

Simulation of a Manufacturing Process

Military Aircrafts

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Foreword

This report is the result of a master's thesis performed for Luleå Technical University (LTU), with Torbjörn Ilar as examiner, in the department of manufacturing engineering. The thesis focuses on simulation of a production system for military aircraft manufacturing at Saab Aeronautics in Linköping. The thesis is the last stage of a master's degree in mechanical engineering and was performed in the spring of 2016. This thesis is a part of a project which involves a collaboration with another thesis "Fighter aircraft manufacturing", where the participants helped with the development of this thesis. I would like to thank Torbjörn Ilar for his support and ExtendSim for giving me an ExtendSim Grant, which included a license for the simulation software ExtendSim. A thank you to all the operators at Saab, which have been helpful at explaining the manufacturing steps and verified the input data. I would also like to thank Björn Thorblad and Bertil Franzén at Saab Aeronautics for continuously support.

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A handwritten signature in grey ink, appearing to read "Sandra Fors".

Sandra Fors

Abstract

The military aircraft manufacturing at Saab is ready to enter the future of production systems and become ahead in their field. Saab predicts an increase in demands of military aircrafts, to meet this new higher customer demands this master's thesis is a part of a project which creates a new production system.

This Master's thesis includes following steps, which has been validated thoroughly:

- A simulation model of a production system for military aircraft manufacturing.
- A system analysis and identification of bottlenecks by investigating the queues in the simulation model.
- Testing of improvement suggestions.
- A simulation model which tests different production volumes.
- Recommendations for how to increase production volume by time, with solutions from two different development processes.

The result of this master's thesis is concepts on how to build a production system for military aircrafts, including number of stations, improvement areas and results of improvement suggestions on a general level.

The simulation model created possibilities to test a lot of scenarios and improvement suggestions and therefore find the best solution. To use a simulation software as an initial part of a project has been proven successful and is recommended to use initially in project in the future.

Sammanfattning

Den militära flygplanstillverkningen på Saab är redo att ta ett steg in i framtiden för produktionssystem och bli ledande inom sitt område. Saab förutspår en ökning av efterfrågan på stridsflygplan, för att möta den större efterfrågan är detta examensarbete en del av ett projekt som ska ta fram framtidens produktionssystem.

Det här examensarbetet omfattar följande steg, vilka är noggrant validerade:

- En simuleringsmodell av ett produktionssystem för militär flygplanstillverkning.
- En analys och identifiering av flaskhalsar, genom att undersöka köerna i simuleringsmodellen.
- Testning av förbättringsförslag.
- En simuleringsmodell som testar olika produktionsvolymen.
- Rekommendationer för hur produktionsvolymen kan ökas succesivt, med lösningar från två olika utvecklingsprocesser.

Resultatet av det här examensarbetet är koncept om hur produktionssystem för stridsflygplan kan byggas upp, vilket inkluderar antal stationer, förbättringsområden samt resultat av förbättringsförslag på en allmän nivå.

Simuleringsmodellen har skapat möjligheter att testa många scenarier och förbättringsförslag för att ta fram den bästa lösningen. Att använda ett simuleringsprogram som en inledande del av ett projekt har varit framgångsrikt och rekommenderas att använda initialt i projekt i framtiden.

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Table 1 Word list.

<i>Abbreviation</i>	<i>Definition</i>
FA	Final assembly
DES	Discrete event simulation
DTW	Dynamic time warping
VSM	Value stream mapping

1. Introduction

This master's thesis is a part of a project which involves a collaboration between two master's theses. This thesis includes a simulation of the production system, where the other master's thesis develops the production system. The project is made at Saab aeronautics in Linköping and involves Luleå Technical University and Linköping University.

1.1. Introduction to Saab

Saab was founded in 1937 to strengthen the Swedish military by supplying aircrafts to the Swedish air force. The first flight was with Saab 17, shown in Figure 1. Today Saab is a global defense and security company which operate in air, land, marine and civilian security together with commercial aircraft. There are around 14 700 employees and exist on all continents, Saab develops and improve continually to meet customer needs. Saab is a leading company in many technical areas and a fifth of their income goes to research and development (saabgroup.com, 2014). This project is at Saab aeronautics in Linköping and belongs to the military aircraft manufacturing division.



Figure 1. Saab 17, 1940 (<http://www.aviastar.org/air/sweden/saab-17.php>, 2016).

1.2. Background

The aircraft manufacturing at Saab is ready to enter the future of production systems to become the leader in their field. Two of the currently produced military aircraft is Gripen and Neuron, shown in Figure 2. This master's thesis is a part of a project together with another master's thesis to create the world's best production system for military aircraft manufacturing. A simulation will be created to provide the other master's thesis with data to test and improve the production system to reach the goals of the project. The project, which involves a collaboration between two master's theses will from now on be entitled as the project.

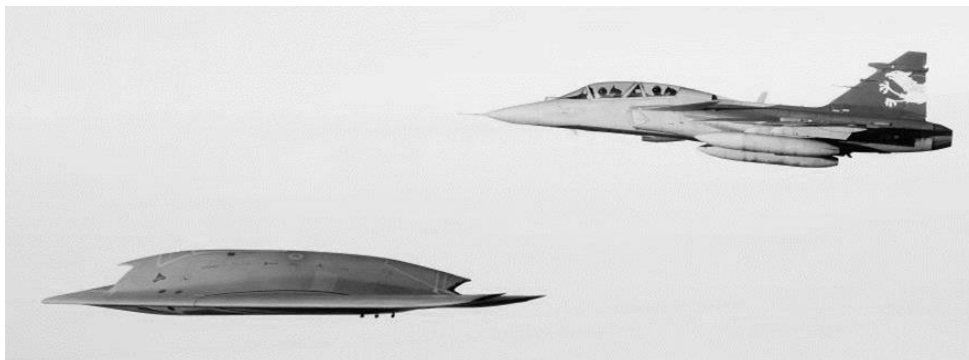


Figure 2. Neuron and Gripen flight (Ericsson, 2016).

A military aircraft is a very complex product which demands a lot of touch labor because the product is almost handmade and therefore have a long lead time (H. Balaji, 2014). The manufacturing at Gripen is shown in Figure 3 and Figure 4. In the future Saab predict an increase in demands of aircrafts, to meet this new higher customer demands the project will create a new production system with a short lead time. This production system needs to be effective and easy for new employees because an increasing demand creates an increasing need of personnel.



Figure 3. Manufacturing Gripen (Kustvik, saabgroup.com, 2016).



Figure 4. Manufacturing Gripen (Kustvik, saabgroup.com, 2016).

The simulation makes it possible to test a lot of concept and test a lot of improvements in a short amount of time (Carson, 2005). There need to be a lot of testing because it is a new production system which makes the simulation important and relevant. By creating a simulation model of the system the need of real-world experiments decreases (Robinson S. , 2014), which

decrease the time needed. The simulation is also cheaper than real-world experiments because it decreases the need of personnel and material.

When changing from touch labor production to serial production, Saab is entering a new working area. This creates a possibility for a new demand of simulation software, where this thesis can be seen as the first step of testing ExtendSim simulation software at Saab.

1.3. Aim and scope

The aim of this master's thesis is to:

- Create a simulation model of the production system.
- Analyze system and identify bottlenecks.
- Give recommendations on how to increase production volume by time.

Every step needs to be validated thoroughly so the simulation model conforms to the real-world system. The improvements need to be tested in the simulation model to be verified and therefore result in the best recommendations.

1.4. Constraints

This master's thesis has a time limit of 20 weeks and will produce a preliminary simulation without real experiments, only assumptions of the production system. The recommendation from simulation will only include which processes needs improvement or change in numbers of resources or stations. Considerations for errors will be a safety margin with a simplified solution of the problem. To simplify the model black-box should be used which means that several operations might be combined into a single process (Fishwick, 2007).

2. Theoretical framework

Theoretical information needed for this master's thesis is presented in following chapter. The theory includes information about development process, simulation development, simulation, ExtendSim simulation software, conceptual modelling, verification, validation & confidence, output analysis and aircraft manufacturing.

2.1. Development process

To create a successful project it is recommended to go through a development process which contains steps and activities (Ulrich & Eppinger, 2012). This thesis is based on a product development process (Ulrich & Eppinger, 2012) which is presented in Figure 5. Detailed instructions on every step will be presented in its own section in the thesis. The development process has six steps which begin with the planning step that includes creating a strategy for the project. Step two is concept development and this is where the customer needs are identified and concepts are generated. The concept develops in the next step, which is system-level design, into a general layout and product architecture is created. The next step is detail design that is specifying details of the product. Thereafter it is testing and refinement which contains testing and improvements of the product. The last step is production ramp-up, which prepares the product for manufacturing. This thesis will not include the last step because the product of the project is not bodily.



Figure 5. Steps in the development process (Ulrich & Eppinger, 2012).

Planning - The planning step is also called step zero, which is a starting step in the development process. The most important in this step is to understand what the project needs to contain to be successful, including customer needs and market potential.

Concept development – This step begins with generating concepts where brainstorming is a common method. The concepts develops to understand the possible results, more information collects by investigating related technology, which gives a wider perspective on the concepts. Demands and requirement are collected into a specification, which will be used throughout the entire project to define product demands. The competition is investigated to evaluate advantages and disadvantages on the market today. After collecting information there is scoring of concept to eliminate concept which does not reach the demands. The process repeats and ends with a concept selection, which narrow down the concept into one to three concepts to develop further.

System-level design – The workload divides into groups to work systematically and simultaneous. A general layout and product architecture are created.

Detail design – In this step the design and details are decided, calculation is made where necessary. The result from this step is usually drawings or models.

Testing and refinement – In this step the product validity tests according to the specification. After testing there will be improvement if needed.

2.2. Simulation development

This report is based on a simulation development process (Robinson S. , 2014), shown in Figure 6. Detailed instructions on every step will be presented in its own section in the thesis. The first step is the conceptual modelling which consists of understanding and developing the problem, including the need of data. The next step is to collect and analysis the needed data. When the information for the model is collected, the modeling of the simulation begins and are followed by experimentation of the model. Thereafter there are verification, validation and confidence control of the model to investigate if the model is accurate.



Figure 6. Simulation development process (Robinson S. , 2014).

Conceptual modelling – This step is a planning step which includes establishing objectives, inputs, outputs, content, assumptions and simplifications. As a result of this step there will be a general layout of the upcoming model.

Data collection and analysis - Data requirements are established, collected and the available data is analyzed.

Model coding – The simulation model is developed step by step and validated throughout the process. The result from this step should be a functioning simulation model.

Experimentation – This step includes experimentation of the model, it is important to obtain accurate result. To accomplish accurate results the system needs to be in steady state and the experiments should consist of a long run or several runs, where the rule of the thumb is three to five runs.

Verification, validation and confidence - Control if the simulation model is valid.

The development process includes an ongoing understanding of the system and thereby an ongoing improvement of the including components in the development process. This process should be repeated to get the desired level of detail, the process is presented in Figure 7.

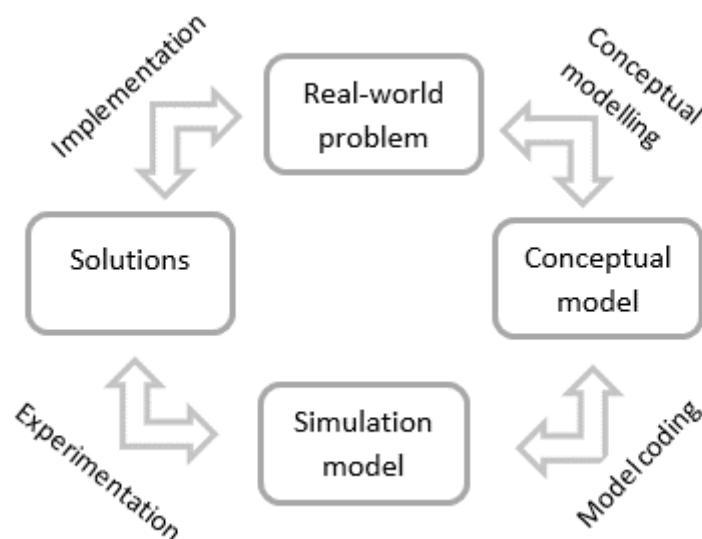


Figure 7. Improving after increasing understanding (Robinson S. , 2014).

2.3. Simulation

A simulation model is a dynamic system that describes how a system changes in time and an imitation of a real-world system (Johnstone V. T., 2015), therefore reduces the need of real-world experiments (Fishwick, 2007).

Simulation modelling is cheaper than real-world experiments because it demands less personnel and material. The simulation is quicker because a simulation can run for months in a short amount of time (Robinson S. , 2014), (Karnon, 2014) . It is easy to try many different improvement suggestions because a simulation model easily runs many different scenarios (Fishwick, 2007).

When simulating a process of time, the method time slicing can be used. Time slicing divides times in variations, which is described by statistical formulas. The time can be divided into scheduled, conditional or random, which simplifies by repetitions (Robinson S. , 2014).

There are different types of simulation software, which is spreadsheets, programming and special software such as ExtendSim and Simio.

2.4. ExtendSim simulation software

The first release of ExtendSim was in 1980 which means it has been used for a long time (Clark, 2015). ExtendSim is a special software for simulation and a leading edge simulation tool. ExtendSim is easy-to-use and helps to understand complex systems (ExtendSim Overview, 2015). The program helps to visualize ideas and systems, therefore gaining understanding of the system. By simulating it is easy to evaluate potential improvements and identify bottlenecks. Simulation is an analysis tool to predict the changing of an existing system or predict behavior of a potential new system. Alternatives can easily be explored by changing data.

In ExtendSim the model is created from building blocks into an assembly where the blocks are connected by a link connector (ExtendSim Overview, 2015). It is also possible to group small assemblies into hierarchical block. The blocks most commonly used is queue and activity, simulation models start with an input and ends with an output, which is illustrated in Figure 8.



Figure 8. Process flow of a simulation model.

2.5. Conceptual modelling

The goal when creating a conceptual modelling is to develop and understand the problem. This is an ongoing process, when more information is collected the model develops and the process repeats until a satisfying level is achieved, which is presented in Figure 9. The goals of the simulation model should be established and the conceptual modelling should be a description of the upcoming model.

The conceptual modelling is good for communication and helps to describe ideas (Robinson S. , 2014), therefor makes it easier to get responses and suggestions from others. It is also an important tool to present the goal of the project to the project owner. Thereby make alteration of the goals if necessary and make the project owner involved in the project (H. Nelson, 2012).

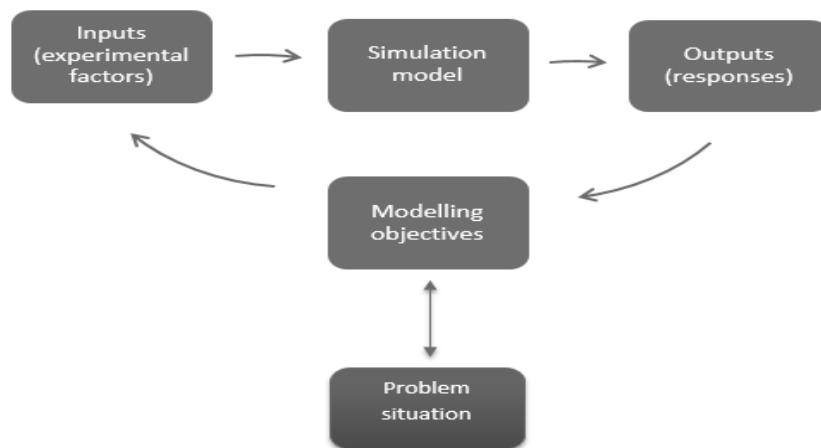


Figure 9. Framework for Conceptual Modelling (Robinson S. , 2014).

The conceptual modelling should contain objectives, inputs, outputs, content, assumptions and simplifications (Robinson S. , 2014). The objectives is to clarify the purpose and goals for the model, and the inputs is to establish the needed data and the type of data. The outputs should describe the required results from the model, and the content is to describe the layout and details of the simulation model (Sargent, Verification and validation of simulation models, 2013) (Robinson S. , 2014).

Assumptions and simplifications is important to keep the model simple because the model should only increase the complexity when necessary to improve the accuracy of the model. A too high complexity level will decrease the accuracy of the model (Robinson S. , 2014), shown in Figure 10.

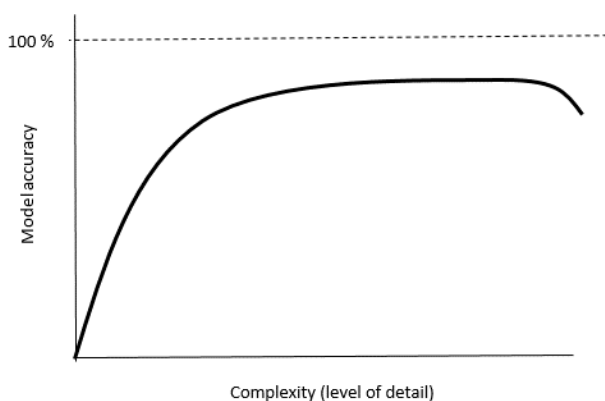


Figure 10. Complexity effect on model accuracy (Robinson S. , 2014).

2.6. Validation, verification and confidence

To be able to use results from a simulation model there have to be a confidence in its results. Therefore the model needs to be validated and verified as a part of the development process. Model verification is to ensure that the simulation model is correct and model validation is to ensure that the model is satisfactory accurate to the real system which it symbolizes. The model should be developed for a specific purpose and it should be validated according to that purpose. Model verification and validation are critical in the development of a simulation model, therefore it is important to use validation techniques.

Following is a list of validation techniques from (Sargent, Verification and validation of simulation models, 2013).

Animation - Validate by observing the displayed operational behavior as the model operates through time.

Comparison to other models - By comparing the results from the simulation model to the results from analytic models.

Data relationship correctness - Proper values in relationship and among different type of data.

Degenerate tests - Selection of inputs and internal parameters, investigate if the sequence is logical.

Event validity – Investigate the similarities between the events in the simulation model in comparison to the real-world events.

Extreme conditions test - Try the system for extreme behavior and investigate if it is relevant results, one example is if the inputs are zero the output should be zero as well.

Internal validity - Create several runs and test the mean and variance as a stochastic variability.

Historical data validation - Use unused input data to test the system.

Face validity - Control model from individuals with knowledge of the system.

Operational graphics - Validate by showing graphically results as the model runs through time, visually display to ensure that the performance and model behaves correctly.

Parameter variable-sensitivity analysis - Analyze the inputs effect on the output, and how it represent the real-world system.

Predictive validation - Use the predicted conclusion regarding the current system and compare it to the simulation model result of an upcoming production system.

Structured walkthrough - Review the model step by step.

Trace an entity – Trace an entity throughout the simulation model to determine if the model is logic.

Multistage validation - Compare several validation methods to test in a series of tests (Sargent, Verification and validation of simulation models, 2013) (TH Naylor, 1967).

When analyzing DES it is usually output analysis, which focuses on process level metrics including utilization rates, waiting times and queue lengths (O.M. Ashour, 2013), (Johnstone

N. L., 2009). Examples of general analyzing tools are White-box validation, which means that each component of the model is being controlled separately and Black-box validation, which controls on system level (Robinson S. , 1997).

The DES software has built in analyzers for these metrics (McGregor, 2002) combined with sensitivity analysis and experiments (Johnstone V. T., 2015). These analysis operates at a local process level and provides information regarding individual processes (Johnstone V. T., 2015).

Dynamic time warping DTW is a method to measure similarities between two time series and discovers relations between behavior and performance. The DTW have been proven successful in a variety of fields (Johnstone V. T., 2015).

It is important to understand that the simulation model can be valid for one set of experimental conditions and invalid for others (Sargent, Verification and validation of simulation models, 2013).

All of the analysing approaches require the model development to conduct verification as a part of the development process, three approaches is shown in Figure 11. One approach is to have the model builder decide whether the model is valid, another approach is to have the users to validate the model. A third approach is to have an independent verification and validation, where the independent source need to have understanding of the purpose of the simulation model. The development process should not proceed until the first one is validated and verified (Sargent, Verification and validation of simulation models, 2013).



Figure 11. Three different analysing approaches.

Tests and evaluations should be conducted until sufficient confidence is obtained so that a model can be considered valid for its intended applications (Sargent, Verification and validation of simulation models, 2013) (Sargent, Progress in Modelling and simulation, 1982) (RG Sargent, 1984)

It is important that the improving of confidence in the model should contribute to value for the user, because a high confidence can be time-consuming and therefor costly, which is shown in Figure 12.

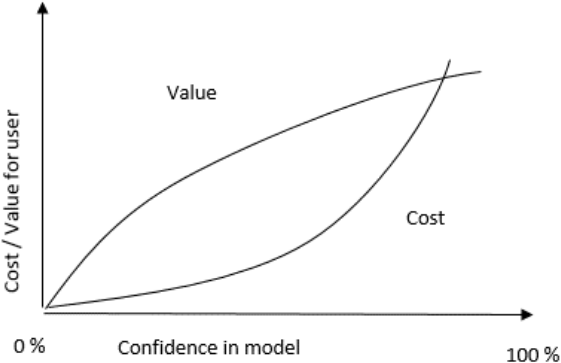


Figure 12. Confidence depending on cost and value for user (Sargent, Verification and validation of simulation models, 2013).

2.7. Output analysis

To obtain accurate results it is important to collect the results when the system is in steady-state (Robinson S. , 2014), which means that the system should present a realistic result. To create a steady-state result it is important to make a long run and several runs, where the rule of the thumb is three to five times (Robinson S. , 2014).

An output analysis can be seen as an ongoing process including improving the model and the results when increasing the level of knowledge in the analysis process, which is presented in Figure 13. Several versions of the simulation model are usually developed before obtaining a valid simulation model (Sargent, Verification and validation of simulation models, 2013).

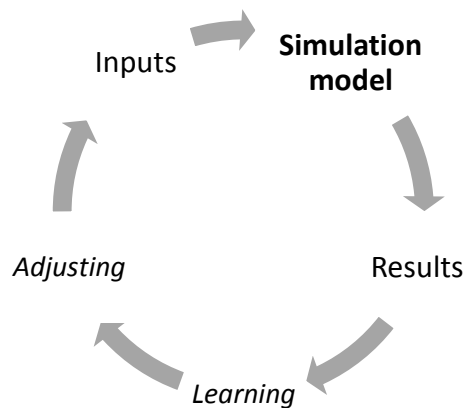


Figure 13. Output analysis learning process (Robinson S. , 2014).

When analysis the results it is important to understand the performance of the model. It is important to have a high level of quality in the ingoing processes to obtain quality results, presented in Figure 14 . It is important that the results answers the questions which the simulation model is built for (Sargent, Verification and validation of simulation models, 2013).

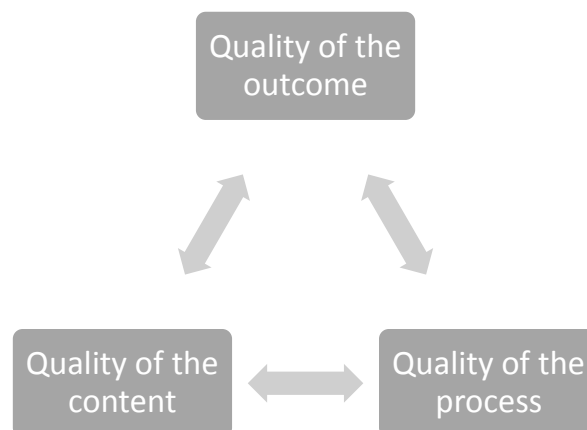


Figure 14. Outcome quality affected by incoming quality (Robinson S. , 2014).

The result is affected from the model inputs, which can be separated into experimental factors and general model data. These inputs and the simulation model itself has impact on the result and should be taken into consideration, this is presented in Figure 15. Data validation is usually difficult, time-consuming and costly, which makes it important to use data which is sufficient, available, appropriate and accurate.

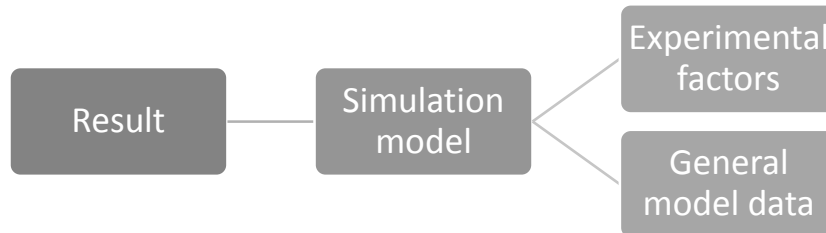


Figure 15. Result is affected from model inputs (Robinson S. , 2014).

Hypothesis tests can be used in the comparisons of means, variances, distributions and time series of the output variables. Each set of experimental conditions should be investigated to understand if the simulation model has a satisfying accuracy.

2.8. Aircraft manufacturing

Generally aircraft production is referred to as a craft and include challenges because of the product complexity involving aerodynamic contour and weight control (H. Balaji, 2014). An aircraft assembly line is a complex industrial installation that involves assembly processes, jigs, tools, machines and skilled human resources (F.Mas, 2015).

Presently the manufacturing is made by conventional machining which require complex and expensive tooling with large cycle times. The aircraft assembly tooling is employed for holding the parts in space during assembly. The tools is mostly product specific and needs regular maintenance and calibrations (H. Balaji, 2014).

Tooling is divided into fixtures and jigs, where fixtures position and holds parts during assembly and jigs are also used to guide cutting tools. A fixture is presented in Figure 16 and a jig is presented in Figure 17. The assembly process is mostly drilling, riveting, fastening, shimming and sealing, where the wings and fuel tank regions must be sealed (H. Balaji, 2014).



Figure 16. Gripen is positioned into a fixture (Kustvik, saabgroup.com, 2016).

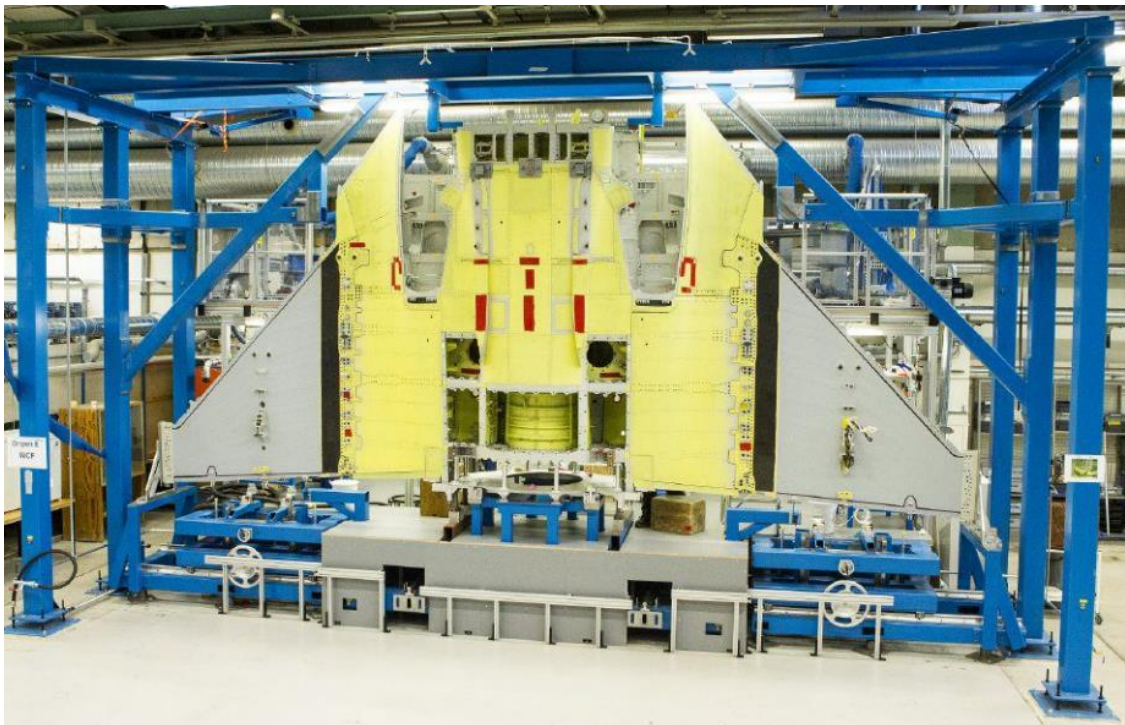


Figure 17. Gripen manufacturing by using a jig (Kustvik, saabgroup.com, 2016).

Assembly techniques such as modular assembly, manufacturing automation improve repeatability and quality in series production. The recent trends of aircraft structures is to use large monolithic parts to reduce part counts and thereby reducing setup time, cost and lead time when building the structure. Such large parts are designed with ribs to obtain high stiffness-to-

weight ratio (H. Balaji, 2014). This creates a possibility to separate the aircraft into separate parts and therefore make it possible to manufacture with parallel flows or sub-flows, which is shown in Figure 18.



Figure 18. Part of Gripen divided by ribs (Kustvik, saabgroup.com, 2016).

Conceptual assembly process or the assembly line definition includes capacity of line, number of stations, basic technologies to be used, placing of stations, the input product top-level structure and the output top-level product structure at each station, and the preliminary layout (F.Mas, 2015). The conceptual assembly also includes creating basic process structure, assigning sub-processes to assembly stations and assigning resources and evaluating alternatives (F.Mas, 2015).

When simulating, each modelling labour can be modelled as an activity, which later can be balanced and positioned as the optimum result according to the simulation model (R.F. Lu, 2002). When running multiple scenarios each situation provides various ideas and options, which contributes to finding the optimum solution. To produce value adding simulation it is necessary to be as accurate and realistic as possible (R.F. Lu, 2002) .

Discrete event simulation models is convenient to analyse numerous scenarios throughout several phases (R.F. Lu, 2002). These models presents a visual understanding of different concepts, and provides quantitative analysis of scenarios. The result presents highly optimized production flows and processes, reducing cost and flow time, by analysis utilization among others.

Simulation modelling was identified as a key tool to help with the level load positioning activities (R.F. Lu, 2002). There is much more simulation that can be performed to get benefits and it is only an initiated realization of the usefulness of the discrete event simulation. (R.F. Lu, 2002).

3. Method

This chapter describes how this master’s thesis was accomplished. The structure and development were made according to the development process in chapter 2.1 in combination with the simulation development in chapter 2.2, shown in Figure 19. The last step from the product development process chapter 2.1 was changed from production ramp-up to testing improvement suggestions.

The development started with a planning step according to the development process chapter 2.1, after are the conceptual modelling step according to the simulation development 2.2, which is separated into concept development and system-level design according to the development process 2.1 to develop the model successively. Next step is detail design according to the development process 2.1, which is separated into data collection & analysis, model coding and experimentation according to the simulation development 2.2, to develop the simulation model. The following step is testing & refinement and verification, validation & confidence according to the development process 2.1 and the simulation development 2.2. The last step is testing improvement suggestions which include testing improvements suggestions from the other master’s thesis.

Planning	Concept Development	System-level design	Detail design			Testing & refinement	Testing improvement suggestions
	Conceptual modeling		Data collection & analysis	Model coding	Experi-mentation	Verification, validation & confidence	

Figure 19. Development process for this master’s thesis.

Documentation was performed continuously during the project, and presentations of the thesis were made at LTU and Saab when the project was made, and most of the report was done. To understand the customer needs there were weekly meeting with the Saab supervisors and there were quarterly updates to ExtendSim.

The data collection was mostly made by the other master’s thesis combined with information from Saab (Saab AB, 2016). To get the correct type of data from the other master’s thesis there were continuously iteration and communication, which included how the data should be represented. The time setting was made from documents from Saab (Saab AB, 2016) to increase the possibility to verify the numbers with real operations and other documents at Saab. These data included a counted number of parts separated by size and then computed by a document (Saab AB, 2016), where the document have been verified and validated by Saab.

3.1. Planning

A Gantt-chart were established initially in the planning step consisting both project and thesis milestones (Ulrich & Eppinger, 2012). The Gantt-chart was changing throughout the project, more specified descriptions were added and changing in time when necessary. The milestones in the Gantt-chart were used to see what should be done and when it should be finished.

The aim was established and then used throughout the project to keep the project on the correct path. The constraints were established to make the thesis ready in time, with all necessary parts included. To be ready in time the risks of the project were analyzed and action to prevent them was taken.

The planning step mainly consisted in understanding the problem and creating a plan of the project.

3.2. Selection of software for simulation

Special software for simulation has a pre-defined library with blocks, which simplifies building of the model and makes the building faster. The building needs to be as quick as possible, which is the mayor reason to choose a special software to work with during this master's thesis.

The selectable special software for simulation in this master's thesis where ExtendSim and Simio, because they are available and have the most available knowledge. ExtendSim has a lot better analyzing tools than Simio and view results more clearly (P. S. Mahajan, 2004) . Because there are the most available knowledge of ExtendSim and because the processes are interchangeable more easily, ExtendSim where chosen for this thesis.

4. Conceptual Modelling

The first step to make the conceptual modelling according to the development process 2.1 is the concept development which will be developed in system level-design, chapter 4.1.

The concept development mainly consists of creating a specification and a conceptual model, shown in Figure 20. The conceptual model is depending on the specification because the demands must be fulfilled, but the information in the conceptual model is incorporated in the specification to add degree of details into the demands (Ulrich & Eppinger, 2012).

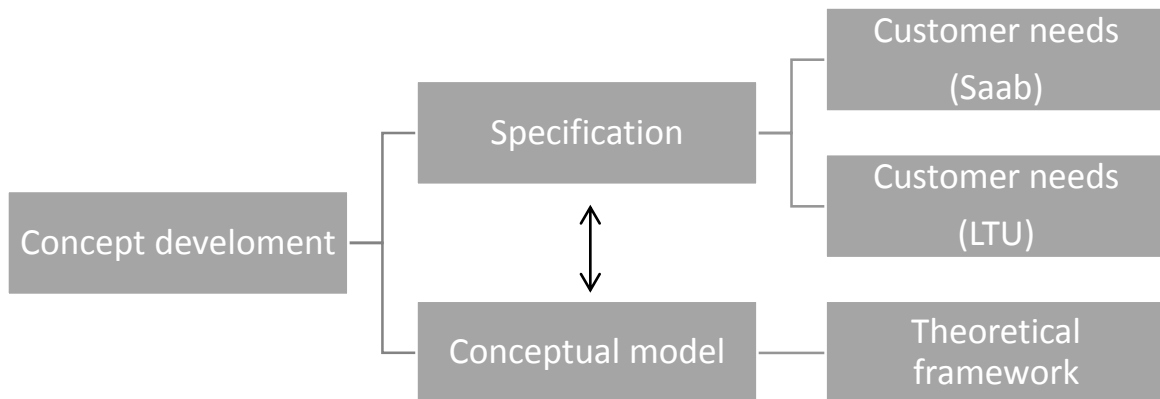


Figure 20. Concept development for this master's thesis.

A specification with demands shown in appendix 10.1 was created to clarify what needed to be done in this master's thesis. To clarify the demands, they were divided (Tonnquist, 2014) into demands for the master's thesis in general and product demands, where the product is the simulation model.

To generate concepts there were a brainstorming session on possible blocks to use and possible simplification. The session included blocks that combined can result in the simulation model, and simplification to make the model clear and quick to run. After the first brainstorming there was a study in theory shown in chapter 2. After the information was searched another brainstorming session was made. The ideas were collected and later used to construct the general appearance of the model.

The ideas combined with details on inputs, output, content, assumptions and simplifications where collected into a chapter 4.1 to create the simulation conceptual modelling. The plan is to develop the model top-down, which in this case means starting to build the general appearance including the known building steps. The construction model of the aircraft is based on these building steps and therefore not easy to change (Saab AB, 2016). When the input is fixed the simulation model will have a solid ground to be built on.

The first conceptual model presented in Figure 21 and shows how the general simulation model should be simulated. It consist of flow in, which will be simulated as create blocks, flow out, which should be simulated as exit block, queues and stations, where the stations should be simulated as hierarchical blocks.

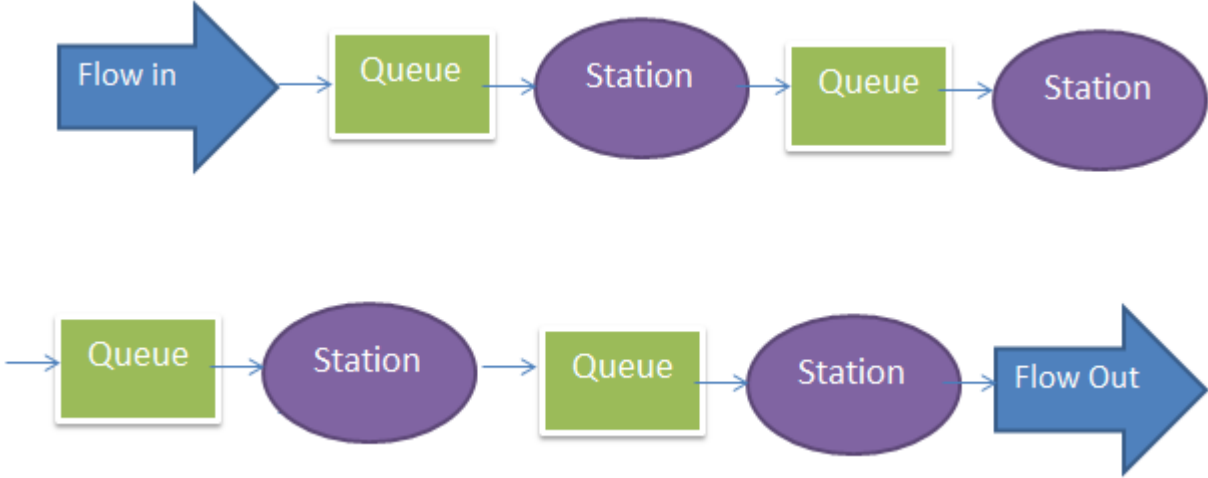


Figure 21. First conceptual model, stations is hierarchical blocks.

The next step in the plan is to test and verify the model. When the general model is verified it could be improved. Extracting the hierarchical blocks will include more information and concept ideas from the other thesis should be implemented. The extraction of the hierarchical blocks will include a process with queues and stations called sub-stations, where an example station is shown in Figure 22. The hierarchical blocks could be extracted separately without the need of concept ideas for the entire model.

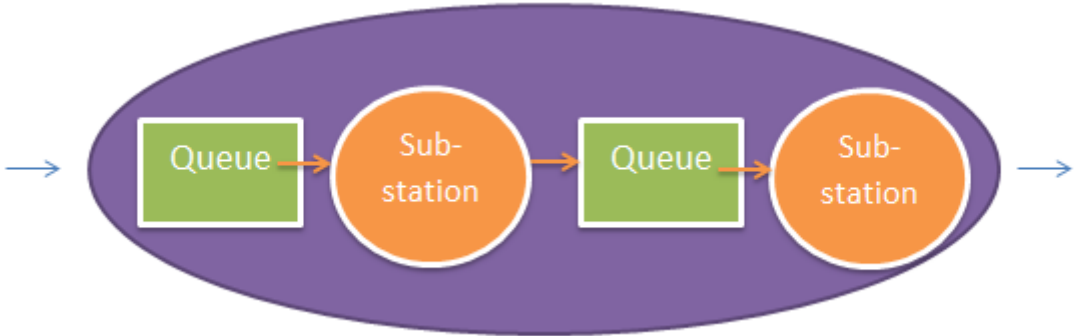


Figure 22. Conceptual model, extracted hierarchical block.

After completing a hierarchical block it can be validated by black-box validation (Robinson S. , 1997), white-box validation and DTW by comparing the extracted hierarchical block with the initial station. This procedure can be implemented on every hierarchical block. During this part and later, the model can be analyzed and the aim and scope could be investigated.

This concept development does not have any scoring of concepts. The concepts for this thesis only contains possibilities and therefore do not need to be chosen.

4.1. System-level design

The general layout and product architecture, shown in Figure 23 was created from the conceptual model chapter 4 and a building plan (Saab AB, 2016) on how to manufacture a military aircraft. The general layout includes an expected appearance and architecture of the model. The general layout is the same as the conceptual modelling for simulation described in the simulation development 2.2.

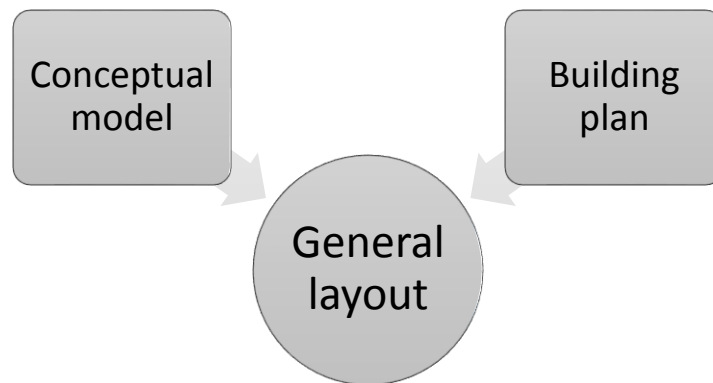


Figure 23. System-level design.

To narrow down the solution space and to create a systematic way of work a decision to start with one area of the aircraft was made.

Rios describes that one example to build an aircraft is to start with a standard fuselage (J.Rios, 2012) and then change the rest of the aircraft according to customer needs. From this and because it is a central part of the aircraft the fuselage will be the initial part of this project, shown in Figure 24, where the other areas will be included if there is enough time.

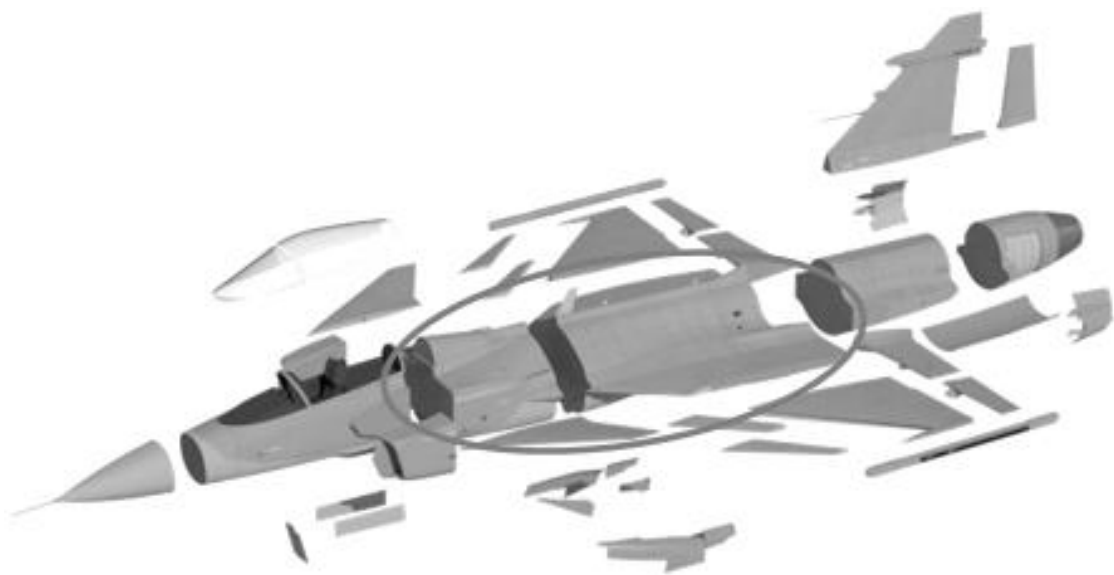


Figure 24. Aircraft, fuselage highlighted (Saab AB, 2016).

First a general flowchart, shown in Figure 25 was created to get a baseline of the simulation model. A station can include many operations and should therefore be built as a hierarchical block in the simulation model.

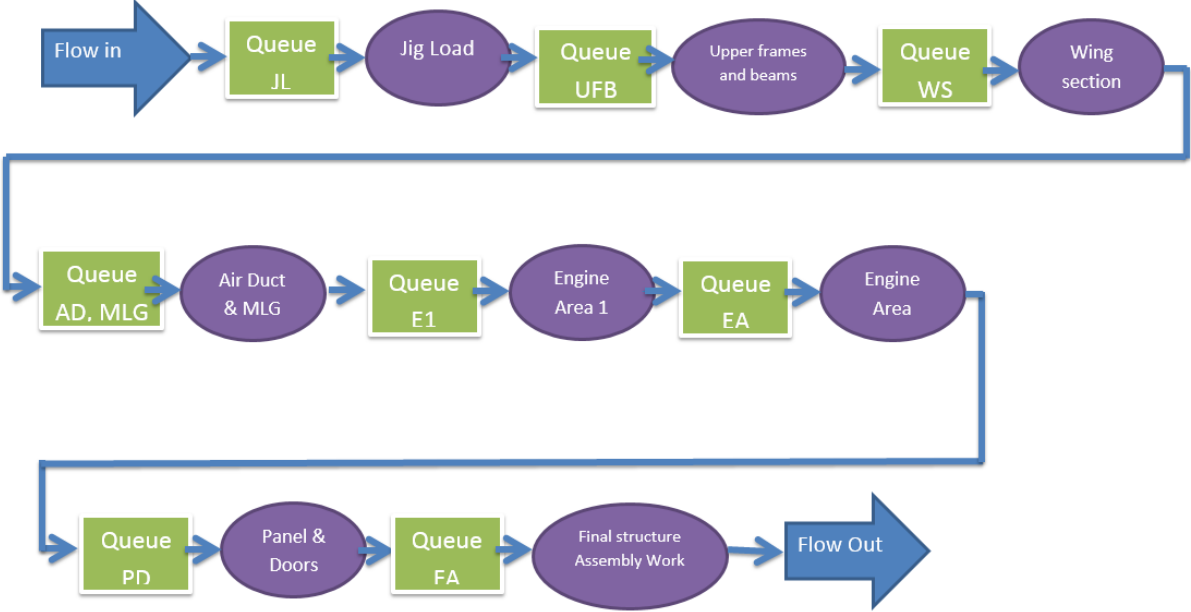


Figure 25. General flowchart.

From the general flowchart a list of functions in the simulation software was listed, which were developed into the general layout. When combining these functions it should be possible to build the simulation model. The functions were developed into preliminary solutions for how to use the functions and solutions to simulate the real-world system. The list also includes details on how to build the simulation system, so that the list can be used as a template when creating the actual simulation model.

The list also includes simplifications, because the model needs to be simplified to be created in a shorter amount of time, to make it more visual and to be able to run it faster (Carson, 2005). Some of the simplifications are grouping (Carson, 2005), which combines several operations into one process, and another is to remove components (Carson, 2005) which add little or nothing to the system without decreasing the reliability of the model. The model should be as simple as it can be but not simpler (Karnon, 2014), which means that the model should be simplified without decreasing the validity. Another simplification was to separate the list into basic conditions and extras, to make a lot of simplifications into the basic conditions to create a model and validate it in time. When the basic conditions are validated the extras can be made and be chosen according to the time needed and depending on information from the other master’s thesis and the most important parts to test. To validate the model the list also includes validation and how the validation should be performed.

The experiments are also listed to make the model able to test different scenarios including testing if the goals are reached, this part includes details on output from the model.

From the general flowchart and the list of functions the stations was improved with information and details. After improving the detail level, a possibility to separate the flow appeared from discussions with employees at Saab. This was investigated further and created a possibility to separate the detail design process, which should make the iteration to the other thesis simplified. The stations was separated according to the need of different type of jigs and fixtures, thereby creating a possibility and freedom to make changes within the stations. The general flowchart was changed according to the suggestion into separate flows, which is presented in Figure 26 .

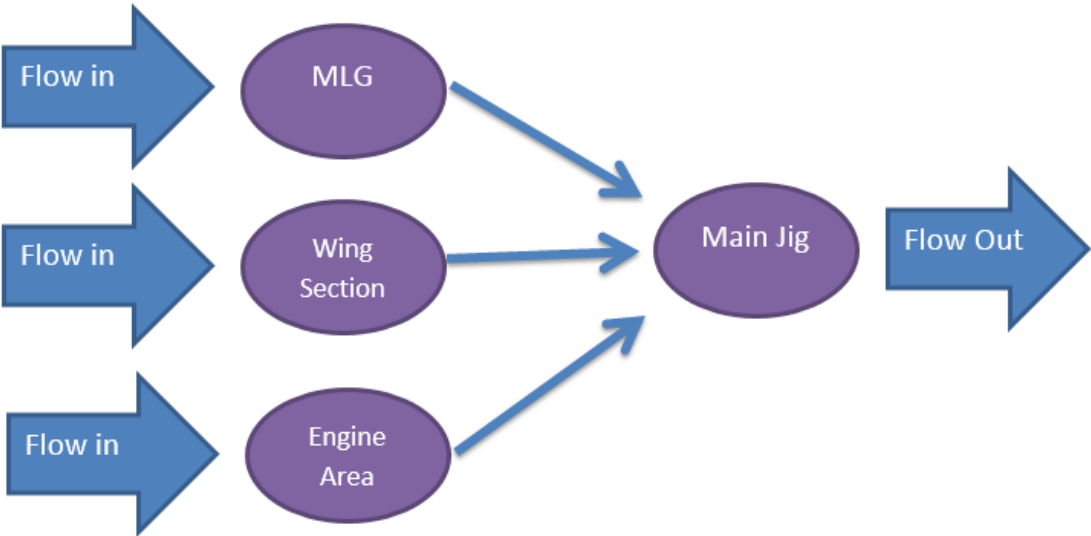


Figure 26. General flowchart, separated flows separated by the need of jigs and fixtures.

The stations were worked through both one-by-one and simultaneous depending on the amount of input from the other master’s thesis and other input knowledge. This part was made successively when information was reached and the detail design step was started simultaneously. One example of an extracted station is shown in Figure 27.

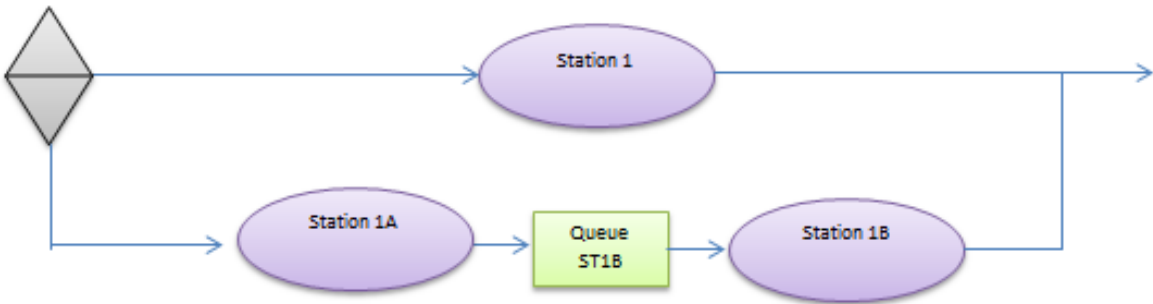


Figure 27. Extracted station, general example.

The list of functions which completes the general flowchart is presented in appendix 10.2.

4.2. Detail design

The detail design was divided into three parts according to the simulation development 2.2, which is data collection & analysis, model coding and experimentation. This decomposition is shown in Figure 28 and include how the stations where worked through, which will be described in its own section in this chapter. The general layout in appendix 10.2 was used as a source of information for the entire detail design step.

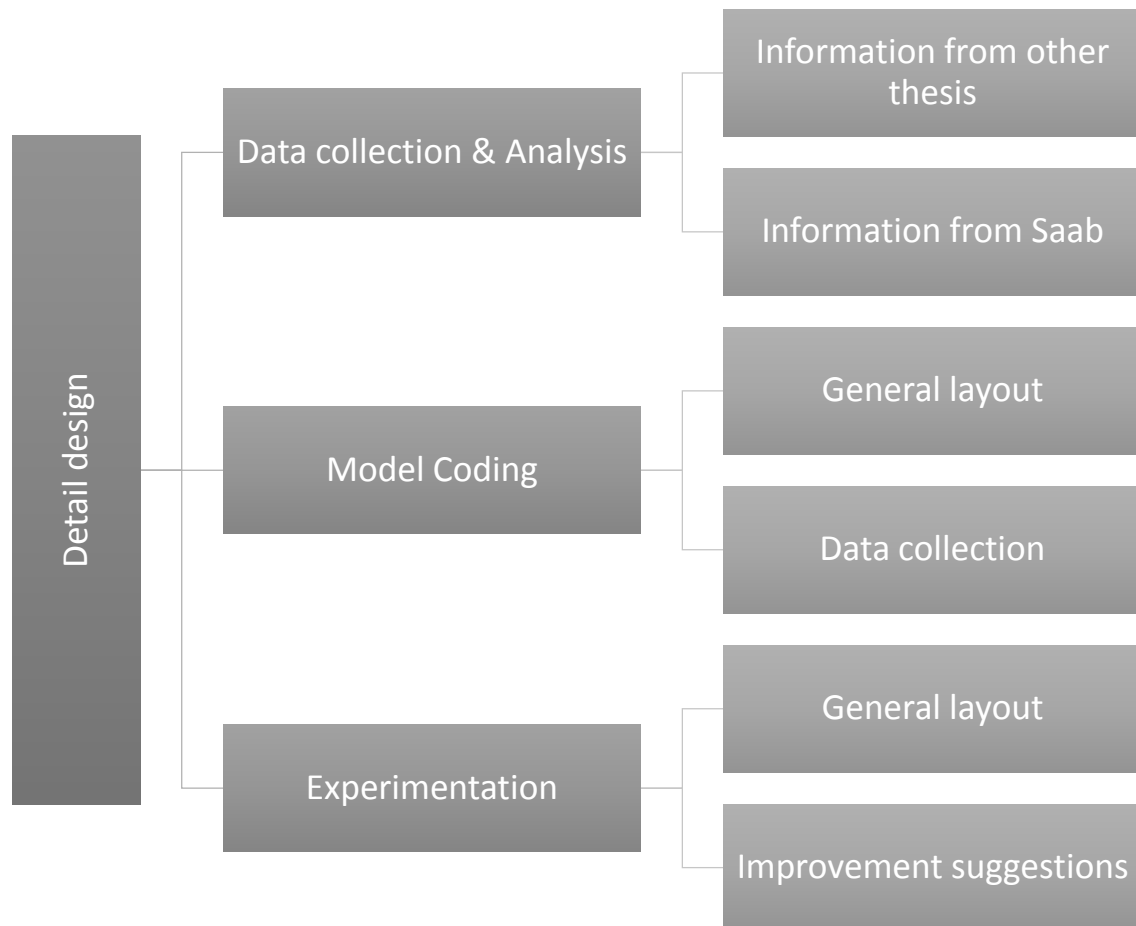


Figure 28. Detail design decomposition.

The detail design step was made by starting with the data collection & analysis and then the model coding and the last step where experimentation. The model coding where proceeding before the data collection & analysis where ready, this was made to understand the need in type of data. It was also to limit the waiting, because it was possible to work while waiting. The experiments was also started before the other steps where ready, to test the simulation model and thereby verify and validate the model continuously.

4.3. Data collection & analysis

To get an overview of a production system for military aircrafts, a VSM was constructed together with employees at Saab. The VSM contained a mapping of the processes in a production system, shown in Figure 29. The time for the processes, needed personnel and capacity of personnel was established together with layouts of the processes, cycle times, layout of the material flows and needed tools in each process. This mapping extends the needs for this master's thesis, but created an understanding of the process and an overview of the entire system.



Figure 29. VSM together with Saab employees (Nordström, 2016).

Analysis of data was made by assumptions to the real-world and assumptions according to outputs from the simulation model. Every input data was verified continuously with operators at Saab, who have long experience from building military and civilian aircrafts. The used documents from Saab has been used and tested before, which increased the reliability of the input data further.

The input data was separated according to the need in type of jigs and fixtures, it was also separated according to the possible building steps. This created a possibility separate on station to another station in the testing and refinement for improvement suggestions.

5. Simulation Model

The model coding were based on the general layout in appendix 10.2, the stations where built according to the general flowchart and the stations where presented as hierarchical blocks. The stations also included inputs from the data collection, which is operating time and other values. Everything was labeled with smart names to get a quick overview of the system (A. Tolk, 2014). The simulation was validated after each station was made and after every improvement to the system.

Animation and operational graphics was used continuously when building the model to ensure that the model appeared logical. This made it possible to see problems early in the model building process and a possibility to correct mistakes directly when they appear. The simulation model was visual from the beginning to get easy access and to continuously verify the model. Predictive validation was used throughout the building process to verify the building steps, even before the real values where included. Structured walkthrough was made after every major change to understand and verify the system. Extreme conditions tests were made continuously, mostly to verify positioning of queues, create blocks, outputs and also to verify the entire model.

To create a changeable simulation model the ExtendSim cloning tool was used to extract changeable numbers into the general appearance of the model according to Figure 30. When the cloning tool were used to extract input numbers these numbers are changeable in the general appearance and therefore creates a visual display and an easy to change simulation model.

The hierarchical blocks was used to get a simple and visual display and thereby hide all the activities, queues, create and exit blocks among others.

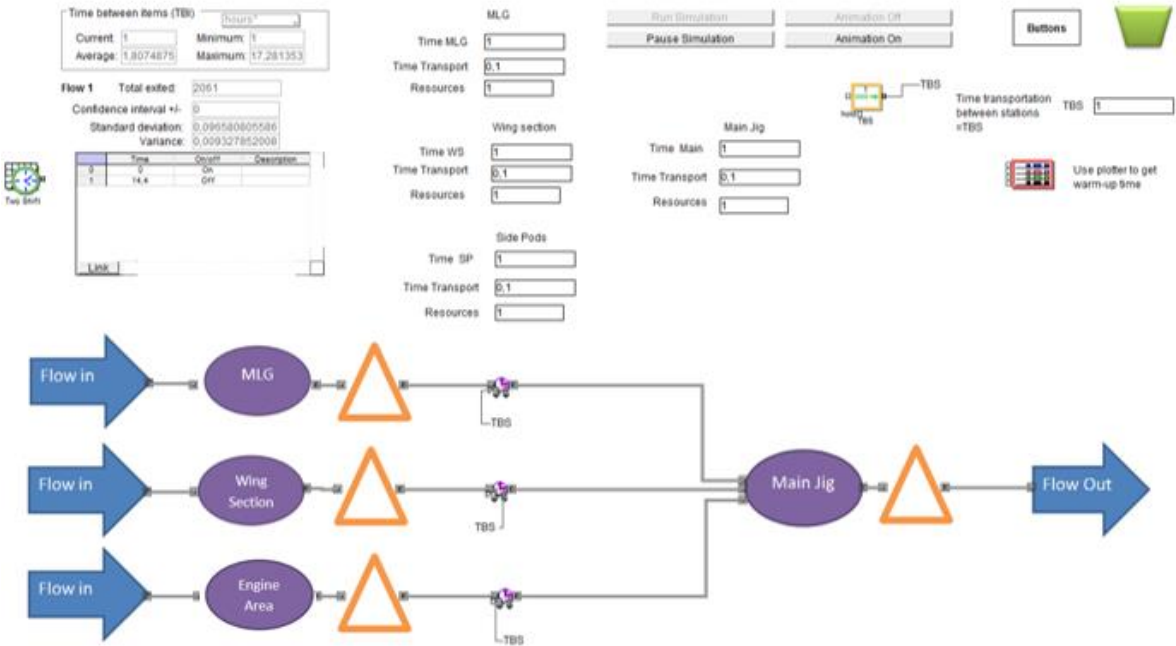


Figure 30. Complete simulation model before adding real numbers.

The hierarchical blocks includes information and internal processes, where the flow is in the first hierarchical block. This block includes a create block and a create queue, where the create block creates a big number of entities to be a non-deciding factor and thereby needs a queue to obtain the big number of entities which later is limited by the activities. The block is presented in Figure 31. The create block is a simulation block to start producing entities and thereby starting the simulation. This block does not conform to the real- world system and are only a function to simplify the simulation model. If this block should represent the real-world system it should be decided by the material flow into the system which involves many different types of materials and will add little or nothing to the simulation model and will increase the run time of the simulation model because it increases the level of detail.

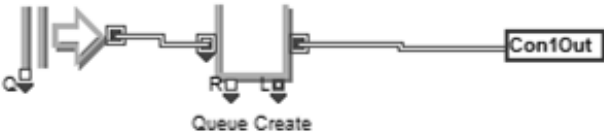


Figure 31. Hierarchical block - Flow In.

The stations at this stage are copies of each other and the first station is presented in Figure 32. These stations includes a select item out block, which represent the possibility to change from one suggestion to another suggestion, which can be useful in the testing and refinement for improvement suggestions. The select item out is chosen by probability where the selection should be “1” for the current suggestion and “0” for the other suggestions and thereby make all the entities follow the same path. The first suggestion starts with a queue which collect a resource and after is an activity where the operating time are controlled by the cloning tool numbers. Suggestion number two includes two activities and because of that it includes transport block and all the operating and transportation times are decided by the cloning tools numbers. The third suggestion symbolizes a third option with three activities.

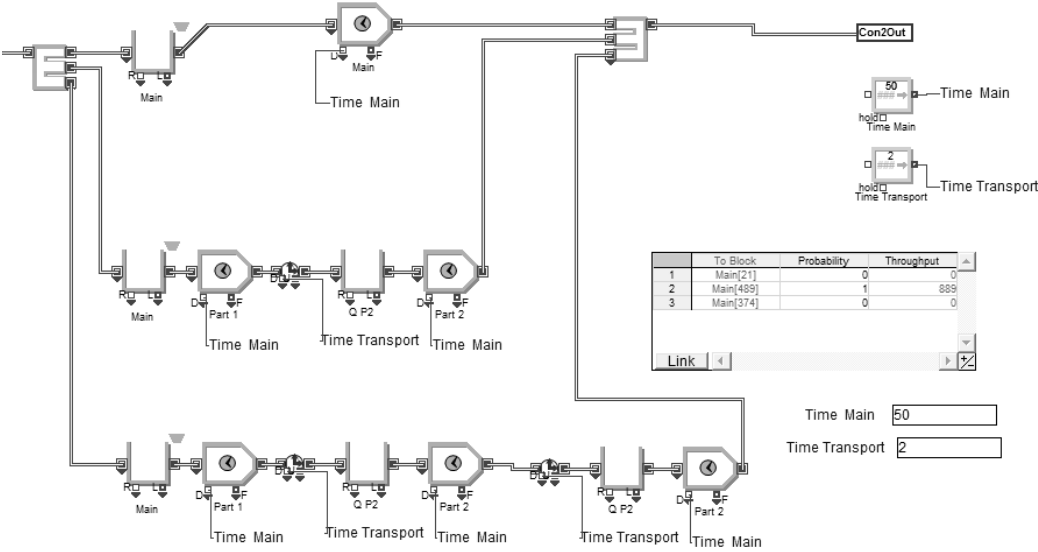


Figure 32. Hierarchical block - general station.

After the stations there are error stations, which is presented in Figure 33. The error stations begin with a queue and are followed by a select item out block which is controlled according to numbers from the cloning tool extraction, which is presented in Figure 34. After the selection the entity will go to the error queue and thereafter the error activity to get repaired or the entity will pass this station and go directly to the release resource block. The resources is used to symbolize the error station to be in the same station as the station before. This makes it easier to change the operating times in the activity in the station before and thereby make the system more changeable. Every station combined with an error station has their own resource pool which have the same amount of resources as the number of activities in the operating station.

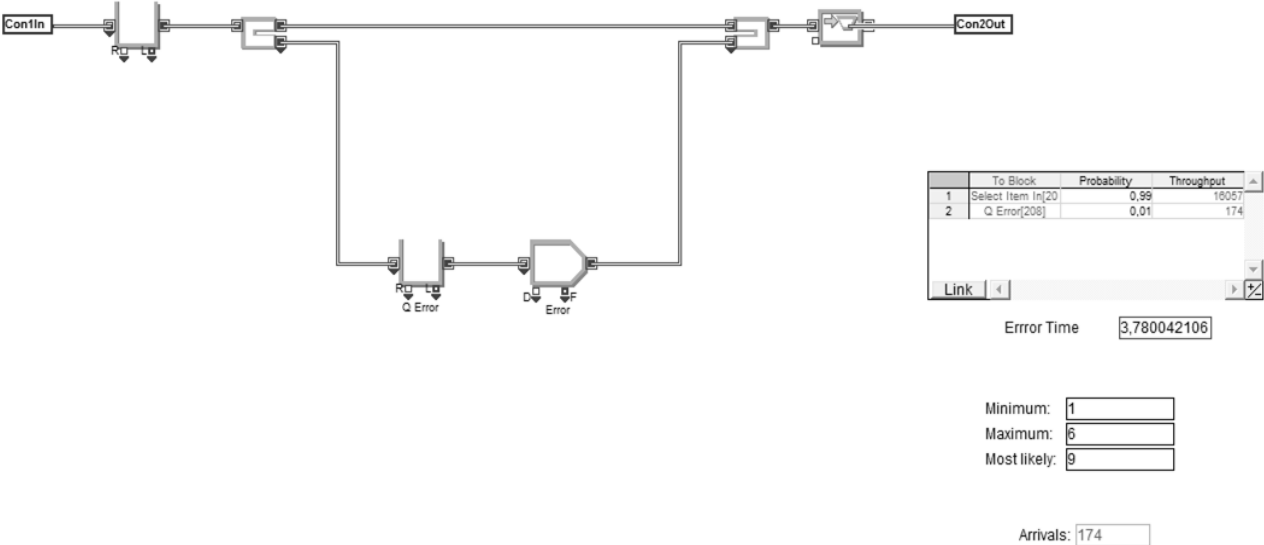


Figure 33. Hierarchical block - Error station.

The numbers extracted with the cloning tool in the error station is presented in the general appearance of the model, which is shown in Figure 34. These numbers include the probability for the error to occur, decided by probability from the select item out block in the error station. The activity operating time is decided by a triangular distribution including a minimum, maximum and most likely values.

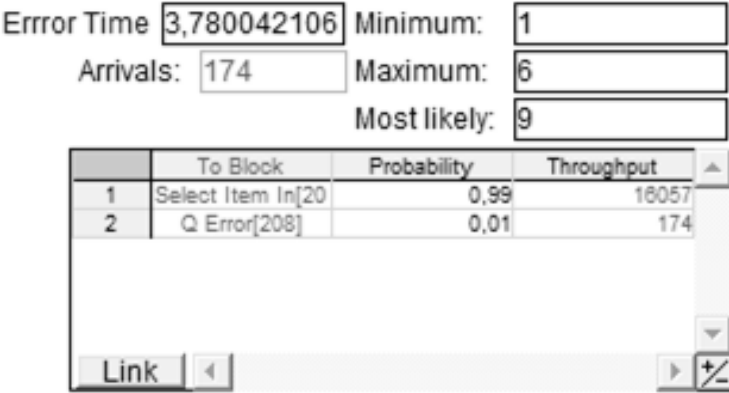


Figure 34. Cloning tool - Error station.

After the stations the hierarchical block with flow out is placed, which is presented in Figure 35. An information block is placed to store information including cycle times and time through system, a mean and variance block is placed to extend the information from the information block to include mean and variance values. This hierarchical block is the last step in the flow and ends with an exit block, which destroys and counts all the entities which has passed through the system.

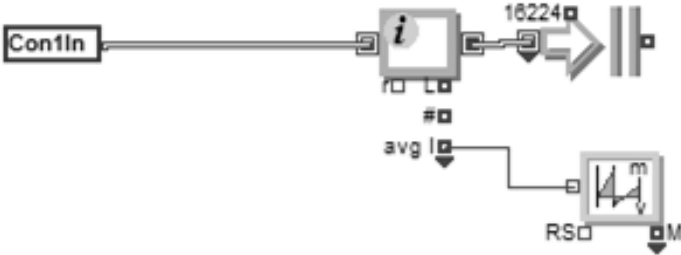


Figure 35. Hierarchical block - Flow Out.

The shift block, which decides the activity operating times is shown in Figure 36. The shifts needs to be changeable to create a changeable system and are therefore shown with the cloning tool. The shift can be changed from the general appearance of the model and currently counts according to two shifts. The shifts repeats every 24 hours and the working week is decided by the simulation setup.

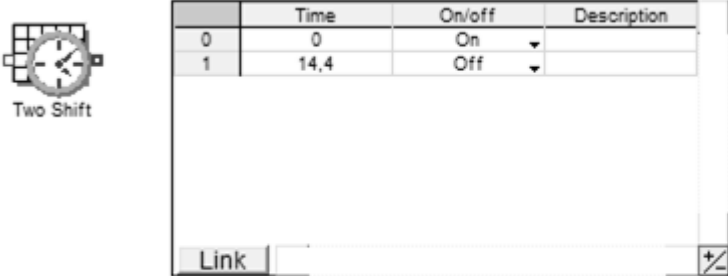


Figure 36. Cloning tool - shifts.

The first three stations are presented as parallel flow, which is combined in the fourth station, the main jig. The combining of these three stations are made in a batching queue, which is shown in Figure 37. The batching queue combines one entity from each station and queues the entities if a complete match are not achieved.

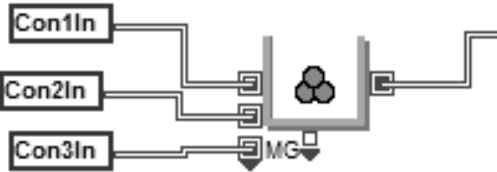


Figure 37. Batching queue.

The cloning tool are used to get changeable numbers into the general appearance of the model, which is presented in Figure 38. The changeable factors are transportation times within the stations and activity operating times for each stations divided by number of personnel, which is counted in an excel sheet for data inputs. The amount of resources to use are the combination of activities in station and error station.

	MLG	<input type="button" value="Run Simulation"/>	<input type="checkbox"/>
Time MLG	<input type="text" value="1"/>	<input type="button" value="Pause Simulation"/>	<input type="checkbox"/>
Time Transport	<input type="text" value="0,1"/>		
Resources	<input type="text" value="1"/>		
	Wing section		Main Jig
Time WS	<input type="text" value="1"/>	Time Main	<input type="text" value="1"/>
Time Transport	<input type="text" value="0,1"/>	Time Transport	<input type="text" value="0,1"/>
Resources	<input type="text" value="1"/>	Resources	<input type="text" value="1"/>
	Side Pods		
Time SP	<input type="text" value="1"/>		
Time Transport	<input type="text" value="0,1"/>		
Resources	<input type="text" value="1"/>		

Figure 38. Cloning tools - Deciding information for stations.

The results from the simulation model is presented in the general appearance using the cloning tool, which is shown in Figure 39. The presented results is cycle times decided as time between items, confidence interval, deviation , variance and total exited which is number of produced units.

Time between items (TBI)		<input type="text" value="hours*"/>
Current:	<input type="text" value="1"/>	Minimum: <input type="text" value="0,014459"/>
Average:	<input type="text" value="1,6670889"/>	Maximum: <input type="text" value="11,572785"/>
Flow 1	Total exited:	<input type="text" value="16224"/>
	Confidence interval +/-	<input type="text" value="0"/>
	Standard deviation:	<input type="text" value="0,017207852837"/>
	Variance:	<input type="text" value="0,000296110199"/>

Figure 39. Cloning tool - Result values.

The transportation time between stations is presented in the general appearance with the cloning tools, according to Figure 40. The time is changeable and gives the same time to all of the transportations between stations.

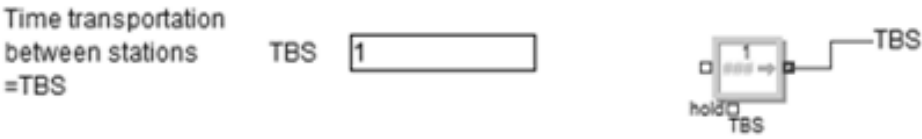


Figure 40. Cloning tool - Transportation time between stations.

To create a user-friendly simulation model the cloning tool combined with the button function was used. These buttons controls the running and animation of the simulation model. The buttons which were created are run simulation, pause simulation, animation of and animation on, which is presented in Figure 41. Resources are combined into a hierarchical block which have a similar appearance as the resource block. The button functions is combined into a hierarchical block which is labeled buttons.

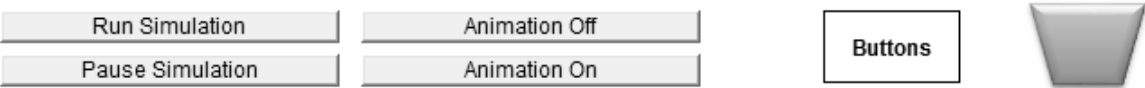


Figure 41. Cloning tool - User-friendly abilities.

The simulation setup for the simulation model has a run time of 52800 hours which is a total of ten years. The numbers of runs are one, because it is a long run instead of several runs. Hours of the day is 24 hours and the working hours are limited by the shift block and thereby needs a freedom of 24 hours. Days per week is five days to symbolize a working week and the number of days per year is 220 days, which is an ordinary working year.

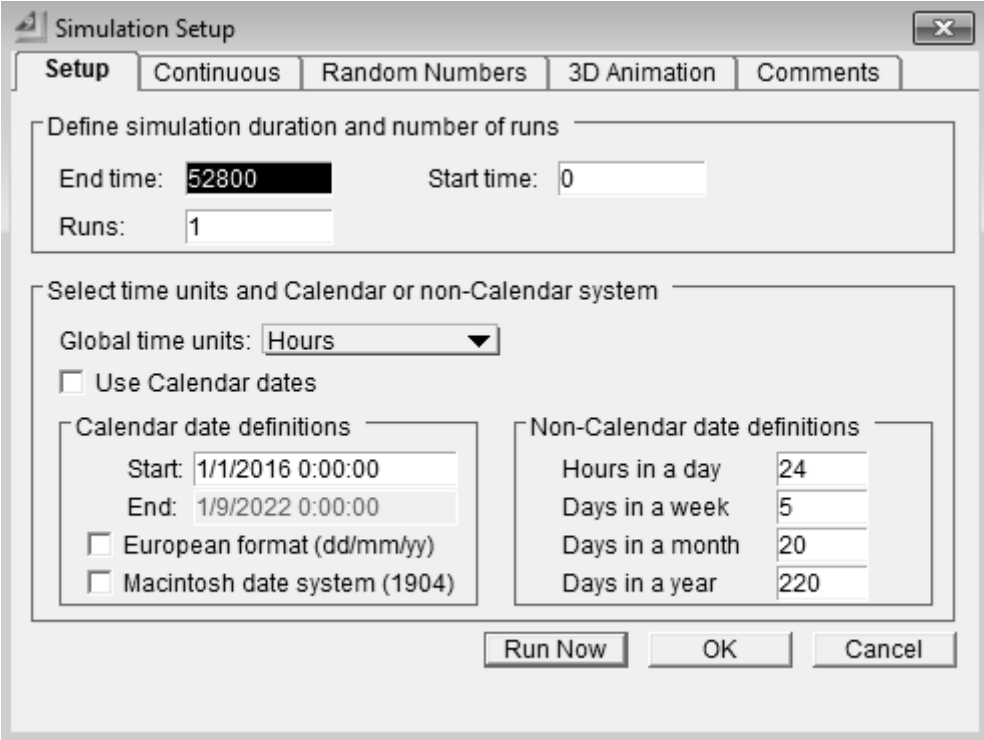


Figure 42. Simulation setup.

When the simulation model was completed and the tested the real numbers from the other master's thesis where applied into the simulation model. When applying these numbers there where continuously verification and validation.

5.1. Experimentation

The Basic condition model in ExtendSim was used in all the experiments, and were expanded with improvements and other values. Experimentations was made according to experiments in the general layout appendix 10.2, to investigate the goals of the project.

The most important of this part was to obtain accurate results and make the testing without decreasing the reliability of the model. To accomplish this the system was experimented when in steady-state and the results was taken from a long run to obtain accurate results (Robinson S. , 2014).

To experiment with the system a scenario manager was created to test different scenarios easily, which is shown in Figure 43. The scenario manager can test for several runs, different length of run and at different confidence levels. The current scenario manager are depending on the input factors which is activity operating time and transportation times between stations. The results are presented as confidence interval, deviation, number of items through system, variation and tact time. The input factors are decided in the general appearance of the model and can be different for different scenarios. Currently there are five scenarios which are used to validate the simulation model.

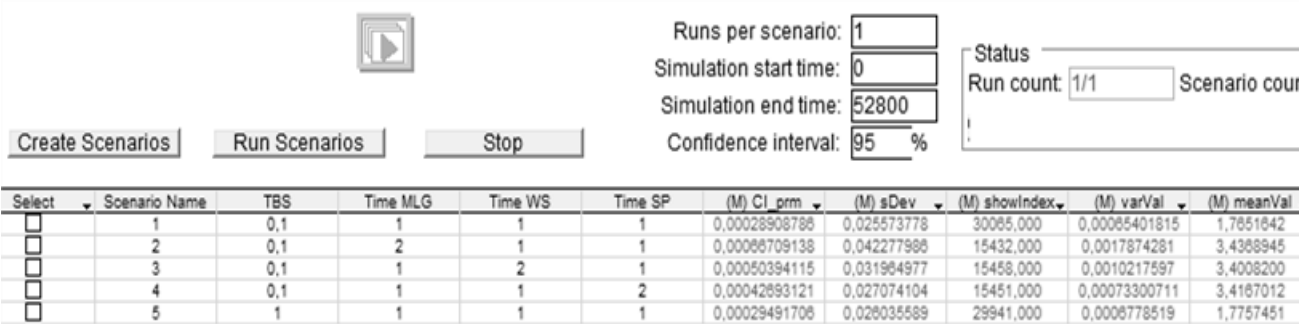


Figure 43. Cloning tool - Scenario manager.

The results from the queue matching are presented in the general appearance of the simulation model, which is shown in Figure 44. The shown values are the current , which means that the results resets after each runs and are changing as the model runs through time. The results for the unbatched items which is presented are queue length, average queue length, maximum queue length, and current waiting time, average waiting time, maximum waiting time, utilization and total cost. The total cost are not used in the experiments for this simulation model.

Length	Avg Length	Max Length	Current Wait	Avg Wait	Max Wait	Utilization
32	10,0551736652	32	50,8155850865	17,9111293441	60,4155850865	0,84705888204
29	13,987034919	30	48,3179803012	25,0473014802	57,9179803012	0,96038202675
0	0,86916562701	17	0	1,62899376145	36,6881848659	0,12570034711

Figure 44. Cloning tool - queue matching unbatched items.

The results from the queue matching for the batched items are also presented in the general appearance of the model, which is shown in Figure 45. The presented results are queue length and waiting times for the batched entities, number of arriving batched entities and how many batched entities departure from the batching queue.

Queue statistics for batched items			
	Current	Average	Maximum
Length:	0	0	1
Wait:	0	0	0
Arrivals:	2119		
Departures:	2119		

Figure 45. Cloning tool - Queue matching batched items.

6. Results

Testing and refinement from the development process 2.1 and Verification, validation & confidence from the simulation development 2.2 is combined in this chapter. The combined process starts with testing, followed by verification, validation & confidence and thereafter refinement according to the first two steps. The process repeats until the model is valid, this is presented in Figure 46.



Figure 46. Testing and refinement process.

6.1. Testing and refinement

The simulation model was verified and validated throughout the building process. To control the entire model the difference between the runs were controlled by a mean & variance block, from this block a confidence level was received. The simulation model was also controlled in the same way as the stations.

To test the model the simulation was run for different scenarios, which is shown in Figure 47. None of these scenarios used any resources or personnel for the transportations between the stations, which needs to be added to get more realistic results. The first two scenarios is an exact copy of each other and are used to test the differences between the runs. The third scenario are two shifts but the rest of the input data are the same, which should give an output with a difference of factor two. This numbers should have roughly the same output as the first two scenarios, because it have half of the personnel but double the time in shifts. The fourth scenario is a preliminary estimation of the operating times before the real values was used. The fifth suggestion have doubled the amount of time per station and doubled the amount of time in shifts which should have the same output as the first two scenarios.

Time MLG	Time WS	Time Main	Time SP	Shift	(M) Cl_prm	(M) sDev	(M) varVal	(M) meanVal	(M) Totalproduced	(M) AveLQMa
135,85	110,75	157,7	125,3	7,2	0,35027088	1,7470975	3,0523497	525,24982	99,000000	7,9452088
135,85	110,75	157,7	125,3	7,2	0,36483378	1,8187374	3,3078058	525,57048	99,000000	7,9348888
135,85	110,75	157,7	125,3	14,4	0,018772051	0,11967253	0,014321515	262,87024	199,000000	16,018966
280	250	360	180	14,4	0,030388292	0,14173615	0,020089136	800,15211	87,000000	12,363871
271,7	221,5	315,4	250,6	14,4	0,048108509	0,23995787	0,057579781	525,90270	99,000000	7,9209865

Figure 47. Output - Scenario manager.

The results from the queue batching is presented in Figure 48 and shows the results from scenario one. The batching queues are after the stations which creates a zero value to be the bottleneck, and high values to be overproduction.

Length	Avg Length	Max Length	Current Wait	Avg Wait	Max Wait	Utilization
0	0	1	0	0	0	0
28	12,7888570549	27	9701,13676901	4895,9846777	9701,13676901	0,96497443182
10	4,38985805301	10	4036,21559408	2030,0760429	4036,21559408	0,90498484848

Figure 48. Output - Queue batching.

To make the number of personnel included in the simulation without the need of implementing personnel an excel sheet which counts the time for the station were made, the equation (1) is presented below.

$$Time\ station = Process\ time / Personnel / Number\ of\ activities\ in\ station \quad (1)$$

The number of personnel has a minimum of two because the operations includes moving large object which needs at least two people. When the simulation model was tested the model was used to identify bottlenecks, which were made from the scenario manager combined with the batching queue results, shown in Table 2. The main station has its queue before the station which means that it should have a value of zero, otherwise it is a bottleneck, and the other three stations has its queue after the stations and are a bottleneck if the value zero is obtained. The average queue length was used and the lowest value of the three ingoing stations into the batching queue are the primary bottlenecks of those three, which is the MLG. The other values should be investigated after the MLG.

The other master's thesis used this areas combined with other suggestions to present improvement suggestions which will be tested.

Table 2. Input-Output iteration.

Station	Process time	Personnel	Time station	Shift	Avg QueueLength	TotalProduced/year
MLG	271,7	2	135,85	1	0	
WS	221,5	2	110,75	1	12,8	
Main	315,4	2	157,7	1	8	
SP	250,6	2	125,3	1	4,4	
Total						9,9
Maximum cycle time						517
Cycle time Average						526
Minimum cycle times						544

6.2. Improvement suggestions

When an improvement suggestion was received from the other master's thesis it was tested in the simulation model, which later was validated, verified and a confidence of the model was created. The improvement suggestions was tested as an iterative process and included communication with the other master's thesis, where the process is presented in Figure 49. The iteration also included results and refinement ideas to optimize the improvement suggestions into relevant solutions for the project. The iteration created a possibility to reach the aim of the project and the goals for this master's thesis.

This process started with an analysis of the bottlenecks followed by tests in the simulation model regarding eliminating bottlenecks step by step as improvement suggestions to the system. Afterwards there were testing regarding improvement suggestions from the other master's thesis. Lastly the step by step suggestions were used to analyze the improvement suggestions from the other master's thesis.

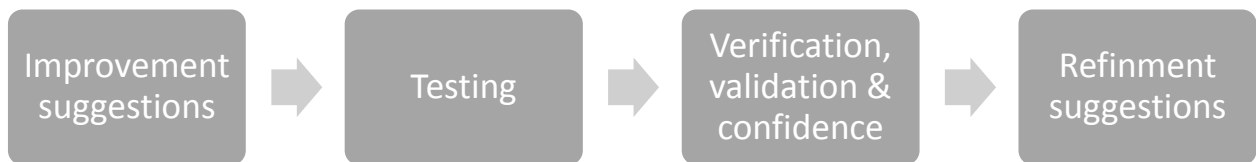


Figure 49. Testing and refinement for improvement suggestions.

When the testing and refinement was finished an analysis of the simulation was made by performing several tests with the simulation model. This testing involved a further investigation of the bottlenecks. The standard deviation in the tests are low, which creates a high confidence in the result.

The Main was investigated to be the primary bottleneck according to testing and refinement chapter 6 and therefore the model was tested by increasing the Main station with one extra in personnel. The result of this are an increase of 1, 5 aircrafts per year and a value of zero in the average queue length which shows that the Main is no longer a bottleneck. The non-increasing values for the other queues shows that the increasing of Main has not affected the previous stations. The results is also presented in Table 3.

Table 3. Test to increase capacity of Main.

Station	Process time	Personnel	Time station	Shift		Avg QueueLength	TotalProduced/year
MLG	271,7	2	135,85	1		0	
WS	221,5	2	110,75	1		12,8	
Main	315,4	3	105,1333333	1		0	
SP	250,6	2	125,3	1		4,4	
Total							11,5
Maximum cycle time							479
Cycle time Average							453
Minimum cycle times							438

To verify and validate the simulation model further the model was tested with two shifts instead of one shift. The result of this test are that the number of produced aircrafts per year are doubled and that the cycle time are half of the value as with one shift. The queue length are also doubled which are logical results and shows that the simulation model are performing in steady

state. When the results of these tests were logical it created a verification and validation of the simulation model.

As seen in the first test presented in Table 2, the WS has a high average queue length. Therefore a test was performed to see the change in output if the WS were decreased to one in personnel, this suggestion are not possible to implement and are only to verify the simulation model. The result of this test are presented in Table 4 and results in a decrease of 5, 5 aircrafts per year and results that the WS becomes the primary bottleneck instead of the Main, because the WS receives the value zero. This verifies the WS to be the least bottleneck and thereby the station with the most overproduction. The queue length of MLG and SP increase to a large number which shows that this suggestion causes WS to be a larger bottleneck than the system had before this test.

Table 4. Test to decrease capacity of WS.

Station	Process time	Personnel	Time station	Shift		Avg QueueLength	TotalProduced/year
MLG	271,7	2	135,85	2		44,6	
WS	221,5	1	221,5	2		0	
Main	315,4	2	157,7	2		0	
SP	250,6	2	125,3	2		54,6	
Total							14,2
Maximum cycle time							383
Cycle time Average							369
Minimum cycle times							382

The following test was to explore and understand the differences if one station separated its work into two activities in the same flow. This results in two activities in a continuous flow which have half of the operating time each, which is presented in Figure 50.

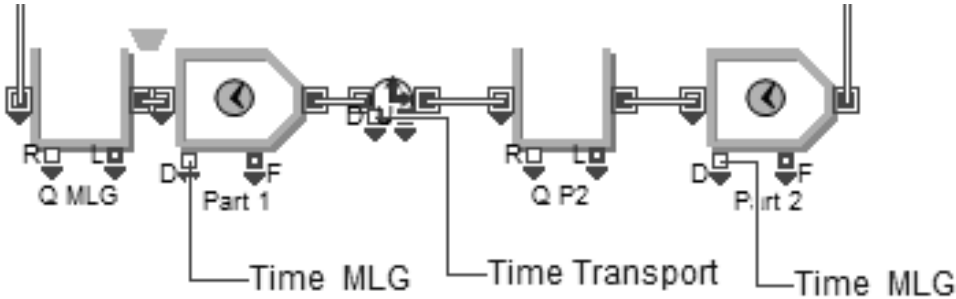


Figure 50. Station increased to two activities.

This test uses two shifts and the double amount of activities, which thereby doubles the amount of personnel. The result are that the number of aircrafts per year are almost four times the output of Table 2 , which are presented in Table 5 and were also the logical result and thereby verifies the model further. The reason to why the results are almost multiplied by four are because when the activities are separated a transportation is added to move the entity from one activity to the next.

Table 5. Test to add an activity to each station and keep two shifts.

Station	Process time	Personnel	Number of activities	Time station	Shift		Avg Queue	TotalProdu
MLG	271,7	2	2	67,925	2		0	
WS	221,5	2	2	55,375	2		49,3	
Main	315,4	2	2	78,85	2		29,9	
SP	250,6	2	2	62,65	2		18,1	
Total								38,9
Maximum cycle time								143,8
Cycle time Average								134,5
Minimum cycle times								123,5

To test the simulation model further a test is performed with one shift and two activities in each station. This results in a little lower result than double shift and one activity, which is because of the transportation between the activities. This verifies and validates the model as it appear logical.

The MLG is the largest bottleneck of the three ingoing stations to test to see if the MLG are the primary bottleneck a test was performed with an increase of number of activities in the MLG. The results from this test are that the number of produced aircrafts per year is the same as when the MLG has not been increased, which shows that the MLG is not the primary bottleneck as expected. The batching queues increases in value and the main queue increases, which further proves that the Main is the primary bottleneck. The SP has the value of zero which means that the SP is the third bottleneck which is consisted with the earlier results. The results from this test are presented in Table 6.

Table 6. Test if MLG is the primary bottleneck by increasing number of activities in MLG.

Station	Process time	Personnel	Number of activities	Time station	Shift		Avg QueueLength	TotalProduced/year
MLG	271,7	2	3	45,28333333	1		44	
WS	221,5	2	2	55,375	1		15,7	
Main	315,4	2	2	78,85	1		24,3	
SP	250,6	2	2	62,65	1		0	
Total								19,6
Maximum cycle time								287,6
Cycle time Average								264,3
Minimum cycle times								241,7

To further test the simulation model the personnel are two for every station and number of activities are two except for Main which have three activities. This test was similar to the test before which included a personnel of two except for Main which have personnel of three. This test is expected to have almost the double output as the similar test performed before. The result of this step was that the output are almost doubled and thereby verify and validate the model further. This was also a verification that the Main is the primary bottleneck. In this test an increase of number of activities in station with one in Main results in an increase of three aircrafts per year.

To investigate if the MLG are the secondary bottleneck a test was performed with an increase in number of activities on both the Main and the MLG to three activities in each station. The result are an increase of two aircrafts per year for increasing the activities in MLG, where the results are presented in Table 7.

Table 7. Test to investigate if MLG is the primary bottleneck.

Station	Process time	Personnel	Number of activities	Time station	Shift	Avg QueueLength	TotalProduced/year
MLG	271,7	2	3	45,3	1	45,9	
WS	221,5	2	2	55,4	1	15,7	
Main	315,4	2	3	52,6	1	0	
SP	250,6	2	2	62,7	1	0	
Total							24,5
Maximum cycle time							238,7
Cycle time Average							212,1
Minimum cycle times							173,4

To verify this test another test was performed by increasing from one shift to two shifts, which gives the double results in aircrafts per year and a double amount in queue length. This results in a verification because the output contain logical results.

These tests combined were used to get a recommendation to the other master's thesis which are verified, validated and includes a high confidence level. These tests resulted that the recommendation from the testing and refinement chapter 6 has been verified, validated and a high confidence level is received. This verification process included an iteration where the other master's thesis received information continuously so they will receive a high confidence level in the recommendations.

6.3. Improvement suggestions as an iterative process

After the verification process and the step by step suggestions, the iterative process to receive the best result began.

The basic principles of the simulation model and the bottlenecks from the start-up model where given in the chapter testing and refinement 6. These results were analyzed combined with creating an understanding for the other master's thesis and thereby understand the possible improvements. The constraints from Table 10 in chapter 6.4 where used to limit the concepts to make realistic solutions. The ongoing process where divided into set of concepts included four to seven concepts which where run in the simulation model. The simulation runs where verified and validated continuously. This process where divided into different sets to create a number of results to analyze for the other master's thesis and to get a manageable simulation process.

Set number one consisted of creating further understanding of the simulation model for the other master's thesis.

Set number two was concepts from the other master's thesis with a goal to create 120 aircrafts per year and thereby reaching a cycle time value of 13, 2 hours for time station when it is one shift and 26, 4 hours for time station when it is two shifts. This was almost reached in several suggestions and later tested in the simulation model.

Set number three consisted of an improvement of the concepts from analyzing concepts from set number two including improvements and levelling, thereby decreasing overproduction at a station. The best concept is presented in Table 8 which have a relative leveled flow and has an output of almost 109 aircrafts per year.

Table 8. Best concept from set number three.

Station	Process time	Personnel	Number of activities /station	Time station	Shift	Avg QueueLength	TotalProduced/year
MLG	271,7	2	5	27,17	1	2	
WS	221,5	2	4	27,69	1	0	
Main	315,4	4	3	26,28	1	0	
SP	250,6	3	3	27,84	1	1	
Total							108,7

To get a continuous flow a suggestion of a line concept was created where the station is placed after each other which eliminate the need of a station which combines the input stations. The time for assembly the parts called Main is divided into the other stations equally. This flow is shown in Figure 51 and starts with MLG, thereafter WS and last is SP which is the engine area.

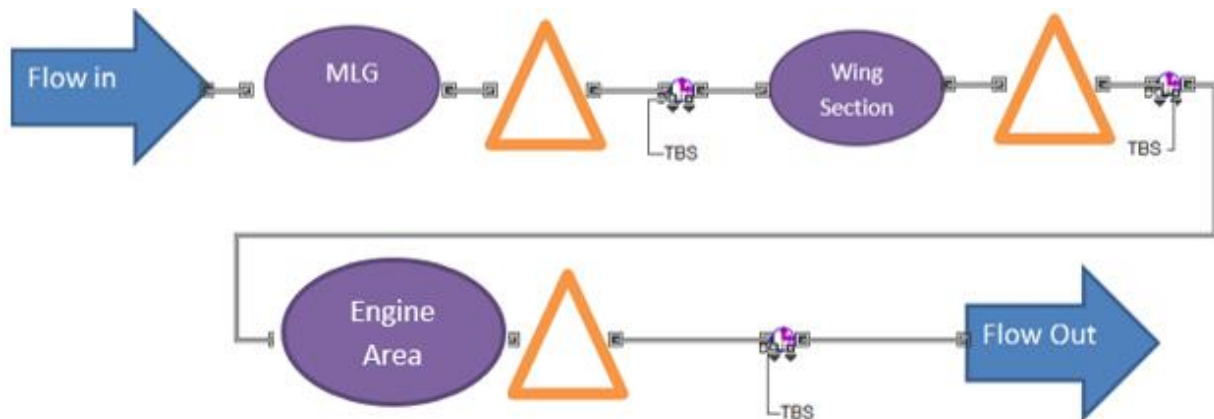


Figure 51. Concept with one line.

The concept generating process was similar to the process when generating concepts according to the jig based layout. To reach the goal of 120 produced aircrafts per year a goal of cycle times for each station was set. When the goal of cycle time was reached in the excel sheet it was tested in the simulation model. This started an iteration which ended with a solution according to Table 9, which results in 103 produced aircrafts per year and a levelled flow.

Table 9. Line concept.

Station	Process time	Personnel	Number of activities /station	Time station	Shift	Avg QueueLength	TotalProduced/year
MLG	350,3	4	3	29,19166667	2	0	
WS	338,5	4	3	28,20833333	2	0	
SP	329,3	4	3	27,44166667	2	0	
Total							103

6.4. Ramp-up

One process to receive a ramp-up from ten to 120 aircrafts per year is to step by step eliminate the bottlenecks until satisfying results are obtained. These tests can be compared with the results from the improvements suggestion from the other master's thesis. Constraints from the other master's thesis were used, and are presented in Table 10.

Table 10. Constraints received from the other master's thesis.

Delimitations
Number of activities/substations at WS 1-58
Number of activities/substations at SP 1-59
Number of activities/substations at MLG 1-98
Number of activities/substations at Main 1-160
Number of workers at WS 2-3 per activity
Number of Workers at MLG 2 per activity
Number of Workers at SP 2-3 per activity
Number of workers at Main 2-4 per activity
Number shifts 1-2, only complete shifts permitted
If a station will be split up, operation time will be equally split up

The first step was to eliminate the first bottleneck which were to increase the Main with one in personnel, it is a quicker and cheaper solution to increase personnel instead of increasing an activity and were therefore used as the primary solution. At this stage the shifts was one shift but can be doubled to obtain the double amount of output. The result of increasing the Main station with one in personnel results in an increase from ten aircrafts per year to 11, 5 aircrafts per year. The next step was to increase every station to two activities to faster get a larger amount of aircrafts per year. This result in a produced amount of 22, 5 aircrafts per year. The current bottleneck is MLG and thereby the activities is increased to three, because this station has the maximum number of personnel. The result of this test are 24, 5 aircrafts per year, at this stage the current bottleneck is WS and is thereby tested for an increase to three in personnel which gives an output of 27, 8 aircrafts per year. The current bottleneck is WS and an increase of capacity of WS will result in a similar flow as the starting test. When the Main has an extra

capacity than the others, the other has the lowest average queue lengths and are thereby the most leveled flow, when this is taken into consideration the system increases of one personnel in Main and one personnel in WS. This results in 33, 5 aircrafts per year and an increase of batching queues. The MLG is increased with one station again, which results in 36, 5 aircrafts per year and an increase of batching queues. To get a ramp-up the steps only includes eliminating bottlenecks step by step. The SP is the current bottleneck and thereby increased with one activity because maximum in personnel is received. This results in an output of 38, 8 aircrafts per year and the current bottleneck is the Main. The Main is increased with one activity and the result is 41, 5 aircrafts per year and the current bottleneck is WS, thereby changed to four activities and two in personnel at each station. This result in 44 produced aircraft per year and a current bottleneck in MLG. The MLG is increasing with one station and results in 54, 2 aircrafts per year.

The step by step improvements are presented in Table 11 and includes the double amount of produced aircrafts per year when double shifts are used.

Table 11. Ramp-up step by step.

<i>Starting with two personnel at each activity and one activity at each station</i>	Aircrafts per year	
	one shift	two shifts
<i>Start</i>	10	20
<i>Increased to three in personnel at Main</i>	11,5	23
<i>Increased to two activities in each station</i>	22,5	45
<i>Increased to three activities in MLG</i>	24,5	49
<i>Increase of personnel in SP</i>	27,8	55,5
<i>Increase to three in activities in WS and four in personnel in Main</i>	33,5	67
<i>Increase of one activity in MLG</i>	36,5	73
<i>Increase of one in activity for SP</i>	38,8	77,5
<i>Increase of one station in Main</i>	41,5	83
<i>Increase of one station in MLG</i>	54,2	108,5

This results in a levelled flow shown in Table 12 and the capacity are 108, 5 aircrafts per year which is relative close to 120 aircrafts per year as it is a levelled flow. Because this suitable levelled flow are obtained it is recommended to improve the system instead of changing the capacity in number of activities and personnel.

Table 12. Levelled flow.

Station	Process time	Personnel	Number of activities	Time station	Shift		Avg QueueLength	TotalProduced/year
MLG	271,7	2	5	27,17	1		0	
WS	221,5	2	4	27,6875	1		0,02	
Main	315,4	4	3	26,28333333	1		0	
SP	250,6	3	3	27,84444444	1		0,95	
Total								54,2

To create a ramp-up of the production system in the iterative process two steps were decided together with engineers at Saab, which is 20 aircrafts per year and 40 aircrafts per year. To

receive these results a goal of tact time has been calculated and used together with different parameters. The parameters includes minimizing personnel or activities for both one and two shifts, where the tests is presented in Table 13.

Table 13. Ramp-up tests.

Produce per year	Layout	Focus	Shifts
40	Jig	Minimise personnel	1 shift
40	Jig	Minimise personnel	2shifts
40	Jig	Minimise activities	1 shift
40	Jig	Minimise activities	2 shift
20	Jig	Minimise personnel	1shifts
20	Jig	Minimise personnel	2 shift
20	Jig	Minimise activities	1 shift
20	Jig	Minimise activities	2shifts
40	Line	Minimise personnel	1 shift
40	Line	Minimise personnel	2shifts
40	Line	Minimise activities	1 shift
40	Line	Minimise activities	2 shift
20	Line	Minimise personnel	1shifts
20	Line	Minimise personnel	2 shift
20	Line	Minimise activities	1 shift
20	Line	Minimise activities	2shifts

The jig concept was first run to produce 40 aircrafts per year, the first test where to minimize the number of activities within the margins of calculated tact time, when using two shifts. The result is presented in Table 14 and give a result of 40 aircrafts per year.

Table 14. Jig concept minimizing number of activities, two shifts.

Station	Process time	Personnel	Number of activities	Time station	Shift	Avg QueueLength	TotalProduced/year
MLG	271,7	2	2	67,925	2	16,4	
WS	221,5	3	1	73,83333333	2		0
Main	315,4	4	1	78,85	2		14
SP	250,6	2	2	62,65	2		35
Total							39,9

The next test included minimizing personnel when using two shifts, which is presented in Table 15. The result of this is 40 produced aircrafts per year.

Table 15. Jig concept minimizing personnel two shifts.

Station	Process time	Personnel	Number of activities	Time station	Shift	Avg QueueLength	TotalProduced/year
MLG	271,7	2	2	67,925	2	0	
WS	221,5	2	2	55,375	2	52	
Main	315,4	2	2	78,85	2	32	
SP	250,6	2	2	62,65	2	19	
Total							39,7

The next test included one shift and minimized the number of activities, which is presented in Table 16. The result of this is 37 produced aircraft per year.

Table 16, Jig concept minimizing number of activities, one shift.

Station	Process time	Personnel	Number of activities	Time station	Shift	Avg QueueLength	TotalProduced/year
MLG	271,7	2	4	33,9625	1	40	
WS	221,5	3	2	36,91666667	1	24	
Main	315,4	4	2	39,425	1	0	
SP	250,6	3	3	27,84444444	1	0	
Total							37,1

The next test included one shift and minimized personnel, which is presented in Table 17. The result of this is 42 produced aircraft per year.

Table 17. Jig concept minimizing personnel, one shift.

Station	Process time	Personnel	Number of activities	Time station	Shift	Avg QueueLength	TotalProduced/year
MLG	271,7	2	4	33,9625	1	17	
WS	221,5	2	3	36,91666667	1	0	
Main	315,4	3	3	35,04444444	1	0	
SP	250,6	3	3	27,84444444	1	68	
Total							41,9

To reach the goal of 20 produced aircrafts per year the same testing approach as to reach 40 produced aircrafts per year were used.

One shifts give half the value of two shifts the minimizing of activities and personnel for 40 produced aircraft can be used. If Table 14 is used for one shift it results in 20 produced aircrafts per year and if Table 15 is used for one shift it produces 20 aircrafts per year. To create a system for one shift both the activities and personnel needs to be minimized, which is presented in Table 18 and results in 20 produced aircrafts per year.

Table 18. Jig concept minimizing personnel and activities, one shift.

Station	Process time	Personnel	Number of activities	Time station	Shift	Avg Queue	Total Produced/year
MLG	271,7	2	1	135,85	2	0	
WS	221,5	2	1	110,75	2	26	
Main	315,4	2	1	157,7	2	16	
SP	250,6	2	1	125,3	2	9	
Total							19,9

To get a ramp-up of the line concept the same development process where used as when getting a ramp-up of the Jig concept. All of these tests produced levelled flow without queues and therefor it is not presented as a result. The first tests has a goal of producing 40 aircrafts per year. The first test has a minimized number of activities when using two shifts, which is presented in Table 19. The result if this are 36 produced aircrafts per year.

Table 19. Line concept minimizing number of activities, two shifts.

Station	Process time	Personnel	Number of activities	Time station	Shift	Total Produced/year
MLG	350,3	4	1	87,575	2	
WS	338,5	4	1	84,625	2	
SP	329,3	4	1	82,325	2	
Total						35,9

The next test included two shifts and minimized personnel, which is presented in Table 20. The result of this is 35, 5 produced aircraft per year.

Table 20. Line concept minimizing personnel, two shifts.

Station	Process time	Personnel	Number of activities	Time station	Shift	Total Produced/year
MLG	350,3	2	2	87,575	2	
WS	338,5	2	2	84,625	2	
SP	329,3	2	2	82,325	2	
Total						35,5

The next test included one shift and minimized the number of activities, which is presented in Table 21. The result of this is 35, 5 produced aircraft per year.

Table 21. Line concept minimizing number of activities, one shift.

Station	Process time	Personnel	Number of activities	Time station	Shift	Total Produced/year
MLG	350,3	4	2	43,7875	1	
WS	338,5	4	2	42,3125	1	
SP	329,3	4	2	41,1625	1	
Total						35,4

The next test included one shift and minimized personnel, which is presented in Table 22. The result of this is 39, 5 produced aircraft per year.

Table 22. Line concept minimizing personnel, one shift.

Station	Process time	Personnel	Number of activities	Time station	Shift	TotalProduced/year
MLG	350,3	3	3	38,92222222	1	
WS	338,5	3	3	37,61111111	1	
SP	329,3	3	3	36,58888889	1	
Total						39,5

The following tests where to reach the ramp-up step of 20 aircrafts per year. The first test was made with both personnel and activities minimized and includes two shifts to reach the low number, which is presented in Table 23. The result is 18 produced aircrafts per year.

Table 23. Line concept minimizing personnel and number of activities, two shifts.

Station	Process time	Personnel	Number of activities	Time station	Shift	TotalProduced/year
MLG	350,3	2	1	175,15	2	
WS	338,5	2	1	169,25	2	
SP	329,3	2	1	164,65	2	
Total						17,8

Because of that one shifts gives half the value of two shifts the minimizing of activities and personnel for 40 produced aircraft can be used. If Table 19 is used for one shift it results in 18 produced aircrafts per year and if Table 20 is used for one shift it produces 18 aircrafts per year.

6.5. Possible improvements to the recommended suggestion

The largest variations in the system are the triangular distributions in the error stations and when the serial production has been run for some time the time in the error stations should be improved. Therefore the system is tested for an improvement where the result is a triangular distribution of one hour as the minimum value, which is the same as before the improvement. The maximum value is six hours, which where the most likely before and the current most likely is three hours, which is in the middle of the minimum and maximum value. The new distribution in the error stations improves the system with 0, 5 aircrafts per year when two shifts are used. To further improve the system, it is tested for several percentages of improvement to the system. A result of the percentage improvement is presented in Table 24 and have ten percent improvement to MLG, 11 percent improvement in WS, five percent improvement in Main and ten percent improvement in SP which results in a produced volume of 121 aircrafts per year.

Table 24. Improvements of error stations and a percentage of improvement on the activities.

	Station		Process time	Personnel	Number of activities	Time station	Shift	Avg QueueLength	TotalProduced/year
10%	MLG	0,9	268,983	2	5	24,20847	2	3,46	
11%	WS	0,89	219,285	2	4	24,39545625	2	4,438	
5%	Main	0,95	312,246	4	3	24,719475	2	0,11	
10%	SP	0,9	248,094	3	3	24,8094	2	0,07	
9%	Total								120,9

The goal are reached, but as this master's thesis does not include any practical suggestions, other suggestions to meet the goal were investigated.

Because the WS has an extra personnel to use the system is tested for an increase of personnel and a decrease in activities instead of the percentages in change. This results that the system has an improvement of zero per cent in the WS and has the same amount of output, which is shown in Table 25.

Table 25. Changing capacity of WS.

	Station		Process time	Personnel	Number of activities	Time station	Shift	Avg QueueLength	TotalProduced/year
10%	MLG	0,9	268,983	2	5	24,20847	2	4	
0%	WS	1	219,285	3	3	24,365	2	10	
5%	Main	0,95	312,246	4	3	24,719475	2	0,3	
10%	SP	0,9	248,094	3	3	24,8094	2	0,1	
6%	Total								120,9

The transportation between the activities within the stations are currently two hours which is also something that can be decreased or eliminated. The end result, which is presented in Table 12 has been improved by limiting the transportation time within the station to one hour. This results in an improvement of 2, 5 produced aircrafts per year compared to Table 12 and are presented in Table 26.

Table 26. Limiting transportation time within stations to one hour.

Station	Per cent	Process time	Personnel	Number of activities	Time station	Transportationtime	Shift	Avg QueueLength	TotalProduced/year
0% MLG	1	268,983	2	5	26,8983		1 2	8,06	
0% WS	1	219,285	2	4	27,410625		1 2	0,28	
0% Main	1	312,246	4	3	26,0205		1 2	0	
0% SP	1	248,094	3	3	27,566		1 2	0,04	
0% Total									111,6

The current bottlenecks is WS and SP and therefore it was tested for zero in transportation time within stations. This test resulted in an increase of two aircrafts per year and are presented in Table 27. The result is 113, 5 produced aircrafts per year without a percentage of improvements and have a relative levelled flow.

Table 27. Limiting transportation time within stations depending on bottlenecks.

Station	Per cent	Process time	Personnel	Number of activities	Time station	Transportationtime	Shift	Avg QueueLength	TotalProduced/year
0% MLG	1	268,983	2	5	26,8983		1 2	0	
0% WS	1	219,285	2	4	27,410625		0 2	6,6	
0% Main	1	312,246	4	3	26,0205		1 2	0	
0% SP	1	248,094	3	3	27,566		0 2	4	
0% Total									113,6

7. Discussion

This chapter is a discussion of the master's thesis and project. The discussion is about how the method was used, about the theory which was used in the master's thesis and lessons learned.

7.1. Method

The product development process (Ulrich & Eppinger, 2012) was chosen because the participant in this project has used it before and considers it helpful. Because of this earlier knowledge it was easier to understand the steps and activities, which helped the project to go on more smoothly. The simulation process was used to specify the development process to collaborate with the simulation model. The GANTT-chart clarified the big picture of the project and gave a better understanding of how to use the time. The milestones were considered as latest possible and were solid in the project, but when extra time occurred the next step was started earlier. Corrections of the report were left to wait for the response and were corrected when response was achieved. This made it possible to proceed with the work simultaneously as waiting for response.

It is difficult to fully follow the development process because it is made for product development and not for simulation modelling. Some of the topics contain very little or no information, but it is still a good development process because it contains everything that the project should contain. In this project some steps were not worked through because they were not relevant to the project but the steps were always controlled to see if some work was needed. This way of work was effective because it was easy to know when work was needed on a step and the project had structure when following a plan from a relevant source.

By specifying the development process to make it adapted to the upcoming simulation model a simulation development process was implemented. It helped to improve the detail level in the development process and to create specific instruction for the simulation model. It was especially useful to create detailed instruction before the detail design, because it was later used when building the simulation model.

The last step in the development process was changed from production ramp-up, because the product is not solid, which made this step unnecessary. Instead a step with testing improvement suggestions was added to separate the testing refinement for model and testing & refinement for project. This made the process more clear and created a milestone for the basic model, and when the basic model was tested and refined the testing of improvement suggestions worked more smoothly and in better cooperation to the real-world system.

7.2. Planning

When establishing the aim, the project was clarified and gave the following work more structure. By establishing constraints the possibilities to get the project ready in time increased, when not focusing on what is less important there were more time to things that matters.

The planning step consisted of creating a plan which made it a lot easier to know what to do and the time available. This made it possible to early decide on what level the working areas should be and therefore be ready in time with the important parts included.

7.3. Conceptual modelling

When creating the specification the most useful was to clarify what the demands are and what the requirements are, to know which areas are the most important and thereafter use most of the time on the demands to fulfill them in time.

Brainstorming which only involves one person is different than being in a group; it is still useful but includes more narrow ideas. From this experience it is recommended to be a group of people when brainstorming to get ideas in a wider perspective.

The first brainstorming session resulted in very few blocks and simplifications, which resulted in need for more information. The need for more information resulted in a theory study, the following brainstorming session resulted in a lot more blocks, simplifications and ideas on how to create the model, because of the theory study. Without the theory study it would have been problematic to go on with the work, because without the extra information it would have been difficult to increase the level of detail and improve the concept ideas.

Not having a concept scoring in this thesis is because the concepts mainly consists of information and suggestions. To have a scoring it needs to be several different concepts which this thesis do not include. Several concepts would take a lot of time, a need of information and would probably end up with the same result. When not having a concept scoring it is relevant not to have a concept selection.

This was an opened minded start with the conceptual modelling, because this part was made with very little amount of information about the real-world system. It was successful to start with concept development without the information and instead focusing on how to build a simulation model in the selected software, and later develop with details regarding the real-world system in the system-level design. When working accordingly it was possible to wait for more information about the real-world system without extending the milestones, which was useful because it took time to get information.

7.4. System level design

The building plan of the real-world system was implemented into the concept model, which made it easy to quickly get a clear picture of the system. When creating the conceptual model it was easier to understand the present suggestions and to describe them to others. This was helpful in the rest of the work, because it was easy to get inspiration when it was possible to watch a suggestion of the result. When making a list of functions it was easy to work systematically, because it was easy to change to work with another function when needed. It was needed when one function gave inspiration the other functions and when they were affecting each other.

The choice to start with the fuselage was good because it narrowed down the possible solutions and therefor made it possible to work successively and have more focus. It might have been good to focus on another part as well because most of the advantages from it was the narrowing.

An easily changeable system was desired to be able to test a lot of scenarios and improvement suggestions. To achieve this a lot of preliminary solutions including databases where made without unnecessary increasing complexity of the model.

The decision to separate the flow made the simulation and the continuous work simplified, because it separated the work and made it possible to work more successively and thereby it improved the collaboration with the other thesis.

When the stations were worked through both one-by-one and simultaneously it was possible to work through one station until all information from the other thesis was implemented. Thereafter work through the next station and then go back to a station when more information where applied. When making this part simultaneously as the detail design it was possible to work while waiting for information.

7.5. Detail design

It was successful to use the general layout when performing the detail design, because when the variables of the model was set they were easy to insert into the model.

Starting with the model coding before the data collection was necessary to decrease the waiting time, it was also suitable because it gained understanding of the system and the need in type of data. The negative part of this was that it needed some remodeling when the data input was changed.

To start with the experimentation before the other steps was ready was necessary because when creating the simulation model there where need of continuously verification and validation and to do that experimentation was needed.

7.6. Data collection & analysis

When not doing all of the data collection a lot of time where saved, but when not performing the data analysis it included some waiting. The end result is that it was good to have the other master's thesis to do most of the data collection to get more time to develop the simulation model and run as many scenarios as possible. The iteration and communication was necessary to get the correct type of data and to gain a confidence in the input data. The verification and validation of the data was made from communication with engineers and aircraft builders at Saab, combined with verified and validated documents. This created as high confidence level as possible for the upcoming system.

The VSM created an overall understanding of how building of a military aircraft are made. The mapping of the processes was useful because the VSM created numbers which were used to verify the data from the data collection.

The separation of the data according to type of jigs and fixtures where suitable for creating a changeable simulation model.

7.7. Simulation model

When everything was planned in advance it was easy to create a clear model because the end result were established. It was also easy to create the model from the list of functions and to use the preliminary solutions, because it was only to insert them into the simulation model.

By working top-down it was possible to start modelling earlier and insert the known building steps. By using the extraction of the hierarchical blocks one by one it added to the possibility to start earlier. When the other master's thesis had details on a station the simulation model could be improved. This was made continuously and therefore made it easy to work parallel

with the other thesis. When building the model early, there was more time to verify the model and to create a model which are changeable.

The labeling in the simulation model simplified both the model building and experiments, because it made it easier to communicate with others and to understand the connection to the real-world system. When receiving recommendations from others they usually use the existing names of steps and components and not station one, station two and so on, this is why the labeling created an easier understanding and communication.

Limiting of rules was made but where difficult, because it is usually a request to increase the level of detail so the model appear more similar to the real-world system. This can cause a decrease in reliability of the output values. The hierarchical block made it possible to extract a block with more information and still keep the model clean and simple. Batching queue instead of a batching and a queue simplified the building and limited the need of blocks.

The use of the cloning tool has been extended from the expected from system level design and has been a useful tool. The cloning tool extraction has been used instead of database to control shifts, safety margin and to control which suggestion should be used in the stations. This resulted in a lot of functions and results presented in the general appearance of the model which gives a quick overview of the system.

The scenario manager has been used instead of the database to control the operating time for the activities. This tool has also been used as a tool for output data when verifying and validating the simulation model. The scenario manager is a suitable tool, easy to change and creates a quick understanding of the simulation model.

By having the create block as a non-deciding factor has created a possibility to ignore the materials in which is something that can be studied by others but does not fit the timeframe for this project.

Error stations share the same resource as the activities in the stations which symbolizes that the operations appear in the same station. This is logical for a simulation model, but difficult to explain for others. Statistical distribution was used to symbolize different types of error and makes the simulation model more realistic.

The continuously verification and validation created a confidence in the simulation model from the beginning, and did not need major changes when verifying and validating the entire simulation model. To do this before the real values where added resulted in a more quick insert of the real values and thereby get a quick response to the other master's thesis. This created a decreased need of waiting in the iterative process. A long run of ten years is made to decrease the impact of warm-up time.

When the simulation model was created, more understanding of the system was established which improved the progress of the project.

7.8. Results

By keeping the model simple it was easy to insert the improvement suggestions, and therefore easy to run a lot of scenarios. To test a lot of scenarios it created more creative thinking when seeing the result in a short amount of time, this helped the progress in this master's thesis and the other.

A numeric result from the simulation model can be different from the real-world because of simplifications, assumptions and other differences to the real-world system. As the system is presented as a general flow the real times can be different for the system in the simulation model.

The warm-up time in the simulation model is limited by having a long run of ten years. This limits the error but do not eliminate it, the system was therefore tested with 26, 4 as tact time for zero errors and without transportation times, this should result in a yearly production of 120 aircrafts per year but only created 119, 3 per year. This test gives a result of a slightly lower value which should be taken into consideration.

The model building has a valid testing because it is a comparison of similarities and differences between two systems with the same basic conditions, where the comparison is a more valid testing method than to only compare with the real-world system.

Iteration with the other master's thesis

Developing a system by focusing on a calculated tact time from the wanted output of 120 aircrafts per year a model which creates 120 aircrafts per year was obtained more quickly. This system is more difficult to level as it is not the equally amount of gained understanding in the system in the development process. This results in a relatively levelled flow with a possibility of improvements.

Both processes receives the same result which verifies the concept as the best possible solution from two different development processes which are a development process where the bottlenecks are limited step by step and a development process where the wanted solution are in focus.

7.9. Improvement suggestions

When testing and refinement was combined with verification, validation & confidence it was easy to create a testing process with separate steps, which was helpful. By having development steps it was easy to work systematically.

A lot of testing and refinement was created during the building of the model in the detail design which resulted in a decrease in time and the simulation model was almost valid at the beginning of this development step.

The verification process for the first recommendations increased a high level of confidence in the simulation model and increased the understanding of the manufacturing system a lot. This part created an overview and understanding of the process and created a creative thinking to the future progress.

Because the simulation model was built simple the run time was low (A.Tolk, 2014), which made the testing process a lot faster. The cloning tool made it simple to see the results quickly in the general appearance of the simulation model and thereby see the error when they appear.

By not having personnel or resource in the transportation blocks between the stations a difference to the real-world problem was created, but created a good starting point and an easy changeable simulation model.

The scenarios which was run with the same input data performed similar results and when both the operating time and the time for shifts where doubled similar results were obtained. When the time for shifts where doubled the results changed with a factor of two. The results from the preliminary estimation were relative similar to the simulation results. These results combined with earlier verifications and validations results in a model with a high confidence level of the outputs.

The result that the Main station was the largest bottleneck is logical, because it have the highest operating time.

7.10. Ramp-up

In the step by step suggestion the system only increased with one step at the time when removing bottlenecks to create a step by step process which resulted in a ramp-up which was decided by the simulation model.

The number of activities is doubled at an early stage because the relatively levelled flow combined with a higher need of ramp-up causes a need for a quick ramp-up. Increase of personnel is a cheaper and a quicker solution than the activities and thereby the increase of personnel is used as a primary solution. It is quicker and cheaper because it is less need of equipment, jigs and fixtures, when it is only a change in personnel.

Iteration with the other master's thesis

The ramp-up tests to minimize personnel and number of activities with one or two shifts creates a possibility choose a ramp-up depending on economic probabilities and other potential factors. The goal of 40 and 20 aircrafts per year were reached within a margin of 15 %, the margin is high because the ramp-up steps are only temporary and it will probably be possible to get closer to the goal if the workers help each other. As this system mostly consist of assumptions the system can be different from the real-world system.

7.1. Possible improvements to the recommended suggestion

The testing process shows a lot of possibilities to improve the system including transportation, error and activity time. As it is many improvement areas and possibilities for improvement there can be left room for improvement in the suggestions for the serial production.

8. Future work

Following is suggestions on how to improve the suggested production system and how to implement it at Saab.

If the suggestions should be implemented it is important to investigate the ramp-up regarding customer needs depending on when the needs are and how it should be implemented, when considering economic interest. Evaluate the economic probabilities and disadvantages to one shift and two shift and the cost of jigs and fixtures, to understand when and how it is the most profitable. This investigation can create a cost efficient ramp-up of the production system.

A recommendation is to investigate possible transportations between the activities within the stations initially as it may need changes in the factory layout.

The pre work is not included in this report and therefore it is important to make an analysis of the pre work and investigate the possibility to use a supplier to make the pre work.

If suggestion with a third personnel and only three activities in WS should be used, the fourth activity should not be used in the ramp-up. Because an extra activity uses a jig which is expensive and it is almost unnecessary to invest in a jig when only using it in the ramp-up. This can cause temporary overproduction which can be solved by using the personnel for improvement work.

The improvement suggestion of the system tested in chapter 6.5 should be implemented as a continuous improvement to the system.

To produce a complete aircraft all parts must be included therefore it is necessary to create an analysis of the final assembly to meet the suggested production system for the fuselage assembly. Make analysis of the rest of the aircraft including differentiation depending on customer needs and make it consistent to the suggested production system.

This master's thesis is only a general investigation of a production system and therefore it is important to develop the suggested production system including more details and further investigation regarding if the suggestion are realistic and suitable to Saab. It can also be compared to other suggestion to meet the optimum result.

9. Conclusions

The following recommendations are two different suggestion where both system are recommended to be investigated further as they are very different and contain different advantages. The first suggestions are based on the simulation model presented in Figure 52, which involves one station for each jig type which later are combined in the main jig. These station involves several substations which is decided in improvement suggestions, chapter 6.2.

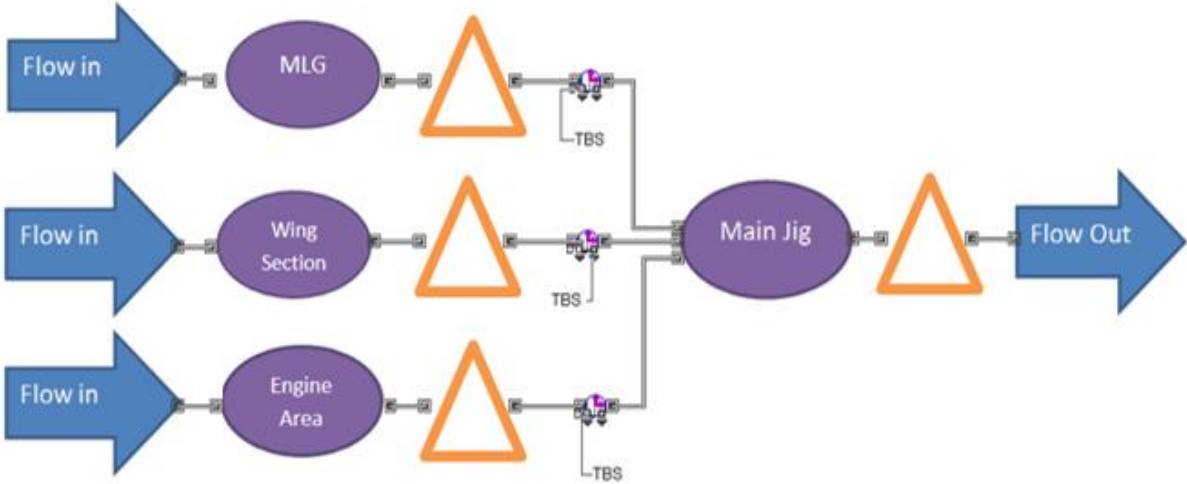


Figure 52. Simulation model.

The end result which can be a serial production is presented in Table 28 which results in a produced volume of 108, 5 aircrafts per year and are supposed to increase its capacity when the system has run for a long time and thereby reach a higher outcome. If the end result in the serial production improves and causes an overproduction some pre work can be added into the stations. Recommendations regarding how to improve the concept is presented in chapter 6.5. This recommendations has the same result as the iterative process with the other master’s thesis when the layout is according to jig types.

Table 28. Suggestion of layout for serial production, JIG concept.

Station	Personnel	Number of activities
MLG	2	5
WS	2	4
Main	4	3
Engine area, SP	3	3

Another recommendation is to use a continuous flow which is presented in Figure 53 and starts with MLG, thereafter WS and last is SP.

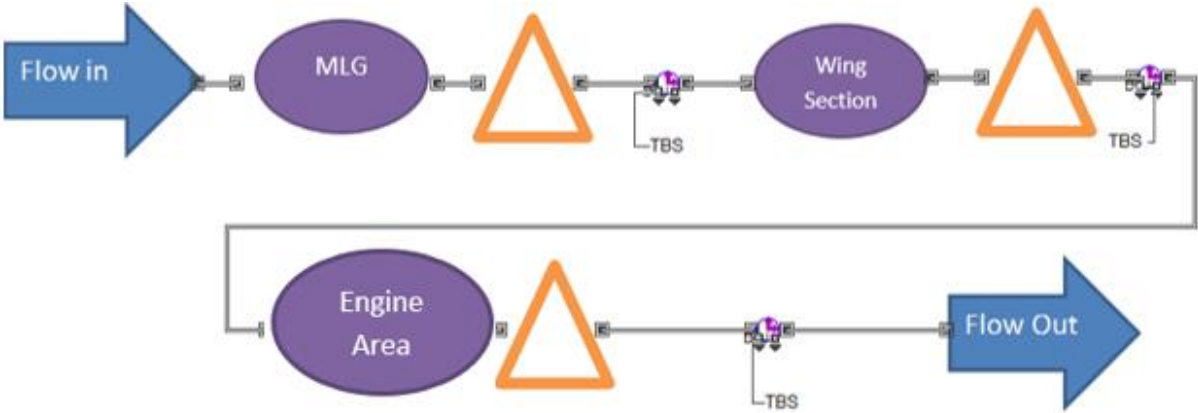


Figure 53. Concept with one line.

This line concept has a recommended solutions according to Table 29 which results in 103 produced aircrafts per year. This results in four in personnel in each station and three activities of each type of jig.

Table 29. Suggestion of layout for serial production, line concept.

Station	Personnel	Number of activities
MLG	4	3
WS	4	3
Engine area, SP	4	3

The ramp-up process to reach these production system is described in ramp-up chapter 6.4 and are recommended to be decided according to customer needs, economic probabilities and according to best calculated profit.

This master’s thesis shows how it is possible to meet an increasing demand of military aircrafts. This thesis only includes estimations of the real-world system and needs to be validated further to get a correct understanding of the system. The simulation model created possibilities to test a lot of scenarios and improvement suggestions and therefore increased the possibility to find the best solution. To use a simulation software as an initial part of a project has been proven successful and is recommended to use initially in project in the future.

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10. Appendix

10.1. Specification of demands

Demands and request for simulation model and thesis.

Demands for simulation model

- Present simulation model for the concept of a production process for military aircraft manufacturing by other master's thesis
- The simulation should show results that correlates with real-world operations
- The simulation should be verified and validated
- Bottlenecks should be identified and processes which needs improvement should be presented
- Ideas for improvement should be tested
- The system should be tested for different produced volumes
- Deliver needed data to other master's thesis

Requests

- Create animation on simulation for visual effect
- Create production system for 3-4 different types of aircraft.

Demands for thesis

- Deliver a master's thesis before 10 of June.
- Presentation of master's thesis on Saab
- Presentation of master's thesis on LTU

10.2. General layout

Following section includes the general layout and concept modelling for simulation.

10.2.1. Basic conditions

- **Activity (Stations / sub-stations)** - operating time three values depending on the working rate, shown in Table 30. The values are calculated by the other thesis and include information from Saab (Saab AB, 2016). The basic condition will only include the medium values. The working hours are decided by shifts, and the layout is according to the general layout.

Table 30. Activity operating time.

Working rate	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6
Low						
Medium						
Perfect						

- **Shift** – Create shift-blocks for every line depending on database, shown in Table 31. Assumptions are 2-3 shifts, where an eight hour shift includes 7, 2 hours. The data should repeat itself every 24 hours. Basic conditions are two shifts.

Table 31. Database for shifts.

	Line 1	Line 2	Line 3	Line 4
One shift	7,2	7,2	7,2	7,2
Two shift	14,4	14,4	14,4	14,4
Suggestion 1	7,2	7,2	14,4	14,4
Suggestion 2	7,2	14,4	7,2	7,2

- **Simulation setup** – 24 hours per day (shift controls machine operations), 220 days per year, Time unit is hours.
- **Error** - Safety margin contains two suggestions to solve the problem. None of the suggestion has thrown anything, added if needed, example is if we use material flow and need a new piece. Second suggestion is chosen because of its modularity and therefore a better possibility to test more scenarios.

First suggestion is to have a deviation on the current process time for the repair time, which will result in a statistical distribution shown in Figure 54.



Figure 54. Safety margin first suggestion.

Second suggestion is to have a separate operation for the repair, shown in Figure 55, which in reality happens in the same station and therefore have a shared resource. The resource is collected in the queue before the stations and released after. The sorting of errors is in the “select item out” which is separating according to probability which is decided in a database.

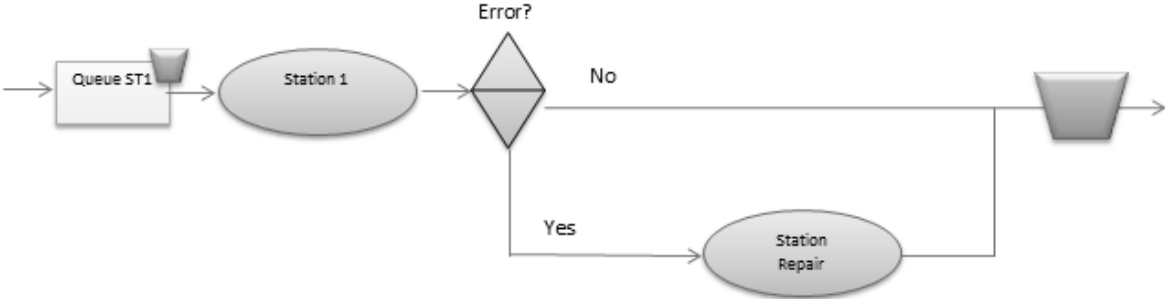


Figure 55. Safety margin second suggestion.

Database to control safety margin, shown in Table 32, where the basic conditions should have a safety margin shown as a percentage.

Table 32. Safety margin depending on database.

	Stations
Safety margin %	

- **Limit rules** -One example is to always take shortest lane even if it is not always like that. (Robinson S. , 2014)
- Label every block with smart names (SDL) when creating the simulation (A. Tolk, 2014).
- Excluding machine error, because it happens rarely (Carson, 2005).
- **Batch** – when material is attached to aircraft by separated flows. Wait for correct amount.
- **Cloning tool** – Use it to get buttons and visualize information.
- **Flow in** – Basic condition, produce infinity number of items into a queue from a create block.
- **Flow out** – Number of produced aircrafts per year, exits the system in an exit block .
- **Warm-up time** - Needed because the simulation starts empty and inactive, start simulation after an amount of time, which is the time it takes for the system to become steady-state.
- **Transportations**- use transportation blocks depending on database, shown in Table 33. Simplify by having no time in basic condition until other thesis provide the time.

Table 33. Transportation time depending on database.

	transportation in line	Transportation between lines
Time		

- **Deviation** in station and transportations is zero because of a standardized way of work (J.Liker, 2012).

10.2.2. Extras

- **Separated flows to meet customer needs** –The “select item out” are sorting according to “set value”, shown in Figure 56, which is decided by a database. This is because the same customer takes the same amount of time.

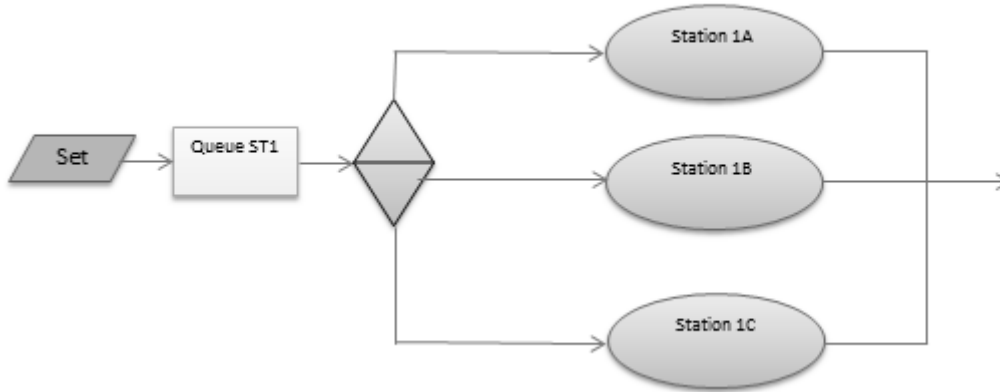


Figure 56. Change to customer needs with set block.

If it is one station in reality make it as a hierarchical block and use resource by collecting it in the queue and release after the stations. Number of stations can be computed by controlling the resource with a database or by changing it manually.

- **Resources** - Personnel and machines will be used as a resource if necessary.
- **Separate stations** - Different scenarios for number of stations within a station, shown in Figure 57. Try to separate one station into several stations.

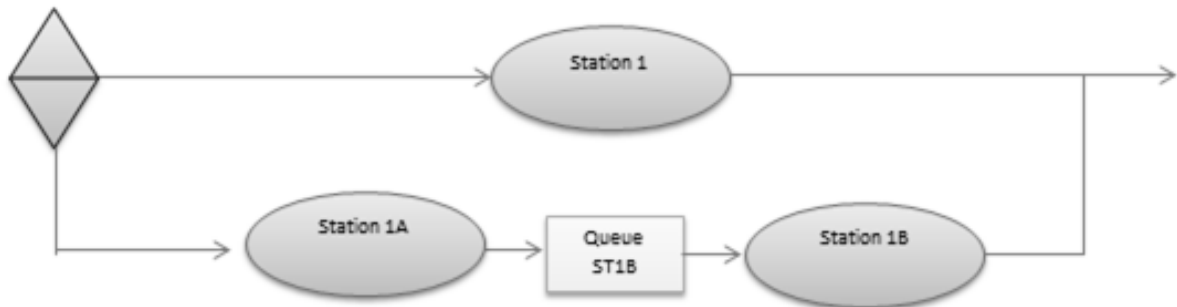


Figure 57. Separate one station into several stations.

The “select item out” should be decided according to database, Table 34 and therefore easily be able to test different scenarios. The first station is kept to verify and test the model.

Table 34. Separated flows decided by database.

	Select item out
Stations	0
Separated flows	1

- **Animations** - Add picture – by picture, change green circle to aircrafts. Animate hierarchical blocks.

- **Cloning tool** – Make it user friendly or make it user friendly for easy visualization.
- Machines might have other working hours than personnel if it is possible to go without personnel. This involves different shifts for machines and personnel. This is used if it is a request from other thesis.
- Create a one-piece flow for the system or a system with buffer zones.

10.2.3. Experiments

Output should be steady-state, long run or several runs, rule of the thumb 3-5 times. Investigate deviations between runs.

How the experiments should be tested

- **Identify bottlenecks** – By investigating queues with database or event manager, and investigate efficiency on activities.
- Information block
- **Plotter** – log data (use name connections) / Event manager
- **Connection to excel** - How and what? Is it necessary? Perhaps the output?
- Made by database or event manager
- Which volumes should be produced by time? Do we reach the goals? How, where?

Testing depending on output number (aircrafts per year) Basic

- Number of stations of the same kind
- Identify bottlenecks by investigating queues and activity rates on activities.

Testing depending on output number (aircrafts per year) Extras

- Working rate
- Number of shifts
- Number of sub-stations
- Safety margin
- How should the volumes increase by time
- Number of stations in customer needs area

10.2.4. Validation

- White-box check every box separately
- Black- box check entire system and hierarchical blocks.
- Dynamic time warping, DTW – measure similarities and differences between other system, within system and to real-world systems.
- Combination of the three above.