Improving New Product Development

Using Process Simulation

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ABSTRACT

Bombardier Aerospace currently puts more effort into developing new products at a faster pace. The goal of this thesis is to study the effect of sharing an aeroelastic model between the Loads and Dynamics departments at Bombardier Aerospace as well as to seek out other opportunities in order to reduce total effort. The work in this thesis is based on a previous project that was conducted two years ago in order to establish process maps for the two departments and to simulate the aeroelastic model sharing scenario.

In the present thesis, two types of strategies are applied: (1) add resources to the tasks located on the critical path to shorten project span time; (2) seek opportunities for sharing design processes which in turn reduce total effort. Firstly, the process maps for the two departments were updated and verified. Secondly, the critical tasks were identified on the process maps. In addition, the process maps were shown to the engineers in both departments to look for potentially sharable design processes. Thirdly, the scenarios with additional resources and with shared processes were simulated. The benefits of the scenarios were observed by comparing two factors: (1) project span time and (2) effort. Afterwards, the quality of the inputs and the design processes was investigated. Finally, this thesis concludes with validated simulation results, suggested optimal solutions to reduce the span time and effort, and guidance for future work.

ABRÉGÉ

Présentement, Bombardier Aéronautique cherche à accélérer le développement de leurs nouveaux produits. Le sujet de cette mémoire est l’étude de l’effet du partage du modèle aéroélastique entre le département de charges et le département de la dynamique de Bombardier Aéronautique sur la durée des projets, ainsi que de la recherche de différentes méthodes pour réduire l’effort total. Le contenu de cette mémoire est basé sur le travail d’un projet précédent qui avait pour but de créer les cartes de processus pour les deux départements et simuler le scénario de partage du modèle aéroélastique.

Dans cette mémoire, deux types de stratégies sont proposés : augmenter les ressources aux tâches sur le chemin critique du projet afin de réduire sa durée, et chercher des possibilités de partager les processus de conception pour réduire l’effort total. Premièrement, les cartes de processus des deux départements ont été mis à jour et validés. Deuxièmement, les tâches critiques ont été identifiées sur les cartes de processus. Les cartes de processus ont également été présentés aux deux départements afin d’identifier les possibilités de partager des processus de conception. Troisièmement, les scénarios appliquant les deux types de stratégies proposés ont été simulés. Les résultats des simulations ont été analysés en comparant la durée du projet et l'effort total des scénarios. Puis, la qualité des donnés entrées et les processus de conception ont été étudiés. Finalement, les résultats des simulations ont été présentés, et des recommandations pour améliorer le processus de développement de nouveaux produits sont proposées.

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1.1 Background and Objectives

1.1.1 Model Sharing at Bombardier Aerospace

Bombardier Aerospace, a division of Bombardier Inc., is the third largest aircraft manufacturer in the world. It puts great effort into accelerating the pace and improving the quality of its New Product Development (NPD) in order to increase its competitiveness in the aircraft manufacturing market.

System and Technical Engineering, also known as Core Engineering, is a project centered unit composed of more than 20 design departments at Bombardier Aerospace. Its duty is to design, analyze, validate, test and certify an aircraft. Within Core Engineering, the aeroelasticity analyses for all of the aircraft are held by the Dynamics department. Aeroelasticity is the term used to denote the field of study concerned with the interaction between the deformation of an elastic structure in an airstream and the resulting aerodynamic force (Hodges and Pierce 2002). It is concerned with the significant mutual interaction among inertial, elastic, and aerodynamic forces (Dowell and Clark 2004). An aeroelastic model is comprised of a structural model and an aerodynamic model. In the design phase, different aeroelastic models are developed within different departments in Core Engineering instead of using a common model. This results in duplicated effort and can potentially cause miscommunication between departments.

Loads and Dynamics are two very important departments in Core Engineering and play a critical role in the design and certification of an aircraft. The Loads department has a great impact on sizing and adjusting the structure of an aircraft. Its duties comprise calculating and analyzing cases with different design loads, and providing resultant data and new aircraft requirements to the Stress department so that it can process these analytical results, apply structural changes to the aircraft and if necessary redesign the aircraft. Design processes in the Loads department are mainly composed of distributed loads analysis and discretized loads analysis.

The distributed loads are made up of shear forces, bending moments and torques distributed over the external area of an aircraft at specified points and reference axes. Distributed loads analysis is performed on all aircraft components. At the end of the distributed loads analysis, checks are made by a distributed loads program on the validity of aerodynamic distributions, mass distributions and overall aircraft balance. Discretized loads analysis starts after all the distributed loads are complete, then a discretized loads are read by a program that breaks down a consistent distributed load case into discrete nodal forces for use in an FEM model. Then, the discretized loads are delivered to the Stress department.

There are several different types of analyses in the Loads department, where most engineering work is multidisciplinary. The engineers working in the same discipline are organized into a “group”. 3 specific groups are mentioned in this thesis: High Lift, Flight Maneuvers, and Dynamic Gust groups.

The High Lift Loads group determines the externally applied loads on any high lift device and on the airframe for use in the design of primary and secondary structures and high lift systems. The Flight Maneuvers group calculates aerodynamic coefficients, aircraft attitudes and conditions to feed the distributed loads program which creates a set of distributed external loads using the known weights at each preset aircraft station. The

Dynamic Gust group analyzes the dynamic response of an aircraft to size the corresponding design loads.

The Dynamics department plays an important role in the aircraft design and certification. It influences the design to ensure an adequate stiffness distribution and flutter suppression and it ensures the safety of the aircraft under any possible vibration frequencies by performing Ground Vibration and Flight Flutter tests. Ultimately, they are responsible for the vibration and flutter certification for an aircraft. Besides, there are a few additional departments that provide input data to Loads and Dynamics. These include: Flight Sciences, Stress, Masterlines, Mass, Fly-by-Wire, Advanced Aerodynamics, Landing Gear Suppliers, and Engine Manufacturer Suppliers. The focus of this thesis is the design processes in the Loads and Dynamics departments.

The design processes in the Loads and Dynamics departments are performed in loops. A loop is a complete cycle of analysis (Hisarciklilar, Sheikh et al. 2012). A whole product development cycle is comprised of several design loops. Normally, the Loads department has 4 loops in a program's aircraft design. They are labeled consecutively from loop 0 to loop 3. In loop 0, the Loads department helps the Stress department sizing the aircraft. At the same time, the Dynamics department does not have a prototype aircraft yet in order to test the effect of vibrations; hence, it does not have a loop 0. Usually the Dynamics department has 6 loops within a program depending on the aircraft.

It was initially suggested that an aeroelastic model should be provided solely by the Dynamics Department for the departments in Core Engineering where the use of an aeroelastic model is imperative. In order to create a methodology that assesses potential benefits and risks between the Loads and Dynamics departments, a project "Improvements in the Aeroelasticity Process in Core Engineering at Bombardier Aerospace" involving McGill University and Bombardier Aerospace was performed between May 2011 and June 2012. This project was based on a representative program at Bombardier Aerospace.

Similarly, Loads and Dynamics departments receive several other inputs from upstream departments, and the two departments use similar methods to process the input data in some cases. The two departments investigated the processes and discussed whether one department could do the work for both, and thereby, saving some effort and resources.

1.1.2 Process Improvement

Since it becomes more challenging to achieve satisfactory quality within scheduled due dates and planned budgets for Core Engineering with an increase in product complexity, this project is also intended to improve the design processes in order to shorten span time and reduce duplicated effort in the Loads and Dynamics departments. The Loads design processes are critical and deadlines for the Loads department are usually not postponed even when there is any delay in the inputs. As a result, the Loads Department is usually under time pressure to perform its activities and this puts the quality of its work at risk. Data of inferior quality can cause unexpected design iterations which can further delay project completion and entail additional cost. Therefore, effective measures should be taken to improve any situation that would lead to additional design iterations.

1.1.3 Objectives

Aiming at cycle time and cost reduction, 3 specific objectives are proposed in this thesis:

1. To find potential improvements in the Loads Department such that its span time can be reduced;
2. To seek sharing opportunities between the Dynamics and Loads Departments in order to reduce duplicated effort;
3. To find mechanisms to improve data quality so unplanned iterations can be reduced.

The metrics used in this thesis to measure NPD performances are:

(1) Span time. Span time is the time duration from the start of a design loop to its time of completion on the calendar, is used to indicate the time length of a loop. Its unit is unit(s)[1].

(2) Effort. Effort is the total required hours or days to complete a design loop, is used to imply the total cost. Its unit is person-unit(s).

For example, there are two engineers: A and B. The timelines for their tasks are shown in figure 1-1.

[1] Out of confidentiality purposes, all the units have been removed, and the use of the word “unit(s)” have been implemented.

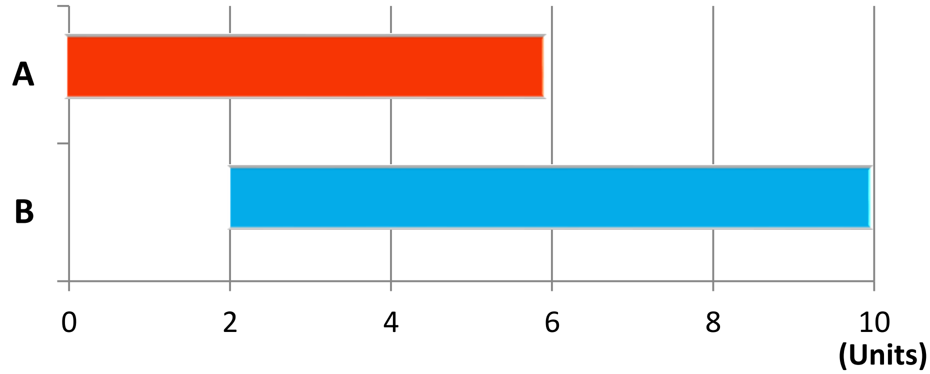

Figure 1-1. Example: Timelines for engineers A and B

In figure 1-1, span time is the time length on the calendar, which is 10 units; the effort is 6+8=14 person-units.

In order to achieve the objectives, it is necessary to understand and analyze the design processes, look for opportunities of potential improvement, and conduct simulations to study the impact of possible changes. The previous project established the process maps for the Loads and Dynamics Departments through an activity-based approach where processes were first decomposed into a series of individual tasks. Then, pieces of information that were exchanged between pairs of tasks were mapped to simulate information flows among the tasks. In this thesis, interviews were arranged with Loads and Dynamics engineers to gather related information, update the process maps, and discuss potential improvements to the design processes.

After process maps were updated, critical paths were analyzed and duplicated effort was found. Approaches to shorten the critical path, reduce effort, and improve quality were simulated using the Cambridge Advanced Modeller (CAM). Finally, simulation results were validated through discussion with engineers.

1.2 Thesis Outline

This thesis comprises 6 chapters. Chapter 2 introduces several principal definitions and reviews the relevant literature on NPD, process simulation, Cambridge Advanced Modeller (CAM), Monte-Carlo simulation, Gantt chart, Critical Path Method, Design Structure Matrix (DSM), Applied Signposting Model (ASM), and quality. Chapter 3 describes the methods to gather data and to update and verify the process maps using CAM. Chapter 4 is a detailed description of the simulation methods, simulation scenarios, simulation results, and validation of the results. Chapter 5 is a brief discussion about the data quality of design processes at Bombardier Aerospace. Chapter 6 concludes this thesis, reviews the accomplishments of the objectives and the benefits for Bombardier Aerospace, and provides guidance for future research.

Chapter 2 Literature Review

This chapter first introduces several principal definitions that are used in this thesis. Then, it reviews the relevant literature in the fields of New Product Development (NPD), process simulation, Cambridge Advanced Modeller (CAM), Monte-Carlo simulation, Gantt chart, Critical Path Method, Design Structure Matrix (DSM), Applied Signposting Model (ASM), and quality.

2.1 Principal Definitions Used in this Thesis

In order to simulate the product development processes, there are several basic definitions that need to be elaborated first.

1. Process (or Design Process). A process is an organized group of related activities that are done together to create a result of value (Hammer 2001).
2. Activity (or Task). An activity is a unit of work defined by its attributes such as name, type, inputs, outputs, resources used, and duration (Browning, Fricke et al. 2006).
3. Input. An input is a deliverable from a supplier task (or an upstream task) used by a consumer task (Browning, Fricke et al. 2006).

4. Output. An output is a deliverable resulting from task work, and provides value to a consumer task (or a downstream task) (Browning, Fricke et al. 2006).
5. Deliverable (or Outcome). A deliverable is either an input or an output to a task (Browning, Fricke et al. 2006). A task can generate several deliverables, and a deliverable can also be used by multiple succeeding tasks.
6. Resource (or Human Resource). A resource refers to a person who executes a task (Browning, Fricke et al. 2006).
7. Simulation Model (or Model, Process Model, Process Map). A model is an abstract representation of reality that is built, verified, analyzed, and manipulated to increase understanding of that reality (Browning, Fricke et al. 2006).
8. Random Experiment. An experiment that can be repeated under the same conditions and whose outcome cannot be predicted with certainty is called a random experiment (Lefebvre 2006).
9. Probability Distribution. Probability Distribution assigns a probability to the outcome of a random experiment (Hayter 1996, Everitt 2006).

2.2 New Product Development

As the market competition in the aircraft manufacturing field becomes increasingly more fierce, the process of NPD becomes the focal point of industrial competition and has had much more attention due to its long design iterations and significant adjustment cost (Clark, Chew et al. 1987, Clark and Fujimoto 1991). NPD is a complex process of conceptualization, design, production, and product sales (Mital, Desai et al. 2008). In order to improve its NPD pace, Bombardier Aerospace has paid more attention to its processes. In order to measure NPD performance, span time and effort are used as two metrics in this thesis. Their values should be calculated based on a simulation model that is able to reflect the actual situation.

2.3 Process Simulation and Cambridge Advanced Modeller

A simulation model indicates time delays due to waiting resources and identifies bottleneck activities. Thus, it helps companies manage their concurrent projects in an environment where human and technical resources are shared (Adler, Mandelbaum et al. 1995). Process simulation is a method that allows the placement of all of the design processes and their interaction relationships into a model. It enables computer-based model building and presentation; it also supports project planning, process tailoring, staffing, budgeting, and scheduling (Browning, Fricke et al. 2006). Process simulation has proven to be a very useful analytical tool to improve NPD in many industries such as construction (Baldwin, Austin et al. 1999), chemical manufacturing (Adler, Mandelbaum et al. 1995), and automobile manufacturing (Krishnan, Eppinger et al. 1997).

A variety of software is available and able to perform process simulations and conduct experiments. In this thesis, the Cambridge Advanced Modeller (CAM) is chosen for the following reasons:

(1) CAM simulation logic is specifically tailored to simulate product development processes, which makes it easier to set up, configure and modify.
(2) CAM also has tailored analyzing and reporting functionalities, such as creating Gantt charts based on simulations.

Formerly known as P3 Signposting, the Cambridge Advanced Modeller (CAM) was developed by the Engineering Design Centre (EDC) at Cambridge University. CAM provides an Applied Signposting Model (ASM), Dependency Structure Matrix (DSM), and force-directed-layout views for constructing and visualizing models of complex systems (Wynn, Nair et al. 2009, Wynn, Wyatt et al. 2010). DSM and ASM are the two most frequently used views in CAM.

A Dependency Structure Matrix (DSM) is a structured network of activities with substantial and cyclical dependencies (Browning, Fricke et al. 2006). DSM is used to analyze relationships among activities involved in a design process. It can represent relationships among interdependent tasks in a simple and elegant manner (Yassine and Braha 2003). On the other hand, an Applied Signposting Model (ASM) is developed to simulate iterative design processes. It is based on a simple graphical notation reminiscent of a flowchart, designed to be easily read for large models and by unfamiliar users (Wynn, Nair et al.). Both ASM and DSM are able to represent the relationship between input variables and outcomes. Compared with DSM, ASM is not perfect for heavily interconnected processes in the matter of readability. However, for the not-too-heavily-interdependent design processes in the Loads and Dynamics departments at Bombardier Aerospace, ASM is a better choice due to its simple graphical representation which makes it more visually oriented and easier to comprehend complex processes, even for unfamiliar users (Wynn, Nair et al.).

In order to establish an ASM, it is necessary to gather related information for tasks, resources, and variables. This project has updated and verified the data in the ASM built during the previous project. Data gathering was essentially acquired through interviews with engineers. After an ASM was built, Monte-Carlo simulation was conducted.

2.4 Monte-Carlo Simulation

Monte-Carlo simulation, also known as the Monte-Carlo method, is an algorithm that relies on repeated random sampling to obtain numerical results. Typically, simulations are run many times in order to obtain the distribution of an unknown probabilistic entity (Hammersley and C. 1964, Anderson 1986, Eckhardt 1987). The objective of the Monte-Carlo simulation is to discover the distribution of certain variables when the method is applied to a model with inherent randomness (Gentle 2003).

For Monte Carlo simulations, the following procedures are used. Models are first simulated repeatedly. The execution of each model is performed with initial conditions and task durations. The analysis is terminated after a user-defined number of simulations (Scavia, Powers et al. 1981). Then, the average span time and effort are calculated from all of the Monte-Carlo simulations.

Each Monte-Carlo simulation is a random experiment. Therefore, the outcome of Monte-Carlo simulation is not deterministic (Guo, Doub et al. 2010). It gives a duration histogram with the X-axis as process duration and the Y-axis as normalized frequency (%). The histogram is comprised of a number of bins, each of which contains several cases. The simulation result of each case is exported as a Gantt chart; thus, 100 simulation runs create 100 unique Gantt charts (Wynn, Nair et al.).

2.5 Gantt Chart

The Gantt chart is a classical project management representation method for a process model. It contains activity attributes, including name, duration, start and finish time, resources used, precedence relationships (dependencies), etc. (Gantt 1919, Browning 2009, Browning 2010). It is a useful tool for project planning and for monitoring the progress of a project (Barone and Franco 2012). The purpose and use of the Gantt chart range from status reporting, to costing, to tracking project labor hours, to presenting project progress, and to determining whether or not the project is on schedule. The Gantt chart allows the project manager, the project team, and all of the interested parties to visualize the project and its progress in calendar or timeline terms (McGhee and McAliney 2007). In this thesis, Gantt charts are utilized to observe the total span time of the project and the interdependent relationships among tasks. They are also used to calculate the total effort and to identify critical paths and critical tasks.

After a series of Gantt charts are obtained, several project management methods could be applied. Project management is the application of knowledge, skills, tools, and techniques to project activities to meet the project requirements (Project Management 2008). Overlapping and critical path methods are two very important tools to manage a project (Levitt, Thomsen et al. 1999, Austin, Newton et al. 2002, Yassine 2007).

Overlapping is an important technique in concurrent engineering approach and is commonly utilized to improve NPD processes. However, due to the complexity of the design processes within the Loads and Dynamics departments at Bombardier Aerospace, it is almost impossible for people who lack process analysis expertise to identify such overlapping opportunities. Nevertheless, overlapping does not necessarily lead to less effort and shorter span time unless a careful inspection of the relationship between tasks is conducted. For example, in a study of 29 automobile companies located in US, Japan, and Europe, Clark, Chew et al. (1987) showed that the effect of overlapping on lead time and cost depends on communication and information transfer among NPD activities. Therefore, the study of overlapping has to be conducted with careful inspection and with analysis of effective functional interaction. On the other hand, the critical path method is quite practicable.

2.6 Critical Path Method

The critical path is the longest path in a project comprising a series of interdependent activities that together determine the duration of the project. For the activities on the critical path, there is no time between the completion of one activity and the start of the next one. Identifying the critical path determines the length of the project (Hill and Solt 2010). Therefore, any delay of a task on the critical path would delay the completion of the whole project. Conversely, any time saved on critical tasks would shorten the whole project. As a result, it is important to seek opportunities in locating such tasks and to take measures to shorten their durations.

The Critical Path Method is a widely used management tool that helps project managers recognize where in the project schedule their management effort should be applied. It identifies critical tasks as the ones that cannot be delayed without delaying the completion of the project (Newell and Grashina 2004). It assumes that the lead time for a project can be shortened by applying additional resources — labor, equipment, and capital — to certain key activities. It is capable of resource reallocation from one task to another in order to achieve the greatest reduction in project duration for the least cost (Nicholas 2004). The critical path method also has its limitation since only one value is picked randomly from a time duration that follows a triangular probability distribution for each task (This will be explained in more detail in chapter 3.), such that there is no statistical treatment of uncertainty (Nicholas 2004). However, this limitation can be reduced in CAM, where a large number of iterations can be run and an average calculated so that the estimated total span time is not affected on account of the random selection of task durations.

In this thesis, first of all, certain critical tasks were located by inspecting the Gantt charts of the simulation results. Secondly, several scenarios with additional resources added to the most critical tasks were identified with engineers in the Loads and Dynamics departments. Lastly, simulation experiments were conducted according to the estimations for task durations they provided.

2.7 Quality

The International Standards Organization (ISO) defines quality as “the totality of features and characteristics of a product or service that bear on its ability to satisfy stated or implied needs” (ISO Standard 9000). It is conventionally believed that quality in NPD can be improved only at the expense of longer cycle times and greater development effort (Harter, Krishnan et al. 2000). However, if a company adopted a strategy emphasizing upstream improvement and problem prevention, then improving quality could actually reduce the life-cycle cost, because there would be less rework, less recall, less firefighting, and therefore, less product development cost (Yang and El-Haik 2009).

According to the engineers in the Loads department, additional iterations occurred as a result of unexpected updates of the input data provided by other departments. As well, Loads by updating its deliverables can cause additional iterations in a downstream department that receives data from it. Therefore, it is necessary to take effective measures to control both the quality of the input data that the Loads department receives from other departments and the quality of the deliverables that the Loads department provides to the downstream departments in order to reduce unnecessary, additional design iterations.

2.8 Summary

Bombardier Aerospace has put more effort in its NPD processes in an attempt to enhance its competitiveness. One of its intentions was to share an aeroelastic model between the Loads and Dynamics departments. In order to accomplish this objective, the Cambridge Advanced Modeller was chosen in this project to perform process simulations. First of all, process models were updated for both departments. Secondly, Monte-Carlo simulations were run on the process models, and the simulation results generated Gantt charts. Thirdly, critical tasks were identified using the Gantt charts. Furthermore, scenarios with additional resources and sharing of design processes were simulated and compared. Finally, conclusions were made, and optimal solutions were suggested to Bombardier Aerospace. In the following chapters, details of building process models are described in chapter 3; chapter 4 describes the simulation methods and results; the quality of the product development process is discussed in chapter 5; and chapter 6 concludes the thesis.

Chapter 3 Model Building

3.1 Model Building

3.1.1 Process Maps

In order to allow the Loads and Dynamics departments to be fully aware of each other's design processes, it is necessary to have process maps that include all of the project's design processes for the two departments as well as all task durations, information relationships among the tasks, deliverables, and all of the resources needed to carry out the tasks.

As long as the process maps have adequate detail, engineers can have not only a deeper understanding of the design processes and the information flow within their own department, but also a general idea of what design analyses are being done in the other departments. This way, critical tasks can be found so that extra resources, if appropriate, can be allocated to them. Moreover, there may be more potential opportunities for information sharing or for cooperation on certain processes.

3.1.2 Cambridge Advanced Modeller (CAM)

Figure 3-1 is an example of the diagram view of an Applied Signposting Model (ASM) in Cambridge Advanced Modeller (CAM). Available types of views in CAM are diagram view, Design Structural Matrix (DSM) view, and network view, among which, a diagram view allows models to be drawn using a simple interface (Wynn, Nair et al.), and the dependency relationships are more visualized due to the use of wire connections. Only diagram views are used in this thesis. An ASM is also called a process model or a process map.

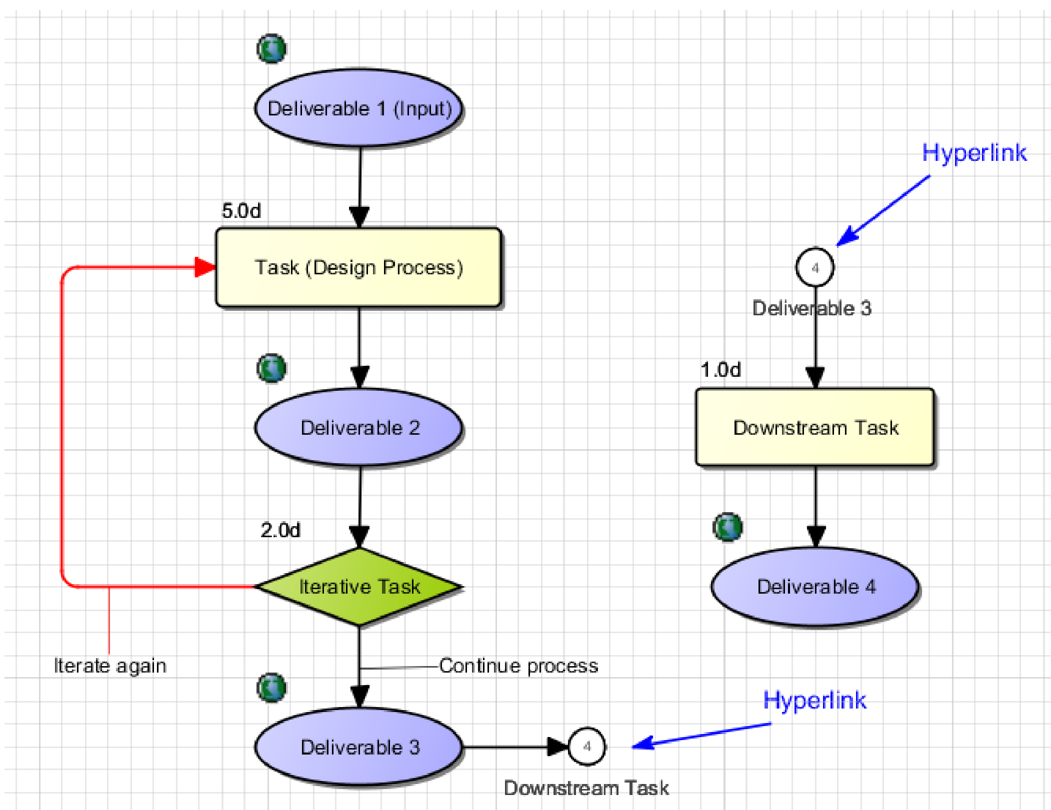

Figure 3-1. A simple example of an Applied Signposting Model in CAM

In figure 3-1, a square denotes a task that receives inputs and creates outputs; an ellipse denotes a deliverable; a diamond denotes an iterative task, which is usually a checking procedure related to quality control; a small white circle denotes a hyperlink, which is used to simplify the process map by breaking an arrow line into two segments, where a hyperlink is used when a connection goes across a long distance or multiple worksheets (Wynn, Nair et al. , Wynn, Eckert et al. 2006, Wynn 2007).

Tasks in a process map have attributes such as name, type, inputs and outputs, resources, duration, pre-conditions, pre-processes, variables, and outcome probabilities (for an iteration task). Some attributes are interpreted as follows:

(1) Resource. Performing a task requires at least one unit of resource (one person). When there are two tasks requiring the same resource, the one that starts first seizes the resource; if they start at the same time, the one that has higher priority (defined by user) seizes the resource while the other one waits. The amount of

available resource corresponds to the number of available engineers in real life. Also, the tasks executed by the same resource are marked in the same color; so, it can be easily recognized in the process maps and the Gantt charts.

(2) Duration. Task durations can be assigned with a point, uniform or triangular probability distribution, or variable functions in CAM. The duration of a task varies with different programs, people, progress of the project, etc. Therefore, triangular distributions are used in this thesis to address duration uncertainties. A triangular distribution is defined using 3 parameters (Nicholas 2004, Sleeper 2007) as shown in figure 3-2: (a) minimum value, the lower bound of the distribution, is the optimistic estimation of the situation where everything goes well; (b) expected value, or the most likely value, can be any value between the minimum value and the maximum value; and (c) maximum value, the upper bound of the distribution, is the pessimistic estimation of the situation where everything goes wrong.

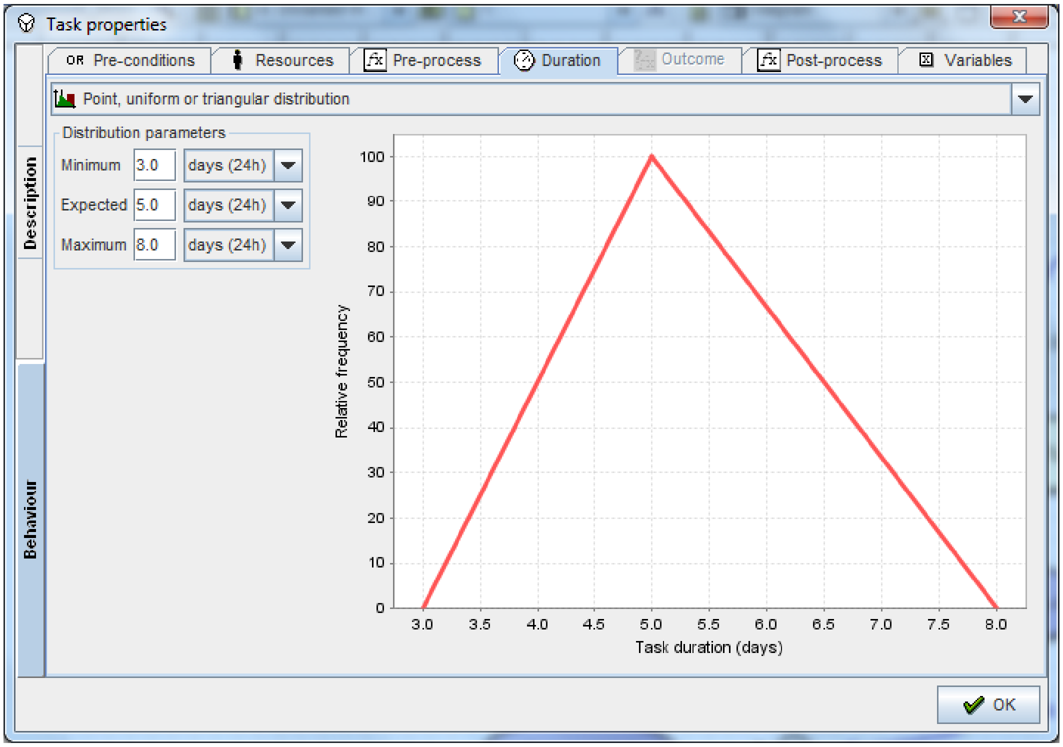

Figure 3-2. A triangular probability distribution

In addition, several pseudo-tasks were created in the process model in order to simulate the situation where the inputs arrive late at a department. Each pseudo-task represents an input. These pseudo-tasks are not real tasks; thus, they are not performed by resources, but are assigned with time durations. The durations are uniformly distributed, ranging from 1 unit to 15 units, as shown in figure 3-3. The reason for setting the minimum time to 1 unit instead of zero is that CAM does not allow task durations to be set to zero. Therefore, for example, if a pseudo-task has the duration of

10 units in a random experiment, it simulates the situation where the corresponding input arrives late by 10 units.

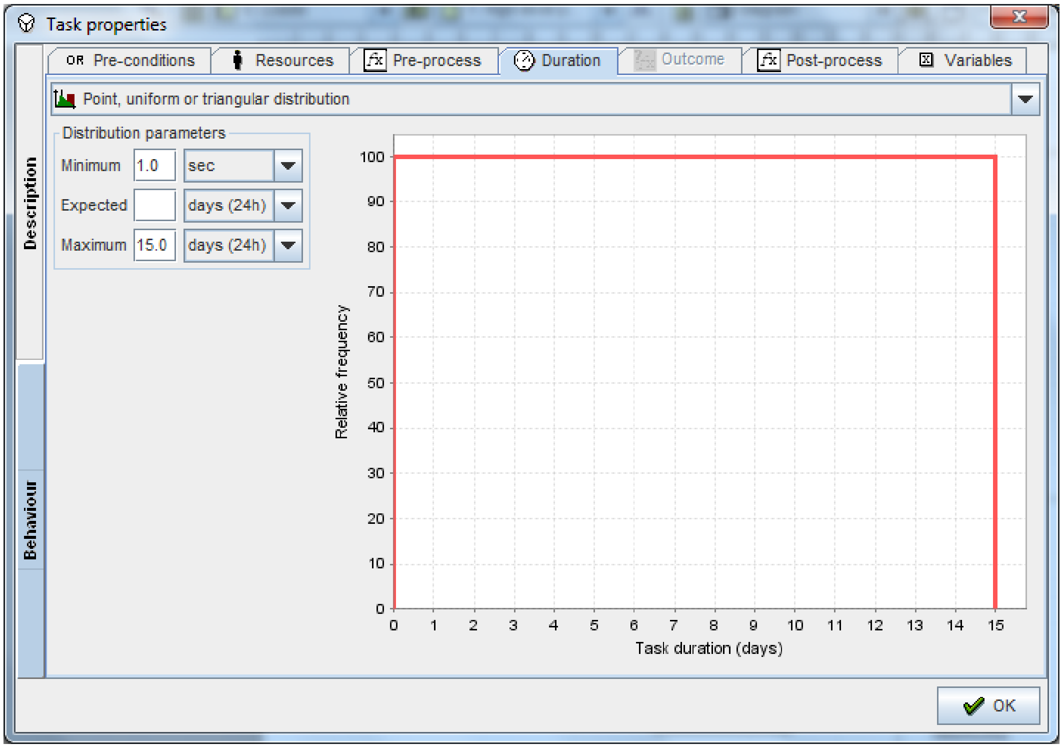

Figure 3-3. A uniform probability distribution for pseudo-tasks

(3) Variables. Variables are used in two situations in this thesis: (a) as task durations in order to determine what tasks to execute and how much time is needed in different scenarios; (b) in simulation experiments in order to simulate different scenarios in one process model. Simulation experiments with the use of variables are discussed in detail in chapter 4.

3.1.3 Data Gathering and Model Updating

The preceding project established process maps for the Loads and Dynamics departments. Since then, some of the design processes in the Loads and Dynamics departments have been improved. In addition, actual situations and the feasibilities of the simulation scenarios were not fully considered in the previous project. Thus, the process map needed to be updated.

In this project, in order to update a process map, interviews were arranged to collect data. The process map created in the previous project was shown to professional engineers, senior engineers and project managers, and all tasks in the map were verified. Any task that was not in accordance with the actual situation was further clarified with the engineers who were involved in or were in charge of the corresponding task. The validated process maps for Loads and Dynamics departments are displayed in figures 3-4 and 3-5[2].

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[2] Process figures are shown to indicate the magnitude of the process and the number of steps involved, not process detail.

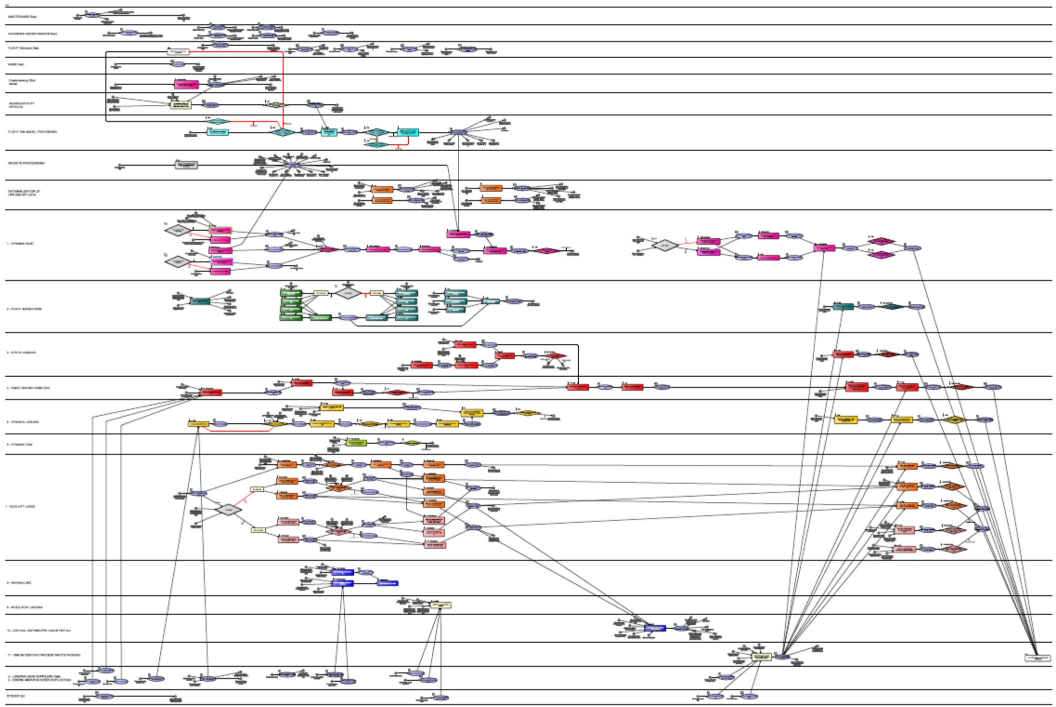

Figure 3-4. Process map for the Loads department

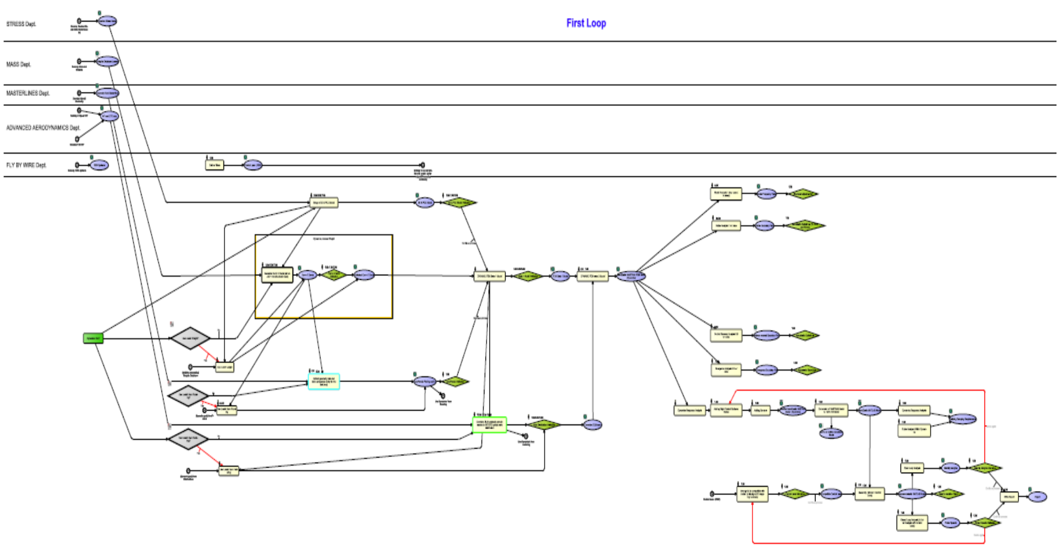

Figure 3-5. Process map for the Dynamics department

Updated process maps for both departments have been inspected by several engineers in Core Engineering, and it was agreed that the process maps were appropriate to simulate the actual situations in the Loads and Dynamics departments. Therefore, the process maps were ready for further simulations of different scenarios (model sharing, overlapping, and resource allocation) in CAM.

3.2 Summary

The Loads and Dynamics departments both have the need to reduce project lead time and effort. In order to achieve these objectives, two approaches were explored:

(1) More resources could be added to the critical tasks;

(2) Similar design processes could be shared between the two departments.

Accordingly, process maps for the Loads and Dynamics departments were updated in preparation for analysis of the above two approaches. Detailed simulation methods and results are discussed in Chapter 4. In the end, several suggestions were made to improve design processes according to their structural analysis and critical path analysis.

Chapter 4 Simulation

4.1 Monte-Carlo Simulation and the "As-is" Scenario

In the Cambridge Advanced Modeller (CAM), the Monte-Carlo simulation runs many times, and generates a duration histogram in the end. Since the time duration for all of the tasks in the process maps are picked randomly from their own probability distributions, the total span time varies from scenario to scenario. Hence, an average span time needs to be calculated out of a large number of simulations.

To find out how many simulations are adequate enough to generate an unbiased average value with a small deviation, a parametric experiment was conducted where 50, 100, 200, 500, and 1,000 simulations were run separately, and their corresponding average and standard deviations were calculated and are shown in figure 4-1.

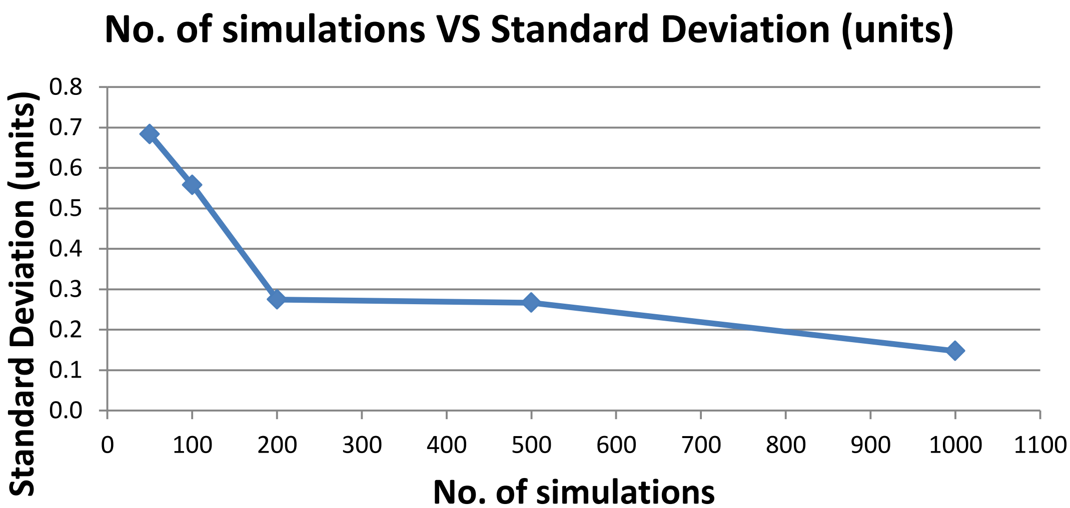

Figure 4-1. Scatter chart: Standard Deviation (units) VS No. of simulations

From figure 4-1, it can be seen that as the number of simulations increases, the standard deviation decreases. The standard deviation for 1,000 simulations is 0.15 units, which is 0.12% of the average value. Therefore, it is sufficiently accurate to run the simulation 1,000 times.

There are many scenarios discussed in this thesis. The simulation of the process model without additional resources or shared design processes is called the “as-is” scenario. The “as-is” scenario acts as a baseline to compare information flow, critical paths, span time, and effort with other scenarios (Hisarciklilar, Sheikh et al. 2012). The simulation of the process model with any variable changes is called a “to-be” scenario. Figure 4-2 is the duration histogram for 1,000 runs of the Monte-Carlo simulation for the "as-is" scenario in the Loads department. In the histogram, the X-axis represents the total span time, and the Y-axis indicates the nominalized frequency (%). There are several bins in the histogram, and the frequency of the tallest bin is 100%. The height of a bin indicates the frequency density of its interval, and the intervals are evenly distributed. Each bin contains multiple cases, and each case generates a unique Gantt chart for each simulation run. Therefore, the cases in the tallest bin(s) represent the most-likely-to-happen situations.

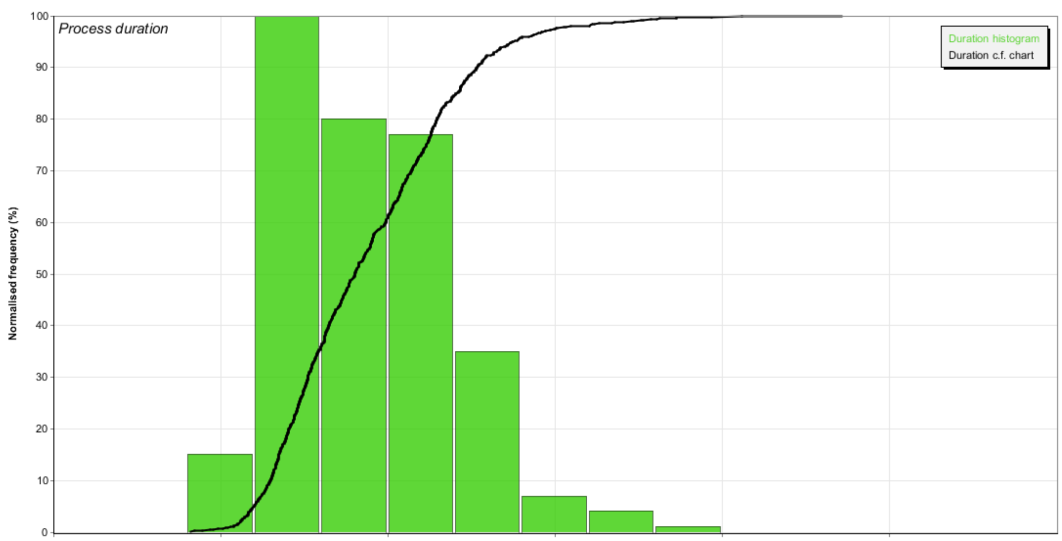

Figure 4-2. Histogram of the Monte-Carlo simulation for the "as-is" scenario in the Loads department

The average span time of one loop for the “as-is” scenario in the Loads department calculated using 1,000 runs is 120.9 units. The average total effort spent in one loop is 566 person-units.

Figure 4-3 is the duration histogram for 1,000 runs of the Monte-Carlo simulation for the “as-is” scenario in the Dynamics department. The average span time of one loop for the “as-is” scenario in the Dynamics department calculated using 1,000 runs is 88.3 units. The average total effort spent in one loop is 160 person-units. After consultation with several engineers in the two departments, it was agreed that the average span time in the “as-is” scenario for both departments was a proper estimation of the actual situation.

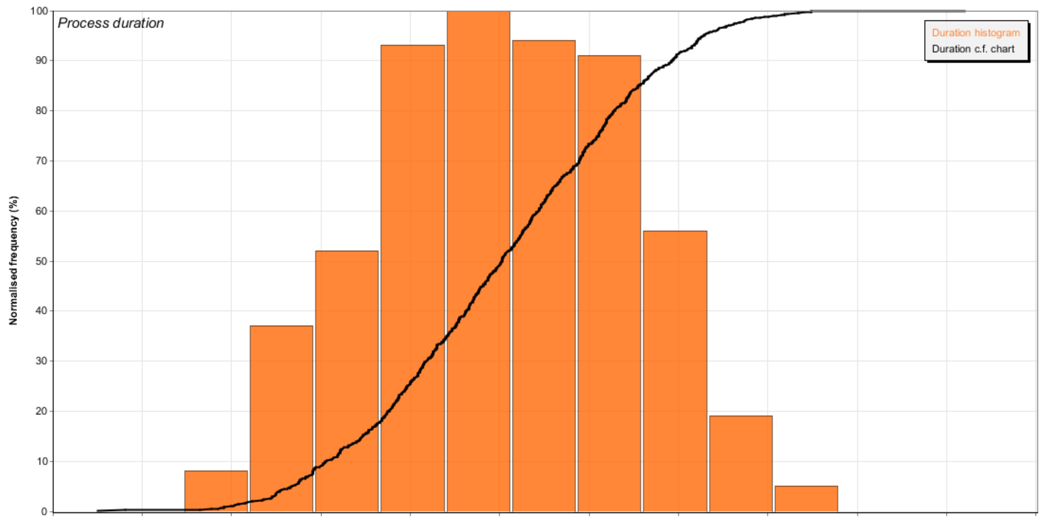

Figure 4-3. Histogram of the Monte-Carlo simulation for the “as-is” scenario in the Loads department

Furthermore, the robustness of the process model and data was tested. Due to the fact that task duration estimates were provided by engineers through interviews, and people naturally tend to underestimate or overestimate their workloads, errors could arise in estimates of time duration for each task, which could lead to an inaccurate amount for the total span time, which, as a result, could deviate from the actual span time (In general, people tend to be optimistic.). Therefore, an experiment was conducted to observe the sensitivity of the process model to a certain amount of variation in the data. 10% was added to the most likely value of a triangular probability distribution for all tasks. This simulated the situation where all of the estimations of task durations were 10% greater than the actual situation (very unlikely to occur). As a consequence, the total span time increased by 6%. This signifies that any estimation error is relatively small; the outcome is not very sensitive to the values of the input data; and the process model and data are robust.

4.2 Gantt Chart Analysis

To study the interaction among tasks for further improvements, the bin with the largest frequency density in the histogram is chosen in the “as-is” scenario to view the simulation results in the Gantt chart. As shown in figure 4-2, 1,000 simulation runs correspond to 1,000 different Gantt charts. Figure 4-4 shows the Gantt chart of a case chosen from the tallest bin in the histogram generated from the “as-is” scenario.

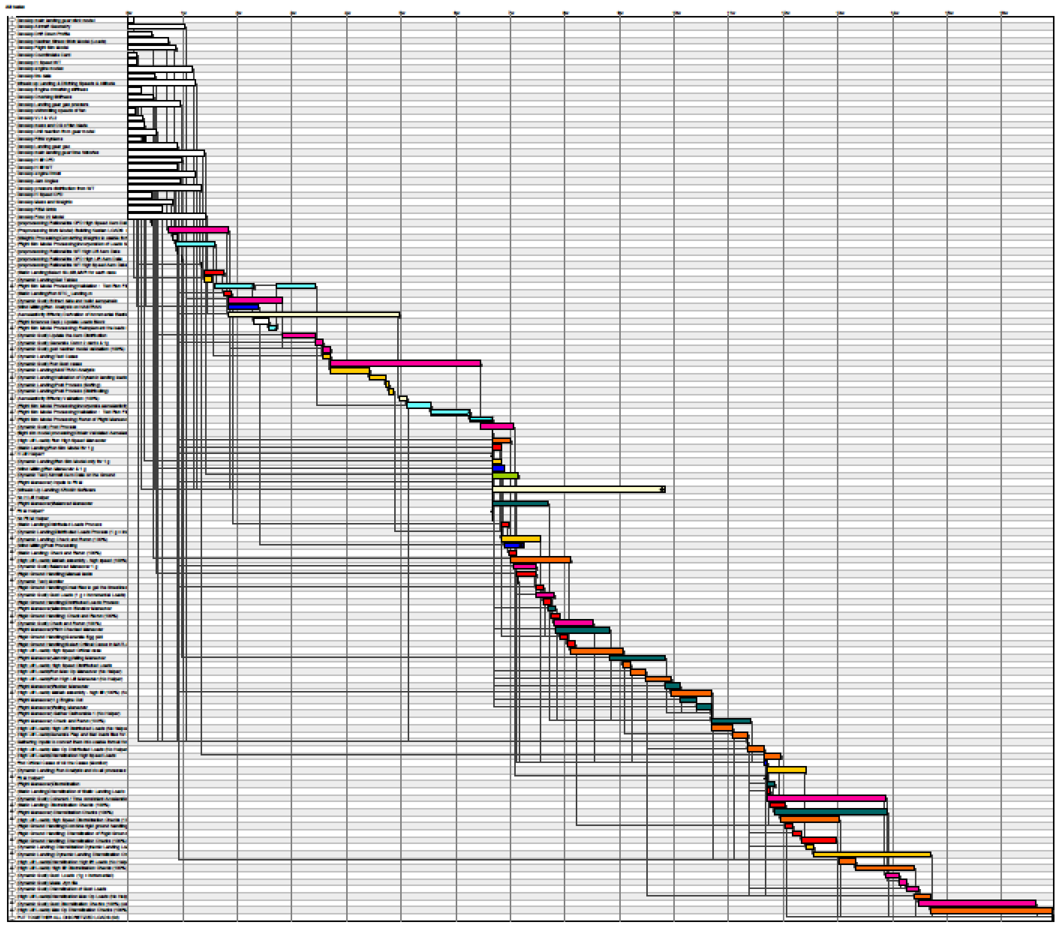

Figure 4-4. The Gantt chart for a case generated from the “as-is” scenario

It can be observed from the Gantt chart in figure 4-4 that:

(1) Some task durations are very long;

(2) Some tasks are critical because multiple downstream tasks cannot start without the deliverables from these tasks.

To find out which were the critical tasks and to be able to easily shorten the design processes for the Loads and Dynamics departments, the Critical Path Method was applied.

4.3 Critical Path and Critical Tasks

By observing the Gantt chart in figure 4-4, it is obvious that some tasks in either one or two groups cause the long waiting time by their downstream tasks. These are usually the critical tasks. The durations of these tasks directly affects the total span time.

Critical tasks were located and discussed with engineers to look for any opportunity that could possibly shorten their execution time, thereby reducing the total span time. However, additional effort would be needed in order to shorten span time. Thus, it would be necessary to balance the benefits and costs for maximum profit.

Figures 4-5 and 4-6 show the main critical tasks for a loop in the Loads department. In figure 4-5, the time when several tasks commence simultaneously is a “dividing point”, separating the distributed Loads analyses and discretized Loads analyses, as illustrated by the blue circle. Prior to the dividing point, there are a series of tasks belonging to the High Lift Loads and the Flight Maneuvers groups, as illustrated by the red circle. It is observed that:

(1) There are no tasks being carried out in other departments while the tasks in the red circle are in progress;

(2) Downstream tasks cannot start until all the tasks in the red circle are finished.

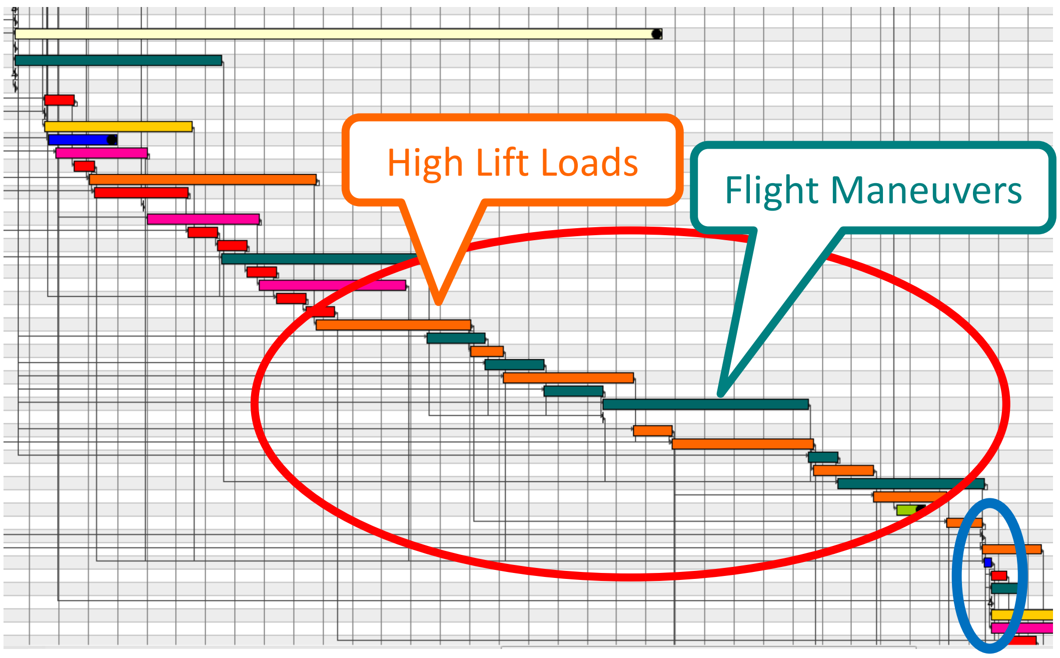

Figure 4-5. Tasks in the High Lift Loads and the Flight Maneuvers groups

In figure 4-6, there are a series of tasks belonging to the High Lift Loads group and the Dynamic Gust group, as shown in the red circles. The time span between any two adjacent vertical lines is one unit. It can be seen from the figure that there are no tasks taking place in other departments while the tasks in the circles are in progress until the end of the loop. The waiting time for other groups is about 3-4 weeks.

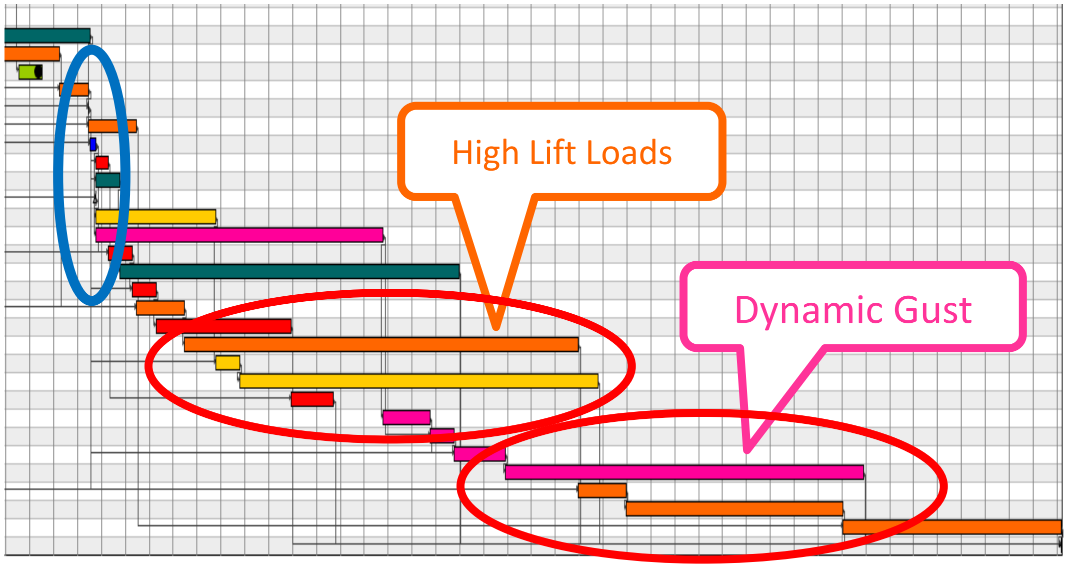

Figure 4-6. Tasks in the High Lift Loads and the Dynamic Gust groups

In a word, the tasks located on the critical path mostly belong to the High Lift Loads, Flight Maneuvers, and/or Dynamic Gust groups. Typical characteristics of these tasks are:

(1) Their deliverables are critical to downstream tasks;

(2) They are the only tasks in progress while other groups standby.

Accordingly, it is necessary to appoint more resources to help with these tasks in order to execute several tasks in parallel, or several engineers can work on one task simultaneously, and thus, possibly reduce span time. The simulation of these scenarios is discussed in the next section.

4.4 Simulation of Adding Resources

The main purpose of adding resources is to shorten span time. Additional resources need to be added to critical tasks, according to the discussion in section 4.1, in the High Lift Loads, Flight Maneuvers, and/or Dynamic Gust groups. There are mainly two ways to add resources. The first way is to hire a new employee. However, a long and expensive procedure for hiring and training of a new employee is required, and the relevant cost should be considered. The second and less expensive way is to reallocate existing resources from other groups in the Loads department to the targeted groups.

Regardless of the way of acquiring new resources, a training period is always necessary and important; plus, a familiarization period is unavoidable. Accordingly, all of the estimations of the task durations in the “to-be” scenarios assume that:

(1) Engineers are trained for using the new design processes;

(2) Execution of the new processes is stable.

Nevertheless, adding resources to the design processes causes another problem: additional coordination and interaction time is needed among the personnel working on interdependent tasks. This phenomenon is known as “design churn”, which is a fundamental property in the product development processes. It results in information delays among development teams (Yassine, Joglekar et al. 2003). The more interaction there is for information sharing, the more design churn occurs. (Bhuiyan, Gerwin et al. 2004). Although design churn has its disadvantages, they normally do not outweigh the advantages produced by adding more resources. In order to take into consideration the effect of design churn in the process model, additional time caused by design churn was added to the durations of some tasks. Alternatively, pseudo-tasks were added into the process model, and their durations represented the design churn.

Through discussions with engineers, extra resources were added to the tasks in the High Lift Loads, Flight Maneuvers, and Dynamic Gust groups. According to the characteristics of the tasks, extra resources were distributed in the following way:

(1) Tasks in the High Lift Loads group were viewed as a whole, where extra resources could be added. This is referred to as position A;

(2) Tasks in the Flight Maneuvers and Dynamic Gust groups were viewed as a whole. No matter how many extra resources were

added here, each resource did the work in both groups. This is referred to as position B.

According to the estimations given by the engineers, the number of extra resources added to each position could be either 1 or 2. Hence, including the “as-is” scenario (No extra resources were added to the position.), the number of extra resources in each position have the values 0, 1, or 2.

In order to simulate different numbers of extra resources added in different positions and to simulate the combinations of the scenarios, variables are used, so that all the scenarios could be simulated with one process model. As well, different combinations of variable values correspond to different scenarios. This section utilizes two variables: resource_position A and resource_position B. Their functions, values, and corresponding scenarios are listed in Table 4-1:

Table 4-1. Variable names, functions, values, and their corresponding scenarios

Variable Name	Function	Value	Scenarios
resource _position A	How many extra resources added to position A	0	No extra resource
		1	1 extra resource
		2	2 extra resources
resource _position B	How many extra resources added to position B	0	No extra resource
		1	1 extra resource
		2	2 extra resources

In total, there are 9 different combinations (3 X 3) of the two variables, which give us 9 different scenarios. Simulation results for all of the 9 scenarios are given in section 4.5. Among these, 3 scenarios are discussed in detail:

1. One extra resource is added to position A, while no resource is added to position B;
2. One extra resource is added to position B, while no resource is added to position A;
3. One extra resource is added to position A, and one extra resource is added to position B.

4.4.1 One extra resource in position A

Figure 4-7 illustrates the timeline difference before and after one resource is added in position A. Tasks 1 and 2 are two typical tasks in the High Lift group. They are carried out in sequence, not because there is any dependency between them, but due to the limit of the number of the resources performing them. Therefore, when an extra resource is added in this position, the two people (the original engineer in position A plus the extra resource) perform the two tasks in parallel and a certain amount of span time is reduced as shown in figure 4-7.

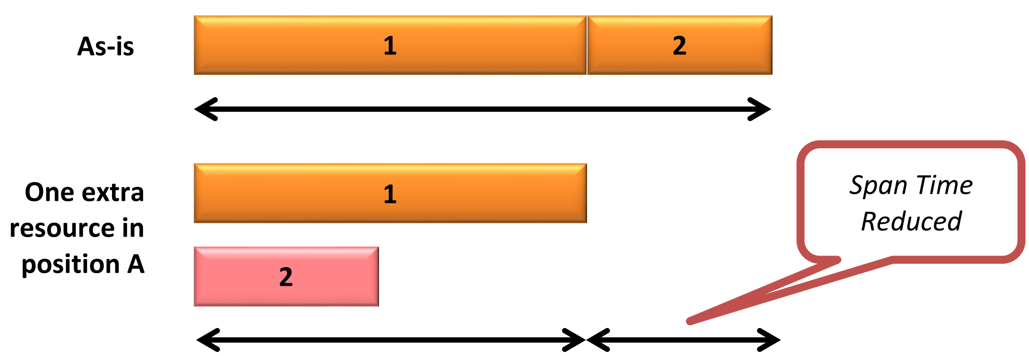

Figure 4-7. Timeline difference before and after one extra resource is added in position A

However, the effort in this scenario does not change compared to the "as-is" scenario, since the actual hours or days spent on the two tasks remain the same. In the “to-be” scenario, the span time in the Loads department is 117.5 units, which is 3.4 units per loop less than the “as-is” scenario.

4.4.2 One extra resource in position B

Figure 4-8 illustrates the timeline difference before and after one resource is added in position B. Position B involves two groups: Flight Maneuvers and Dynamic Gust. In the Flight Maneuvers group, the situation is similar to position A: the two people perform the tasks in parallel when an extra resource is added. However, the tasks in the Dynamic Gust group cannot be performed in parallel; therefore, the two people work together on the same task simultaneously. The design churn is the reason why the span time is not cut into half.

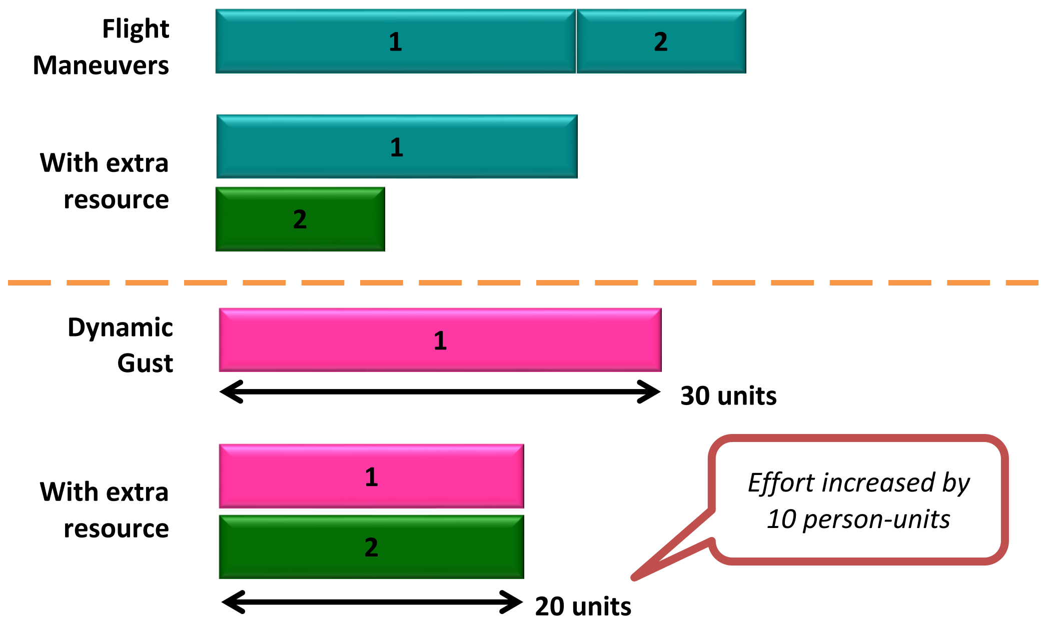

Figure 4-8. Timeline difference before and after one extra resource is added in position B

In the "to-be" scenario, each person spends 20 units on the task; so, the total effort becomes 20+20 = 40 person-units, which is 10 person-units per loop more than the "as-is" scenario. The span time in the Loads department becomes 120.5 units, which is 0.4 units per loop less than the "as-is" scenario.

4.4.3 One extra resource in position A, and one extra resource in position B

With one extra resource in position A and one extra resource in position B, the total effort is increased by 10 person-units compared with the "as-is" scenario. The span time becomes 95.1 units, which is 25.8 units or 21%

per loop less than the “as-is” scenario. The reason for the significant decrease of the span time is illustrated in figure 4-9.

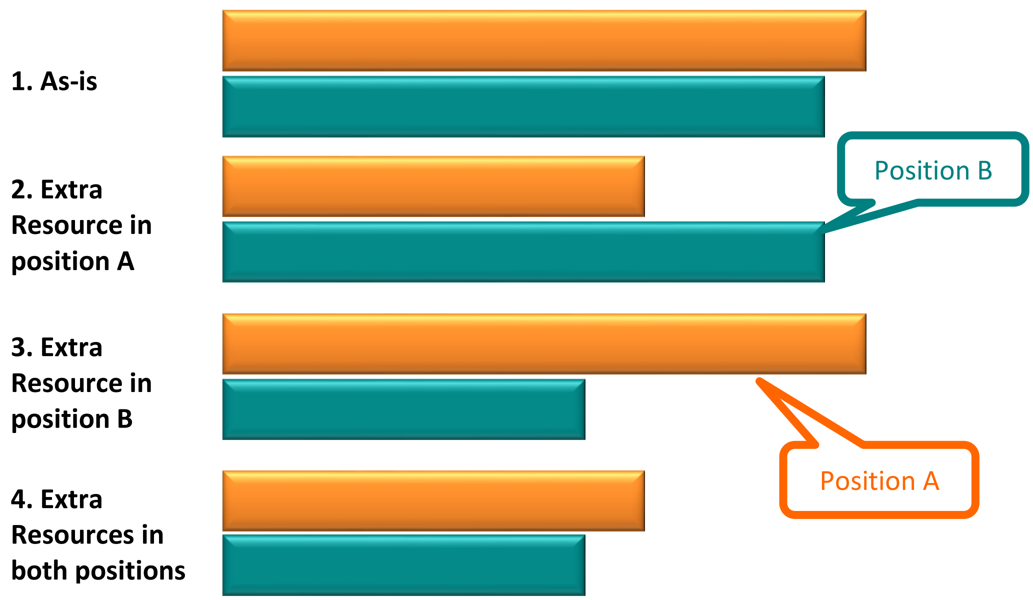

Figure 4-9. Comparison of the timelines for different scenarios

In figure 4-9, in the “as-is” scenario, the span time is long since the resources are limited. In the second scenario, an extra resource is added in position A; therefore, the duration for the tasks is reduced in position A. The critical path has moved from the tasks in position A to position B; so, the span time does not change a lot. A similar situation occurs in the third scenario. The span time does not change a lot since the extra resource is added to only one group. In the fourth scenario, one resource is added in position A and one resource is added in position B. The span time is greatly reduced because the additional resources are added to the critical tasks in both positions. This explains the significant reduction of span time for the whole loop. This is a sufficient reason to advocate for assigning the extra resources into both positions in spite of the extra 10 units of effort.

4.5 Simulation Results for Adding Resources

According to section 4.4, the two changeable variables with listed values constitute 9 scenarios. Both of the variables are equal to zero in the "as-is" scenario. After all simulation results are gathered, whether a "to-be" scenario is beneficial is apparent by comparing the project span time and effort with the "as-is" scenario, and the objective is to find the optimal scenario. The simulation results for each of the 9 scenarios are listed in table 4-2.

Table 4-2. Simulation results for all of the 9 scenarios for adding resources

Scenario#	Resource _position A	Resource _position B	Average Span Time (units)	Effort (person-units)
1	**0**	**0**	**120.9**	**0**
2	0	1	117.5	0
3	0	2	117.9	+3
4	1	0	120.5	+10
5	1	1	95.1	+10
6	1	2	94.5	+13
7	2	0	120.7	+14
8	2	1	94.5	+14
9	2	2	92.4	+17

In table 4-2, the second and the third columns are the different values of the variables resource_position A and resource_position B, respectively. The fourth column displays the average span time (units). The last column displays the effort (person-units). Scenario 1 is the “as-is” scenario with both variables equal to zero; the effort for this scenario is set to zero for easier comparison.

It is seen in table 4-2 that the span time for scenarios 2, 3, 4, and 7 do not vary too much due to the fact that the extra resource(s) is(are) assigned to just one position in these scenarios. As a result, their corresponding span time does not change a lot. The remaining 5 scenarios are listed in table 4-3:

Table 4-3. Simulation results for the best 5 scenarios for adding resources

Scenario#	resource _position A	resource _position B	Average Span Time (units)	Effort (person-units)
1	**0**	**0**	**120.9**	**0**
5	1	1	95.1	+10
6	1	2	94.5	+13
8	2	1	94.5	+14
9	2	2	92.4	+17

By comparing scenarios 5, 6, and 8, it can be observed that adding a third resource into either position does not shorten the span time too much (0.6 units), while the effort is increased by 3 or 4 person-units. Therefore, adding 3 resources does not gain much benefit.

Finally, scenarios 5 and 9 are compared. Scenario 9 adds two more resources than scenario 5; the span time is shortened by 2.7 units while the effort is increased by 7 person-units. The decision on which scenario (scenarios 5 and 9) is better depends on which aspect managers value more: shorter span time or less effort. As for this thesis, since the objective of adding extra resources is to reduce the span time, it is recommended to choose scenario 9 for its shortest span time.

It also can be observed from the comparison of scenarios 5 and 9 that the span time reduction is rather small (2.7 units) while the number of resources is increased by 2 in positions A and B, since most of the critical tasks have been transferred from the aforementioned 3 groups to other groups. Also, more tasks are carried out in parallel than the “as-is” scenario. If more resources were to be added, they would need to be assigned to other groups as well as to positions A and B, which makes the situation more complex. In the meantime, the span time reduction would be less while effort would increase. Therefore, the scenarios where 3 or more extra resources are added in each position or extra resources are added to other groups are not discussed due to the combination of reduced decrease in span time and increased effort.

Average span time and effort for all of the 9 scenarios are plotted in figure 4-10. It can be observed that as the span time decreases, the effort increases.

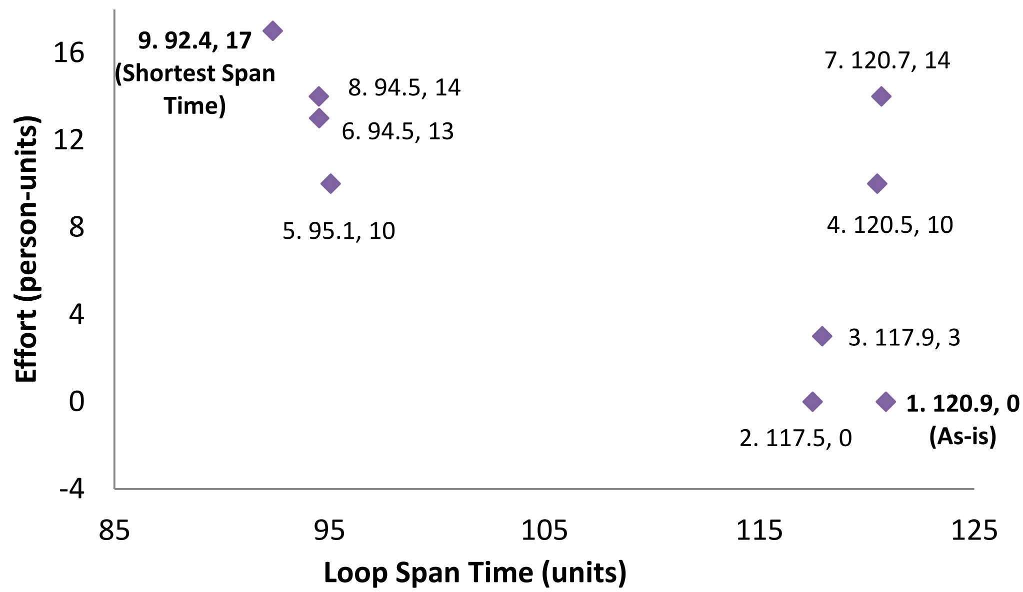

Figure 4-10. Span time VS Effort for adding resources

4.6 Simulation of Sharing Design Processes

One of the objectives of this project is to share an aeroelastic model between the Loads and Dynamics departments in order to reduce duplicated effort. Engineers in both departments noticed the use of similar design processes in the other department when looking at process maps. As a result, they discussed the feasibility of sharing several tasks between the two departments, including an aeroelastic model, weights data processing, aero-factoring, and aero-paneling.

4.6.1 Aeroelastic Model

There were several discussions on the feasibility of sharing an aeroelastic model between the two departments. After receiving the aeroelastic model from the Stress department, the Loads department extracts the data it needs and builds its own stick model, which is a “simple” FEM composed of beam elements, masses, and spring elements representing the beam attachment connections. The stick model contains all the required stiffness to carry out Loads analysis. Meanwhile, the Dynamics department extracts the data it needs and builds its 3D FEM model, which is a much more complex model which includes thousands of specific elements representing the actual complete aircraft structure. The Dynamics department also employs stick models, depending on the aircraft program. However, the two departments use the aeroelastic models with different levels of detail. The 3D FEM model is far more complex and requires more computer calculations than a stick model. Plus, the Loads department does not have the computer software needed for FEM model calculation. On the other hand, the same arrival time of the aeroelastic models leads to another problem: if the two departments were to share the aeroelastic model, one department would build the model for both departments, while the other department would have to wait until this process is done and could not proceed with its tasks. Therefore, sharing an aeroelastic model proves to be infeasible at present.

4.6.2 Weights Data Processing

According to the discussions with the engineers we interviewed, the effort change (person-units) per loop after weights data is shared is shown in table 4-4[3].

Table 4-4. Effort change (person-units) per loop after weights data is shared

	As-is	**To-be**	**Change**	**Total Change**
Loads	0.5	1.5	+1	**-3.5**
Dynamics	6	1.5	-4.5	

As shown in the table 4-4, the effort spent for the weights data processing tasks in the Loads and Dynamics departments in the “as-is” scenario is 0.5 person-unit and 6 person-units, respectively. According to the discussions and the estimation on the amount of work required, if the two departments were to share the weights data, Loads would do most of the work for both departments (1.5 person-units), whereas Dynamics would

[3] The expected effort and task durations are estimations after the preparation for sharing and after the adaptation or learning period.

need 1.5 person-units to process the data the Loads department delivers. The total effort for both departments is reduced by 3.5 person-units per loop. However, the span time for the Loads department does not change in the sharing weights data scenario. Since the weights data processing task is not located on the critical path, minor changes of its duration do not influence the total span time. The span time for the Dynamics department is reduced by 4.5 units per loop compared to the “to-be” scenario.

It can be observed from table 4-4 that both the effort spent in Dynamics and the total effort has been reduced except that the Loads department spends a little more effort. Therefore, it is always beneficial to share weights data between the two departments.

4.6.3 Aero-Paneling

The estimation of effort change (person-units) per loop after aero-paneling data is shared is shown in table 4-5.

Table 4-5. Effort change (person-units) per loop after aero-paneling data is shared

Effort	As-is	Loads do	Dynamics do
Loads	6	8 (+2)	3 (-3)
Dynamics	5	2 (-3)	7 (+2)
Total Change		**-1**	**-1**

As shown in the table 4-5, the effort spent for the aero-paneling task in the Loads and Dynamics departments in the "as-is" scenario is 6 person-units and 5 person-units, respectively. If the two departments were to share aero-paneling, either department would be able to do most of the work for both departments.

(1) If Loads did the work, it would need 8 person-units (2 person-units more) to do the work, while Dynamics would need 2 person-units (3 person-units less) to process the data the Loads department delivers. The total effort change for both departments would be 1 person-unit less per loop;

(2) If Dynamics did the work, it would need 7 person-units (2 person-units more) to do the work, while Loads would need 3 person-units (3 person-units less) to process the data the Dynamics department

delivers. The total effort change for both departments would be 1 person-unit less per loop.

The estimations of the span time change (units) per loop after aero-paneling data is shared are shown in table 4-6.

Table 4-6. Span time change (units) per loop after aero-paneling data is shared

Span Time	Loads	Dynamics
Loads do	+0.7	-2.5
Dynamics do	-1.5	+2

As shown in the table 4-6, if Loads did the work, its span time change would be 0.7 units more per loop, whereas the span time change in the Dynamics department would be 2.5 units less per loop. If Dynamics did the work, its span time change would be 2 units more per loop, whereas the span time change in the Loads department would be 1.5 units less per loop.

4.6.4 Aero-Factoring

The estimation of the effort change (person-units) per loop after aero-factoring data is shared is shown in table 4-7. As shown in the table 4-7, the effort spent for the aero-factoring task in the Loads and Dynamics departments in the “as-is” scenario are 5 person-units and 12.5 person-units, respectively. If the two departments were to share aero-factoring, the situation would be as follows.

(1) If Loads did the work, it would need 6 person-units (1 person-unit more) to do the work, whereas Dynamics would need 2.5 person-units (10 person-units less) to process that data the Loads department delivers. The total effort change for both departments would be 9 person-units less per loop;

(2) If Dynamics did the work, it would need 13 person-units (0.5 person-unit more) to do the work, whereas Loads would need 1 person-unit (4 person-units less) to process the data the Dynamics department delivers. The total effort change for both departments would be 3.5 person-units less per loop.

Table 4-7. Effort change (person-units) per loop after aero-factoring data is shared

Effort	As-is	Loads do	Dynamics do
Loads	5	6 (+1)	1 (-4)
Dynamics	12.5	2.5 (-10)	13 (+0.5)
Total Change	0	**-9**	**-3.5**

The estimations of the span time change (units) per loop after aero-factoring data is shared are shown in table 4-8.

Table 4-8. Span time change (units) per loop after aero-paneling data is shared

Span Time	Loads	Dynamics
Loads do	0	-10
Dynamics do	-1	+0.5

As shown in the table 4-8, if Loads did the work, its span time would not change, whereas the span time change in the Dynamics department would be 10 units less per loop. If Dynamics did the work, its span time change would be 0.5 units more per loop, whereas the span time change in the Loads department would be 1 unit less per loop.

4.7 Simulation Results for Sharing Design Processes

Similarly, variables are used in order to simulate all of the scenarios with one process model. This section utilizes two variables: Share_Aero-Paneling and Share_Aero-Factoring. Their functions, values, and corresponding scenarios are listed in Table 4-9.

Table 4-9. Variable names, functions, values, and their corresponding scenarios

Variable Name	Function	Value	Scenarios
Share_Aero-Paneling	Whether or not to share aero-paneling; which department does the work	0	Not shared
		1	Shared; Loads do
		2	Shared; Dynamics do
Share_Aero-Factoring	Whether or not to share aero-paneling; which department does the work	0	Not shared
		1	Shared; Loads do
		2	Shared; Dynamics do

The simulation results for all of the scenarios for sharing design processes are listed in table 4-10.

Table 4-10. Simulation results for all of the scenarios for sharing aero-factoring and aero-panelling

Scenario#	Share_Aero-Factoring	Share_Aero-Paneling	Average Span Time (units)	Effort (person-units)
1	**0**	**0**	**121.1**	**0**
2	0	1	121.7	-1
3	0	2	119.6	-1
4	1	0	121.3	-9
5	1	1	122.6	-10
6	1	2	119.4	-10
7	2	0	120.1	-3.5
8	2	1	120.8	-4.5
9	2	2	119.1	-4.5

In table 4-10, the second and the third columns have different values for the variables Share_Aero-Factoring and Share_Aero-Paneling, respectively. A value of 1 means that the Loads department does the work, and delivers the results to Dynamics; a value of 2 means that the Dynamics department does the work, and delivers the results to Loads. The fourth column shows the average span time (units). The last column shows the effort (person-units). Scenario 1 is the “as-is” scenario with both variables equal to zero; the effort for this scenario is set to zero for easier comparison.

It can be observed from table 4-10 that the span time for each scenario does not vary a lot. Therefore, the scenario with the least effort is the optimal choice. It is obvious from table 4-10 that the effort spent in scenarios 4, 5, and 6 is a lot less than the others. These scenarios are listed in table 4-11:

Table 4-11. Simulation results for the remaining 4 scenarios

Scenario#	Share_Aero-Factoring	Share_Aero-Paneling	Average Span Time (units)	Effort (person-units)
1	**0**	**0**	**121.1**	**0**
4	1	0	121.3	-9
5	1	1	122.6	-10
6	1	2	119.4	-10

By the comparison of scenarios 4, 5, and 6, it can be observed that scenario 6 has the shortest span time and the least effort compared with the other scenarios. In a word, it is suggested to let the Loads department do the aero-factoring and let the Dynamics department do the aero-paneling. Average span time and effort for all of the 9 scenarios are plotted in figure 4-11.

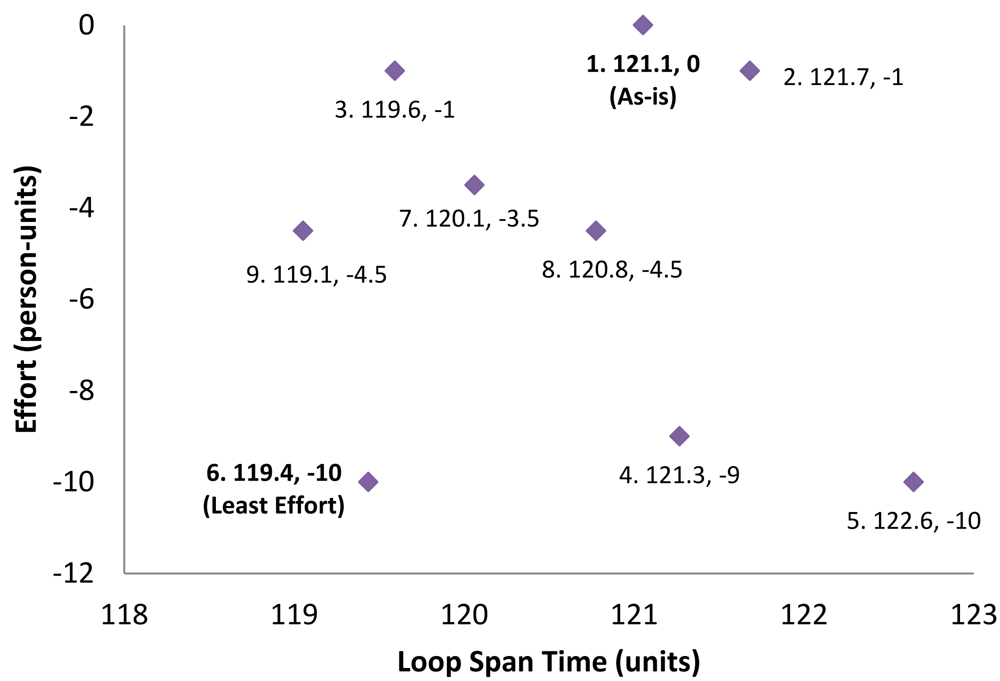

Figure 4-11. Span time VS Effort for sharing design processes

However, by the time this project ended, the discussion on sharing the aero-paneling and aero-factoring data was still in progress. The obstacles the two departments have encountered are that:

(1) Their timelines need to be synchronized;

(2) Some minor procedures differ in the analyses of the aero-paneling and aero-factoring data in the two departments, and they need to be harmonized.

4.8 Summary

In this chapter, the simulation and the results for adding extra resources and sharing design processes were discussed in detail. To shorten span time as far as possible, it was suggested to add two extra resources to the tasks in the High Lift Loads group and two extra resources to the tasks in the Flight Maneuvers and Dynamic Gust groups. To reduce duplicated effort, it is suggested to let the Loads department process the weights data and do the aero-factoring task, and let the Dynamics department do the aero-paneling task.

Supposing both optimal scenarios were carried out simultaneously, the span time for the Loads department would be reduced by 30.2 units per loop, and the total effort for both departments would be increased by 3.5 person-units per loop. For a new product development program, the total span time could be reduced by 25% with the effort increased by only 0.48%.

Furthermore, the simulation results suggested that the more efficient way of reducing span time was to add extra resources, whereas the better way for reducing effort is to share design processes (weights data processing, aero-paneling, and aero-factoring) between the two departments.

Chapter 5 Quality

In the industrial world, companies attempt to accelerate their New Product Development (NPD) in order to increase their marketing competitiveness. However, during this attempt, engineers rush to meet their deadlines, but cannot guarantee the quality of their deliverables. Sometimes they have to hand in the deliverables that may have to be updated later on. When the downstream departments receive the latest deliverables, they usually have to discard some of their previous work and redo part of their analyses, leading to additional design iterations, cost and time.

The Loads department is now facing a quality problem. During a recent aircraft development program at Bombardier Aerospace, the number of design iterations was larger than expected mainly because of the following reasons.

(1) Upstream departments updated their deliverables while the Loads department was still conducting analysis using the previous version of the inputs. Thus, the Loads department discarded what they were doing and started using the new data.

(2) Loads had extra iterations inside the department because their deliverables did not meet the requirements for the downstream department.

These phenomena could be avoided if the quality of the deliverables from all of the upstream departments as well as the Loads department itself was well controlled.

Several measures are suggested to control quality:

(1) Establish quality gates for the deliverables from the upstream departments;

(2) Establish quality gates for the groups providing deliverables inside the Loads department;

(3) Document the quality levels and issues after checking the results;

(4) Have a “process owner” who supervises all of the current quality gates and decides whether to amend the process or a checklist at a quality gate.

Chapter 6 Conclusion

This chapter contains a review of this thesis, the contributions of this thesis, and some recommendations for further research.

6.1 Review

This thesis proposed 3 objectives in chapter 1:

1. Find potential improvements in the Loads Department such that its span time can be reduced;
2. Seek sharing opportunities between the Dynamics and Loads Departments in order to reduce duplicated effort;
3. Find mechanisms to improve data quality so unplanned iterations can be reduced.

The above objectives were achieved and discussed in detail in chapter 4 and 5. Specific points are given below.

In this thesis, process maps for the Loads and Dynamics departments at Bombardier Aerospace were updated and validated using the Cambridge Advanced Modeller (CAM), and the “as-is” scenario was simulated as a reference. Then, Gantt charts were studied and critical tasks were located in preparation for the simulation of different scenarios for different strategies. There are two types of strategies applied in this thesis:

(1) Adding resources;

(2) Sharing design processes.

The purpose of adding resources is to shorten project span time and the purpose of sharing design processes is to reduce the effort.

The scenarios with extra resources added to critical tasks were simulated. Among all of the scenarios, the optimal solution was to add two resources to the High Lift group and two resources to the Flight Maneuvers and Dynamic Gust groups. This would result in the maximum span time reduction of 28.5 units (objective 1).

As well, scenarios with sharing design processes were simulated, and the following conclusions were drawn (objective 2):

(1) If possible, it is always beneficial to share weights data;

(2) It is better for the Loads department to perform the weights data processing task for both departments;

(3) It is better for the Loads department to perform the Aero-Factoring task for both departments;

(4) It is better for the Dynamics department to perform the Aero-Paneling task for both departments.

If all optimal scenarios were carried out simultaneously, the span time in the Loads department would be reduced by 30.2 units per loop, while the total effort for both departments would be increased by only 3.5 person-units per loop. For a new product development program, the total span time could be reduced by 25% with the effort increased by only 0.48%.

In chapter 5, the problems of the quality were identified, and several measures were suggested to oversee, control and improve the quality of the design processes in the Loads department (objective 3).

6.2 Contributions

This thesis updated and validated the process maps for the Loads and Dynamics departments at Bombardier Aerospace. The “as-is” scenario was simulated and Gantt charts were obtained. The process maps and the Gantt charts can be useful in many aspects.

(1) Process maps provide a virtual environment that simulates reality. They can be used as a reference for engineers and to help them

better understand the design processes and their interdependencies in both departments.

(2) Process maps help the engineers better understand the connections between the two departments and the similarity/differences of design processes.

(3) Process maps help managers identify potential problems, manage resource allocation, and monitor the durations of tasks in the two departments.

(4) Gantt charts help engineers better understand the role and the criticality of the design processes for which they are responsible during an entire project.

(5) Gantt charts help managers better understand project timelines and help them reallocate resources within a department.

The optimal solution provides the Loads and Dynamics departments the anticipated benefits. As a result, they could balance the investment and the outcome, and make adjustments accordingly in order to gain maximum profit.

Finally, several suggestions regarding the quality control provide the Loads department guidance for design process improvement.

6.3 Recommendations for further research

This thesis updated and validated the process maps for the Loads and Dynamics departments. Since all of the departments in Core Engineering are closely related, future work could establish process maps for the other departments. This way, engineers can better understand their own design processes as well as the ones from other departments, and help them identify potential problems or potential inter-department sharing opportunities in order to reduce duplicated effort.

In addition, in order to better understand quality and to manage quality gates, the quality of the inputs, design processes and deliverables can be simulated in CAM.

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