
36	36: 2888.5	37:76.7864	38: 1		
37	1:593.706	2:314.714	3: 106	4:49.8836	5:184.016
37	6:131.228	7:162.074	8: 164.83	9: 73.935	10:152.322
37	11:112.254	12:35.9658	13: 1.908	14:17.8186	15:35.6266
37	16: 36.517	17: 1	18:19.9386	19:16.2074	20: 1
37	21: 1	22:16.9282	23: 1	24:19.5994	25: 1
37	26:249.206	27: 1	28: 1	29:29.3938	30: 1
37	31: 1	32: 46.322	33: 78.387	34: 244.33	35:455.058
37	36: 41.87	37:2134.84	38: 64.13		
38	1:548.126	2: 128.26	3:53.4452	4: 1	5: 177.55
38	6:136.316	7:160.378	8: 219.42	9:282.596	10:387.642
38	11:159.636	12:86.4006	13:36.6866	14: 1	15: 1
38	16: 3.18	17: 1.06	18:33.8458	19: 1	20:16.0378
38	21:71.2638	22: 1	23: 1	24: 1	25: 1
38	26:35.6266	27: 1	28: 1	29:35.6266	30: 1
38	31: 1	32: .954	33:17.8186	34: 74.518	35:109.604
38	36: 1	37: 50.774	38:1550.78		

D4-2: Time impedance (mf61)

```
------------------------------------------------------------
EMME/2 Module: 3.12  User: E938/INRODEMO..mgh    Page: 4127
Project:         IMPACT: GMA decentralization
Matrix   mf61: autm10    auto time, from mf66, s25-a10
------------------------------------------------------------
```

origin	dest:..value	dest:..value	dest:..value	dest:..value	dest:..value
1	1: 0	2: 8.886	3: 10.551	4: 11.124	5: 11.812
1	6: 8.207	7: 7.443	8: 14.28	9: 13.392	10: 21.278
1	11: 25.111	12: 21.702	13: 15.398	14: 28.428	15: 24.212
1	16: 15.723	17: 18.786	18: 31.123	19: 32.702	20: 38.985
1	21: 32.173	22: 50.823	23: 46.32	24: 40.404	25: 47.999
1	26: 52.893	27: 32.94	28: 24.938	29: 29.92	30: 30.709
1	31: 40.792	32: 34.553	33: 24.049	34: 17.46	35: 14.059
1	36: 40.55	37: 18.014	38: 31.197		
2	1: 9.929	2: 0	3: 9.083	4: 7.232	5: 16.409
2	6: 14.664	7: 13.677	8: 19.481	9: 18.593	10: 26.479
2	11: 30.537	12: 20.539	13: 12.598	14: 25.491	15: 21.275
2	16: 12.796	17: 17.089	18: 28.186	19: 31.565	20: 44.293
2	21: 37.374	22: 56.024	23: 49.223	24: 42.964	25: 44.874
2	26: 49.956	27: 36.134	28: 27.498	29: 28.211	30: 33.269
2	31: 37.667	32: 34.24	33: 23.972	34: 17.147	35: 19.176
2	36: 40.237	37: 23.131	38: 36.398		
3	1: 13.657	2: 10.834	3: 0	4: 9.035	5: 20.391
3	6: 18.331	7: 17.422	8: 23.226	9: 22.338	10: 30.224
3	11: 34.282	12: 23.92	13: 14.442	14: 22.797	15: 18.559
3	16: 10.063	17: 13.14	18: 25.47	19: 28.051	20: 48.038
3	21: 41.119	22: 59.769	23: 52.772	24: 46.513	25: 42.346
3	26: 47.24	27: 39.683	28: 31.047	29: 28.07	30: 34.842
3	31: 35.139	32: 31.984	33: 21.716	34: 14.891	35: 17.922
3	36: 37.981	37: 21.877	38: 40.143		
4	1: 14.855	2: 10.848	3: 9.653	4: 0	5: 11.408
4	6: 18.066	7: 18.603	8: 24.407	9: 20.72	10: 25.44
4	11: 26.089	12: 15.043	13: 5.959	14: 18.974	15: 14.772
4	16: 8.437	17: 17.432	18: 21.683	19: 25.062	20: 39.963
4	21: 38.004	22: 56.654	23: 43.895	24: 37.636	25: 38.326
4	26: 43.453	27: 30.806	28: 22.17	29: 22.001	30: 27.941
4	31: 31.119	32: 34.849	33: 24.581	34: 17.756	35: 20.787
4	36: 40.846	37: 24.742	38: 41.324		
5	1: 16.316	2: 20.026	3: 22.07	4: 12.322	5: 0
5	6: 13.219	7: 15.93	8: 20.252	9: 14.309	10: 12.755
5	11: 13.404	12: 11.41	13: 8.744	14: 20.847	15: 17.496
5	16: 18.093	17: 25.967	18: 24.407	19: 27.786	20: 27.278
5	21: 25.319	22: 43.969	23: 34.613	24: 30.112	25: 39.161
5	26: 46.177	27: 21.233	28: 14.646	29: 19.628	30: 20.417
5	31: 31.954	32: 47.275	33: 36.208	34: 30.182	35: 26.218
5	36: 53.272	37: 30.173	38: 37.099		
6	1: 10.989	2: 16.529	3: 18.309	4: 16.76	5: 10.159
6	6: 0	7: 5.965	8: 11.098	9: 9.41	10: 18.096
6	11: 19.232	12: 19.421	13: 18.611	14: 28.858	15: 25.924
6	16: 23.184	17: 26.544	18: 32.835	19: 36.214	20: 33.106
6	21: 28.991	22: 47.641	23: 40.441	24: 38.123	25: 47.172
6	26: 54.605	27: 27.061	28: 22.657	29: 27.639	30: 28.428
6	31: 39.965	32: 42.311	33: 26.243	34: 25.218	35: 16.253
6	36: 43.498	37: 20.208	38: 28.015		
7	1: 8.168	2: 14.678	3: 16.346	4: 16.629	5: 15.217
7	6: 8.417	7: 0	8: 10.553	9: 12.335	10: 20.221
7	11: 24.29	12: 24.479	13: 20.903	14: 33.916	15: 30.007
7	16: 21.518	17: 24.581	18: 36.918	19: 38.497	20: 38.035
7	21: 31.116	22: 49.766	23: 45.37	24: 43.181	25: 52.23
7	26: 58.688	27: 31.99	28: 27.715	29: 32.697	30: 33.486

7	31: 45.023	32: 39.748	33: 23.429	34: 23.255	35: 13.439
7	36: 40.684	37: 17.394	38: 30.135		
8	1: 19.278	2: 25.244	3: 26.912	4: 27.195	5: 22.184
8	6: 15.384	7: 11.737	8: 0	9: 7.246	10: 15.114
8	11: 24.584	12: 31.446	13: 30.636	14: 40.883	15: 37.949
8	16: 32.084	17: 35.147	18: 44.86	19: 48.239	20: 32.946
8	21: 26.027	22: 44.677	23: 40.281	24: 40.564	25: 52.469
8	26: 66.63	27: 26.901	28: 23.273	29: 36.535	30: 36.526
8	31: 49.933	32: 50.22	33: 33.901	34: 33.821	35: 23.911
8	36: 51.156	37: 22.219	38: 20.701		
9	1: 19.899	2: 24.984	3: 26.652	4: 21.96	5: 15.129
9	6: 12.784	7: 14.28	8: 5.615	9: 0	10: 9.879
9	11: 19.297	12: 24.391	13: 23.689	14: 33.828	15: 30.894
9	16: 28.296	17: 34.887	18: 37.805	19: 41.184	20: 27.659
9	21: 20.74	22: 39.39	23: 34.994	24: 35.277	25: 47.182
9	26: 59.575	27: 21.614	28: 17.986	29: 31.248	30: 31.239
9	31: 44.646	32: 50.654	33: 34.558	34: 33.561	35: 24.568
9	36: 51.813	37: 23.98	38: 22.462		
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10	6: 23.533	7: 23.357	8: 14.416	9: 10.76	10: 0
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10	16: 32.872	17: 37.308	18: 34.512	19: 37.891	20: 18.097
10	21: 16.425	22: 34.789	23: 29.738	24: 30.021	25: 41.926
10	26: 56.282	27: 16.358	28: 12.73	29: 25.992	30: 25.983
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11	16: 31.286	17: 35.722	18: 32.926	19: 36.305	20: 22.799
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11	26: 54.696	27: 12.975	28: 9.347	29: 16.901	30: 17.69
11	31: 30.3	32: 62.648	33: 46.827	34: 45.555	35: 36.837
11	36: 64.082	37: 40.227	38: 38.709		
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12	6: 26.322	7: 29.033	8: 32.958	9: 27.109	10: 21.031
12	11: 15.59	12: 0	13: 12.307	14: 12.066	15: 15.794
12	16: 21.065	17: 25.501	18: 22.705	19: 26.084	20: 34.46
12	21: 33.595	22: 51.152	23: 32.134	24: 25.875	25: 28.21
12	26: 44.475	27: 19.045	28: 10.409	29: 9.974	30: 16.18
12	31: 21.003	32: 52.537	33: 42.269	34: 35.444	35: 38.475
12	36: 58.534	37: 42.43	38: 47.926		
13	1: 21.392	2: 17.944	3: 16.146	4: 7.254	5: 9.97
13	6: 22.403	7: 25.114	8: 29.882	9: 23.939	10: 23.202
13	11: 23.851	12: 11.951	13: 0	14: 14.388	15: 10.186
13	16: 11.606	17: 18.88	18: 17.097	19: 20.476	20: 37.725
13	21: 35.766	22: 54.416	23: 40.803	24: 34.544	25: 33.508
13	26: 38.867	27: 27.714	28: 19.078	29: 17.183	30: 23.955
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14	26: 38.617	27: 26.59	28: 24.591	29: 15.514	30: 19.814
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16	31: 26.547	32: 34.607	33: 28.806	34: 21.981	35: 25.012
16	36: 45.071	37: 28.967	38: 47.325		
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17	11: 41.686	12: 29.378	13: 21.041	14: 21.016	15: 15.231
17	16: 9.072	17: 0	18: 10.985	19: 13.686	20: 56.018
17	21: 54.059	22: 72.709	23: 57.73	24: 51.467	25: 35.258
17	26: 32.755	27: 44.641	28: 36.505	29: 32.664	30: 37.865
17	31: 32.764	32: 27.975	33: 30.662	34: 15.955	35: 30.033
17	36: 38.453	37: 33.988	38: 53.389		
18	1: 42.83	2: 39.151	3: 34.091	4: 29.983	5: 33.581
18	6: 47.079	7: 46.578	8: 52.382	9: 48.071	10: 42.551
18	11: 41.471	12: 26.905	13: 24.808	14: 9.339	15: 13.092
18	16: 22.429	17: 14.208	18: 0	19: 7.803	20: 57.074
18	21: 55.115	22: 73.765	23: 46.479	24: 40.216	25: 28.697
18	26: 26.194	27: 33.39	28: 33.446	29: 22.314	30: 26.614
18	31: 21.513	32: 42.991	33: 45.678	34: 30.971	35: 45.049
18	36: 53.469	37: 49.004	38: 69.299		
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19	11: 48.141	12: 35.833	13: 30.207	14: 21.28	15: 21.686
19	16: 25.751	17: 17.822	18: 9.823	19: 0	20: 62.473
19	21: 60.514	22: 79.164	23: 49.022	24: 39.989	25: 22.811
19	26: 20.308	27: 46.491	28: 42.96	29: 35.415	30: 39.715
19	31: 31.173	32: 42.322	33: 45.009	34: 30.302	35: 44.38
19	36: 52.8	37: 48.335	38: 71.061		
20	1: 70.005	2: 73.83	3: 75.438	4: 66.073	5: 52.576
20	6: 62.143	7: 64.613	8: 55.917	9: 51.996	10: 37.69
20	11: 45.759	12: 56.831	13: 61.594	14: 67.556	15: 65.081
20	16: 70.352	17: 74.788	18: 71.992	19: 75.371	20: 0
20	21: 29.581	22: 44.057	23: 59.453	24: 59.736	25: 71.641
20	26: 93.762	27: 46.073	28: 42.445	29: 55.707	30: 55.698
20	31: 69.105	32:100.987	33: 84.891	34: 83.894	35: 74.901
20	36:102.146	37: 70.363	38: 68.845		
21	1: 52.153	2: 57.238	3: 58.906	4: 51.379	5: 37.882
21	6: 46.796	7: 46.534	8: 36.1	9: 34.03	10: 26.099
21	11: 34.168	12: 43.884	13: 46.9	14: 53.321	15: 50.387
21	16: 55.658	17: 60.094	18: 57.298	19: 60.677	20: 17.295
21	21: 0	22: 16.49	23: 49.792	24: 50.075	25: 61.98
21	26: 79.068	27: 36.412	28: 32.784	29: 46.046	30: 46.037
21	31: 59.444	32: 82.908	33: 66.812	34: 65.815	35: 56.822
21	36: 84.067	37: 50.545	38: 49.027		
22	1: 75.058	2: 80.143	3: 81.811	4: 74.284	5: 60.787
22	6: 69.701	7: 69.439	8: 59.005	9: 56.935	10: 48.13
22	11: 56.199	12: 66.789	13: 69.805	14: 76.226	15: 73.292
22	16: 78.563	17: 82.999	18: 80.203	19: 83.582	20: 39.182
22	21: 23.214	22: 0	23: 71.823	24: 72.106	25: 84.011
22	26:101.973	27: 58.443	28: 54.815	29: 68.077	30: 68.068
22	31: 81.475	32:105.813	33: 89.717	34: 88.72	35: 79.727
22	36:106.972	37: 73.45	38: 71.932		
23	1: 80.668	2: 80.594	3: 80.154	4: 71.673	5: 63.033
23	6: 72.93	7: 75.548	8: 66.852	9: 62.931	10: 54.451
23	11: 53.582	12: 55.857	13: 66.31	14: 59.205	15: 63.86
23	16: 75.068	17: 77.601	18: 65.505	19: 62.612	20: 62.172
23	21: 66.372	22: 82.369	23: 0	24: 20.613	25: 32.518
23	26: 55.369	27: 15.801	28: 31.35	29: 33.223	30: 28.499
23	31: 45.643	32:105.305	33: 95.826	34: 89.538	35: 85.836
23	36:112.628	37: 83.338	38: 81.82		
24	1: 78.288	2: 76.661	3: 76.14	4: 67.74	5: 60.724
24	6: 72.306	7: 75.017	8: 68.118	9: 64.197	10: 55.717
24	11: 53.895	12: 51.924	13: 62.377	14: 54.326	15: 58.981
24	16: 70.758	17: 71.856	18: 60.626	19: 54.166	20: 63.438
24	21: 67.638	22: 83.635	23: 21.596	24: 0	25: 24.072
24	26: 46.923	27: 23.374	28: 30.69	29: 25.778	30: 20.739
24	31: 37.197	32:100.426	33: 92.349	34: 85.524	35: 85.305
24	36:108.614	37: 84.604	38: 83.086		

25	1: 78.523	2: 74.844	3: 69.985	4: 64.644	5: 65.991
25	6: 78.149	7: 80.86	8: 78.822	9: 74.901	10: 66.421
25	11: 64.256	12: 52.664	13: 58.589	14: 42.557	15: 47.212
25	16: 58.989	17: 53.873	18: 44.089	19: 36.183	20: 74.142
25	21: 78.342	22: 94.339	23: 32.3	24: 23.267	25: 0
25	26: 28.94	27: 34.078	28: 41.394	29: 26.162	30: 31.443
25	31: 17.516	32: 82.59	33: 85.277	34: 70.57	35: 82.855
25	36: 93.068	37: 86.81	38: 93.79		
26	1: 90.924	2: 87.245	3: 82.185	4: 78.077	5: 81.675
26	6: 95.173	7: 94.672	8:100.476	9: 96.165	10: 90.645
26	11: 90.836	12: 78.187	13: 72.902	14: 60.934	15: 64.381
26	16: 70.523	17: 62.302	18: 52.518	19: 44.612	20:105.168
26	21:103.209	22:121.859	23: 66.083	24: 57.05	25: 39.872
26	26: 0	27: 67.861	28: 74.271	29: 59.945	30: 65.226
26	31: 48.234	32: 90.74	33: 93.427	34: 78.72	35: 92.798
26	36:101.218	37: 96.753	38:117.393		
27	1: 61.687	2: 61.695	3: 61.661	4: 53.053	5: 44.052
27	6: 53.949	7: 56.482	8: 47.786	9: 43.865	10: 35.385
27	11: 34.516	12: 37.039	13: 47.817	14: 41.032	15: 45.687
27	16: 56.575	17: 59.428	18: 47.332	19: 58.329	20: 43.106
27	21: 47.306	22: 63.303	23: 13.447	24: 18.678	25: 30.583
27	26: 53.434	27: 0	28: 12.434	29: 15.05	30: 11.762
27	31: 28.448	32: 87.132	33: 76.76	34: 70.926	35: 66.77
27	36: 94.015	37: 64.272	38: 62.754		
28	1: 48.683	2: 47.056	3: 46.616	4: 38.135	5: 31.119
28	6: 42.701	7: 45.412	8: 40.695	9: 36.774	10: 28.294
28	11: 24.424	12: 22.319	13: 32.772	14: 32.246	15: 35.754
28	16: 41.53	17: 45.966	18: 41.542	19: 46.549	20: 36.015
28	21: 40.215	22: 56.212	23: 23.159	24: 20.779	25: 32.602
28	26: 51.859	27: 9.783	28: 0	29: 11.996	30: 12.347
28	31: 25.395	32: 73.093	33: 62.825	34: 56	35: 55.7
28	36: 79.09	37: 57.181	38: 55.663		
29	1: 52.479	2: 48.483	3: 45.801	4: 38.768	5: 38.691
29	6: 50.849	7: 53.56	8: 55.656	9: 51.636	10: 43.255
29	11: 34.349	12: 25.026	13: 32.713	14: 26.508	15: 30.056
29	16: 40.715	17: 44.904	18: 32.808	19: 43.805	20: 50.976
29	21: 55.176	22: 71.173	23: 26.43	24: 20.171	25: 21.266
29	26: 40.523	27: 13.341	28: 13.984	29: 0	30: 6.632
29	31: 14.059	32: 72.278	33: 62.01	34: 55.185	35: 58.216
29	36: 78.275	37: 62.171	38: 70.624		
30	1: 63.056	2: 60.597	3: 58.047	4: 51.014	5: 45.492
30	6: 57.074	7: 59.785	8: 58.775	9: 54.854	10: 46.374
30	11: 38.821	12: 36.692	13: 44.959	14: 36.269	15: 40.924
30	16: 52.701	17: 54.665	18: 42.569	19: 53.566	20: 54.095
30	21: 58.295	22: 74.292	23: 23.726	24: 17.456	25: 29.361
30	26: 50.149	27: 12.166	28: 16.045	29: 10.423	30: 0
30	31: 23.685	32: 82.369	33: 74.256	34: 67.431	35: 70.073
30	36: 90.521	37: 74.028	38: 73.743		
31	1: 67.46	2: 63.781	3: 58.922	4: 53.581	5: 54.928
31	6: 67.086	7: 69.797	8: 73.652	9: 67.873	10: 61.251
31	11: 52.345	12: 41.601	13: 47.526	14: 31.494	15: 36.149
31	16: 47.926	17: 49.89	18: 37.794	19: 40.156	20: 68.972
31	21: 73.172	22: 89.169	23: 41.691	24: 32.658	25: 13.656
31	26: 32.913	27: 30.834	28: 31.477	29: 19.758	30: 21.612
31	31: 0	32: 77.594	33: 75.586	34: 65.574	35: 71.792
31	36: 88.072	37: 75.747	38: 88.62		
32	1: 55.801	2: 54.331	3: 50.554	4: 53.744	5: 64.093
32	6: 58.997	7: 53.745	8: 62.379	9: 62.926	10: 70.812
32	11: 74.87	12: 65.233	13: 56.896	14: 55.639	15: 51.086
32	16: 43.668	17: 35.784	18: 47.369	19: 45.781	20: 88.626
32	21: 81.707	22:100.357	23: 92.779	24: 86.516	25: 71.642
32	26: 69.139	27: 79.69	28: 72.36	29: 68.519	30: 72.914
32	31: 67.813	32: 0	33: 17.691	34: 29.576	35: 30.464
32	36: 25.482	37: 43.382	38: 67.289		
33	1: 41.519	2: 43.253	3: 39.476	4: 42.666	5: 51.153
33	6: 44.895	7: 39.643	8: 48.277	9: 48.824	10: 56.71
33	11: 60.768	12: 56.991	13: 48.082	14: 55.418	15: 50.865
33	16: 43.447	17: 35.563	18: 47.148	19: 45.56	20: 74.524
33	21: 67.605	22: 86.255	23: 81.859	24: 79.546	25: 71.421

33	26: 68.918	27: 68.479	28: 64.08	29: 61.71	30: 68.482
33	31: 67.592	32: 18.078	33: 0	34: 17.324	35: 12.706
33	36: 19.348	37: 29.44	38: 53.347		
34	1: 31.944	2: 30.501	3: 26.724	4: 29.914	5: 40.534
34	6: 36.646	7: 31.394	8: 40.028	9: 40.575	10: 48.461
34	11: 52.519	12: 44.239	13: 35.33	14: 38.159	15: 33.606
34	16: 26.188	17: 18.304	18: 29.889	19: 28.301	20: 66.275
34	21: 59.356	22: 78.006	23: 73.053	24: 66.794	25: 54.162
34	26: 51.659	27: 59.964	28: 51.328	29: 48.958	30: 55.434
34	31: 50.333	32: 24.989	33: 15.981	34: 0	35: 18.945
34	36: 32.246	37: 26.186	38: 50.093		
35	1: 30.679	2: 34.186	3: 31.475	4: 34.665	5: 39.135
35	6: 32.877	7: 27.625	8: 36.259	9: 36.806	10: 44.692
35	11: 48.75	12: 48.251	13: 40.081	14: 49.407	15: 45.169
35	16: 36.479	17: 31.729	18: 43.314	19: 41.726	20: 62.506
35	21: 55.587	22: 74.237	23: 69.841	24: 67.641	25: 67.587
35	26: 65.084	27: 56.461	28: 52.175	29: 53.709	30: 57.946
35	31: 61.749	32: 30.799	33: 10.785	34: 18.901	35: 0
35	36: 31.735	37: 17.469	38: 41.376		
36	1: 62.961	2: 64.047	3: 60.27	4: 63.46	5: 71.819
36	6: 65.561	7: 60.309	8: 68.943	9: 69.49	10: 77.376
36	11: 81.434	12: 74.949	13: 66.612	14: 65.355	15: 60.802
36	16: 53.384	17: 45.5	18: 57.085	19: 55.497	20: 95.19
36	21: 88.271	22:106.921	23:102.495	24: 96.232	25: 81.358
36	26: 78.855	27: 89.145	28: 82.076	29: 78.235	30: 82.63
36	31: 77.529	32: 27.563	33: 24.525	34: 38.766	35: 37.028
36	36: 0	37: 49.759	38: 73.853		
37	1: 33.566	2: 37.073	3: 34.411	4: 37.601	5: 42.022
37	6: 35.764	7: 30.512	8: 25.574	9: 28.007	10: 34.193
37	11: 44.01	12: 51.04	13: 43.017	14: 52.343	15: 48.105
37	16: 39.415	17: 35.761	18: 47.346	19: 45.758	20: 52.372
37	21: 45.453	22: 64.103	23: 59.707	24: 59.99	25: 71.619
37	26: 69.116	27: 46.327	28: 42.699	29: 55.961	30: 55.952
37	31: 64.685	32: 43.169	33: 26.85	34: 26.943	35: 16.86
37	36: 44.105	37: 0	38: 25.517		
38	1: 43.415	2: 48.596	3: 50.264	4: 49.978	5: 43.147
38	6: 38.068	7: 35.6	8: 25.668	9: 28.101	10: 34.287
38	11: 44.104	12: 51.134	13: 51.707	14: 60.571	15: 57.637
38	16: 55.436	17: 58.499	18: 64.548	19: 67.927	20: 52.466
38	21: 45.547	22: 64.197	23: 59.801	24: 60.084	25: 71.989
38	26: 86.318	27: 46.421	28: 42.793	29: 56.055	30: 56.046
38	31: 69.453	32: 67.304	33: 50.985	34: 51.078	35: 40.995
38	36: 68.24	37: 25.745	38: 0		

D4-3: Cij exponential distributional coefficients.

Matrix mf69 previously called mf7

EMME/2 Module: 3.12 User: E938/INRODEMO..mgh Page: 4122
Project: IMPACT: GMA decentralization
Matrix, mf69: expfun, function of mf61 (autm10) as exponent.

---

origin	dest:..value	dest:..value	dest:..value	dest:..value	dest:..value
1	1: 1	2: .62519	3: .57252	4: .55544	5: .5356
1	6: .64803	7: .67474	8: .47009	9: .49268	10: .32474
1	11: .26518	12: .31754	13: .44312	14: .22253	15: .27809
1	16: .43557	17: .37046	18: .19299	19: .17753	20: .12736
1	21: .18257	22: .06812	23: .08643	24: .11816	25: .07909
1	26: .06106	27: .17531	28: .26762	29: .20566	30: .19726
1	31: .11576	32: .16099	33: .28049	34: .39736	35: .47562
1	36: .11725	37: .38589	38: .19223		
2	1: .59165	2: 1	3: .61871	4: .68231	5: .42006
2	6: .46065	7: .48532	8: .3571	9: .37426	10: .24668
2	11: .19906	12: .33768	13: .5138	14: .25991	15: .32479
2	16: .50845	17: .40523	18: .2254	19: .18853	20: .0962
2	21: .13868	22: .05175	23: .07413	24: .10321	25: .09329
2	26: .07132	27: .14808	28: .23375	29: .2251	30: .17229
2	31: .13655	32: .16367	33: .28164	34: .40399	35: .3629
2	36: .11921	37: .29444	38: .14603		
3	1: .48583	2: .56401	3: 1	4: .62028	5: .34033
3	6: .37948	7: .39816	8: .29296	9: .30704	10: .20238
3	11: .16331	12: .28241	13: .46608	14: .29968	15: .37493
3	16: .58748	17: .49929	18: .2602	19: .22701	20: .07893
3	21: .11378	22: .04245	23: .06145	24: .08555	25: .10663
3	26: .08233	27: .12275	28: .19376	29: .22679	30: .15855
3	31: .15608	32: .1844	33: .31731	34: .45515	35: .38777
3	36: .13431	37: .31462	38: .1198		
4	1: .45602	2: .5636	3: .60035	4: 1	5: .54716
4	6: .38483	7: .37406	8: .27524	9: .33446	10: .26061
4	11: .25182	12: .45151	13: .7298	14: .3668	15: .45802
4	16: .6402	17: .39795	18: .31786	19: .26587	20: .12095
4	21: .13414	22: .05005	23: .09825	24: .13678	25: .13188
4	26: .10057	27: .19625	28: .30978	29: .31256	30: .22834
4	31: .19303	32: .15849	33: .27272	34: .39119	35: .33328
4	36: .11543	37: .2704	38: .11255		
5	1: .42213	2: .34696	3: .31142	4: .52135	5: 1
5	6: .49721	7: .43083	8: .34284	9: .46937	10: .50956
5	11: .49237	12: .5471	13: .6299	14: .33222	15: .3966
5	16: .38428	17: .25345	18: .27524	19: .23022	20: .23648
5	21: .26228	22: .09787	23: .16048	24: .20358	25: .12618
5	26: .08709	27: .32551	28: .46108	29: .35433	30: .33986
5	31: .18469	32: .08217	33: .1475	34: .20283	35: .25011
5	36: .05985	37: .20293	38: .14072		
6	1: .55941	2: .4174	3: .37992	4: .41234	5: .5845
6	6: 1	7: .72957	8: .5562	9: .60811	10: .38422
6	11: .36183	12: .35823	13: .3739	14: .21753	15: .25403
6	16: .29362	17: .24584	18: .17629	19: .14745	20: .17378
6	21: .21601	22: .0806	23: .11793	24: .1333	25: .08262
6	26: .05578	27: .23921	28: .30191	29: .23201	30: .22253
6	31: .12093	32: .10683	33: .24978	34: .26369	35: .42354
6	36: .10033	37: .34364	38: .22745		
7	1: .64937	2: .46031	3: .42146	4: .4152	5: .44738
7	6: .64088	7: 1	8: .57246	9: .52099	10: .3434

7	11: .27694	12: .27419	13: .33124	14: .1665	15: .20471
7	16: .32065	17: .27272	18: .14207	19: .13069	20: .13392
7	21: .19306	22: .07204	23: .09088	24: .10203	25: .06324
7	26: .04495	27: .18434	28: .23108	29: .17758	30: .17033
7	31: .09256	32: .12233	33: .28984	34: .29252	35: .49146
7	36: .11642	37: .39875	38: .20333		
8	1: .36095	2: .26332	3: .2411	4: .23752	5: .30955
8	6: .44344	7: .53773	8: 1	9: .6818	10: .44982
8	11: .27267	12: .18972	13: .19802	14: .11521	15: .13453
8	16: .18343	17: .15601	18: .09336	19: .07809	20: .17526
8	21: .25265	22: .09427	23: .11893	24: .11716	25: .06245
8	26: .02954	27: .24124	28: .29224	29: .14497	30: .14504
8	31: .0714	32: .07033	33: .16663	34: .16734	35: .28255
8	36: .06693	37: .30898	38: .3348		
9	1: .34929	2: .26697	3: .24444	4: .31324	5: .44946
9	6: .50877	7: .47009	8: .74319	9: 1	10: .59322
9	11: .36059	12: .27547	13: .29588	14: .16728	15: .19534
9	16: .22409	17: .15817	18: .13556	19: .11339	20: .23177
9	21: .33411	22: .12467	23: .15728	24: .15494	25: .08258
9	26: .04289	27: .31902	28: .38646	29: .19172	30: .19181
9	31: .09443	32: .06873	33: .16094	34: .16965	35: .2729
9	36: .06465	37: .28152	38: .30504		
10	1: .21618	2: .16523	3: .15128	4: .2206	5: .45025
10	6: .28825	7: .29094	8: .46672	9: .56623	10: 1
10	11: .47607	12: .32784	13: .27953	14: .19908	15: .23248
10	16: .17595	17: .13917	18: .16134	19: .13495	20: .3842
10	21: .4197	22: .15899	23: .20765	24: .20456	25: .10903
10	26: .05105	27: .42119	28: .51023	29: .25312	30: .25324
10	31: .12467	32: .04254	33: .09961	34: .105	35: .1689
10	36: .04001	37: .19544	38: .21177		
11	1: .18719	2: .15362	3: .14623	4: .23148	5: .47246
11	6: .28364	7: .24577	8: .2851	9: .35076	10: .54647
11	11: 1	12: .52083	13: .30398	14: .25757	15: .25281
11	16: .19133	17: .15134	18: .17544	19: .14675	20: .29965
11	21: .28884	22: .124	23: .2483	24: .24462	25: .13771
11	26: .05551	27: .50366	28: .61014	29: .40927	30: .39256
11	31: .20157	32: .03646	33: .08414	34: .09	35: .14268
11	36: .0338	37: .11927	38: .12924		
12	1: .20743	2: .23977	3: .251	4: .39503	5: .47104
12	6: .24874	7: .21553	8: .17515	9: .2386	10: .32901
12	11: .43864	12: 1	13: .52177	14: .52846	15: .43394
12	16: .32842	17: .25977	18: .30114	19: .25189	20: .16178
12	21: .16935	22: .06695	23: .18294	24: .25469	25: .22511
12	26: .09528	27: .36542	28: .57683	29: .59025	30: .42517
12	31: .32949	32: .06222	33: .10707	34: .15358	35: .13084
12	36: .04532	37: .10616	38: .07939		
13	1: .32279	2: .38732	3: .42594	4: .68151	5: .59037
13	6: .30599	7: .26514	8: .20607	9: .28213	10: .29334
13	11: .28344	12: .53168	13: 1	14: .46742	15: .58367
13	16: .54146	17: .36862	18: .40506	19: .3388	20: .13614
13	21: .15099	22: .05634	23: .11569	24: .16106	25: .17013
13	26: .12816	27: .23109	28: .36479	29: .40322	30: .28189
13	31: .24901	32: .10735	33: .18471	34: .26496	35: .22573
13	36: .07818	37: .18315	38: .08458		
14	1: .14019	2: .17028	3: .22015	4: .28124	5: .23517
14	6: .11744	7: .11499	8: .08461	9: .11266	10: .15083
14	11: .18059	12: .39551	13: .37392	14: 1	15: .62813
14	16: .34474	17: .32618	18: .6133	19: .34331	20: .07
14	21: .07764	22: .02897	23: .12278	24: .17096	25: .3139
14	26: .12987	27: .24524	28: .27257	29: .44041	30: .35087
14	31: .45945	32: .07594	33: .09124	34: .14336	35: .1115
14	36: .04365	37: .09046	38: .0364		
15	1: .18078	2: .21959	3: .28389	4: .36221	5: .30289
15	6: .14786	7: .14829	8: .10911	9: .14081	10: .18852
15	11: .18663	12: .35797	13: .48159	14: .64196	15: 1
15	16: .52514	17: .4492	18: .53568	19: .43557	20: .08749
15	21: .09704	22: .03621	23: .10637	24: .14812	25: .27197
15	26: .16477	27: .21248	28: .24554	29: .391	30: .30399
15	31: .39807	32: .10386	33: .11819	34: .19606	35: .14443

15	36: .05969	37: .11718	38: .04549		
16	1: .33206	2: .40335	3: .52348	4: .60343	5: .36206
16	6: .2647	7: .27238	8: .20042	9: .22123	10: .17238
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16	21: .08873	22: .03311	23: .06747	24: .09393	25: .16793
16	26: .12965	27: .13477	28: .21273	29: .25794	30: .18771
16	31: .2458	32: .16053	33: .21813	34: .31289	35: .26657
16	36: .09233	37: .21628	38: .08196		
17	1: .24122	2: .28205	3: .38123	4: .33434	5: .22478
17	6: .18977	7: .19769	8: .14546	9: .15245	10: .11154
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17	16: .61907	17: 1	18: .55953	19: .48509	20: .05176
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18	6: .08303	7: .08526	8: .06273	9: .07879	10: .10548
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18	21: .05429	22: .02026	23: .08571	24: .11934	25: .21939
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18	31: .32073	32: .10306	33: .08941	34: .19454	35: .09244
18	36: .05923	37: .075	38: .02565		
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19	6: .07373	7: .07768	8: .05715	9: .0599	10: .07929
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19	16: .25636	17: .38983	18: .59498	19: 1	20: .0368
19	21: .04081	22: .01523	23: .07493	24: .12078	25: .29946
19	26: .34182	27: .08565	28: .10323	29: .15382	30: .12254
19	31: .19248	32: .10677	33: .09263	34: .20155	35: .09576
19	36: .06136	37: .0777	38: .02337		
20	1: .02471	2: .02019	3: .01854	4: .03042	5: .06209
20	6: .03745	7: .03286	8: .05204	9: .06403	10: .13639
20	11: .08903	12: .04959	13: .03855	14: .02813	15: .03206
20	16: .02426	17: .01919	18: .02225	19: .01861	20: 1
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20	31: .02592	32: .00481	33: .01125	34: .01186	35: .01908
20	36: .00452	37: .02425	38: .02628		
21	1: .0635	2: .04853	3: .04444	4: .06615	5: .13501
21	6: .08428	7: .08546	8: .14835	9: .1655	10: .25169
21	11: .1643	12: .09831	13: .08382	14: .0597	15: .06971
21	16: .05276	17: .04173	18: .04838	19: .04046	20: .40084
21	21: 1	22: .41826	23: .07194	24: .07087	25: .03777
21	26: .01531	27: .14592	28: .17677	29: .08769	30: .08773
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21	36: .01175	37: .06913	38: .07491		
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22	11: .05127	12: .02929	13: .02498	14: .01779	15: .02077
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22	36: .0035	37: .0206	38: .02232		
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23	6: .02117	7: .01844	8: .0292	9: .03592	10: .05623
23	11: .05888	12: .05221	13: .03004	14: .04374	15: .0342
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24	16: .02375	17: .02241	18: .04057	19: .05709	20: .03497

24	21: .02801	22: .01202	23: .31933	24: 1	25: .28015
24	26: .08372	27: .29068	28: .19746	29: .25599	30: .33412
24	31: .13999	32: .00495	33: .00759	34: .01088	35: .01101
24	36: .00321	37: .01142	38: .01238		
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25	6: .01607	7: .01392	8: .01551	9: .01908	10: .02987
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25	31: .39618	32: .01271	33: .01102	34: .02399	35: .01253
25	36: .0073	37: .01017	38: .00703		
26	1: .00818	2: .00994	3: .01298	4: .01613	5: .01334
26	6: .00653	7: .00671	8: .00494	9: .0062	10: .0083
26	11: .00822	12: .01604	13: .0212	14: .03992	15: .03327
26	16: .02405	17: .03713	18: .06228	19: .0946	20: .00385
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26	26: 1	27: .02768	28: .01972	29: .04206	30: .03182
26	31: .07811	32: .00826	33: .00717	34: .01559	35: .00741
26	36: .00475	37: .00601	38: .00202		
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27	6: .05775	7: .05051	8: .07998	9: .09841	10: .15406
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27	26: .05934	27: 1	28: .51828	29: .45134	30: .53702
27	31: .2223	32: .00999	33: .01729	34: .02354	35: .02932
27	36: .00695	37: .03346	38: .03626		
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28	6: .10465	7: .09068	8: .11636	9: .14315	10: .22412
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28	16: .11133	17: .08806	18: .11126	19: .08539	20: .14901
28	21: .11935	22: .05124	23: .294	24: .33342	25: .17847
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28	31: .26123	32: .02099	33: .03612	34: .05181	35: .05264
28	36: .01529	37: .04868	38: .05274		
29	1: .06241	2: .07709	3: .08883	4: .12883	5: .12936
29	6: .06803	7: .05895	8: .05276	9: .06526	10: .10163
29	11: .16273	12: .26638	13: .17743	14: .2463	15: .20418
29	16: .11623	17: .09315	18: .17654	19: .09872	20: .06757
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29	31: .47562	32: .02192	33: .03771	34: .05409	35: .04609
29	36: .01596	37: .03739	38: .02392		
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30	16: .06168	17: .0556	18: .10538	19: .05893	20: .0573
30	21: .04589	22: .0197	23: .28532	24: .39744	25: .21183
30	26: .07059	27: .52567	28: .42822	29: .5764	30: 1
30	31: .28594	32: .01286	33: .01974	34: .02832	35: .02463
30	36: .00836	37: .01998	38: .02028		
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31	6: .02884	7: .02499	8: .02038	9: .02766	10: .03926
31	11: .06286	12: .11092	13: .08109	14: .18924	15: .14796
31	16: .07939	17: .07157	18: .13564	19: .11972	20: .0261
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32	11: .01911	12: .0318	13: .04942	14: .05281	15: .06718
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32	31: .02775	32: 1	33: .39254	34: .20943	35: .19983
32	36: .26003	37: .10095	38: .02853		
33	1: .1114	2: .10164	3: .1241	4: .10484	5: .06694

33	6: .09319	7: .12301	8: .07794	9: .07571	10: .0499
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33	21: .02806	22: .01047	23: .01321	24: .01492	25: .02293
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33	31: .02808	32: .38459	33: 1	34: .40022	35: .51088
33	36: .35962	37: .21094	38: .05961		
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34	6: .14413	7: .19024	8: .12053	9: .1171	10: .07718
34	11: .06228	12: .09648	13: .15451	14: .13305	15: .16925
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34	36: .18186	37: .25053	38: .0708		
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35	6: .1759	7: .23218	8: .1471	9: .14291	10: .0942
35	11: .07601	12: .07804	13: .12019	14: .07342	15: .09185
35	16: .1454	17: .1869	18: .10131	19: .11018	20: .03674
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35	26: .03206	27: .05057	28: .06342	29: .05848	30: .04675
35	31: .03824	32: .19632	33: .56548	34: .36822	35: 1
35	36: .18684	37: .39717	38: .11224		
36	1: .03586	2: .03386	3: .04134	4: .03493	5: .02245
36	6: .03126	7: .04126	8: .02614	9: .0254	10: .01674
36	11: .01351	12: .01903	13: .02957	14: .0316	15: .0402
36	16: .0595	17: .09026	18: .04893	19: .05321	20: .00653
36	21: .00941	22: .00351	23: .00444	24: .00618	25: .01356
36	26: .01548	27: .00899	28: .01306	29: .016	30: .01268
36	31: .0166	32: .23295	33: .27352	34: .12885	35: .14124
36	36: 1	37: .07206	38: .02017		
37	1: .16961	2: .14091	3: .1622	4: .13703	5: .10847
37	6: .151	7: .19932	8: .25877	9: .22754	10: .16408
37	11: .09765	12: .06735	13: .10292	14: .06286	15: .07865
37	16: .1245	17: .15103	18: .08187	19: .08904	20: .06277
37	21: .09048	22: .03376	23: .04259	24: .04196	25: .02269
37	26: .0259	27: .0864	28: .10466	29: .05192	30: .05195
37	31: .03274	32: .10209	33: .24189	34: .24071	35: .41016
37	36: .09716	37: 1	38: .25955		
38	1: .10077	2: .07663	3: .07017	4: .07123	5: .10221
38	6: .13369	7: .15232	8: .25749	9: .22641	10: .16327
38	11: .09717	12: .06701	13: .06501	14: .04069	15: .04752
38	16: .05338	17: .0454	18: .03298	19: .02758	20: .06246
38	21: .09003	22: .03359	23: .04238	24: .04175	25: .02225
38	26: .01043	27: .08597	28: .10414	29: .05166	30: .05169
38	31: .02545	32: .02851	33: .06754	34: .06721	35: .11453
38	36: .02713	37: .25644	38: 1		

APPENDIX D5: 3-D BALANCING.

Calibration-validation process output

```
-----------------------------------------------------------
EMME/2 Module: 3.22   Date: 92 12 13   User: E938/INRODEMO..MGH
Page: 2715   Project:       IMPACT: GMA decentralization
------------------------------------------------------------

Three-dimensional_balancing

matrix to be balanced: mf66
no constraint matrix

maximum number of iterations for balancing =   10
maximum relative error on totals for balancing =  .0001
all  origins   all  destinations
productions on origins: mo05
total of productions on origins =                   321544
attractions on destinations: md05
total of attractions on destinations =              321544

third dimension matrix: mf08

interval number     third dimension totals
         1                  37093
         2                  32852
         3                  14138
         4                 233960

Total of third dimension =                    311041
relative difference on totals =                 .044


iteration   1     maximum current error on totals =   1
iteration   2     maximum current error on totals =  .2031
iteration   3     maximum current error on totals =  .1031
iteration   4     maximum current error on totals =  .0742
iteration   5     maximum current error on totals =  .0782
iteration   6     maximum current error on totals =  .0797
iteration   7     maximum current error on totals =  .0803
iteration   8     maximum current error on totals =  .0806
iteration   9     maximum current error on totals =  .0807
iteration  10     maximum current error on totals =  .0807

Three-dimensional balancing:

balanced matrix saved on mf09

coefficients for origins saved on mo09
coefficients for destinations saved on md09

third dimension distribution coefficients are not saved
  number       coefficient
     1             .694
     2            .7933
     3            .6688
     4           1.5626
```

APPENDIX E

Supplemental to Chapter 5

E1. ZONAL and DISTRICT STATISTICS

Section E1 presents additional statistical data by zone and district.

Minor variations in the number of observations are (unavoidable) detected resulting from the centroidal link deletion process and wrong coded type for Centroidal links (about 20 in 8205).

Statistics for the 1987 base year (from sc. 25-10):

Z	Obs	Variable	Minimum	Maximum	Sum	Mean	Std Dev
Z1	379	ZLL	0.06	3.39	256.71	0.68	0.54
		ZLLA	0.06	2.82	202.87	0.62	0.46
		ZLLF	0.24	3.39	53.84	1.06	0.80
		DEN	0.00	141.69	3328.3	8.78	17.53
		DENA	0.00	87.13	2351.3	7.17	14.60
		DENF	0.03	141.69	977.01	19.16	28.31
		TAU	0.04	4.48	194	0.51	0.46
		SPD	12.58	79.40	12359	32.61	8.74
		VAU	0.00	6501.0	251840	664.49	1201.2
Z2	265	ZLL	0.04	2.22	141.96	0.54	0.44
		ZLLA	0.04	2.22	127.04	0.50	0.40
		ZLLF	0.40	2.08	14.92	1.15	0.63
		DEN	0.00	172.02	2970.9	11.21	20.78
		DENA	0.00	172.02	2548.6	10.11	20.26
		DENF	11.20	62.09	422.34	32.49	20.00
		TAU	0.05	1.66	115	0.44	0.31
		SPD	6.29	55.50	8196	30.93	6.98
		VAU	0.00	6812.0	191028	720.86	1204.6

TABLE E5.4-1: 1987 STATISTICS: ZLL, ZLLA, ZLLF, DEN, DENA, DENF, TAU, VAU. By zone and district. Legend in footnote #1, Chapter 5.

Z	Obs	Variable	Minimum	Maximum	Sum	Mean	Std Dev
Z3	199	ZLL	0.030	5.010	129.13	0.649	0.595
		ZLLA	0.030	2.440	109.75	0.600	0.492
		ZLLF	0.240	5.010	19.38	1.211	1.153
		DEN	0.000	324.53	3902.2	19.609	30.892
		DENA	0.000	324.53	3591.9	19.628	31.877
		DENF	1.633	59.190	310.24	19.390	16.353
		TAU	0.050	3.400	117	0.588	0.467
		SPD	3.740	74.760	6164	30.975	9.881
		VAU	0.000	6685.0	215830	1084.6	1117.6
Z4	156	ZLL	0.09	2.19	106.53	0.68	0.42
		ZLLA	0.09	2.19	106.53	0.68	0.42
		ZLLF	.	.	.	.	.
		DEN	0.00	164.63	2609.4	16.73	22.58
		DENA	0.00	164.63	2609.4	16.73	22.58
		DENF	.	.	.	.	.
		TAU	0.20	3.27	119	0.76	0.46
		SPD	6.36	40.00	4497	28.83	6.87
		VAU	0.00	2925.0	117138	750.88	663.19
Z5	272	ZLL	0.08	7.05	268.62	0.99	0.94
		ZLLA	0.08	4.53	224.45	0.91	0.78
		ZLLF	0.18	7.05	44.17	1.84	1.75
		DEN	0.00	109.87	4156.0	15.28	20.68
		DENA	0.00	66.16	2760.6	11.13	13.51
		DENF	3.76	109.87	1395.4	58.14	31.24
		TAU	0.08	3.98	253	0.93	0.70
		SPD	16.54	59.86	80936	29.75	7.11
		VAU	0.00	6540.0	281007	1033.1	1509.2
Z6	297	ZLL	0.04	3.96	236.75	0.80	0.66
		ZLLA	0.04	3.27	190.53	0.71	0.58
		ZLLF	0.63	3.96	46.22	1.54	0.87
		DEN	0.00	127.75	3083.9	10.38	17.02
		DENA	0.00	64.79	2005.9	7.51	12.72
		DENF	0.90	127.75	1078.0	35.93	26.82
		TAU	0.04	4.21	202	0.68	0.55
		SPD	13.16	79.25	10148	34.17	9.64
		VAU	0.00	6854.0	251506	846.82	1488.0
Z7	257	ZLL	0.07	11.22	306.27	1.19	1.75
		ZLLA	0.07	11.22	243.55	1.07	1.72
		ZLLF	0.50	9.87	62.72	2.16	1.66
		DEN	0.00	136.71	1623.4	6.32	15.41
		DENA	0.00	94.66	927.12	4.07	10.36
		DENF	0.00	136.71	696.23	24.01	30.60
		TAU	0.08	10.55	245	0.95	1.52
		SPD	16.49	80.00	9309	36.22	10.50
		VAU	0.00	6817.0	137897	536.56	1197.4

TABLE E5.4-1: Continue.

Z	Obs	Variable	Minimum	Maximum	Sum	Mean	Std Dev
Z8	227	ZLL	0.04	3.69	186.27	0.82	0.69
		ZLLA	0.04	3.69	176.75	0.79	0.66
		ZLLF	1.40	3.40	9.52	2.38	0.76
		DEN	0.00	158.27	916.90	4.04	14.95
		DENA	0.00	158.27	780.26	3.50	14.39
		DENF	15.40	48.68	136.63	34.16	16.94
		TAU	0.03	2.62	159	0.70	0.50
		SPD	7.77	68.17	7638	33.65	6.45
		VAU	0.00	2708.0	47310	208.41	484.86
Z9	220	ZLL	0.04	3.42	229.92	1.05	0.82
		ZLLA	0.04	3.34	170.38	0.90	0.69
		ZLLF	0.24	3.42	59.54	1.98	0.92
		DEN	0.00	285.17	2944.7	13.38	27.93
		DENA	0.00	285.17	1723.9	9.07	24.40
		DENF	7.13	152.49	1220.8	40.69	33.44
		TAU	0.05	4.99	219	1.00	0.83
		SPD	4.17	74.63	7180	32.64	9.32
		VAU	0.00	6949.0	197279	896.72	1528.4
Z10	221	ZLL	0.04	5.63	286.54	1.30	1.13
		ZLLA	0.04	5.63	180.99	1.07	0.98
		ZLLF	0.12	5.34	105.55	2.03	1.28
		DEN	0.00	152.25	1980.8	8.96	19.98
		DENA	0.00	80.48	691.43	4.09	11.78
		DENF	0.00	152.25	1289.4	24.80	30.51
		TAU	0.03	8.44	274	1.24	1.29
		SPD	10.92	74.19	8437	38.18	14.86
		VAU	0.00	6949.0	179167	810.71	1435.3
Z11	237	ZLL	0.10	7.02	380.85	1.61	1.35
		ZLLA	0.10	7.02	285.81	1.45	1.30
		ZLLF	0.18	4.98	95.04	2.38	1.32
		DEN	0.00	298.81	3810.5	16.08	38.70
		DENA	0.00	298.81	2755.4	13.99	40.87
		DENF	0.12	92.73	1055.1	26.38	23.14
		TAU	0.12	5.26	309	1.30	1.03
		SPD	4.82	73.97	7945	33.52	12.88
		VAU	0.00	6320.0	232743	982.04	1402.3
Z12	277	ZLL	0.07	7.02	291.56	1.05	0.79
		ZLLA	0.07	7.02	263.90	1.00	0.73
		ZLLF	0.36	3.87	27.66	2.13	1.26
		DEN	0.00	210.97	6305.1	22.76	32.41
		DENA	0.00	190.98	5598.7	21.21	29.78
		DENF	4.97	210.97	706.36	54.34	59.98
		TAU	0.12	5.27	318	1.15	0.77
		SPD	5.66	70.78	7879	28.44	9.50
		VAU	0.00	6674.0	287177	1036.7	1243.7

TABLE E5.4-1: Continue

Z	Obs	Variable	Minimum	Maximum	Sum	Mean	Std Dev
Z13	162	ZLL	0.07	3.57	178.95	1.10	0.70
		ZLLA	0.07	3.57	156.18	1.07	0.71
		ZLLF	0.96	2.46	22.77	1.42	0.44
		DEN	0.00	111.30	3308.2	20.42	20.78
		DENA	0.00	111.30	2428.7	16.63	16.56
		DENF	27.76	110.12	879.46	54.97	23.89
		TAU	0.14	2.76	157	0.97	0.57
		SPD	10.12	53.89	4942	30.51	6.25
		VAU	0.00	6539.0	224784	1387.6	1541.1
Z14	94	ZLL	0.13	4.38	110.00	1.17	0.96
		ZLLA	0.13	4.38	105.98	1.16	0.96
		ZLLF	0.63	2.76	4.02	1.34	1.10
		DEN	0.00	247.29	1890.6	20.11	31.62
		DENA	0.00	140.02	1605.4	17.64	21.30
		DENF	17.89	247.29	285.18	95.06	131.84
		TAU	0.21	3.25	125	1.33	0.80
		SPD	9.79	51.25	2706	28.79	8.19
		VAU	0.00	7478.0	91478	973.17	1152.9
Z15	179	ZLL	0.12	7.53	278.05	1.55	1.13
		ZLLA	0.12	7.53	245.32	1.47	1.10
		ZLLF	1.41	4.35	32.73	2.73	0.87
		DEN	0.00	106.83	2616.4	14.62	20.37
		DENA	0.00	97.18	2056.7	12.32	17.91
		DENF	24.36	106.83	559.66	46.64	26.07
		TAU	0.11	6.80	229	1.28	0.83
		SPD	12.98	57.65	5247	29.31	7.29
		VAU	0.00	6502.0	107108	1045.3	1440.6
Z16	193	ZLL	0.14	3.60	239.36	1.24	0.76
		ZLLA	0.14	3.60	239.36	1.24	0.76
		ZLLF	.	.	.	.	.
		DEN	0.00	56.66	2414.6	12.51	13.18
		DENA	0.00	56.66	2414.6	12.51	13.18
		DENF	.	.	.	.	.
		TAU	0.11	2.71	206	1.07	0.57
		SPD	18.69	39.99	6072	31.46	4.81
		VAU	0.00	3443.0	151052	782.65	812.11
Z17	152	ZLL	0.14	7.95	213.34	1.40	1.08
		ZLLA	0.14	4.26	196.57	1.32	0.88
		ZLLF	4.41	7.95	16.77	5.59	1.83
		DEN	0.00	78.26	1930.6	12.70	14.41
		DENA	0.00	66.35	1790.6	12.02	13.33
		DENF	26.08	78.26	140.01	46.67	27.78
		TAU	0.11	6.12	173	1.13	0.77
		SPD	15.87	55.66	4838	31.83	5.88
		VAU	0.00	6100.0	140315	923.12	1052.5

TABLE E5.4-1: Continue.

Z	Obs	Variable	Minimum	Maximum	Sum	Mean	Std Dev
Z18	172	ZLL	0.15	7.26	187.04	1.09	0.85
		ZLLA	0.15	4.26	158.10	1.03	0.72
		ZLLF	0.66	7.26	28.94	1.61	1.48
		DEN	0.00	194.00	2008.9	11.68	24.59
		DENA	0.00	53.08	812.14	5.27	9.48
		DENF	18.68	194.00	1196.7	66.48	41.46
		TAU	0.09	5.36	221	1.29	0.86
		SPD	12.47	64.57	5216	30.32	8.45
		VAU	0.00	7251.0	131224	763.05	1577.8
Z19	163	ZLL	0.14	8.79	297.34	1.82	1.43
		ZLLA	0.14	6.39	241.42	1.60	1.05
		ZLLF	1.83	8.79	55.92	4.66	2.37
		DEN	0.00	81.27	1443.7	8.86	15.95
		DENA	0.00	81.27	1052.6	6.97	14.09
		DENF	12.90	60.40	391.16	32.60	19.34
		TAU	0.17	6.63	282	1.73	1.11
		SPD	9.17	70.44	4949	30.36	9.20
		VAU	0.00	5747.0	110561	678.29	1266.3
Z20	246	ZLL	0.10	5.01	306.00	1.24	1.05
		ZLLA	0.10	5.01	293.46	1.23	1.04
		ZLLF	0.45	4.68	12.54	1.57	1.42
		DEN	0.00	777.30	5994.9	24.37	67.58
		DENA	0.00	777.30	5219.7	21.93	64.11
		DENF	12.12	365.05	775.22	96.90	120.27
		TAU	0.11	14.05	388	1.58	1.61
		SPD	3.49	71.37	6868	27.92	8.59
		VAU	0.00	8046.0	229271	932.00	1333.9
Z21	299	ZLL	0.04	10.96	463.18	1.55	1.52
		ZLLA	0.04	5.01	285.53	1.17	1.06
		ZLLF	0.44	10.96	177.65	3.29	1.99
		DEN	0.00	184.87	3699.4	12.37	27.17
		DENA	0.00	184.87	2247.3	9.17	25.75
		DENF	0.00	136.35	1452.1	26.89	28.90
		TAU	0.04	7.02	392	1.31	1.15
		SPD	6.40	79.64	10978	36.72	12.46
		VAU	0.00	6810.0	232229	776.69	1264.2
Z22	77	ZLL	0.20	75.60	377.03	4.90	8.63
		ZLLA	0.20	75.60	241.63	4.56	10.19
		ZLLF	2.04	10.96	135.40	5.64	3.06
		DEN	0.00	52.79	319.74	4.15	8.68
		DENA	0.00	28.85	68.24	1.29	5.22
		DENF	0.43	52.79	251.50	10.48	11.27
		TAU	0.45	47.27	432	5.61	6.93
		SPD	22.19	79.64	3488	45.30	19.39
		VAU	0.00	3705.0	33213	431.34	819.93

TABLE E5.4-1: Continue

Z	Obs	Variable	Minimum	Maximum	Sum	Mean	Std Dev
Z23	61	ZLL	0.58	17.48	234.52	3.84	3.54
		ZLLA	0.58	17.48	177.98	3.42	3.61
		ZLLF	4.34	8.90	56.54	6.28	1.78
		DEN	0.00	37.79	218.48	3.58	8.52
		DENA	0.00	37.79	99.20	1.91	6.82
		DENF	0.00	26.64	119.27	13.25	11.17
		TAU	0.55	19.66	231	3.79	4.19
		SPD	25.10	80.00	2336	38.30	13.92
		VAU	0.00	2937.0	20109	329.66	782.31
Z24	231	ZLL	0.15	22.24	451.35	3.45	4.38
		ZLLA	0.15	18.78	256.73	2.59	3.41
		ZLLF	0.78	22.24	194.62	6.08	5.82
		DEN	0.00	69.82	1220.3	9.32	15.45
		DENA	0.00	69.82	638.93	6.45	14.38
		DENF	0.00	65.93	581.41	18.17	15.48
		TAU	0.18	12.91	318	2.43	2.48
		SPD	13.16	80.00	5283	40.29	16.27
		VAU	0.00	5870.0	113542	866.73	1457.5
Z25	134	ZLL	0.17	31.96	504.15	3.76	5.87
		ZLLA	0.17	31.96	334.81	3.04	5.17
		ZLLF	1.56	27.92	169.64	7.06	7.59
		DEN	0.00	109.13	530.20	3.96	11.73
		DENA	0.00	20.76	99.43	0.90	2.68
		DENF	0.74	109.13	430.77	17.95	22.63
		TAU	0.16	35.95	507	3.78	5.56
		SPD	19.95	78.74	5543	41.36	14.56
		VAU	0.00	6530.0	51213	382.19	934.55
Z26	105	ZLL	0.19	24.80	358.02	3.41	4.52
		ZLLA	0.19	24.80	231.37	2.57	3.31
		ZLLF	0.76	23.22	126.65	8.44	6.99
		DEN	0.00	279.49	1754.3	16.71	41.58
		DENA	0.00	261.84	1051.3	11.68	32.05
		DENF	0.48	279.49	702.97	46.86	71.97
		TAU	0.28	27.94	423	4.03	4.38
		SPD	8.01	76.94	3862	36.78	12.75
		VAU	0.00	5139.0	67997	647.59	1136.1
Z27	97	ZLL	0.12	5.76	135.13	1.39	1.12
		ZLLA	0.12	3.40	109.87	1.23	0.84
		ZLLF	0.24	5.76	25.26	3.16	2.07
		DEN	0.00	364.48	1243.1	12.82	41.41
		DENA	0.00	68.15	561.56	6.31	11.67
		DENF	15.72	364.48	681.55	85.19	123.61
		TAU	0.12	12.72	182	1.88	1.74
		SPD	7.36	67.85	3302	34.04	9.80
		VAU	0.00	8046.0	65322	673.42	1444.8

TABLE E5.4-1: Continue.

Z	Obs	Variable	Minimum	Maximum	Sum	Mean	Std Dev
Z28	163	ZLL	0.08	5.50	194.15	1.19	1.04
		ZLLA	0.08	2.70	124.10	0.89	0.57
		ZLLF	0.24	5.50	70.05	2.92	1.41
		DEN	0.00	426.52	2603.8	15.97	39.09
		DENA	0.00	426.52	1746.8	12.57	39.18
		DENF	2.06	134.95	857.06	35.71	32.78
		TAU	0.07	4.53	192	1.18	0.81
		SPD	5.55	71.03	5556	34.08	11.26
		VAU	0.00	6310.0	147488	904.83	1464.6
Z29	256	ZLL	0.12	3.96	278.22	1.09	0.69
		ZLLA	0.12	2.66	210.93	0.95	0.56
		ZLLF	0.72	3.96	67.19	1.92	0.85
		DEN	0.00	464.28	4867.1	19.01	50.56
		DENA	0.00	365.26	3135.5	14.19	38.38
		DENF	0.00	464.28	1731.7	49.48	92.37
		TAU	0.11	6.35	300	1.17	0.98
		SPD	3.78	80.00	8842	34.54	12.17
		VAU	0.00	8357.0	211979	828.04	1357.1
Z30	96	ZLL	0.23	6.93	162.13	1.69	1.63
		ZLLA	0.23	5.94	126.43	1.42	1.28
		ZLLF	2.13	6.93	35.70	5.10	1.82
		DEN	0.00	63.83	588.77	6.13	12.06
		DENA	0.00	42.17	343.55	3.86	8.01
		DENF	19.45	63.83	245.22	35.03	17.62
		TAU	0.36	6.68	165	1.72	1.29
		SPD	22.50	63.68	3504	36.50	6.51
		VAU	0.00	5826.0	48041	500.43	1201.9
Z31	194	ZLL	0.10	10.24	301.60	1.55	1.77
		ZLLA	0.10	10.24	224.57	1.33	1.62
		ZLLF	0.57	7.16	77.03	3.08	1.95
		DEN	0.00	352.51	2400.9	12.38	34.82
		DENA	0.00	80.47	1025.9	6.07	15.43
		DENF	0.00	352.51	1375.0	55.00	76.88
		TAU	0.09	11.52	365	1.88	2.29
		SPD	7.68	70.88	6694	34.50	10.11
		VAU	0.00	8119.0	141284	728.27	1518.2
Z32	250	ZLL	0.04	32.88	581.05	2.32	3.97
		ZLLA	0.04	32.88	357.07	1.78	3.70
		ZLLF	0.70	20.56	223.97	4.57	4.29
		DEN	0.00	1660.1	3658.9	14.64	105.68
		DENA	0.00	1660.1	2321.3	11.55	117.17
		DENF	0.00	127.80	1337.7	27.30	23.11
		TAU	0.13	20.60	583	2.33	2.68
		SPD	1.26	79.81	9210	36.84	12.47
		VAU	0.00	4487.0	275088	550.18	1034.4

TABLE E5.4-1: Continue.

Z	Obs	Variable	Minimum	Maximum	Sum	Mean	Std Dev
Z33	179	ZLL	0.06	8.16	273.73	1.53	1.36
		ZLLA	0.06	8.16	200.23	1.36	1.24
		ZLLF	0.56	6.24	73.50	2.30	1.60
		DEN	0.00	41.12	952.58	5.32	8.51
		DENA	0.00	41.12	400.23	2.72	6.56
		DENF	6.66	26.15	552.36	17.26	5.80
		TAU	0.12	9.18	270	1.51	1.31
		SPD	24.00	73.82	6684	37.34	11.41
		VAU	0.00	2661.0	84320	471.06	786.39
Z34	534	ZLL	0.02	7.95	422.39	0.79	0.86
		ZLLA	0.02	4.48	300.08	0.63	0.53
		ZLLF	0.18	7.95	122.31	2.04	1.61
		DEN	0.00	938.51	6055.4	11.34	48.10
		DENA	0.00	938.51	4619.1	9.74	48.52
		DENF	0.00	302.64	1436.2	23.94	42.93
		TAU	0.04	11.65	480	0.90	0.93
		SPD	2.28	79.45	19177	35.91	11.73
		VAU	0.00	7809.0	269893	505.42	1016.2
Z35	496	ZLL	0.04	9.87	503.00	1.01	1.06
		ZLLA	0.04	6.75	349.77	0.84	0.70
		ZLLF	0.18	9.87	153.21	1.94	1.85
		DEN	0.00	146.48	3419.2	6.89	16.09
		DENA	0.00	87.19	1600.8	3.84	9.50
		DENF	0.00	146.48	1818.4	23.02	29.11
		TAU	0.06	11.90	446	0.90	1.05
		SPD	10.28	76.42	18531	37.36	12.40
		VAU	0.00	7156.0	309164	623.31	1229.4
Z36	197	ZLL	0.02	32.13	848.00	4.30	4.88
		ZLLA	0.02	32.13	726.65	4.38	5.24
		ZLLF	0.74	8.64	121.34	3.91	2.12
		DEN	0.00	70.29	636.33	3.23	9.20
		DENA	0.00	70.29	333.66	2.01	7.60
		DENF	0.00	53.02	302.66	9.76	13.52
		TAU	0.04	20.14	788	4.00	3.81
		SPD	13.72	80.00	8581	43.56	14.91
		VAU	0.00	3710.0	49791	252.75	643.02
Z37	93	ZLL	0.18	30.96	456.64	4.91	6.09
		ZLLA	0.18	30.96	375.85	4.53	6.03
		ZLLF	3.48	18.96	80.79	8.08	5.79
		DEN	0.00	43.11	239.31	2.57	5.77
		DENA	0.00	11.81	118.93	1.43	2.76
		DENF	0.13	43.11	120.38	12.04	12.64
		TAU	0.38	18.16	335	3.60	4.22
		SPD	26.07	79.89	3963	42.61	12.04
		VAU	0.00	3518.0	30452	327.44	766.32

TABLE E5.4-1: Continue.

Z	Obs	Variable	Minimum	Maximum	Sum	Mean	Std Dev
Z38	135	ZLL	0.36	75.60	656.7	4.86	7.60
		ZLLA	0.36	75.60	640.9	5.01	7.77
		ZLLF	0.80	3.58	15.80	2.26	1.20
		DEN	0.00	87.34	575.37	4.26	10.41
		DENA	0.00	34.52	375.20	2.93	6.54
		DENF	8.90	87.34	200.17	28.60	28.05
		TAU	0.34	47.26	589	4.36	5.11
		SPD	23.84	56.68	5246	38.85	7.43
		VAU	0.00	4163.0	39509	292.66	635.81
GMA	7865	ZLL	0.02	75.60	11832	1.50	2.56
		ZLLA	0.02	75.60	9193.5	1.32	2.41
		ZLLF	0.12	27.92	2638.6	2.94	3.16
		DEN	0.00	1660.1	94223	11.98	34.71
		DENA	0.00	1660.1	66512	9.55	32.84
		DENF	0.00	464.28	27711	30.82	42.25
		TAU	0.03	47.27	11305	1.44	2.15
		SPD	1.26	80.00	269453	34.26	11.32
		VAU	0.00	8357.0	5.7E6	725.85	1242.4
D1	843	ZLL	0.03	5.01	527.8	0.63	0.53
		ZLLA	0.03	2.82	439.66	0.58	0.45
		ZLLF	0.24	5.01	88.14	1.10	0.86
		DEN	0.00	324.53	10201	12.10	22.72
		DENA	0.00	324.53	8491.8	11.13	22.22
		DENF	0.03	141.69	1709.6	21.37	25.36
		TAU	0.04	4.48	427	0.51	0.43
		SPD	3.74	79.40	26719	31.70	8.56
		VAU	0.00	6812.0	6.6E5	781.37	1194.6
D2	590	ZLL	0.07	7.05	554.12	0.94	0.78
		ZLLA	0.07	4.53	487.10	0.89	0.69
		ZLLF	0.18	7.05	66.94	1.67	1.39
		DEN	0.00	164.63	10074	17.07	21.30
		DENA	0.00	164.63	7798.8	14.18	17.50
		DENF	3.76	110.12	2274.8	56.87	28.24
		TAU	0.08	3.98	529	0.90	0.62
		SPD	6.36	59.86	17533	29.72	6.84
		VAU	0.00	6540.0	6.25E5	1055.8	1367.8
D3	1001	ZLL	0.04	11.22	959.20	0.96	1.09
		ZLLA	0.04	11.22	781.20	0.86	1.03
		ZLLF	0.24	9.87	178.00	1.91	1.21
		DEN	0.00	285.17	8568.9	8.56	19.49
		DENA	0.00	285.17	5437.2	5.99	15.94
		DENF	0.00	152.49	3131.6	33.67	30.34
		TAU	0.03	10.55	826	0.83	0.96
		SPD	4.17	80.00	34274	34.24	9.27
		VAU	0.00	6949.0	6.35E5	633.36	1289.0

TABLE E5.4-1: Continue.

Z	Obs	Variable	Minimum	Maximum	Sum	Mean	Std Dev
D4	550	ZLL	0.07	7.53	679.60	1.24	0.97
		ZLLA	0.07	7.53	615.20	1.18	0.93
		ZLLF	0.36	4.35	64.41	2.30	1.16
		DEN	0.00	247.29	10812	19.66	29.08
		DENA	0.00	190.98	9260.9	17.74	25.37
		DENF	4.97	247.29	1551.2	55.40	58.08
		TAU	0.11	6.80	672	1.22	0.80
		SPD	5.66	70.78	15833	28.79	8.62
		VAU	0.00	7478.0	5.65E5	1028.7	1295.9
D5	1003	ZLL	0.04	10.96	1436.6	1.43	1.30
		ZLLA	0.04	7.02	1045.8	1.23	1.11
		ZLLF	0.12	10.96	390.78	2.54	1.68
		DEN	0.00	777.30	15486	15.44	42.52
		DENA	0.00	777.30	10914	12.85	42.38
		DENF	0.00	365.05	4571.7	29.69	40.59
		TAU	0.03	14.05	1364	1.36	1.29
		SPD	3.49	79.64	34227	34.12	12.93
		VAU	0.00	8046.0	8.80E5	870.80	1355.0
D6	680	ZLL	0.14	8.79	937.10	1.38	1.08
		ZLLA	0.14	6.39	835.45	1.29	0.88
		ZLLF	0.66	8.79	101.63	3.08	2.48
		DEN	0.00	194.00	7797.8	11.47	17.62
		DENA	0.00	81.27	6069.9	9.38	13.02
		DENF	12.90	194.00	1727.9	52.36	36.76
		TAU	0.09	6.63	883	1.30	0.88
		SPD	9.17	70.44	21074	30.99	7.28
		VAU	0.00	7251.0	5.35E5	784.08	1205.3
D7	806	ZLL	0.08	10.24	1071.15	1.33	1.28
		ZLLA	0.08	10.24	795.9	1.13	1.06
		ZLLF	0.24	7.16	275.23	2.78	1.70
		DEN	0.00	464.28	11704	14.52	40.57
		DENA	0.00	426.52	6813.3	9.64	29.28
		DENF	0.00	464.28	4890.5	49.40	77.09
		TAU	0.07	12.72	1205	1.49	1.54
		SPD	3.78	80.00	27898	34.61	10.68
		VAU	0.00	8357.0	6.15E5	761.93	1416.6
D8	239	ZLL	0.17	31.96	862.15	3.61	5.31
		ZLLA	0.17	31.96	566.20	2.83	4.43
		ZLLF	0.76	27.92	295.99	7.59	7.35
		DEN	0.00	279.49	2284.5	9.56	29.54
		DENA	0.00	261.84	1150.8	5.75	22.38
		DENF	0.48	279.49	1133.7	29.07	49.21
		TAU	0.16	35.95	930	3.89	5.07
		SPD	8.01	78.74	9405	39.35	13.97
		VAU	0.00	6530.0	119210	498.79	1035.3

TABLE E5.4-1: Continue.

Z	Obs	Variable	Minimum	Maximum	Sum	Mean	Std Dev
D9	192	ZLL	0.15	22.24	685.85	3.57	4.14
		ZLLA	0.15	18.78	434.71	2.88	3.50
		ZLLF	0.78	22.24	251.16	6.13	5.20
		DEN	0.00	69.82	1438.8	7.49	13.87
		DENA	0.00	69.82	738.14	4.89	12.48
		DENF	0.00	65.93	700.68	17.09	14.66
		TAU	0.18	19.66	549	2.86	3.19
		SPD	13.16	80.00	7614	39.66	15.57
		VAU	0.00	5870.0	133651	696.10	1305.2
D10	1209	ZLL	0.02	9.87	1199.1	0.99	1.06
		ZLLA	0.02	8.16	850.1	0.82	0.78
		ZLLF	0.18	9.87	349.02	2.04	1.73
		DEN	0.00	938.51	10427	8.62	33.82
		DENA	0.00	938.51	6620.2	6.38	33.55
		DENF	0.00	302.64	3806.9	22.26	32.26
		TAU	0.04	11.90	1196	0.99	1.07
		SPD	2.28	79.45	44392	36.72	11.98
		VAU	0.00	7809.0	6.65E5	548.70	1082.1
D11	447	ZLL	0.02	32.88	1429.05	3.20	4.50
		ZLLA	0.02	32.88	1083.75	2.95	4.64
		ZLLF	0.70	20.56	345.31	4.32	3.62
		DEN	0.00	1660.1	4295.3	9.61	79.40
		DENA	0.00	1660.1	2654.9	7.23	86.89
		DENF	0.00	127.80	1640.3	20.50	21.63
		TAU	0.04	20.60	1371	3.07	3.33
		SPD	1.26	80.00	17791	39.80	14.00
		VAU	0.00	4487.0	187335	419.09	895.36
D12	305	ZLL	0.18	75.60	1490.35	4.89	7.45
		ZLLA	0.18	75.60	1258.4	4.77	7.83
		ZLLF	0.80	18.96	231.99	5.66	4.12
		DEN	0.00	87.34	1134.4	3.72	8.79
		DENA	0.00	34.52	562.38	2.13	5.39
		DENF	0.13	87.34	572.04	13.95	16.51
		TAU	0.34	47.27	1356	4.44	5.44
		SPD	22.19	79.89	12696	41.63	13.04
		VAU	0.00	4163.0	103174	338.28	727.32

TABLE E5.4-1: Continued.

E2. FREQUENCY DISTRIBUTIONS: DENA and DENF

PERCENTAGE OF DENF

DENF MIDPOINT	DENSITY in EPC/KM	FREQ	CUM FREQ	PERCENT	CUM PERCENT
2	********************************	32	32	15.02	15.02
6	***************	15	47	7.04	22.07
10	***************	15	62	7.04	29.11
14	****************	16	78	7.51	36.62
18	*************	13	91	6.10	42.72
22	*********	9	100	4.23	46.95
26	******************	18	118	8.45	55.40
30	****	4	122	1.88	57.28
34	*******	7	129	3.29	60.56
38	************	12	141	5.63	66.20
42	********	8	149	3.76	69.95
46	*********	9	158	4.23	74.18
50	************	12	170	5.63	79.81
54	****	4	174	1.88	81.69
58	***	3	177	1.41	83.10
62	****	4	181	1.88	84.98
66	***	3	184	1.41	86.38
70		0	184	0.00	86.38
74	**********	10	194	4.69	91.08
78	**	2	196	0.94	92.02
82	**	2	198	0.94	92.96
86	*	1	199	0.47	93.43
90	**	2	201	0.94	94.37
94	***	3	204	1.41	95.77
98	*	1	205	0.47	96.24
102	********	8	213	3.76	100.00

```
----+---+---+---+---+---+---+--
    2   4   6   8   10  12  14
```

PERCENTAGE

FIG. E5.1-4: 1987 BASE YEAR; SD1.

Trip link-density frequency distribution: Freeways and Expressway roads.

PERCENTAGE OF DENA

DENA MIDPOINT	DENSITY in EPC/KM	FREQ	CUM FREQ	PERCENT	CUM PERCENT
2	***************************	1212	1212	54.57	54.57
6	******	267	1479	12.02	66.59
10	****	188	1667	8.46	75.06
14	***	137	1804	6.17	81.22
18	**	86	1890	3.87	85.10
22	*	57	1947	2.57	87.66
26	*	50	1997	2.25	89.91
30	*	45	2042	2.03	91.94
34	*	37	2079	1.67	93.61
38		18	2097	0.81	94.42
42	*	39	2136	1.76	96.17
46		15	2151	0.68	96.85
50		8	2159	0.36	97.21
54		6	2165	0.27	97.48
58		3	2168	0.14	97.61
62		9	2177	0.41	98.02
66		6	2183	0.27	98.29
70		6	2189	0.27	98.56
74		6	2195	0.27	98.83
78		3	2198	0.14	98.96
82		0	2198	0.00	98.96
86		5	2203	0.23	99.19
90		4	2207	0.18	99.37
94		1	2208	0.05	99.41
98		1	2209	0.05	99.46
102		12	2221	0.54	100.00

```
-----+----+----+----+----+--
    10   20   30   40   50
```

PERCENTAGE

FIG. E5.1-5: 1987 BASE YEAR; SD1.

Trip link-density frequency distribution: Arterial roads.

PERCENTAGE OF DENF

```
DENF       DENSITY in EPC/KM                    CUM                CUM
MIDPOINT                               FREQ   FREQ   PERCENT   PERCENT


    2    |************************      51     51     11.92     11.92
    6    |************                  25     76      5.84     17.76
   10    |*************                 28    104      6.54     24.30
   14    |**********************        47    151     10.98     35.28
   18    |*******************           41    192      9.58     44.86
   22    |*********                     19    211      4.44     49.30
   26    |****************              35    246      8.18     57.48
   30    |*****                         11    257      2.57     60.05
   34    |*********                     19    276      4.44     64.49
   38    |*********                     19    295      4.44     68.93
   42    |*******                       15    310      3.50     72.43
   46    |*******                       14    324      3.27     75.70
   50    |*******                       16    340      3.74     79.44
   54    |*****                         10    350      2.34     81.78
   58    |****                           8    358      1.87     83.64
   62    |***                            7    365      1.64     85.28
   66    |**                             5    370      1.17     86.45
   70    |                               0    370      0.00     86.45
   74    |*****                         10    380      2.34     88.79
   78    |***                            7    387      1.64     90.42
   82    |***                            6    393      1.40     91.82
   86    |*                              2    395      0.47     92.29
   90    |*                              2    397      0.47     92.76
   94    |**                             5    402      1.17     93.93
   98    |*                              2    404      0.47     94.39
  102    |***********                   24    428      5.61    100.00
         ----+---+---+---+---+---+
             2   4   6   8  10  12

                PERCENTAGE
```

FIG. E5.1-6: 1987 BASE YEAR; MONTREAL ISLAND.

Trip link-density frequency distribution: Freeway and Expressway roads.

PERCENTAGE OF DENA

DENA MIDPOINT	DENSITY in EPC/KM	FREQ	CUM FREQ	PERCENT	CUM PERCENT
2	***************************	2261	2261	53.34	53.34
6	******	467	2728	11.02	64.35
10	****	323	3051	7.62	71.97
14	***	259	3310	6.11	78.08
18	**	171	3481	4.03	82.12
22	**	160	3641	3.77	85.89
26	*	106	3747	2.50	88.39
30	*	99	3846	2.34	90.73
34	*	72	3918	1.70	92.43
38	*	45	3963	1.06	93.49
42	*	65	4028	1.53	95.02
46		38	4066	0.90	95.92
50		22	4088	0.52	96.44
54		22	4110	0.52	96.96
58		7	4117	0.17	97.12
62		13	4130	0.31	97.43
66		10	4140	0.24	97.66
70		12	4152	0.28	97.95
74		10	4162	0.24	98.18
78		13	4175	0.31	98.49
82		9	4184	0.21	98.70
86		7	4191	0.17	98.87
90		7	4198	0.17	99.03
94		1	4199	0.02	99.06
98		2	4201	0.05	99.10
102		38	4239	0.90	100.00

```
-----+----+----+----+----+--
    10   20   30   40   50
```

PERCENTAGE

FIG. E5.1-7: 1987 BASE YEAR; MONTREAL ISLAND.

Trip link-density frequency distribution: Arterial roads.

PERCENTAGE OF DENF

DENF MIDPOINT	DENSITY in EPC/KM	FREQ	CUM FREQ	PERCENT	CUM PERCENT
2	**************************	119	119	13.24	13.24
6	***************	69	188	7.68	20.91
10	******************	83	271	9.23	30.14
14	**************************	117	388	13.01	43.16
18	***********************	106	494	11.79	54.95
22	*********	42	536	4.67	59.62
26	**************	64	600	7.12	66.74
30	*****	22	622	2.45	69.19
34	*********	39	661	4.34	73.53
38	*******	30	691	3.34	76.86
42	******	27	718	3.00	79.87
46	******	25	743	2.78	82.65
50	****	18	761	2.00	84.65
54	***	15	776	1.67	86.32
58	***	13	789	1.45	87.76
62	**	11	800	1.22	88.99
66	***	12	812	1.33	90.32
70		0	812	0.00	90.32
74	***	12	824	1.33	91.66
78	**	10	834	1.11	92.77
82	*	6	840	0.67	93.44
86	*	4	844	0.44	93.88
90	*	3	847	0.33	94.22
94	**	7	854	0.78	94.99
98	*	3	857	0.33	95.33
102	*********	42	899	4.67	100.00
	----+---+---+---+---+---+--				
	2 4 6 8 10 12				

PERCENTAGE

FIG. E5.1-8: 1987 BASE YEAR; GREATER MONTREAL AREA.

Trip link-density frequency distribution: Freeway and Expressway roads.

PERCENTAGE OF DENA

```
DENA      DENSITY in EPC/KM                       CUM                 CUM
MIDPOINT                               FREQ      FREQ   PERCENT   PERCENT


   2     |*************************    4301      4301     61.74     61.74
   6     |****                          662      4963      9.50     71.25
  10     |**                            434      5397      6.23     77.48
  14     |**                            339      5736      4.87     82.34
  18     |*                             248      5984      3.56     85.90
  22     |*                             220      6204      3.16     89.06
  26     |*                             134      6338      1.92     90.98
  30     |*                             124      6462      1.78     92.76
  34     |                               81      6543      1.16     93.93
  38     |                               55      6598      0.79     94.72
  42     |                               85      6683      1.22     95.94
  46     |                               47      6730      0.67     96.61
  50     |                               31      6761      0.45     97.06
  54     |                               33      6794      0.47     97.53
  58     |                                7      6801      0.10     97.63
  62     |                               16      6817      0.23     97.86
  66     |                               15      6832      0.22     98.08
  70     |                               18      6850      0.26     98.33
  74     |                               15      6865      0.22     98.55
  78     |                               19      6884      0.27     98.82
  82     |                               11      6895      0.16     98.98
  86     |                               10      6905      0.14     99.12
  90     |                                9      6914      0.13     99.25
  94     |                                1      6915      0.01     99.27
  98     |                                2      6917      0.03     99.30
 102     |                               49      6966      0.70    100.00
         ----+---+---+---+---+---+-
            10  20  30  40  50  60

               PERCENTAGE
```

FIG. E5.1-9: 1987 BASE YEAR; GREATER MONTREAL AREA.

Trip link-density frequency distribution: Arterial roads.

E3. GMA BASE MODEL

SAS Proc reg output.

1. Descriptive Statistics

Variables	Sum	Mean	Uncorrected SS	
INTERCEP	6	1	6	Intercept
DEM	3285.406	547.56766667	1805920.3144	DEMAND in 1000s
DEN	91.17	15.195	1415.1919	DENSITY EPC/KM

Variables	Variance	Std Deviation	
INTERCEP	0	0	Intercept
DEM	1387.6433875	37.251085722	DEMAND in 1000s
DEN	5.97275	2.4439210298	DENSITY in EPC/KM

2. Model: M1.

GMA linear regression from Eq. 5.1 without intercept

<u>NOTE: No intercept in model. R-square is redefined.</u>

Dependent Variable: DEN DENSITY in EPC/KM
Independent Variable: DEM DEMAND in 1000s.
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	1	1405.24696	1405.24696	706.514	0.0001
Error	5	9.94494	1.98899		
U Total	6	1415.19190			

Root MSE	1.41031	R-square	0.9930
Dep Mean	15.19500	Adj R-sq	0.9916
C.V.	9.28144		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	T for H0: Parameter=0	Prob > |T|
DEM	1	0.027895	0.00104946	26.580	0.0001

Dependant Variable DEN: 95% Lower and Upper Bounds

Obs	Dep Var DEN	Predict Value	Std Err Predict	Lower95% Mean	Upper95% Mean	Lower95% Predict	Upper95% Predict
1	12.0200	13.8859	0.522	12.5430	15.2288	10.0199	17.7519
2	13.2900	14.4412	0.543	13.0446	15.8378	10.5563	18.3262
3	14.4700	14.9967	0.564	13.5464	16.4470	11.0921	18.9013
4	15.7000	15.5522	0.585	14.0481	17.0562	11.6273	19.4770
5	17.0300	16.1076	0.606	14.5499	17.6653	12.1618	20.0534
6	18.6600	16.6630	0.627	15.0515	18.2744	12.6957	20.6303

Residual Analyses

Obs	Residual	Std Err Residual	Student Residual	-2-1-0 1 2	Cook's D
1	-1.8659	1.310	-1.424	**	0.323
2	-1.1512	1.301	-0.885	*	0.136
3	-0.5267	1.293	-0.407		0.032
4	0.1478	1.283	0.115		0.003
5	0.9224	1.273	0.724	*	0.119
6	1.9970	1.263	1.581	***	0.615

Sum of Residuals -0.476541815
Sum of Squared Residuals 9.9449
Predicted Resid SS (Press) 14.4031

```
   UPPER BOUND  U95
   |                                                                   |
25 +                                                                   +
   |                                                                   |
20 +                                        -         -         -      +
   |        -         -         -                               x      |
   |                                                  x                |
15 +                            x         x                            +
   |                  x                                         -      |
   |        x                   -         -         -                  |
10 +        -         -                                                +
   -----+----+----+----+----+----+----+----+----+----+----+----+------
   490  500  510  520  530  540  550  560  570  580  590

   DEMAND in 1000s  DEM
```

3. **MODEL: M2.**

GMA linear regression from Eq. 5.1

Dependent Variable: DEN   DENSITY in EPC/KM
Independent Variable: DEM   DEMAND in 1000s.

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	1	29.77029	29.77029	1274.183	0.0001
Error	4	0.09346	0.02336		
C Total	5	29.86375			

Root MSE	0.15285	R-square	0.9969
Dep Mean	15.19500	Adj R-sq	0.9961
C.V.	1.00595		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	T for H0: Parameter=0	Prob > |T|
INTERCEP	1	-20.672856	1.00675853	-20.534	0.0001
DEM	1	0.065504	0.00183507	35.696	0.0001

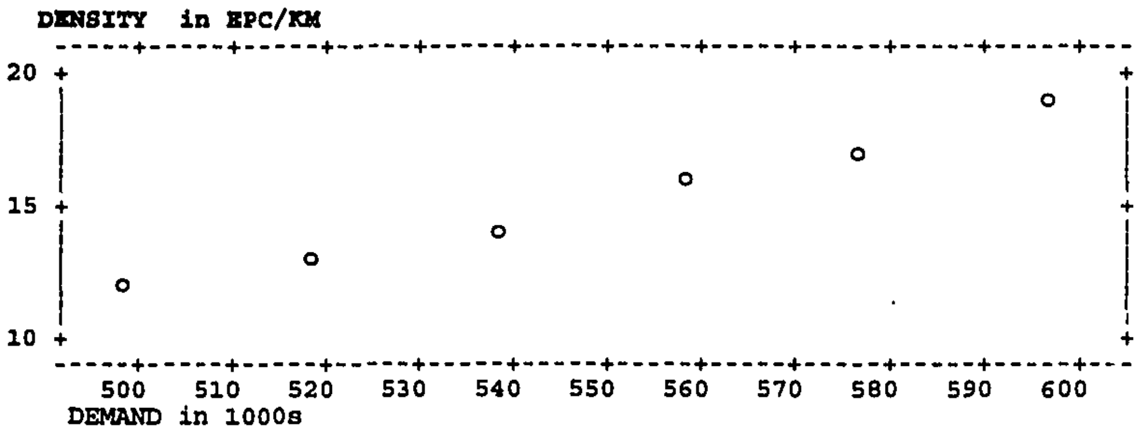
Dependant Variable DEN: 95% Lower and Upper Bounds

Obs	Dep Var DEN	Predict Value	Std Err Predict	Lower95% Mean	Upper95% Mean	Lower95% Predict	Upper95% Predict
1	12.0200	11.9344	0.111	11.6272	12.2415	11.4105	12.4582
2	13.2900	13.2385	0.083	13.0079	13.4691	12.7555	13.7215
3	14.4700	14.5428	0.065	14.3623	14.7233	14.0816	15.0040
4	15.7000	15.8472	0.065	15.6667	16.0277	15.3860	16.3084
5	17.0300	17.1515	0.083	16.9209	17.3821	16.6685	17.6345
6	18.6600	18.4557	0.111	18.1485	18.7628	17.9318	18.9795

Residual Analyses

Obs	Residual	Std Err Residual	Student Residual	-2-1-0 1 2	Cook's D
1	0.0856	0.105	0.812	*	0.362
2	0.0515	0.128	0.401		0.034
3	-0.0728	0.138	-0.526	*	0.031
4	-0.1472	0.138	-1.064	**	0.125
5	-0.1215	0.128	-0.947	*	0.188
6	0.2043	0.105	1.937	***	2.064

Sum of Residuals -5.15143E-14
Sum of Squared Residuals 0.0935
Predicted Resid SS (Press) 0.2917



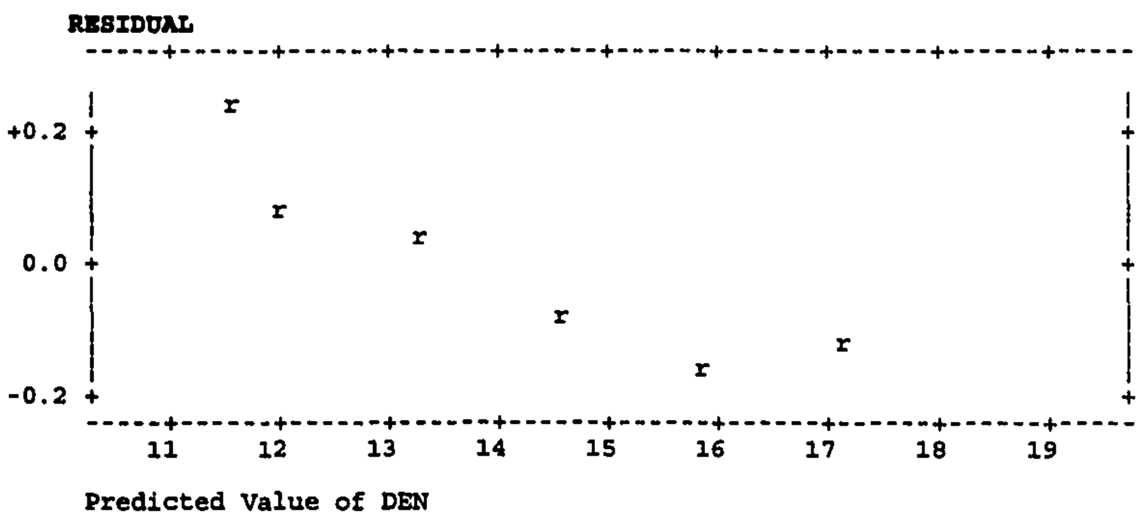


TABLE E3: SAS PRINTOUTS; DENSITY and RESIDUALS.

Regression analysis for the GMA.

E4. SDLM MODEL'S STATISTICS

Standard deviations of Beta 1, the slope of the curve, and test of the null hypothesis that Beta 1 is zero (two-tail test) probability.

SDLM MODELS EQUATIONS; ST. DEV.; PROB. > |T|

■ SDLM BASE MODEL

SD1: DEN = -15.11 + 0.205396 * DEM; 0.06864; 0.0001

SD2: DEN = -26.23 + 0.648049 * DEM; 0.20940; 0.0001

SD3: DEN = -22.15 + 0.378214 * DEM; 0.10865; 0.0001

SD4: DEN = -46.24 + 1.200669 * DEM; 0.38446; 0.0001

SD5: DEN = -18.93 + 0.673938 * DEM; 0.11356; 0.0001

SD6: DEN = -12.36 + 0.261920 * DEM; 0.23296; 0.0001

MTL: DEN = -19.52 + 0.112234 * DEM; 0.10782; 0.0001

GMA: DEN = -20.67 + 0.065504 * DEM; 0.15285; 0.0001

■ SDLM SUB-MODEL

SD1: DEN = -8.35 + 0.153856 * DEM; 0.03309; 0.0001

SD2: DEN = -30.69 + 0.719602 * DEM; 0.07109; 0.0001

SD3: DEN = -38.55 + 0.546432 * DEM; 0.05338; 0.0001

SD4: DEN = -65.04 + 1.581258 * DEM; 0.10287; 0.0001

SD5: DEN = -22.08 + 0.749526 * DEM; 0.12225; 0.0021

SD6: DEN = -16.43 + 0.314217 * DEM; 0.08341; 0.0001

MTL: DEN = -15.41 + 0.098473 * DEM; 0.02931; 0.0001

GMA: DEN = -19.67 + 0.063618 * DEM; 0.03384; 0.0001

√ Where: DEN is in EPC/km, DEM is in 1000s person-trips.