John H. Clark

Automatic Control of Field Machines

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ENGINEERING, ECONOMIC AND SOCIAL ASPECTS

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by

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Ph. D. AGRICULTURAL ENGINEERING

ABSTRACT

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AUTOMATIC CONTROL OF FIELD MACHINES: ENGINEERING, ECONOMIC AND SOCIAL ASPECTS

The history of both power farming and the automation of field machines indicates that the development of both has been evolutionary rather than revolutionary. The feasibility of applying to field operations, the automatic guidance equipment as proposed for highways, appears limited. The requirements of an automatic guidance system for application to a tractor are complex. Two possible concepts are proposed for an automatic tractor and its required guidance system. The automation of field operations is economically justified under certain conditions. Mechanization of farming operations has been required because of a continuing shortage of labor and further mechanization is required. Rural life should improve with automation.

Ph. D. GENIE RURALE

PRECIS

John H. Clark

LA COMMANDE AUTOMATIQUE DES MACHINES AGRICOLES: LES ASPECTS TECHNIQUES, ECONOMIQUES ET SOCIAUX

L'histoire de la motoculture et de l'automation des machines agricoles montre que le développement de l'un aussi bien que de l'autre s'est fait d'une façon plus évolutive que révolutionnaire. Les possibilités d'application aux travaux des champs, des systèmes de conduite automatique proposés pour les routes semblent limitées. Les exigences d'un système de conduite automatique applicable au tracteur sont complexes. Deux conceptions possibles de tracteur automatique et de système de conduite sont presentées. L'automation des travaux des champs est justifiable économiquement sous certaines conditions. La diminution constante de la main d'oeuvre a rendu nécessaire la mécanisation des travaux de la ferme et demande une mécanisation encore plus complète. L'automation devrait améliorer le mode de vie sur la ferme.

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PROLOGUE

This thesis will concern itself with three aspects of the automation of field operations. These are:

1. the probable and possible direction that design for automation will take in the future
2. the economics of automation
3. the effect of automation on rural sociology

Included is a history of automation to the present day.

The recounting of the history is the easiest because hind sight, in modern parlance, is always nearly perfect. In recounting history, an author is safe because, even though he may have to contend with biased writing, he is dealing with facts. To attempt to predict the economic and sociological effects of an oncoming phenomenon is risky. Only some historical review written sometime in the future will indicate how close the predictions came to actuality.

The contributions to original knowledge by the thesis are: the evaluation of engineering, economic and social implications of automatic control of field machines and the details of the automatic power unit necessary for automation of field operations and a guidance system.

I. DEFINITION OF AN AUTOMATIC SYSTEM

A working definition of the word automatic is necessary.

Automatic, when used as an adjective, is defined by the Funk and Wagnalls dictionary as: "self-moving, self-regulating, or self-acting". It is defined when applied to mechanisms as: "Having a self-acting mechanism by which certain operations are performed under predetermined conditions". As a noun it is said to be "a self-acting machine....".

Automation is said to be: "The theory, art, and technique of converting a mechanical process to maximum automatic operation, especially by the use of electronic control mechanisms and electronic computers....".

To add to the above definitions, automatic (or automation) refers to the establishment of a process or a system of processes which will repeat within a set of prescribed limits without human aid. These limits may be widespread requiring that the system be quite sophisticated. The limits are limits of variability from a mean, within the process, over which the controlling mechanism must be able to compensate - i.e. a range of values from a maximum to a minimum. An automatic process depends on feedback* for control. In this sense,

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* Feedback: Some of the output signal is returned to the input and compared against a reference signal to create an error signal which controls the device. The difference between the feedback signal and the reference signal creates the error signal. Often the size of the error signal controls the rate of change of the control signal. The polarity of the error signal controls the direction in which the change is made.

an automatic system is not normally open ended.

One example of a simple automatic system is the engine governor, such as is fitted to a small aircooled engine. Cooling air is blown past a spring loaded air vane. The air vane is linked to the carburetor throttle valve. As the engine speeds up, more cooling air is blown past the vane forcing it to move against the spring, thus decreasing the throttle setting. At a specific speed the vane is balanced between air pressure and spring force. If the engine slows under load, air pressure diminishes and the spring moves the vane and the throttle shaft to increase speed.

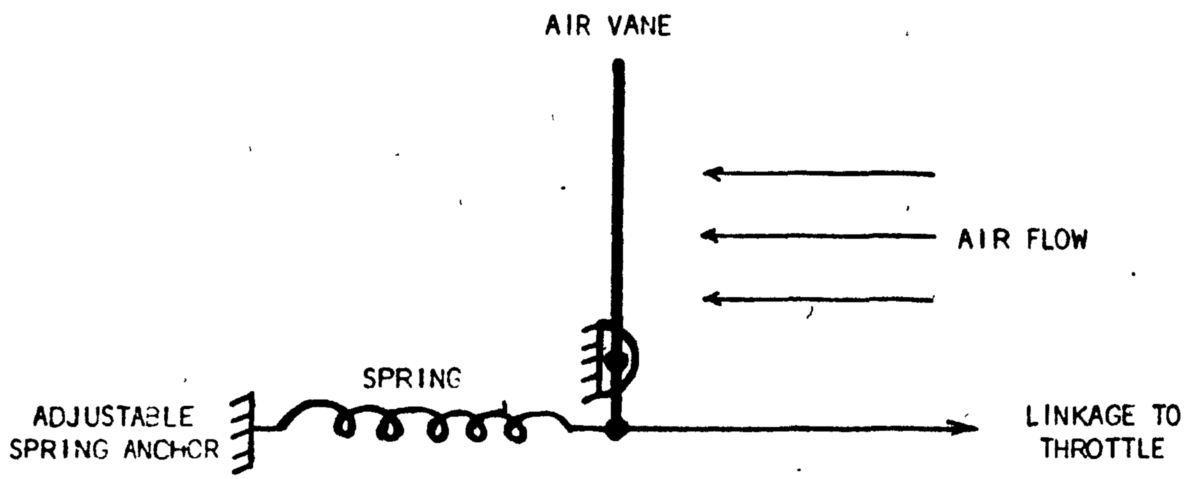


Figure 1. Diagram of air vane governor

Changes in the tension on the spring alter the governed engine speed.

A system such as this can be represented by the following diagram.

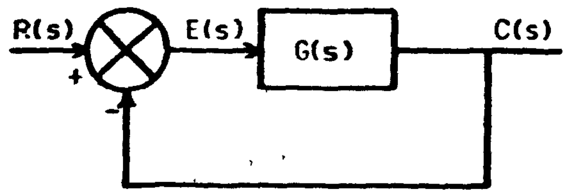


Figure 2. Diagram of simple control system

The reference signal R(s) is provided by the spring tension on the air vane. The summing point, which in this case is the air vane, produces an error signal E(s) to the carburetor throttle causing a change in the motor represented by G(s). A change in air speed C(s) is made. Air velocity changes against the summing point, the air vane, creating a change in E(s), the error signal.

G(s) is actually a composite of several transfer functions, these being those for the carburetor, the engine, and the engine cooling air fan.

Unity feedback is used - unity meaning that it is not modified. Sometimes however, the feedback signal is very weak or is in an unsuitable form thus requiring modification. In that case the diagram becomes as follows.

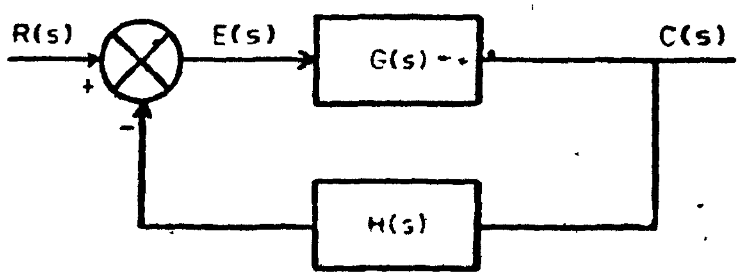


Figure 3. Diagram of control circuit with gain in feedback circuit

H(s) is the transfer function of the feedback path. In many cases the error signal must be amplified and G(s) then becomes comprised of two or more sections, as is the case in the previous example (Figure 2).

The system stability can be predicted mathematically from the system transfer function W(s). For the simple system with unity feedback

$$W(s) = \frac{C(s)}{R(s)} = \frac{G(s)}{1 + G(s)}$$

and for the second

$$W(s) = \frac{G(s)}{1 + H(s)G(s)}$$

These transfer functions are written as Laplace transforms. Each can be analyzed according to the most appropriate method in order to predict the system stability. If the system is oscillatory in nature it is referred to as being underdamped; if the system is sluggish in response it is termed overdamped; if the system is marginally stable it is referred to as being critically damped. The methods of stability prediction vary with the type of transfer function to be analyzed.

Some methods (5) for predicting the stability of the system transfer function are:

1. construction and the visual analysis of a pole-zero map for simple systems
2. use of Routh's stability rule. Some of the polynomials of a transfer function are complicated and difficult to factor. Routh's rule can be applied to the polynomial as a first step to predict stability without the need to factor the polynomial.

3. root locus method. This is a graphical method to show changes in the locations of the poles of the transfer function with changes in the physical parameters of the system.

4. use of the Nyquist Stability Criterion. This determines the number of poles of the transfer function which lie in the right half plane of the S map.

Systems using automatic feedback control can become very complicated. However, many of these systems are comprised of sub-systems which are simpler. An example follows.

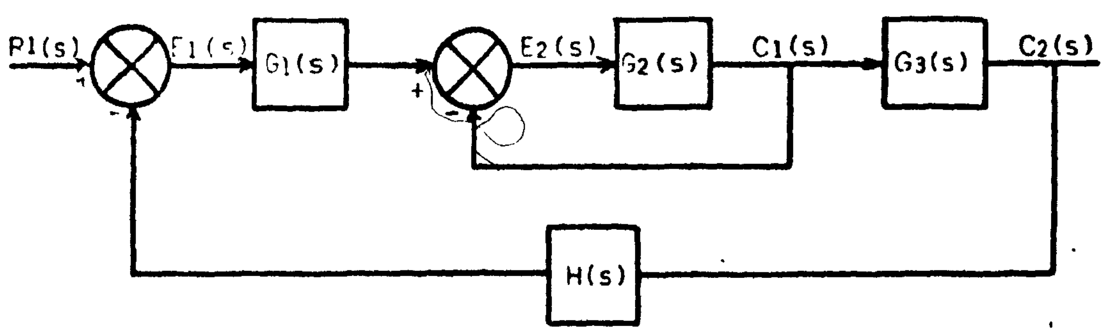


Figure 4. Control system with multi-feedback paths

Systems used for automatic guidance of field equipment will all employ feedback of some description. Even guidance employing humans uses feedback. In turning at the end of a field the human operator raises the implement as his eyes tell him he has reached the correct point. He then initiates a turn varying the rate as his eye feeds back information. He establishes the power unit in the new direction and lowers the implement at the correct point, all of this requiring feedback. In an automated system other forms of feedback signals would be fed to a control point which would issue control signals for steering and implement control.

II. HISTORY

2.1 HISTORY OF FARM POWER

In ancient times, as man discovered that seeds could be planted to ensure a more predictable food supply, crop farming was invented. He found that if he employed some tillage he could give his seeds a better start. At first this tillage was done with human labor but man discovered ways and means of coupling domesticated animals to tillage devices allowing larger machines to be used. This required a human labor force of two - one to guide the animal, usually an ox, and one to control the machine. Productivity was then greater than the total of that which the two could accomplish individually using their own power only.

Machines were improved. Horses were employed. The horse, while not necessarily as strong as the ox, provided more flexible power. The horse, when properly trained, could be guided by the machine operator, reducing the labor force and improving efficiency. Inventive (or lazy) operators found ways of riding on the implement to reduce their own labor and thus their fatigue. A well trained horse required very little guidance after it had made a few rounds of a repetitive task and the operator generally just rode the implement making a few adjustments to conveniently placed levers, when necessary. Horses were used to develop rotational power. A single horse walked in a treadmill from which a rotating shaft or belt drove a threshing machine, saw, or some similar equipment. Threshing machines had been developed to replace the arduous operation of flailing and winnowing the grain. To develop still more power, horses were coupled to a sweep power.

This development of power farming has been evolutionary rather than revolutionary. Portable mechanical power was developed first as an external combustion engine and secondly as an internal combustion engine of two types - spark or heat ignition. About 1849 A.L. Archambault built a portable steam engine to provide mechanical power. The first self-propelled steam engine appeared in 1855. Between 1870 and 1880 suitable gearing between the steam engine and traction wheels was developed along with a steering mechanism. The latter mechanisms were somewhat unreliable and for a while it was recommended that horses be used for steering purposes as well as providing extra traction.

By 1900 five thousand steam traction engines were being produced each year in the United States. Some of these were capable of pulling a large number of plow bottoms, even by today's standards. In 1909 a 40 horsepower unit pulled 16 14-inch bottoms and plowed up to 160 acres in 24 hours (14).

Steam had many disadvantages, such as the bulk, as required by the boiler and firebox and, the necessity to replenish fuel and water. The internal combustion engine required fuel only which, being a liquid, was much more easily replenished at longer intervals. Since there was more power per pound than with solid fuels, such as coal or wood, liquid fuel was much less bulky. Development of the Otto cycle engine, about 1876, led to these being used experimentally to replace steam engines in the smaller steam engine chassis. Later, chassis designed especially for gasoline engines were developed. The Charter Gas Engine Co. of the United States built six gasoline tractors in 1889, all built on steam tractor trucks.

Development continued until tractors were supplying power in several forms: drawbar or traction power, belt power,

power take-off power, lifting power for mounted implement control, hydraulic power and electric power. Only four of these remain on modern tractors: traction, power take-off, power to lift mounted implements and hydraulic power.

In the evolutionary development of tractors the power to weight ratio has increased. Power was equated with bulk but the development and application of weight transfer systems have changed this concept. One of the earliest systems to accomplish this was the Ferguson system developed by Harry Ferguson and first marketed in 1936 (9). In this system implement and tractor became an integral unit. The implements were fastened to the tractor at three points. Development of this system has continued to the present day to become almost universally used. Dimensions and positioning of the hitch points and linkages are standardized to allow interchange of equipment of various manufacturers around the world (1).

In the process of tractor evolution the driver has almost always sat at the rear of the tractor. One exception to this was in one of the first tractors built, the 1892 Froelich. Here the driver was located at the front. The rear location placed the driver where he could observe the work under way and be in a location to reach the adjustment levers. At the start, horsedrawn equipment was modified for use with the tractor. This was a natural process since the tractor was bought to replace horses and the horsedrawn equipment was available. Often the labor force rose to two - the tractor driver and the machine operator. However, new machine designs eliminated the machine operator. One of the final stages of evolution was the integrated mounting system as developed by Ferguson.

Traditionally then, when there has been one operator for both the power unit and the implement, this operator has been located to the rear of the power unit. This tradition has continued to the present time even on large sized units fitted with a cab from which the operator often has little chance to observe the implements at work. In an effort to improve visibility, experimental units have been fitted with closed circuit television.

One variation from this technique was the development of a machine systen wherein a power unit was designed over which or on which it was intended to mount several pieces of equipment, as these were required. Most of this equipment was for harvesting and included grain and corn equipment.

Thus the development of power farming to date has been evolutionary and not revolutionary.

2.2 HISTORY OF AUTOMATION OF GUIDANCE

Some farm tractors have always had a form of automatic guidance although most operators have never thought of it as such. This guidance occurred in plowing. Once the land had been struck out it was possible to continue plowing without the necessity for steering control except to turn at the end of the field. All one had to do was to turn the front wheels of the tractor slightly towards the left to the furrow wall. Since most tractors used a worm steering gear which was not reversible the steering stayed in this position and the tractor followed the furrow. This technique only worked with tractors with that type of steering mechanism and in land free of stones. It did not work if the right front wheel did not run in the furrow.

There have been further developments in this form of guidance. Some modern tractor designers, in an effort to improve traction, use dual rear wheels which are too wide to run in the furrow. These tractors run completely on the unplowed ground. Accessories have been developed to sense the furrow edge and provide a steering signal from it to guide the tractor (17).

In the early 1920's a small motorized manless plow (14) was developed in Iowa. The unit carried two plows, one in the ground and the other out. The initial furrow was plowed with the tractor driven manually but from then on the tractor worked automatically. A trip lever out in front of the tractor and behind caused the tractor to reverse direction (and plows) when it contacted the fence. At the other end of the field the same thing happened and the tractor shuttled back and forth between the fences.

One system of guidance developed by Gilmour (12) relied on dead-reckoning. Subject to error from disturbances and side slippage it was not successful.

Some designs have used radio control signals but these were not automatic, in that an operator sat in a central place and guided the remote tractor.

Most of the more successful automatic guidance systems have used buried cable (3, 22) as the guidance source. In several examples the cable carried a signal which the guidance unit on the tractor followed. A second set of cables at each headland carrying a signal of a different frequency signalled the control unit to lift or lower the implement and to begin a turn sequence. Accuracy of repeatability of passes across the field is high in these systems making them suitable for row crop work as well as for gross field cultivation. In some, the cables are reasonably closely spaced while in others, such as the one developed by D.I. Brooke (3), the tractor can be operated up to 100 feet away from the guidance cable. In this system the amount of cable required is reduced. At least one such system is marketed in England by Autotrack Systems Ltd., Farnborough, Hants.

In all of these systems the expense of burying the cable and the inflexibility of the system once the cable has been buried are disadvantages. The amount of cable required can be quite large. For example, if cable were to be installed in a 30 acre field to provide guidance for an operation using a machine 10 feet wide, approximately 33,330 feet of cable (6.3 miles) would be needed.

However, in another system the buried cable is actually a small rope (25). The machine pulls the rope from the ground, passes it through the guidance system and then relays it some distance to one side to provide guidance on the next pass.

A simple guidance system which works from a score furrow made during the previous passes is that developed by Grovum and Zoerb (16). Two small wheels follow the score furrow. The information obtained from these is compared against a gyro and a steering signal is developed. The gyro compensates for discrepancies occurring in the furrow.

But not all automatic control systems have been this sophisticated.

A saving in labor can be obtained by coupling two or more tractors together (11). The operator drives the first, and steering signals are provided by a cable to the second, thus automatically duplicating the first tractor's movements and speed. Tension on the cable controls the speed of the second tractor. Another system (24) steers field machines along a crop row by using a feeler to contact the stalks. A spring forces the feeler against the row but displacement of the feeler from the neutral position creates the corrective steering signal. Parish and Goering (19) developed a somewhat similar device to guide a windrower along the edge of a crop. They included a unit to cause the windrower to execute a 180 degree turn at the end of each pass.

None of these systems have used a centralized controller except in the case where the human controlled a remote machine using radio signals (14). Some experiments with radio control were carried on in the 1930's. In this case the human with his faculties for vision and thought relayed the corrective signals to the power unit. This type of system never developed beyond the experimental stage since there was not any particular gain in efficiency. As before, the human controller was required for one power unit and he also had to be in a position to observe.

III. GUIDANCE SYSTEMS FOR OTHER INDUSTRIES

Guidance systems have been developed for other industries. Patents have been issued for components, such as a guidance sensor for a leader cable system (U.S. patent number 3,614,990). One company, Barrett Electronics Corporation, Northbrook, Illinois, manufactured a leader cable system which guided small power units pulling trailers along a preset route through factories or warehouses.

One other industry, the transportation industry, is working towards the development of automated highways. Required for this will be suitably automated vehicles to use the highway. The automated vehicles would be manually driven when away from the automated highway but would be automatically controlled while on the highway.

Some of the advantages of automatic control are: greater utilization of an existing highway because of the possible increase in traffic density; greater safety since speed and vehicle separation are automatically maintained; less boredom on the part of the driver since he would function only as a supervisor while the vehicle is operating on the highway.

3.1 PROPOSED DESIGN FOR AUTOMATIC HIGHWAYS (24)

3.1.1 Vehicles

Vehicles could be built for personal or public transportation of people or goods. When away from the automated highway these would be manually controlled; but while on the highway they would be automatically controlled. In addition to the usual equipment found on a standard highway vehicle there would be two types of equipment required to automate the vehicle. One type would be that which would respond to the guideway signals providing steering and speed control.

The second type would provide emergency control in the event of complete or partial failure of signals from the guideway. This emergency control would be comprised of: steering control until the vehicle operator resumed control, and brake control to provide separation from the vehicles in front.

If impending problems were diagnosed, signals which would be radiated from the vehicle to the highway control system would cause the highway sectional command to provide signals to divert the vehicle into a service lane.

3.1.2 Highway

Besides its usual function of providing a suitable path for vehicles, the highway would provide the guidance signals to the control units of the vehicles. These signals would be separated into two kinds: one would be those originating from a central source and the other, the command signals related to the particular section of guideway on which the vehicle was operating. The former would control traffic flow on the highway system; the latter would control vehicle speed and separation, as well as respond to signals related to vehicular problems. Entry to and exit of the vehicle from the highway would be controlled. Each traffic lane would be controlled separately from the others and would have a guidance device built into it. This could be in the form of a leader cable or some mechanical system. It is likely that in cold areas a leader cable system would be used because of weather problems. Each lane might be physically separated from the next by a curb or barrier, although this could create problems in snow clearing.

3.2 FEASIBILITY OF APPLICATION TO AGRICULTURE

Unfortunately, the type of guidance required for fast moving, high density traffic is quite different from that required by slow moving agricultural power units. It is true that the steering equipment intended for the high speed units could be modified for the low speed units. However, the steering commands required by the high speed equipment would not call for the extreme changes in direction required by a field unit at each end of the field. The secondary controls of the highway vehicle which provide separation in the event of the primary system failure by sensing the distance to the vehicle ahead could be used to sense the field boundary in order to initiate turns of the power unit.

The application to agriculture of the guidance control of the highway vehicle presupposes that the guidance methods used in the field would be based on the leader cable system. If another system were used then the highway system of guidance would be of little use. There is, therefore, little of the hardware required for the highway system that could be directly adapted to field guidance.

3.3 AVIATION GUIDANCE

Automatic guidance in the form of automatic pilots, or autopilots, as they are now called, has been used for a long time by aircraft. Autopilots provide two types of guidance, namely: aircraft control in three dimensional space, and course tracking utilizing special radio signals from ground stations. These stations transmit a very high frequency (VHF) signal which carries omni-directional navigational information. Autopilots vary from the simpler devices which keep the aircraft wings level to the very sophisticated devices which completely control the aircraft and follow a preset course. These latter units can electronically move the ground station to another geographic position (within radio range of the station) and develop a track related to that position. Aircraft control information from the autopilot is based on reference gyros which develop directional information in the horizontal and vertical axis.

3.4 APPLICATION TO AGRICULTURE

Gyros have been applied to agricultural guidance in a similar fashion to that employed in autopilots. Grovum and Zoerb (16) used a gyro to provide a direction signal and Gilmour (12) used a dead-reckoning device. As far as is known the second feature of autopilots, that of following a predetermined course based on a VHF omni-directional navigation ground radio station, has not been applied to agriculture. There are several reasons:

1. the distance that VHF radio signals can be received at ground level is very short, meaning that equipment could only be used in close proximity to the station
2. the equipment as used in aircraft is very expensive
3. although the equipment is very accurate there are still tracking errors which would be too great for guidance in row crop work

IV. DESIGN FOR AUTOMATIC CONTROL OF FIELD MACHINES

4.1 GENERAL

There are two methods of automating an operation. The first is that of replacing the human operator and his reasoning capability with a control system which attempts to duplicate his function; that is, existing machines are modified for automatic control.

The second method develops a completely new system to accomplish the task required; a system in which the designer does not need to account for an operator whose function has been replaced. The new machines are designed strictly for automatic control. This method of approach can, therefore, be revolutionary as opposed to being evolutionary.

Little of the world's development of automatic control for field machines, however, has been of this second, revolutionary type. On the contrary, most developments have been attempts to automate existing machines as opposed to developing new systems.

In spite of the definition used earlier which might imply an all or nothing situation, there are varying degrees of automation. By 'varying degrees' it is meant that some, but not all, of the operations now under human control are automated. It is useful to note that some worthwhile labor reductions can be made in this manner. For instance, the operator can oversee a bigger unit or a larger number of small units than was possible before. One simple way of partially automating field work would be by remote radio control. As stated before, radio control has been applied to tractors. One human controller was required for one tractor. A more sophisticated approach would employ some type of self-contained row guidance device, such as described before, with the human controller making the turns using closed circuit television to monitor the position of the power unit. The controller could control several power units in this manner, increasing labor efficiency. The device would, however, still be subject to the frailties of human control.

Most automatic guidance systems developed so far are on-board units. The unit issuing the various control signals is part of the power unit. It may, and often does, rely on external signals on which it establishes the guidance pattern.

The following is an example of a new approach to automatic control of field machines. It would require a central controller, a power unit and implements.

Central Controller: Command signals would be issued as necessary. These signals would be based on telemetry received from the power unit and related to a preset program for that particular operation previously stored in the controller's memory. Because of the fact that the controller would be a computer and that slow moving field operation would require a fraction of the controller's capacity, the controller could control several power units, each performing a different operation.

If operated in a time-sharing mode, the computer could provide guidance for several farms. The computer would momentarily sample a job and issue the required command signals before going onto the next job. It would move from job to job, returning to the starting point in a sort of round-robin fashion. Operations could be added to or subtracted from the system as necessary when the farm operator (or farm operators) required them. Suitable control programs could be called up for a specific function for a certain field on a particular farm.

The cost of the controller would be spread over several farms.

Power Unit and Implements: If an automatic tractor were developed then the physical layout of the power unit could be changed. As stated before, the operator of the non-automatic tractor sits on the rear of the tractor up high enough to observe the equipment operation. He can watch where the tractor is going and monitor the work being done. If the tractor is to be automatically controlled then there is not the necessity to provide for a human operator; controls no longer need terminate at a central position within the operator's reach; no operator safety requirements need be met, although there will be other new safety requirements for the vehicle; there will not be any requirement for cabs to provide for operator confort and safety. Since the power unit will not have all these limitations imposed on it through the necessity of providing for operator convenience, safety and comfort, it now can be designed for maximum efficiency. The designer of implements for the conventional tractor has also had similar limitations imposed on his designs. He has had to compromise because his device had to match the requirements of operator convenience, safetv and location. He could now design his implement to fit on the power unit at the optimum point without concern for the operator..

A power unit designed for automatic control, i.e. an automatic tractor, would become an integral part of the complete processing unit consisting of the power unit and implement. The auxiliary parts, i.e. the implement, could fit over the power unit, much as the body of a car is lowered over a chassis.

If one discounts the automatic control, the power unit without the need for the operator-oriented auxiliaries would be less expensive to produce. This cost difference could be applied to the cost of automation.

4.2 CURRENT AUTOMATION OF TRACTOR SUB-SYSTEMS

Tractors have become larger in an effort to spread the operator's working hours over a larger unit which in turn could cover more ground in less time. In order to do this certain sub-systems of the tractor have been made automatic. An example of one of the earliest attempts at automating some of the operations was the governor control of the engine. The function of the governor is that of maintaining a constant engine speed regardless of engine loading. The operator was thus relieved of the fatiguing chore of monitoring speed. Uniformity of speed is important to many operations. Safety is affected by non-uniform speed - lurching of the vehicle because of changing speed can throw the operator off balance. Quality of product and efficiency of operation can be affected; for example, the importance of maintaining a constant threshing speed within a combine.

The governor not only does the job but does it more exactly than the human operator could. However, the governor operates within certain limits imposed by design and by conditions. When these limits are exceeded as, for example, in harvesting operation in a non-uniform crop, the human operator must intervene. He may change to a lower gear to slow the input of the heavy crop or, in plowing, he may adjust the depth to keep the load uniform. Because operators do not always do what they should, automatic devices have been fitted to some units to do the work automatically. Torque monitors have been added to tractors to lift hitch points to reduce load.

If a change in depth is made to alter the load on the tractor, uniformity of work suffers. Various draft sensors have been evolved which lift and lower the implement in response to changes in draft. The better method is to use an automatic transmission, as well as the other devices.

The total automatic control of forward motion of a tractor would be by:

1. an engine governor to maintain a uniform engine speed
2. an automatic transmission to provide an uniform load between the engine and the driving wheels
3. a draft sensor to reduce or increase the load between the engine and the driving wheels

The priority of control would be in the order given above, the draft sensor having the least priority of all. Using that priority of control work uniformity would suffer least since depths would be adjusted only as a last resort.

Coupled to all of these control mechanisms would be some device to determine true forward speed. Comparison of wheel speed and true forward speed would indicate wheel slippage and would control depth if the difference exceeded a preset amount. At the other end of the scale, zero forward speed and normal wheel speeds would indicate a stuck-tractor condition and would cause shutdown of the vehicle and warn the remote system overseer.

These automatic controls reduce the effort required of the operator in overseeing these operations and allow him to devote that time to controlling the machine. In most cases the automatic monitors perform the function better than the operator could. As stated previously, fatigue affects the overseer's quality of work but not that of the machine. Thus, automatic operation of a machine can maintain more uniform quality of work.

Some functions have not, as yet, been automated. Instead, the brain of the operator is depended upon for control. Chief among these functions is the guidance operation, where the eye of the operator is relied on to initiate the necessary muscular reaction for correct guidance.

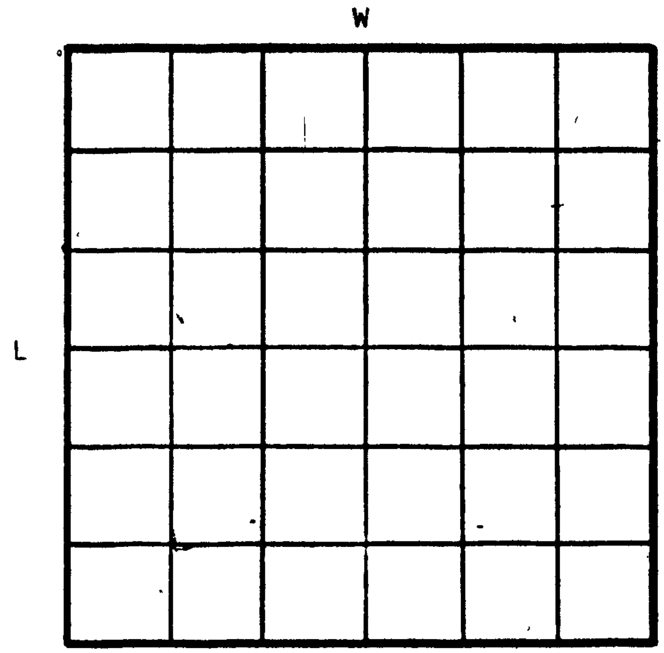
4.3 REQUIREMENTS FOR A GUIDANCE SYSTEM

In order to design the guidance system it is necessary to determine what the inputs would be. Once the inputs have been determined then the design of the replacement system is begun.

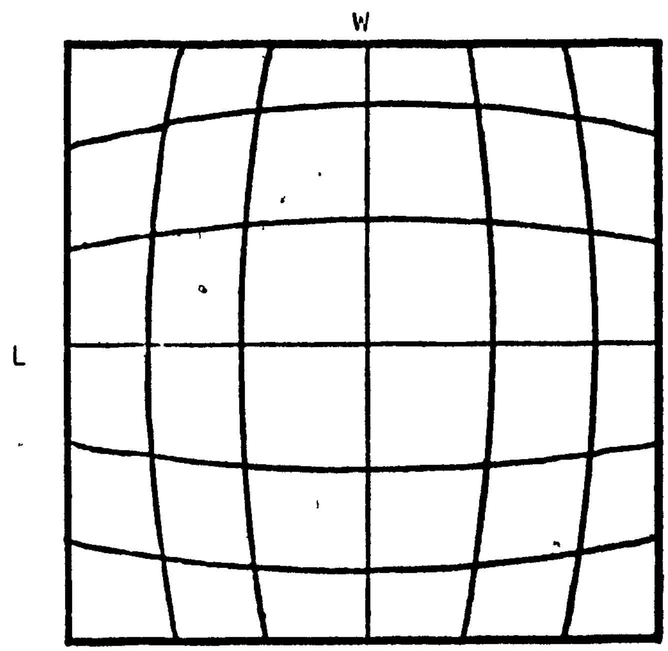
The guidance required from the operator of a tractor can be broken down into several functions or stages. These are:

1. Straight-line Guidance

   i. The word straight-line is somewhat of a misnomer. The work is started as a straight line and will continue as a straight line only on fields without irregularities, such as humps or hollows. In fields where these occur, the work will not continue as straight lines owing to the extra area of a hump or hollow in comparison to the even area with the same outside dimensions (Figure 5). Coupled to the fact that there is extra area in a rectangle containing a hump or hollow is the problem that, when the device is working



EVEN TERRAIN



UNEVEN TERRAIN

Figure 5. Diagram showing change in area between an even and uneven section bounded by the same dimensions

along a slope and its steering mechanism calls for a track at an angle to that slope, it does not exactly follow the steering mechanism. The final direction of travel is at some angle between the direction intended by the steering mechanism and the direction of slope. An operator compensates for this by crabbing the tractor so that it climbs the slope as fast as gravity pulls it down the slope. This side slip is further complicated by the side thrust on the implement.

There are, therefore, two problems, the first being the increase in area caused by the topographical irregularity and the second the side slip created on the power unit by the slope.

If the guidance system is to be controlled through the use of leader cables, these can be implanted in such a way as to compensate for the problem of the extra area created by the irregularity. If the guidance is otherwise provided, or if the leader cable were installed in straight lines, then the only way to completely process the area would be to deliberately plan for processor overlap. This could create problems in row crop work or in seeding. Since rows must be equidistant from each other, the area might have to be manually planted. The extra seed involved in seeding might be offset by other gains from the automatic system.

ii. Maintenance of proper clearance from the previous pass of the machine to prevent machine overlap and underlap or the maintenance of the correct distance of the machine with relation to the crop.

iii. Maintenance of correct speed. The maintenance of speed and load are now automated but the operator can override these functions, if he wishes.

iv. Correction of machine problems. Maintenance of correct machine functions is dependent on the operator's perception. More functions will need to be automated. Some have been, as for example: combine speed control related to the discharge of grain from the rear of the machine (21); automatic self-leveling of the combine body (U.S. patent 3,703,298); automatic combine header height control (U.S. patent 3,704,574).

2. Turning Guidance, as required

a. to avoid obstructions

b. to begin a new pass across the field

The turning operations to begin a new pass are comprised of:

i. raising the implement, if necessary, at the correct point

ii. turning to run at right angles to the previous direction

iii. continuing the run in this direction as far as necessary

iv. turning to a new path 180 degrees removed from the previous prime guidance direction

v. if necessary, lowering the implement

vi. speed control, as required, during the turning sequence. The speed of the power unit is reduced as the point of turn commencement approaches. It may be increased after the first phase of the turn (usually 90 degrees) has been effected. It is again reduced prior to the second phase and increased to normal field speed at the end of the second phase.

Turns sometimes are not exact functions of the angle assumed by the steering mechanism. Whether the vehicle turns exactly in response to this angle is determined by several factors. These are:

a. speed, and hence its effect on

b. vehicle inertia

c. the traction of the steering mechanism on the surface

d. the field surface characteristics - loose or wet surface will provide different turning responses

e. the effect of the processing device. A trailing processing device absorbing a large amount of draft force will tend to keep the power unit moving in a straight line despite the fact that the steering mechanism is calling for a turn.

Often, in order to force the power unit to turn in the direction being demanded by the steering device, a brake must be applied to the driving wheel on the side to which the turn is to be made.

3. Commencement Guidance

This includes the establishment of the first pass across the field and the delineations of the extent of the work pass, i.e. definition of headlands.

4. Termination Guidance, includes:

   i. the decision that the work is to be terminated

   ii. the method of termination

An example is the furrowing out at the finish of plowing a section, or the adjustment of the final pass across the field as required by the proximity of a ditch, fence or other field boundary. Fields with non-parallel opposite sides create problems.

5. Other Guidance

The four stages outlined above would be followed for row crop harvesting; but the guidance required for certain cropping operations does not fit these four stages. In grain harvesting, for example, it is customary to harvest by continuous travel around the area.

Thus, a guidance system would have to be developed for the continuous system of harvest. It might be less expensive to use the guidance technique outlined for all crop operations even though there would be some loss of efficiency in this method as compared to the continuous harvesting method.

Redefinition of some of the work parameters can reduce guidance problems. The removal of obstacles, elimination of headlands and the creation of fields of an even number of implement width wide would simplify control procedures for the controller. Areas which cannot be converted to suitable shapes may either have to be worked manually or taken out of the crop system because of the added control complexity.

4.4 REQUIREMENTS FOR THE DESIGNING OF THE AUTOMATED TRACTOR

1. As many of the minor control functions as possible must be made automatic. These will become small sub-systems. Included would be: the engine speed control, the vehicle speed control (automatic transmission), the load control, the wheel slip indicator and the detection system to determine improper implement function.

2. Major control functions must be controlled by the main guidance system through a form of programmed control preset for each operation for a specific farm area (field).

3. The field must be tailored to the system in order to simplify it by: altering field size or shape, removing obstructions, eliminating headland cultivation. If headland cultivation is required the cultivation practice should be changed to provide cultivation without the necessity of either disengaging or raising the implement.

4. The power unit must be designed as a power unit only. All parts would be easily accessible for rapid service. The guidance controller would be located at one point on the machine, remote controlling other functions of that machine from that point. The controller should be modular in form, these modules being plug-in units for ease of servicing in the event of malfunction or failure.

4.5 DESIGNS

Previously, it has been suggested that the best design for automation would center around a central controller which would control different operations in different areas at the same time.

One scheme for development of a method for land cultivation used two power units located at opposite sides of the area to be processed. The processing unit (a reversible plow, for example) was towed back and forth between the two units by a cable. The two power units moved along the edge of the field in increments of distance as the area was processed.

There are several advantages to the system:

1. an accurate positioning was possible allowing good repeatability for subsequent passes
2. there were no problems with lack of traction since the draft was provided by the cable from the power units

The processing unit, if it required vertical support, was mounted on castoring wheels which allowed the unit to move freely in the direction dictated by the cables. Cables would tend to move the processing unit in a straight line across depressions.

Such a device, although it seems futuristic in its conception, was built and used in 1859 in England (14). A modern adaptation functions in the Netherlands.

Unfortunately there were many drawbacks to this system, not the least of which was the anchoring of the power unit and its companion unit. In addition, there were problems related to cables. But suppose the system were updated and instead of cables another method of guidance was used. The processing device, instead of being passive, would become a power unit carrying the particular processing device required for the operation. The power unit would carry all of the automatic controls necessary to the proper functioning of both power unit and processing unit. A guidance mechanism would be required to allow the power unit to follow the path laid down by the control unit. This path could be a laser beam or a narrow beam electro-magnetic signal projected by either of the two control units, depending on which had control. Both controllers would carry a laser projector and receiver. The device controlling the power unit, at any given point in time, would be the device from which the processing unit was proceeding. Meanwhile, the controller at the other end of the area being processed would advance until its receiver lined up with a second control beam projected by the first controller. The angle of projection would determine the width of the area being worked. When control was switched from the first controller to the second, the former would then advance the required increment. Proximity-sensing devices on the power unit would detect the area boundary and the power unit would begin a 90 degree programmed turn. (The proximity detection device could be a modification of the laser obstacle detection device described at the 1970 congress of S.A.E. (27).)

A second 90 degree programmed turn would be effected when the power unit intercepted the laser beam from the controller at that same end of the area. The power unit would travel away from the controller, following the laser beam (Figure 6).

The laser beam should be narrow in the vehicle path direction and wide in the vertical direction, the wide vertical beam being created by turning the projector through a vertical arc at regular intervals. By mounting the projector and receiver as high as possible and utilizing the wide vertical beam, guidance would be provided over undulating terrain (Figure 7). (Higher hills would still create beam shadows preventing operation.) In spite of the advantages gained from a higher receiver mounting, height should be kept to the minimum required unless provision was made to keep the receiver mounting vertical. If it were not vertical and the vehicle was moving across a slope, there would be an undesirable path offset (Figure 8).

If the laser receiver could be positioned on the vehicle in such a way that it could 'see' the master controller whether the vehicle was moving away from or toward the controller, the guidance system could be simplified. The slave controller would not be needed. One receiver could receive the laser from either direction if it were mounted to face vertically up and mirrors were used to reflect the laser from either direction down into the receiver. Loss of reception of the laser beam could be tolerated for short periods of time during a pass and for longer priods during a programmed turn. If reception were lost on a pass for more than a few seconds the equipment would fail-safe, i.e. stop, (Figure 9).

The laser beams would provide a method of guidance as accurate as that obtained from the buried leader cable. Unlike

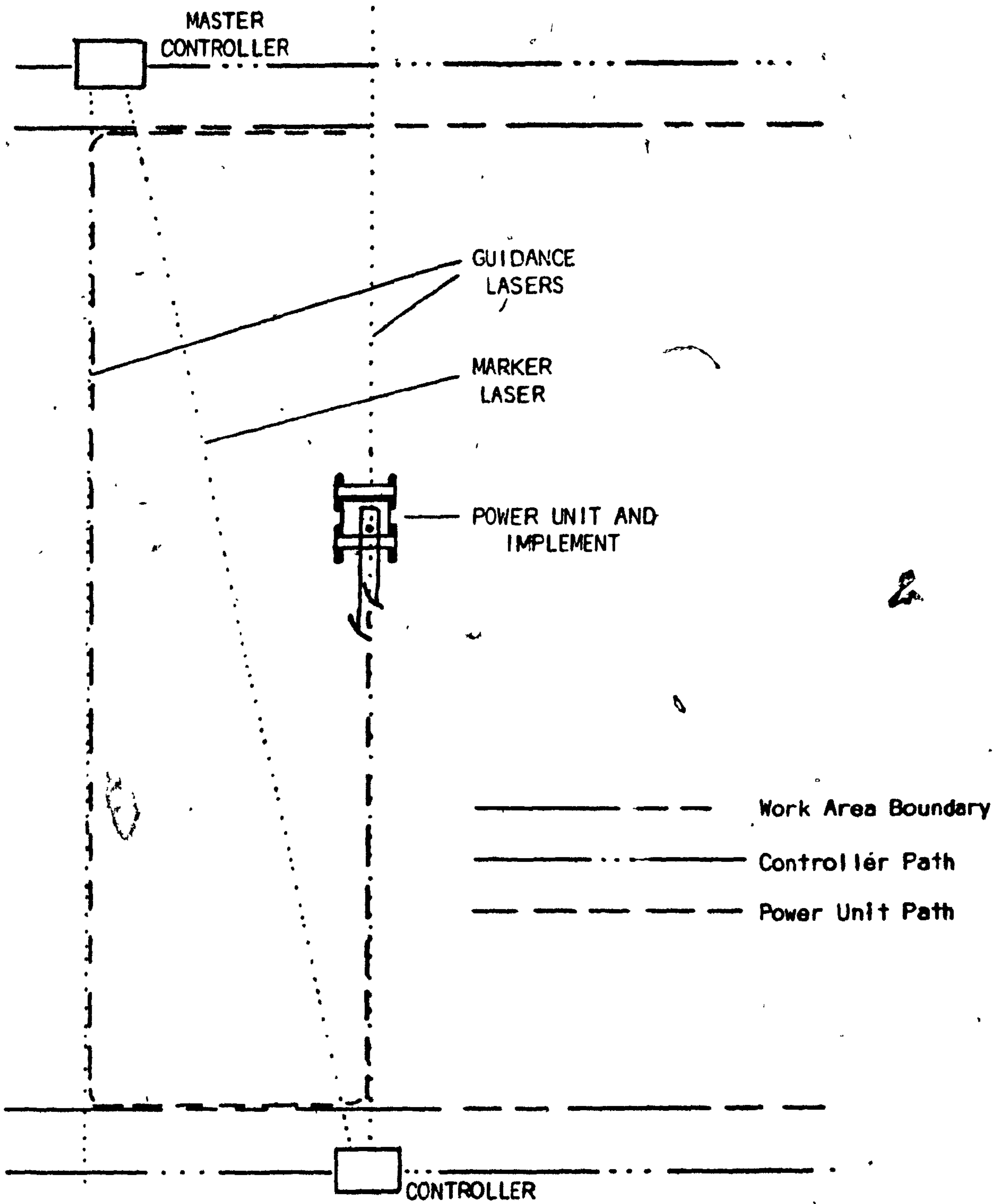


Figure 6. Diagram of laser control automatic guidance system using two controllers

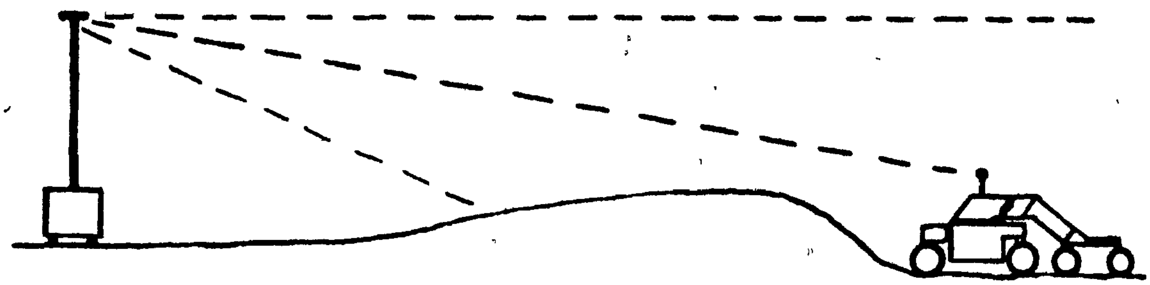


Figure 7. Diagram showing effect of wide vertical beam on uneven terrain

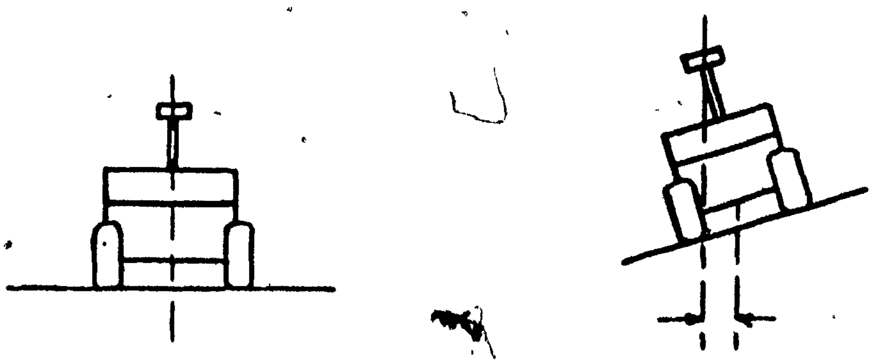


Figure 8. Diagram to show path offset on sidehills

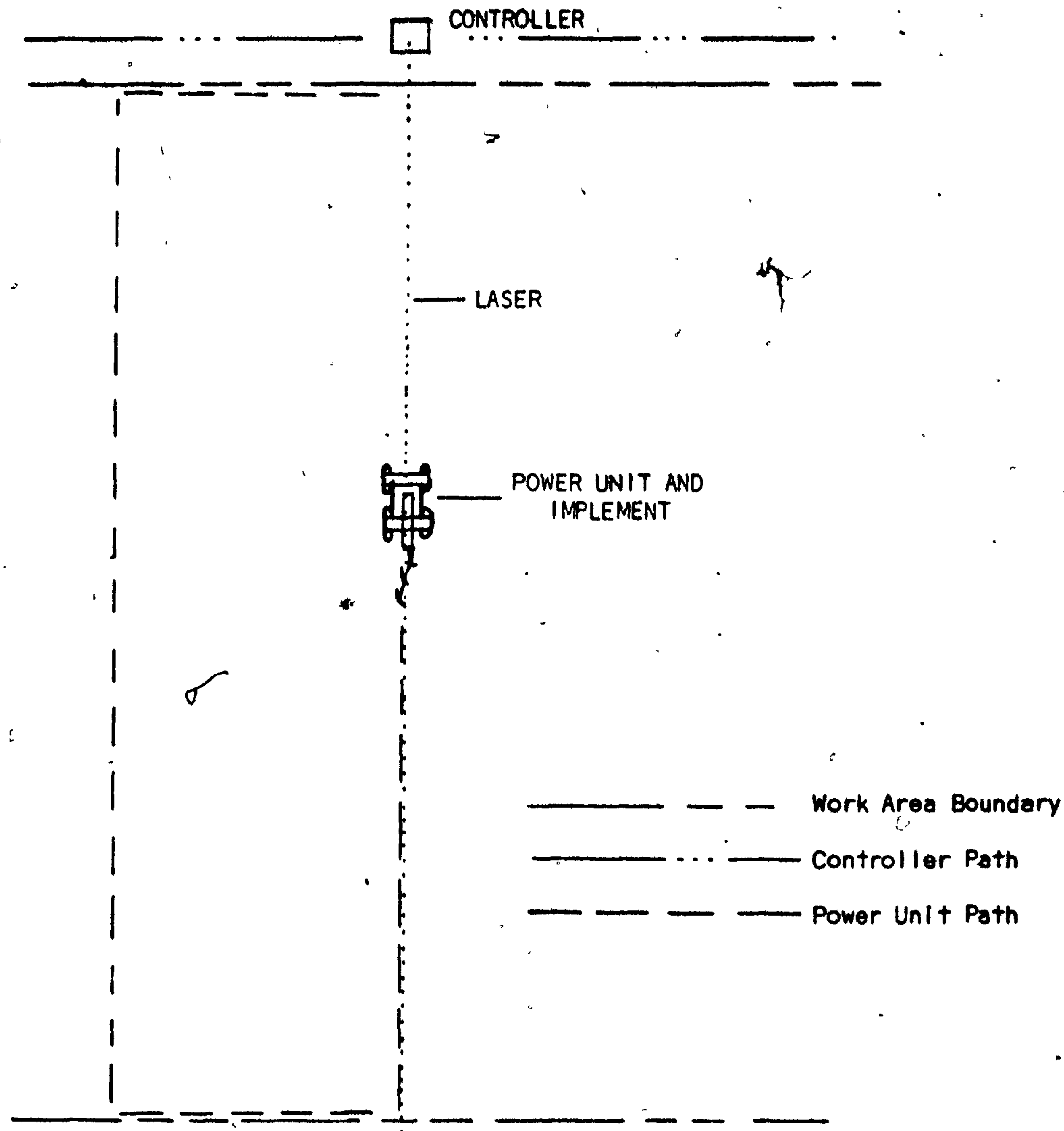


Figure 9. Diagram of simplified laser control system using one controller

the buried cable method, however, this operation would be much more flexible in that it could easily be changed. The system can be easily moved to another area.

4.6 POWEP UNIT REDESIGN

Steering: Up to this point the automated power unit has been a redesigned tractor built for automatic control and without a driver's position or any driver-oriented devices. Most guidance systems, the one just described included, are designed for vehicles using the Ackerman-type of steering. When the front (and/or rear wheels, in some instances) turn at some angle to the longitudinal axis of the vehicle, the moving vehicle executes a turn. The system could be applied to the type of wheeled vehicle where steering is achieved by articulated front and rear sections. A point at the centre of any of these vehicles would describe an arc as the vehicle turned.

There is another method. If all of the wheels turned, in the same direction, to a new angle of 90 degrees to the longitudinal axis of the vehicle, the vehicle would move at right angles to its previous path. The word 'turn' would then not be applicable since the vehicle would still be oriented in the same compass direction as before. Again, if the four wheels turned another 90 degrees in the same direction, the vehicle now would move across the field on a parallel path, 180 degrees from the first path but the body would be unchanged in direction. (Whether the wheels actually swivelled a further 90 degrees or went back to the original direction and reversed rotation, is immaterial.) Vehicle course direction changes could be made at any angle. If each wheel were independently driven by a hydraulic or electric motor and the swivelling of the vertical wheel mounting shaft controlled by another motor, such a vehicle would be feasible. The body would be articulated at some point to allow for uneven ground (Figure 10).

Implements: There are many ways of mounting implements on such a power unit. One method would utilize a tool bar or an adaptation of the three-point linkage at each end. Some reversible implements could be used and either pulled or pushed, depending on direction of travel. One other concept would employ a fifth wheel type of implement mounting which, if necessary, would be rotated through 180 degrees at each end of the field.

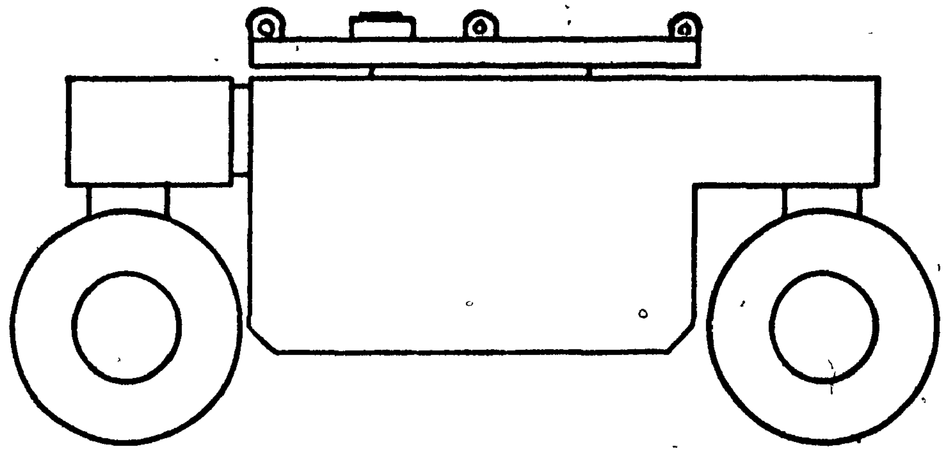
Implement Attachment: Although the term fifth wheel might imply a circular turntable type of attachment surface, the device may be rectangular. One of the many forms that the attachment could take is shown in Figures 11 and 12.

Provision is made to provide for two types of implement attachment:

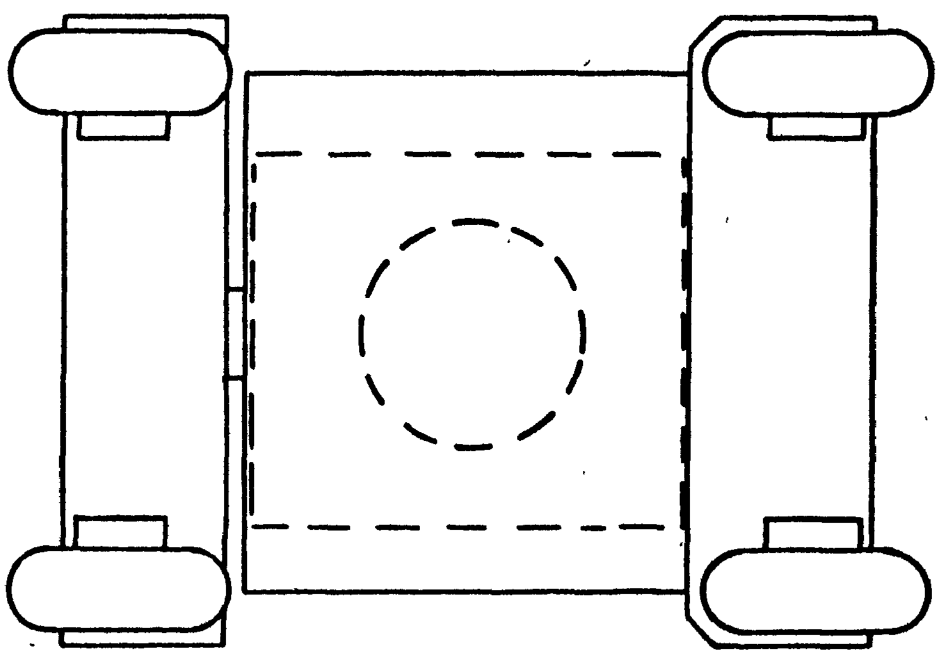
1. Attachment of implements, such as plows, which would be more or less completely carried on the power unit, will be to the outside attachment points as per Figure 13.

2. Attachment of other implements which are only partially carried, such as the combine, would be to the two centre mounts since some of the implement weight will be carried on castoring rear wheels. This method will also allow the implement to pivot in the vertical plane, independently from the power unit, as both units move over uneven terrain (Figures 14 and 15).

Power for implement operation might be obtained from a power take-off shaft located between these



SIDE VIEW



UNDER VIEW

Figure 10. Diagram of power unit with swivel mounting of drive wheels and fifth wheel type of implement mounting

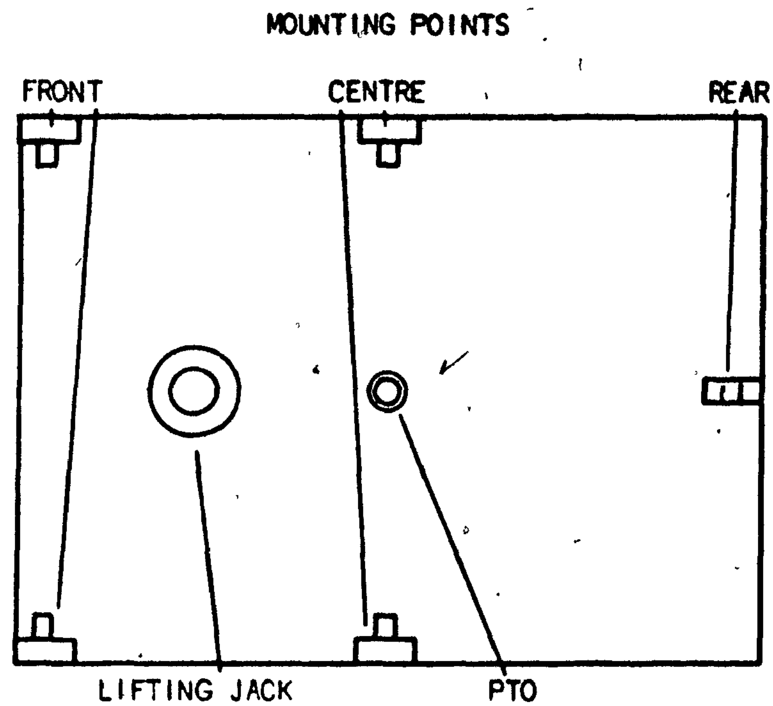


Figure 11. Top view of fifth wheel type of implement attachment

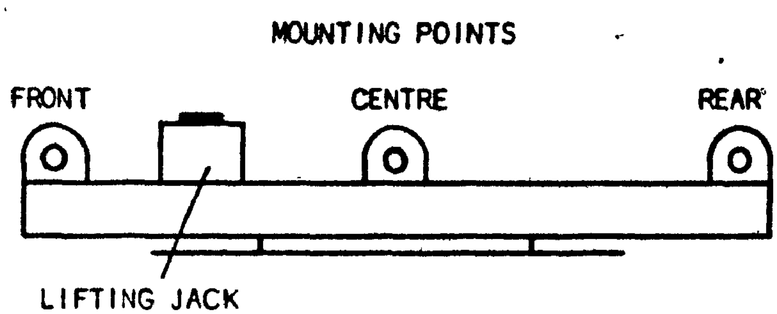


Figure 12: Side view of fifth wheel implement attachment

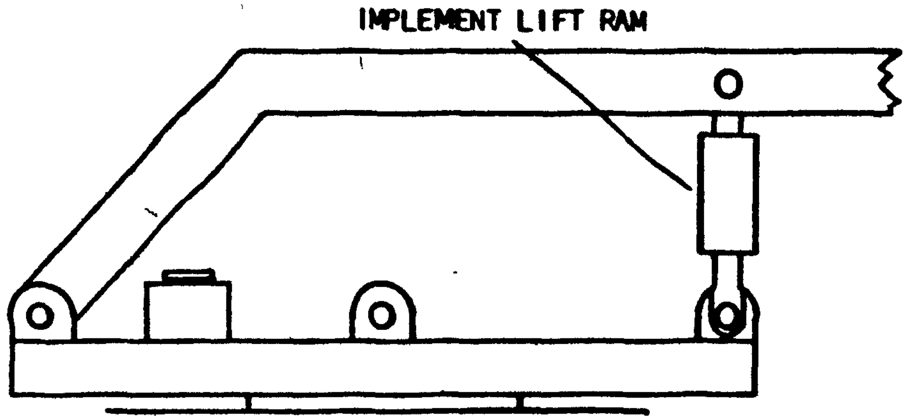


Figure 13. Method of attachment of mounted implements using front mounting points

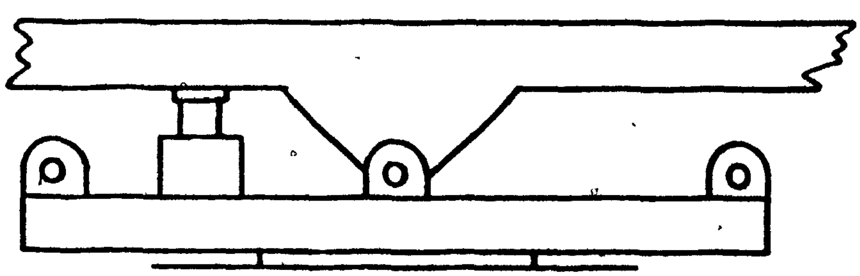


Figure 14. Method of attachment of semi-mounted implements - lifting jack partially extended

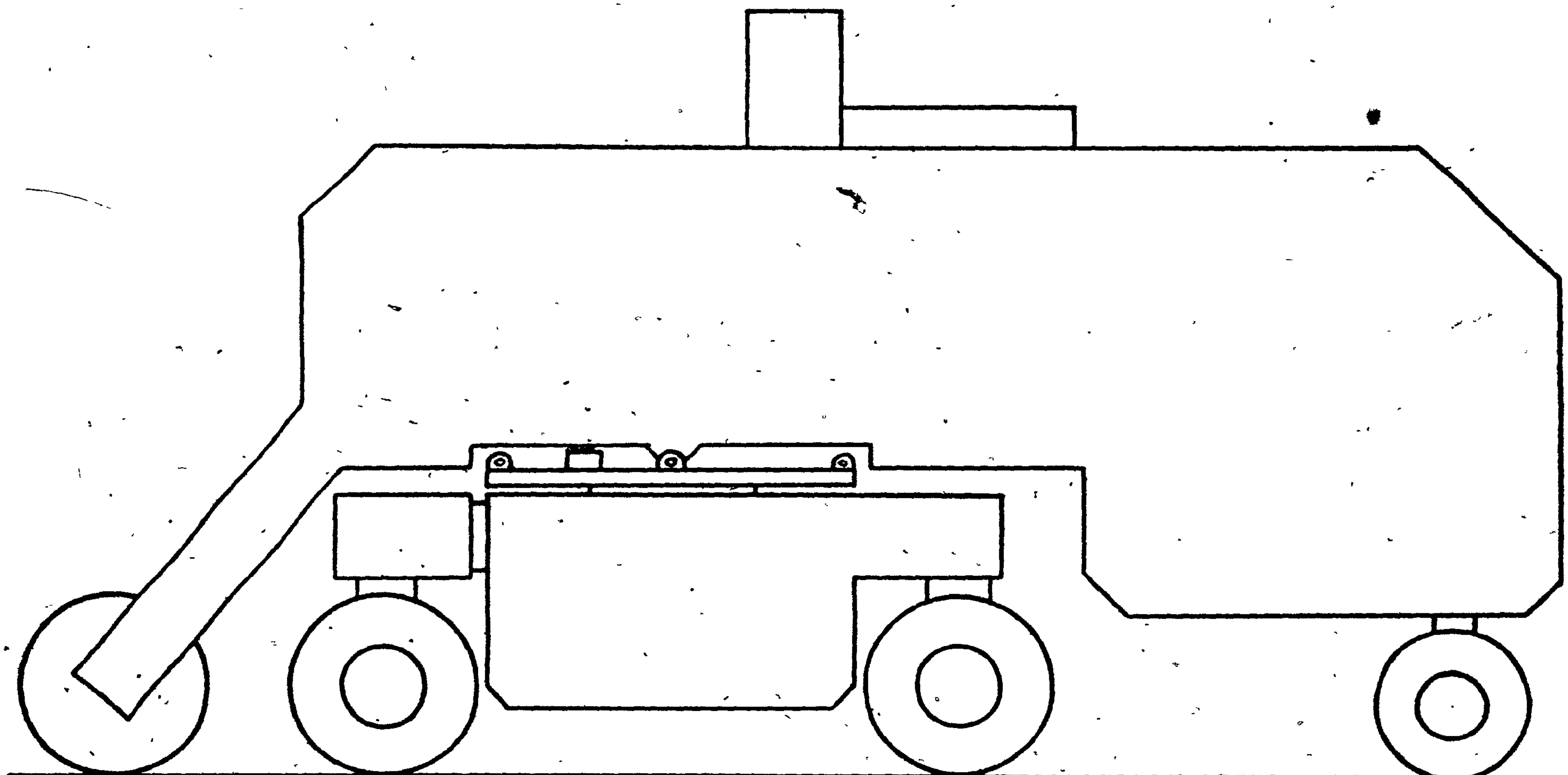


Figure 15. Diagram of power unit with semi-mounted implement

two mounting points, hydraulic outlets, or an electrical outlet. Coupling devices for sensor inputs from the combine to the power unit would be located at the same point.

A small hydraulic cylinder on the attachment device would lift or lower the implement for attachment or detachment. Suitable legs on the implement would lock down to support the implement when detached.

Guidance: Guidance for this vehicle would be simpler than that required for the vehicle with normal steering. One laser controller only would be required, since the vehicle body would face only the one direction. Path reversal at each end could be controlled by: a leader cable or a laser beam, or a proximity device detecting the distance to a fence.

Changes in power unit direction required at each end of the field path would be effected by all four wheels. Guidance signals, correcting the path across the field, could be made to act on one pair of wheels or on all four.

The basis of the system would be one self-powered controller and one automatic power unit. The controller would advance along a preset path and all power unit passes across the field would be made at right angles to this path. The path might be determined by: a guidance cable which was simply an electric fence wire with clips on the wire to set the pass widths, a leader cable buried in the ground or, for that matter, another laser beam.

V. ECONOMICS OF AUTOMATION

Often it is stated that if something cannot pay for itself then it is not justified economically. However, this gives only part of the story since there are considerations other than the economic justification. Sometimes, because of changing conditions, there is no other way to accomplish the operation - shortage of labor being a prime example.

What are the economic justifications for automation?

1. Less labor is required for a specific operation as mechanization of that operation increases. The former cost of this labor can be applied against the cost of mechanization. The average farm laborer in Eastern Ontario and Western Quebec is paid Y dollars per hour. If an automatic tractor does not require a driver then the saving is Y times the total number of hours that that tractor is used per year, less the cost required to maintain the system.

2. A tractor is used for a certain number of hours per day. This number could theoretically be 24 hours but in practice this is not approached for two reasons.

   The first reason is that a specific time is required to service the tractor. Changes in techniques of service and in tractor design to reduce service time can shorten the service time or lengthen out the periods between service but it cannot be eliminated. For example, during car races the length of service time is reduced to a minimum. In order to do this, many skilled mechanics are used for servicing. However, the man hours for service time are high.

The second reason that 24 hour a day operation is not approached is the limiting factor of the human driver. He eventually needs his own service time for rest and relaxation, refueling and sleep. This can be overcome by using two or more drivers, working in shifts. However, excluding service time and presuming all operators operating under similar conditions to be equally efficient there will be a difference in tractor efficiency between shifts. Daytime operation will be more efficient than nighttime because of the operator's ability to see better.

If an automated tractor were used it could operate 24 hours a day, less the required service time. Each hour would be equally efficient since the guidance system would be unaffected by light or darkness.

As demonstrated, conventional tractors do not operate 24 hours a day and this must be accounted for in determining the size required when a purchase is made. Allowing for timeliness there are only so many days in which a specific operation, such as planting, can be accomplished. Every day late in finishing the operation exacts a penalty in yield. For example, the most recent issue of the bulletin Corn Production in Ontario published by the Ontario Ministry of Agriculture and Food stated, "yield reductions of as much as three-quarters of a bushel per day will result as planting is delayed beyond the optimum date". One machinery management computer program (2) incorporates a cost penalty factor related to timeliness. If some time is lost because of operator service time, a larger tractor and larger implements must be used to make up the difference. However, the automated tractor can more closely approach the 24 hour a day operation. A smaller unit can be used for the same size of operation since it works a longer time, or conversely the same size unit can cover more work per 24 hour day. Of course, this line of reasoning works only on those operations which are not dependent on the sun. Operations, such as haying, where drying is dependent on the sun, could only be continued for part of the 24 hours.

Among the first automated devices were the so-called automatic screw machines. These devices produced simple items which were formerly made by operators on lathes. Once perfected, the screw machines turned out hundreds of units and were stopped only for servicing. Production of the items increased and the quality of the items improved. Since there was no operator involved who could become fatigued, sidetracked or take coffee breaks, quality remained consistently high, if the machine was properly maintained. Occasionally something could go wrong and the machine would produce defective parts but careful design minimized this probability. A human overseer, of course, would detect the defect. Later, built-in detection for defects was added and machines shutdown themselves.

The same performance is true for an automated tractor. Its work would be uniform since it would not be subject to fatigue, boredom or distractions. As stated before, this uniformity would continue hour after hour, day or night.

Once the screwmachine was automated certain other machine operator-oriented functions had also to be automated. These were functions related to the safety of the machine - lubrication supply, for example. Failure of a component affecting machine safety resulted in either machine shutdown or an alarm being given, all functions of this type had to be made operate in this fashion. An automatic tractor would need to be similar. Tractor safety-oriented functions would be oil pressure, engine temperature and fuel level. The automatic tractor would have to provide either warning to those in charge of servicing or automatic shutdown. On a standard tractor such things are left to the observation of the operator. Therefore, failure by the human to observe falling oil pressure or increasing temperature still leads to expensive repairs. This, the automated tractor would avoid.

Moreover, less than accurate control by the human operator can reduce crop yield. Careless cultivation, careless adjustment of implements as these proceed across the field, wrong speed, all can cause reduction of yields. Farm tractors and implements have increased in size in an effort to spread the operator's time over a larger unit in order to make more efficient use of his labor. However, quality of work from the larger implements can be lower than that from smaller units since the larger machine may scalp the tops of hummocks and inadequately cultivate the bottom of depressions. Taken to the extreme, inaccurate control can result in damage to the implement or tractor and even damage to the operator. Proper design of the automatic tractor would minimize these probabilities, resulting in further economic gains.

Research by the United States Department of Agriculture has shown that a 15% gain in crop yield is possible by simply having the tractor follow the same path every time it performs any operation in that field (13). Undesirable soil compaction is confined to specific areas. Therefore, accurate repetition of travel is essential. This would be possible with automatic guidance.

5.1 COST PREDICTIONS

It has been suggested that if the work were spread over 24 hours a day, where possible, certain economics could be effected. The corollary to this statement was that equipment intended to do the job in a normal length of working day could, therefore, accomplish much more over a longer day. Through the use of a Comsolve (4) program the following can be predicted. (Comsolve is a facility developed by the Ontario Ministry of Agriculture and Food to provide computer solutions to agricultural engineering problems. One of the programs evolved by the author predicts tractor horsepower requirements for several farm operations and the average cost of these operations.) Suppose, on an example farm, it is intended to grow the following acreages: 60 acres of corn silage, 65 acres of grain corn. 70 acres of small grains, 75 acres of soybeans and 80 acres of hay for haylage. One tractor is to supply the motive power for the operations of: plowing, disc-harrowing, combining, corn forage work and haylage. Of these, combining is dependent on the sun for conditioning of the grain, and haylage is partially dependent on the sun. The rest could be 24 hour a day operations. The program requires user entered variables. These relate to soil type, field sizes, acreages of various crops, number of operational hours per day and crop yield data.

Using this information and built-in parameters the program calculates the power take-off horsepower required for each operation. On the assumption that the farm operator will use a tractor of sufficient horsepower for the job requiring the largest horsepower the computer recalculates the effect of using this large horsepower on each of the five operations.

Certain costs occur related to the size of the area to be worked. These include fuel, lubrication and repairs. It is reasonable to suppose that regardless of the tractor size that fuel costs, repair costs and lubrication costs will be nearly the same for a specific area. Stated another way, it requires about X gallons of fuel for an operation over a certain number of acres regardless of whether this operation is done in Y hours or Y/2 hours with a tractor of Z or 2Z horsepower. However, the capital cost of the tractor, cost of its depreciation and cost of investment will be less per year for a cheaper, smaller tractor. These latter are the fixed costs.

Labor costs are fixed per hour of operation if an operator is required. The two most relevant costs then will be the fixed cost of the investment and the labor cost. If a smaller tractor is used over longer hours without an operator then a saving should result.

Using the acreages given above and the data built into the program, both with regard to the number of days available for each operation and the related weather data, two sets of tables were generated. The only change between the sets of tables is in the number of hours the tractor is operated per day. In the first set (Tables 1 and 2) the number of net driving hours for plowing, disc-harrowing, combining and forage chopping of corn and haylage were set to 10, 10, 7, 10, 10 hours, respectively. In the rest of the tables (Tables 3 to 6) the same information was used except that the hours of operation were set to 22, 22, 7, 22, 12, respectively. It was presumed that the automatic power unit would require 2 hours per day for servicing and refueling. In all examples the amount of time spent at jobs other than those listed was set to zero. Investment costs are based on costs of conventional tractors and since the second example requires the lesser horsepower its cost was lower. Table 5 is based on an automatic tractor costing $10,000.00, instead of $5,824.00, as calculated by the program. This cost selection was strictly arbitrary. The basic power unit, since it would be stripped of operator-oriented controls would be less expensive than $5,824.00. The difference between this and the $10,000.00 used would be the cost of control hardware. For the final table (Table 6) the automatic tractor cost was set equal to the cost of the 102 horsepower tractor.

5.2 ANALYSIS OF TABLES

Table 1: The first part of Table 1 gives the optimum power take-off horsepower required for each of the five operations as well as the total crop acreage, machine size and hours of work. The largest horsepower required is that for plowing. (The horsepower of any operations marked with an asterisk is ignored by the computer in determining the largest horsepower.) The second part of the table is a recalculation of machine size and hours of work for each of the five operations using the 102 horsepower calculated for plowing. Total operating time has been reduced from 266 hours to 189.2 hours for these operations.

Table 2: This table shows the estimated costs for operating the 102 horsepower tractor for the 189.2 hours. The program has estimated the tractor to cost $12,212.00. Hourly cost is $13.20. The total cost for the year is $2,496.47. Of this amount the fixed cost which includes depreciation and interest is $1,636.41 and the labor cost is $435.10. The total cost less the labor cost is $2,061.37.

Table 3: Horsepower requirements and hours of work are calculated for a tractor operating for the longer hours per day, as outlined above. The largest amount of horsepower (49) is required for haylage operations. Total tractor hours for the five operations are 415.4. This number drops to 384.1 when the data are recalculated using 49 horsepower for each job. It should be noted that the hours required for combining using the smaller tractor have risen from 36.1 to 56.8 so that completing the combining operations within the time available could be a problem.

Table 4: This table contains the cost of operation calculations for a 49 horsepower tractor estimated to cost $5,824.00 operating for 384.1 hours. Fixed costs are $780.49 per year and labor costs are $883.53. Total annual cost less labor is $1,193.65.

Table 5: Table 5 gives the costs of operation for a 49 horsepower automatic tractor estimated to cost $10,000.00. Fixed costs are $1,340.00 per year. Total annual cost less labor is $1,913.56.

Table 6: This time costs are computed for a 49 horsepower automatic tractor estimated to cost the same as the 102 horsepower tractor, that being $12,212.00. In this table fixed costs are $1,636.41 per year. Total annual cost less labor is $2,294.94.

5.2.1 Summary of Tables

Cost of operating the manually operated 102 horsepower tractor valued at $12,212.00 $2,496.47

Cost of operating the automatic 49 horsepower tractor valued at $5,824.00 $1,193.65

Difference from 102 horsepower tractor $1,302.82

Cost of operating the automatic 49 horsepower tractor valued at $10,000.00 $1,913.56

Difference from 102 horsepower tractor $ 582.91

Cost of operating the automatic 49 horsepower tractor valued at $12,342.00 $2,316.47

Difference from 102 horsepower tractor $ 180.00

The difference in cost between the manually operated 102 horsepower tractor and the automatic 49 horsepower model valued at $10,000.00 would be approximately $600.00 per year. Added to this difference would be the economic advantages attributable to better uniformity of work. These latter costs however, would be difficult if not impossible to predict.

The tables show the fact that, if the labor were available, there would be a financial advantage to using the small tractor long hours instead of the big tractor over shorter hours.

However, there is one advantage of the bigger tractor.

All of the tractor hours for each operation are calculated from information based on weather data incorporated into the program. The Province of Ontario was arbitrarily divided into six regions. The program contains the number of days available during the average year for each of the five operations. These numbers are based on long term weather data. Thus, both tractors operate the same number of days. The smaller tractor simply operates longer hours per day. The weather data is based on long term averages. If the year turns out to be adverse with fewer working days the owner of the bigger tractor can run it for longer than normal periods each day, to make up those days he could not operate, providing he can find the labor. The size of the smaller tractor was calculated on the basis of operating for longer hours and there is, therefore, little margin of safety. (There is a small margin of safety because in the recalculation of operations using 49 horsepower the total hours of annual use dropped from 415.4 to 384.1.) In that case there would be an advantage in owning the bigger tractor if the extra labor were available. The argument hinges on the word if.

Using the figures given above, there is an advantage in favor of the automatic tractor even allowing a 122% increase in cost over the non-automatic. For the automatic tractor of equal cost to the 102 power take-off horsepower tractor, after subtracting the labor cost, the automatic tractor was approximately $180.00 cheaper per year. The cost of $12,212.00 (as calculated by the computer) represents a 210% increase in cost over a standard tractor at $5,824.00.

The cost of the equipment to automate will be almost the same regardless of the tractor size. If it is desirable to reduce the risk then a larger unit than that required for 22 hours a day operation could be selected. The farm operator might feel that the additional fixed costs incurred would be offset by the lower risk factor.

These calculations have been based on the assumption that the automatic tractor would not require any labor input, other than that required for servicing. However, some labor would be needed to establish the tractor in each area in which it was to function and to move it to the next. The amount of this labor could be reduced to a minimum by making the work areas as large as possible.

One could argue that there is a further economic gain because of the improved precision resulting in higher crop yields and recovery. There is also a further saving because the labor removed from the tractor can be used to better advantage at other operations which cannot or have not been mechanized. It is difficult to estimate these savings.

Much is said about all forms of pollution. One form is that of noise and its effect on the hearing of the operator (6). Tests made on older farmers show a marked deterioration in hearing in comparison to other males of the same age who have been engaged in other occupations. This results from excessive tractor noise to which the farmer has been exposed. There is thus, more than a gain in economics if the would-be operator becomes a controller and is not exposed to damaging noise pollution. Allied to this is the incidence of other physical problems related to the constant shaking of the body occurring from the motion of the tractor. Many improvements have been made to tractor seats. But some of these are extra cost options that the buyer ignores. The controller of the automatic tractor would not be exposed to these conditions.

Every year there is a loss of life and a loss of productive man hours caused by tractor accidents. It would be presumptuous to suggest that all tractor-oriented accidents would stop if the human operator were removed but it is logical to suggest that these would be greatly reduced.

These types of improvements cannot be measured in monetary terms.

It should be noted that none of the cost estimates has taken into account the fact that the machinery for the smaller tractor will be smaller and cost less, resulting in further savings.

A table of current machinery costs applicable to the examples used above is given in Appendix 2.

Table 1

Tractor Size: Normal Day

MACHINE TYPE	CROP ACREAGE	MACHINE SIZE	MACHINE HOURS	SPEED MPH	CAPACITY PER HR	TRACTOR PTO HP
PLOW	273.	7 BOTTOM	72.5	4.0	3.8 ACS	102.
DISC	273.	12.7 FT WIDE	49.0	4.0	5.6 ACS	59.
*COMBINE	70.	5 FOOT	36.1	4.0	116.4 BUS	79.
FORAGE,CORN	60.	1 ROW	55.0	4.0	15.3 TONS	59.
FORAGE,HAYLAGE	80.	5 FOOT	53.3	3.3	7.5 TONS	49.

* NOTE: THIS MACHINE HAS MORE CAPACITY THAN IS REQUIRED FOR THIS OPERATION.

TOTAL TRACTOR HOURS: 266.0

THE TRACTION FORCE REQUIRED FOR PLOWING IS 9072. POUNDS (PULL).

OPERATIONAL DATA FOR A 102. HP TRACTOR

WITH 18" BOTTOMS.

MACHINE TYPE	CROP ACREAGE	MACHINE SIZE	MACHINE HOURS	SPEED MPH	CAPACITY PER HR
PLOW	273.	7 BOTTOM	72.5	4.0	3.8 ACS
DISC	273.	20. FT WIDE	31.2	4.9	8.7 ACS
COMBINE	70.	6 FOOT	28.4	4.5	147.8 BUS
FORAGE,CORN	60.	2 ROW	27.5	4.0	30.5 TONS
FORAGE,HAYLAGE	80.	9 FOOT	29.5	3.3	13.6 TONS

TOTAL TRACTOR HOURS: 189.2

Table 2

Cost Table For 102 Horsepower Tractor

OPERATIONAL COSTS FOR A DIESEL TRACTOR

ESTIMATED TRACTOR COST: $12212.00   TOTAL HOURS: 189.2

AVERAGE COSTS PER HOUR

FUEL	LUBRICATION	REPAIR	FIXED COSTS	LABOR	TOTAL
.89	.13	1.22	8.65	2.30	13.20

** TRACTOR OPERATIONAL COSTS PER YEAR **

TRACTOR OPERATION	FUEL	LUBR	REPAIR	F CST	LABOR	TOTAL COST	TOTAL COST PER ACRE
PLOWING	64.66	9.70	88.57	627.40	166.92	957.14	3.51
DISCING	27.83	4.17	39.12	270.05	71.80	411.98	1.51
COMBINE	25.33	3.90	34.70	245.83	65.36	375.03	5.36
FORAGE,CORN	24.52	3.69	33.59	237.88	63.25	362.91	6.05
FORAGE,HAY	26.31	3.95	36.04	255.25	67.97	389.41	4.87
GRAND TOTAL	169.65	25.30	231.02	1636.41	435.10	2496.47	

TOTAL ANNUAL COSTS: $ 2496.47

Table 3

Tractor Size: 22 Hour Day

MACHINE TYPE	CROP ACREAGE	MACHINE SIZE	MACHINE HOURS	SPEED MPH	CAPACITY PER HR	TRACTOR PTO HP
PLOW	273.	4 BOTTOM	163.2	4.0	1.7 ACS	46.
DISC	273.	5.8 FT WIDE	107.8	4.0	2.5 ACS	26.
*COMBINE	70.	5 FOOT	36.1	4.0	116.4 BUS	79.
*FORAGE,CORN	60.	1 ROW	55.0	4.0	15.3 TONS	59.
FORAGE,HAYLAGE	80.	5 FOOT	53.3	3.3	7.5 TONS	49.

* NOTE: THIS MACHINE HAS MORE CAPACITY THAN IS REQUIRED FOR THIS OPERATION.

TOTAL TRACTOR HOURS: 415.4

THE TRACTION FORCE REQUIRED FOR PLOWING IS 4032. POUNDS (PULL).

OPERATIONAL DATA FOR A 49. HP TRACTOR

WITH 14" BOTTOMS.

MACHINE TYPE	CROP ACREAGE	MACHINE SIZE	MACHINE HOURS	SPEED MPH	CAPACITY PER HR
PLOW	273.	4 BOTTOM	154.2	4.2	1.8 ACS
DISC	273.	10. FT WIDE	64.9	4.9	4.2 ACS
COMBINE	70.	5 FOOT	56.8	2.7	73.9 BUS
FORAGE,CORN	60.	1 ROW	55.0	4.0	15.3 TONS
FORAGE,HAYLAGE	80.	5 FOOT	53.3	3.3	7.5 TONS

TOTAL TRACTOR HOURS: 384.1

THE TRACTION FORCE REQUIRED FOR PLOWING IS 4032. POUNDS (PULL).

Table 4

Cost Table For 49 Horsepower Tractor

($5,824.00)

OPERATIONAL COSTS FOR A DIESEL TRACTOR

ESTIMATED TRACTOR COST: $ 5824.00 TOTAL HOURS: 384.1

AVERAGE COSTS PER HOUR

FUEL	LUBRICATION	REPAIR	FIXED COSTS	LABOR	TOTAL
.43	.06	.58	2.03	2.30	5.41

** TRACTOR OPERATIONAL COSTS PER YEAR **

TRACTOR OPERATION	FUEL	LUBR	REPAIR	F CST	LABOR	TOTAL COST	TOTAL COST PER ACRE
PLOWING	66.10	9.91	89.78	313.19	354.56	833.52	3.06
DISCING	27.81	4.17	37.77	131.76	149.17	350.69	1.29
COMBINE	24.35	3.65	33.08	115.39	130.64	307.11	4.39
FORAGE,CORN	23.58	3.54	32.03	111.74	126.50	297.39	4.96
FORAGE,HAY	22.87	3.43	31.06	108.35	122.67	288.39	3.60
GRAND TOTAL	164.71	24.71	223.73	780.42	883.53	2077.09	

TOTAL ANNUAL COSTS: $ 2077.09

Table 5

Cost Table For 49 Horsepower Tractor

($10,000.00)

OPERATIONAL COSTS FOR A DIESEL TRACTOR

ESTIMATED TRACTOR COST: $10000.00 TOTAL HOURS: 384.1

AVERAGE COSTS PER HOUR

FUEL	LUBRICATION	REPAIR	FIXED COSTS	LABOR	TOTAL
.43	.06	1.00	3.49	2.30	7.28

** TRACTOR OPERATIONAL COSTS PER YEAR **

TRACTOR OPERATION	FUEL	LUBR	REPAIR	F CST.	LABOR	TOTAL COST	TOTAL COST PER ACRE
PLOWING	66.10	9.91	154.15	537.73	354.56	1122.45	4.12
DISCING	27.81	4.17	64.86	226.24	149.17	472.25	1.73
COMBINE	24.35	3.65	56.80	198.13	130.64	413.57	5.91
FORAGE, CORN	23.58	3.54	55.00	191.85	126.50	400.47	6.67
FORAGE, HAY	22.87	3.43	53.33	186.04	122.67	388.34	4.85
GRAND TOTAL	164.71	24.71	384.14	1340.00	883.53	2797.09	

TOTAL ANNUAL COSTS: $ 2797.09

Table 6

Cost Table For 49 Horsepower Tractor

($12,212.00)

OPERATIONAL COSTS FOR A DIESEL TRACTOR

ESTIMATED TRACTOR COST: $12212.00 TOTAL HOURS: 384.1

AVERAGE COSTS PER HOUR

FUEL	LUBRICATION	REPAIR	FIXED COSTS	LABOR	TOTAL
.43	.06	1.22	4.26	2.30	8.27

** TRACTOR OPERATIONAL COSTS PER YEAR **

TRACTOR OPERATION	FUEL	LUBR	REPAIR	F CST	LABOR	TOTAL COST	TOTAL COST PER ACRE
PLOWING	66.10	9.91	188.25	656.68	354.56	1275.50	4.68
DISCING	27.81	4.17	79.20	276.29	149.17	536.65	1.97
COMBINE	24.35	3.65	69.36	241.95	130.64	469.96	6.71
FORAGE,CORN	23.58	3.54	67.17	234.29	126.50	455.08	7.58
FORAGE,HAY	22.87	3.43	65.13	227.19	122.67	441.29	5.52
GRAND TOTAL	164.71	24.71	469.12	1636.41	883.53	3178.47	

TOTAL ANNUAL COSTS: $ 3178.47

VI. SOCIOLOGICAL ASPECTS OF AUTOMATION

Each change in basic production methods has been accompanied by a change in sociological conditions. Perhaps the most famous example of this was the industrial revolution of Great Britain. Here, hand production methods in cottages were replaced by machines in factories which resulted in increased production in less time.

Before the industrial revolution, work was carried on in the workers' cottages. Then came the inventions in the weaving industry, which led to the establishment of weaving factories. These factories, at first, were located near sources of water power. Besides supplying power, the river supplied the necessary transport for the raw materials and finished products. Then, as mechanical power in the form of steam power became available, the factories located near sources of labor. Since factories paid better, workers moved from rural areas to urban areas to supply the demand for labor.

Commodities now became cheaper, allowing the worker to purchase more goods, still further increasing the demand for product. This, of course, heightened the demand for further mechanization and/or further laborers.

Changes in agricultural production techniques have generally not met with reactions similar to those occurred during the industrial revolution.

About the time that the industrial revolution was in full swing certain developments in agricultural processes improved efficiency in food production. These occurred notably in plant and animal breeding, management techniques and the application of labor. One or two examples should serve.

Jethro Tull, in 1701, developed a primitive drill which allowed plants to be sown in rows instead of by broadcast methods. This technique also allowed cultivation between the rows and lessened the amount of seed required and the competition of weeds. In harvesting, McCormick developed the reaper in 1831.

It can be argued either that the migration of labor from the rural areas to the urban areas began with the increased demand for factory labor or that improved farm techniques lessened the demand for labor which then had to find jobs elsewhere. The first argument is probably more valid.

Much is written by modern sociologists with respect to current rural living; much is said about the past effects of mechanization on rural living; and much is predicted about the future effect of mechanization. What were the sociological conditions of the rural community 110 or more years ago? Was there a labor surplus or was there a labor shortage?

James Croil, a farmer in Dundas County from 1841 to about 1870, wrote in 1861 the first county history of the Province of Ontario. Later he became an official of the Church of Scotland in Canada and wrote other books. Before he came to Canada he had had, to quote G. Tulchinsky of Queen's University, "an excellent education in Scotland". His book Dundas or A Sketch of Canadian History (7) besides being a history of Canada in general and Dundas County in particular, gives an insight into social conditions as they existed in rural Ontario, both during and before his time. With regard to labor, Croil states, "If one farmer is blessed with a family of sons, seldom more than one or two of them remain at home", (page 219). He then goes on to state that these entered a variety of jobs. Yet earlier in the same volume when writing about the opening up of the county some 60 to 70 years before, he had stated, "There being ample employment on the father's farm, yet uncleared, for all his sons....", (page 135).

At another point he describes the operation of a particularly prosperous farmer about whom he says, "His farm embraces 500 acres, whereof 300 acres are cleared.... He employs cheap labor, say three men at $8.00 per month for the year round.... In hay and harvest time, he employs six of the best men that can be had....", (page 195).

Finally, when speaking about laborers, "The greater part of the labor of the farm in Canada, is performed by the farmer himself, his sons and his daughters.... The average size of Canadian farms is 100 acres each, with 50 to 60 acres cleared.... The demand for labor is therefore limited and the supply is generally equal to the demand.... Laborers are chiefly immigrants, Irish, German and a few Scotch, they seldom continue at service longer than four years, and if during that time they are industrious and economical, they will have laid by enough to stock a small farm....", (page 212, italics mine).

He concludes that chapter by substantiating his statement that "The agricultural implements of the county are keeping pace with other improvements".

The differences between the two time periods he covered in the above examples are the differences between subsistence farming and production farming. In the early days immense amounts of labor were required to produce enough for existence. However, as farm conditions improved, subsistence production gave way to greater production than the immediate family required. Labor demands changed with the improved production. Less labor was required to maintain the status quo than that required for routine farm work plus the necessary land clearing.

In his book, A History of Agriculture In Ontario (20), covering the same historical period, G.E. Reaman writes: "From a survey made by the minister of agriculture in 1857, it was estimated that there was a need of 24,000 immigrants; 9,300 farm servants and laborers, 3,600 female servants, 5,700 boys and girls, 900 mechanics, and 4,500 undefined."

From these references we see that, in the 1861 period, the supply of labor only matched the demand in spite of the facts (a) that the amount of labor required had dropped considerably in the 60 to 70 years and (b) that some mechanization had occurred. Even in those days, while there was not a shortage of labor neither was there a surplus.

The labor shortage existed in the early 1900's. To again quote from Reaman, "Because of higher wages in industry several things were happening: there was a rapid increase in urbanization which increased the local market for farm products. Labor was getting scarce which forced the farmer to increase his mechanization as much as possible....".

Two periods in Canadian history, however, have produced serious shortages of farm labor. Both occurred during the two world wars. After the first war the situation partly corrected itself because the supply of available farm labor rose as some servicemen returned to the farm. This supply was further improved during the depression years because labor which might have moved to the city labor markets remained in the rural area. The second shortage developed rapidly during the second world war, but after this war, in contrast to World War I, a very small labor force returned to the farm. Many of those who did return went into farming for themselves with aid of such plans as the Veterans Land Act. Both eras caused increases in mechanization because of labor shortage. R.B. Gray (14) states that "in 1917, the year the United States entered World War I, tractor production more than doubled".

It can be argued that there is currently a labor shortage on Canadian farms which began with the second world war. The migration of labor from the farm areas to the city has continued, with a decreasing percentage of rural labor in the entire work force. This is substantiated by statistics in the 1972 Canada Year Book. There it is stated that there were 683,000 employed in agriculture in 1960 and 512,000 in 1970.

The farmer has continued to mechanize to maintain or increase production in spite of the decreasing supply of labor force. The reasons for the decrease of labor are many, not the least of which are better working conditions in the urban jobs. One could question the definition of the word 'better'. When used in this context 'better' can be taken to mean fewer hours or less arduous labor.

The labor force remaining on the farm divides into two categories. One is a highly skilled employee who can command a good income when the many fringe benefits he receives, such as a rent-free house, are considered. This type of individual is attracted to the highly mechanized farm. The second type of employee is one who, because of lack of ability and/or initiative, is unable to find employment off the farm in the urban area. He is forced to remain in the rural area and often lives in a rural slum area. Depending on his initiative he works when he can or when he has to. His plight is alleviated by modern social welfare programs.

This type of labor is unsatisfactory to the modern farm because generally it requires either close supervision or relegation to a mundane, repetitive, unskilled type of operation. Since much of this labor is unreliable and because these operations are the most easily mechanized, this type of labor operation is being or has been phased out on many farms.

There is an idea among those concerned with problems of the unemployed that many could be moved back to the farm, both to provide them with employment and to minimize the farm labor shortage. Further mechanization is viewed as the worst possible solution.

Whether one recognizes it to be so or not, farm labor is a skilled occupation and requires a long period of training. This fact is not realized by those who suggest the back to farming approach as a solution to unemployment. Most of those who are farm laborers have been involved in the work almost all of their lives. To no other occupation is the word apprenticeship more applicable.

A good farm laborer has served many years of apprenticeship or on-the-job training, whatever one chooses to call it. One cannot convert the unskilled into a skilled agricultural worker overnight.

What are the present trends in the farm labor force? The farm labor in all areas is mainly made up of farm operators and family members. The amount of outside labor - outside the family - is decreasing. Larson and Richardson (18) state, "In New York, the outlook is for continued decrease in the number of farm workers.... With this trend is the expectation of a greater relative dependence upon farm operators and family members for this state's farm work." Conditions in New York State are similar to those existing in Eastern Ontario and Western Quebec.

Further mechanization will be required to offset these trends. Much of this mechanization will be in the field of automation of field operations.

Consider, too, the changes in rural living as presented by the changes in rural ownership, particularly where the area is close to a large urban area. There are roughly five categories of owners.

1. the owner whose sole income is from the land he owns
2. the owner who earns part of his income from the land and part from a job in an urban area
3. the owner who makes his entire living away from the farm but continues to live on it. He may rent his land to adjacent farmers.
4. the owner who makes his livelihood in the urban area and lives in the urban area. He may own the land as a speculative venture or may have plans to eventually farm it.
5. the absentee farm operator who owns a farm, does not live on it, but employs a farm manager

These types of ownership affect the social organization of the area. The newcomers attempt to bring the impersonal approach of urban living with them, that of live and let live with respect to neighbours and their institutions of school and church. They often enter little into the rural social life, although they may be outspoken in matters which concern them directly, in regard to local government and local improvement. Those with jobs in the urban area tend to make their purchases there, maintain their contact with the professional people whom they consult. Because the numbers in category one are diminishing, the number of rural people who serve them - shop owners, farm repair men - diminish also and the local social centre (village, for example) deteriorates. Only in those rural sections where the numbers in categories three and four are small has rural life, as known previously, remained relatively unchanged.

A second modern phenomenon is the appearance of rural-urban districts in previously strictly rural areas (6). A rural-urban district contains from several to many homes concentrated in a small district which had previously been totally rural. This small urban development, if larger, may have a store or stores and suppliers of services located within it. It is a self-sustaining unit. It is then in competition with and adds to the further deterioration of the older centre. The members of the population of this rural-urban district are used to the services they expected from an urban section and to the newer methods of doing business. These are not supplied by the tradesmen of the older established centre.

Similar situations exist elsewhere in Canada and the United States. The United States Department of Agriculture estimates in 1970 of the size of the labor force in 17 seaboard states showed a 61 percent decrease from the 1950 estimates (18).

All these features of change affect mechanization on the farm and increase the demand for it. Evidence would thus support the conclusion that changes in the availability of the farm labor force have caused farms to mechanize rather than the other way around, i.e. farm mechanization has been forced by changes in the farm labor force.

What prompts further mechanization? Garrett and Burkhardt (10) state, ".... an actual labor shortage is not needed to spur interest in mechanization. It may be an impending shortage or even an imaginary impending shortage.... He (the farmer) knows that mechanization doesn't occur overnight and he wants to be ready....".

What further changes can one expect with automation of field operation?

1. There will be a further reduction in farm labor as related to field operation. Whether this will cause a further numerical drop in farm labor force or a shift of this labor to farmstead operations which are not so easily mechanized remains to be seen. It is probable that the latter will occur.

2. The farm operator who now supplies part of the farm labor will shift his time to supervisory and managerial operations. Any field operations still to be done manually will be done by other members of the farm labor force.

3. Much of the field operations are repetitive and boring. The former tractor operators will be freed from this to do jobs for which their mental skill and manual dexterity equip them. Many farm philosophers maintain that much of their serious thinking was done while driving the tractor up and down the rows. That time, in the automated situation, would have to be found elsewhere.

4. Since the operator would not be tied to his farm to carry out the field operations he had formerly to do, he should be better able to enjoy leisure time and the social amenities that go with it.

To many, present day farming is a way of life as well as a method of earning a livelihood. Further expansion in the use of automatic operations in farming will tend to create a more industrial-type of life. The farm operator will oversee these operations, performing fewer himself as the amount of automation increases. Life style will change since he will not be bound by the number of mundane jobs now common on most farms. In farm operations of the future, therefore, automation will provide an effective and challenging blend of sophisticated management and skilled labor.

VII. SUMMARY AND RECOMMENDATIONS

7.1 SUMMARY

A. Development of automatic control will continue towards full automation of field operations. The stages that it will follow will probably be as follows.

I. As many as possible of the existing methods of automation will be applied to tractors as sub-systems that will function without operator control. The operator may intervene if this is desired. All of these systems exist; some are currently fitted to some tractors, some are in the laboratory stage. Included would be:

i. automatic engine speed control

ii. automatic engine load control in the form of automatic transmissions

iii. for cultivation: automatic draft control in the form of implement depth control. Coupled to the draft control would be a wheel slippage detector. These two units would work together to allow up to a preset maximum wheel slippage before a change in draft was made.

for harvest: sensors on the harvesting equipment would be used to provide control of forward speed related to crop density and other equipment functions, such as header height.

iv. automatic guidance along rows, furrows or crop edges

II. The next stage of development will be the inclusion of a system to provide guidance across the field and controlled turns.

III. Then will come the automatic tractors using the crab-type of steering and fifth wheel mounting of implements and providing automatic operation within a specific field.

IV. The final step will be complete automatic operation of these power units from a central programmed controller.

B. Such units will be economical providing their cost does not exceed the cost of existing tractors and that a unit of smaller horsepower, working 22 out of the 24 hours, is used where feasible.

C. It is unlikely that automatic guidance will have little effect on rural living other than to provide a further shift from mundane tasks to managerial tasks. Hopefully, this would provide more leisure time to the farmer.

7.2 RECOMMENDATIONS

It is recommended that further research into the development of the automatic power units and their companion implements should be continued. This research should include:

1. the power units
2. the implements
3. further automation of sub-systems

4. guidance systems
5. central control system
6. further investigation of the sociological impact

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APPENDIX 1

The tractor program of the Comsolve series is designed to predict the size of tractor required for each of five farm operations. These are: plowing, disc-harrowing, combining (small grain), forage harvester operation for corn silage and for hay or haylage. The program calculates the horsepower required for each of these operations, selects the largest horsepower and recalculates each of the operations using that horsepower.

Some of the information required for the calculations is entered at the time of execution as data. The remainder of the information is part of the program, the pertinent information being selected in response to some of the data being entered.

Data required are:

- the area of Ontario where the user is located
- soil type
- stoniness factor
- plowing depth, speed and width of plow bottoms
- size of field in order to determine field efficiency
- slope factor for the area
- number of acres of silage corn, grain corn, small grains, soybeans and hay
- number of acres to be plowed or disced, if different from that which would be calculated from the above acreages
- length of the driving day for: combining, plowing,

discing, corn silage and haying operation

- number of days available for each of the above operations. By-passing any of these will cause the computer to use program data based on the area of Ontario selected, and built-in weather factor data.
- yields per acre of: tons of silage, bushels of small grains, tons of hay or haylage
- the horsepower of a proposed tractor. If a horsepower is entered then that horsepower will be used in the recalculation of each operation instead of the maximum horsepower determined.

After the tables showing the horsepower requirements for each operation and the effect of the maximum horsepower on each have been printed, the user has the option of selecting a cost analysis. If this is desired then the following data are entered: costs of fuel per gallon and labor per hour, number of hours the tractor spends performing other jobs at or near full horsepower, the cost of the tractor, if known, and the cost of interest, if known. Default of the last two will cause the program to estimate the tractor costs and to use an interest rate of 8%.

A second table printed as part of the cost analysis shows the effect of using tractors with 80, 90, 100, 110 and 120% of the power required. This table is not printed if the user entered a cost for the tractor.

Maximum horsepower is limited to 175. If the calculated horsepower exceeds 175 for plowing the calculated horsepower is divided by a factor determined from the number of times 175 divided into the horsepower + 1. For example, if the calculated horsepower was 210 it would be divided by 2 and the plow horsepower of the tractor set equal to 105.

At a later point 105 would be compared with all the horsepower calculated for the other operations and the maximum selected.

This maximum is used in the recalculation of operations and in the cost analysis.

The user has the option of entering data in response to questions or as data strings to shorten input time. Output can be printed (a) complete with all headings and notes
(b) with headings only and without notes
(c) without headings and without notes.
Again, the options are selected at the time of execution.

At the conclusion of the cost analysis, the user may change any or all of the cost analysis parameters that were entered. All of the tractor selection data are retained and new cost analysis tables are printed.

If the option of changing the cost analysis is bypassed the user has a further option of changing some of the data pertaining to the tractor selection. These data are: plowing speed and plow depth. If either is changed new tables will be printed and a new cost analysis can be run.

At the beginning of execution the user can select a short form analysis wherein only the first output table is printed. He then has the option of changing plowing speed or depth.

The formulae used within the program to calculate implement sizes, horsepower requirements and costs of operation are based on those given in the 1972 Agricultural Engineers Yearbook published by the American Society of Agricultural

Engineers. Some changes have been made to match Ontario conditions.

This program has been revised constantly in order to keep program data, such as those related to tractor costs, updated.

Table 7

List Price of Equipment*

Plow	4, 14" furrows, mounted	$1,281.	7, 18" furrows, manual reset	$3,800.
Disc-harrow	10'3" 32, 18" discs	$1,206.	20' 20" discs	$2,786.
Forage chopper	basic unit	$2,318.	basic unit + recutter	$3,930.
	corn head	$ 747.	2-row corn head	$1,424.
	pick-up head	$ 682.	pick-up head	$ 905.
Total		$6,234.		$12,845.

*. in effect at time of writing