UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

9/29/2016

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

BPJ 420 Final Report

Designing the Final assembly line concept for a Small African Regional Aircraft

ESTEQ ENGINEERING

Supervisor: Dr. Nico De Koker | Boshoff du Toit 12023095

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

DEPARTEMENT BEDRYFS- EN SISTEEMINGENIEURSWESE
DEPARTMENT OF INDUSTRIAL AND SYSTEMS ENGINEERING

VOORBLAD VIR INDIVIDUELE WERKOPDRAGTE - 2016
FRONT PAGE FOR INDIVIDUAL ASSIGNMENTS - 2016

Persoonlike besonderhede / Personal details	
Studentenommer Student number	12023095
Voorletters en van Initials and surname	JHB du Toit
Titel Title	Mr.
Selnommer Cell number	079 496 2216
Werkopdrag / Assignment	
Modulekode Module Code	BPJ 420
Werkopdragnommer Assignment number	Final Report
Onderwerp Subject	Final Year Project
Dosent Lecturer	Dr. Nico De Koker
Datum Date	29/09/2016

Verklaring / Declaration

1. Ek begryp wat plagiaat is en is bewus van Universiteitsbeleid in hierdie verband
2. Ek verklaar dat hierdie my eie oorspronklike werk is
3. Waar iemand anders se werk gebruik is (hetsy uit 'n gedrukte bron, die internet of enige ander bron), is dit behoorlik erken en die verwysings ooreenkomstig departementele vereistes gedoen
4. Ek het nie 'n ander student se vorige werk gebruik en as my eie ingedien nie
5. Ek het niemand toegelaat en sal niemand toelaat om my werk te kopieer met die doel om dit as sy of haar eie werk voor te hou nie

1. I understand what plagiarism is and I am aware of the University's policy in this regard.
2. I declare that this is my own original work
3. Where other people's work has been used (either from a printed source, internet or any other source) this has been carefully acknowledged and referenced in accordance with departmental requirements
4. I have not used another student's past work to hand in as my own
5. I have not allowed and will not allow, anyone to copy my work with the intention of handing it in as his/her own work

Handtekening Signature	[signature]
Datum van inhandiging Date of submission	28/09/2016

Kantoorgebruik / For office use:		
Dosent Lecturer		Kommentaar / Comments:
Uitslag Result		
Datum Date		

Executive Summary

In this document, the need for the design of a final assembly line concept for a small African regional aircraft is addressed. The project sponsor needed the design of an assembly line concept for the assembly of a new small regional commercial aircraft that needs to be produced in high volumes, thus they sent out the student to do industry research to see how other aircraft manufacturers around the world produce and assemble commercial aircraft for the mass market. The student then started working on designing and testing his own design concepts. The Assembly line concepts were designed based on various facilities planning theories and techniques. These concepts where tested by using SIEMENS plant simulation software provided by the project sponsor. The data used in the simulation models, such as time studies, order arrivals etc. were based on industry research, past projects in the industry and calculated estimates. These models where then tested and validated to see which option would fit the company's goals and needs best and provide them a concept from where to start designing the highly detailed assembly line. Three concept layouts where explored that was the most promising to fit the project sponsor's needs: The Product family assembly layout concept, the Moving assembly line layout concept and the Fixed position assembly layout concept. These concepts all turned out to meet the requirements, however the moving assembly line layout concept was the most promising one of them all. Further recommendations would be to look at multiple fixed position assembly layouts in the short term and a combination of the moving assembly line layout and the product family layout for the long term.

Table of Contents

1. Introduction

1.1 Project Background

Denel aerostructures specialises in advanced manufacturing of complex aerostructures. Denel primarily designs and build military aircraft and aircraft pieces such as fairings and structural parts for their clients. Denel Aerostructures is a current design partner to Airbus Military and also participate in commercial and military aircraft projects with OEMS.

They are currently investing in the commercial aircraft market thus the demand for regional air travel is rising. This is an entirely new undertaking for Denel. Thus they are currently undertaking the SARA, the Small African Regional Aircraft. This is a locally designed and manufactured passenger aircraft to serve regional destinations.

The project is currently in development phase. Applying concurrent engineering while the project is still in development will ensure for a much more efficient assembly process as the end product.

Denel is switching from their usual military theme to the domestic market. They sought that there is a need for a modern, point-to-point regional airliner on low-density routes, seating approximately 15-24 passengers. There is a rapid growth in the demand for air travel in South Africa and to reach regional areas that is not currently accessible for commercial passengers.

Figure 1.1: SARA aircraft

1.2 SARA production

1.2.1 General

The assembly line will be designed and built for the SARA (Small African Regional Aircraft) which will be mass produced for the domestic market to fly passengers to regional destinations. The production process can be divided into three sections namely:

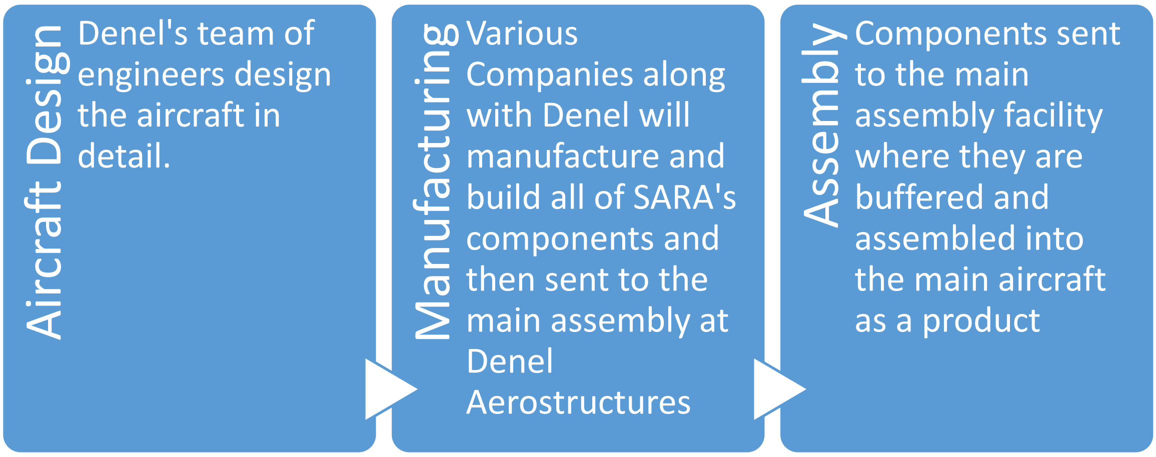


Figure 1.2: Diagram indicating production process

1.2.2 SARA aircraft

This will be a modern, well designed aircraft that is fuel efficient, economically viable and safe for passengers.

The aircraft will have three different configurations:

- Full passenger (max 24 passengers).
- Combi (12 seats and one LD2 container).
- Full cargo (3 LD2 containers).

Other specifications:

- Max take-off weight = 8,400 kg
- Range = 2,600 km

One very important thing to keep in mind is that the SARA project will be led by Denel but is not solely a Denel project. Denel will be collaborating with various companies on a global scale where different companies will produce and construct certain parts of the aircraft and ship them to Denel. Denel however will be in charge of final assembly and dispatch of the aircraft.

1.2.3 Assembly Process

This project is a total green-field project thus the assembly process needs to be designed from scratch. Denel is looking into new modern techniques of assembly to act as an enabler for the workers assembling the aircraft. The modern assembly-equipment should not replace the worker but help the worker improve his/her duty since Denel should comply with the government to keep and or create jobs for this project.

Since this project is aimed at the mass domestic / commercial market it needs to produce a much larger amount of aircraft per year than previous military themed projects.

The assembly process needs to be extremely efficient to meet these goals.

1.3 Project Definition

The student was appointed by ESTEQ to do research on various assembly methods and production lines used by other commercial aircraft manufacturers for the mass market.

The student was also appointed to research certain technicalities in assembling an aircraft.

This data and research was then used by the student to design various iterations of an assembly line that adheres to Denel aerostructures' needs and requirements for the SARA project.

The following is required by the student:

- Research on various assembly techniques
- Research on aircraft assembly technicalities
- Designing an assembly line / process and layout for assembling the SARA aircraft
- Build simulation models on the various iterations of assembly lines to compare them against each other
- Economic viability study

2 Literature study

The designing of the assembly line for the Small African Regional Aircraft is a project that requires various Industrial engineering principles such as:

- Facilities planning
- Simulation modelling
- Engineering economic analysis

The principles listed above will be necessary to execute the project successfully.

Outcomes of using these principles include:

- Simulation models
- Line Balancing
- Value stream mapping
- Various iterations of different assembly facility layouts
- Various concepts of assembly applied to the assembly facility

Research has been done by the use of websites, engineering related textbooks and books.

2.1 Proposed layouts design approach

2.1.1 Requirements analysis

Before designing the assembly line and facility can begin, Denel aerostructures' requirements should first be taken into consideration. These requirements include:

- Facility to be used for production.
- Facility size.
- Production goals per year.
- How many aircraft to be built? (Per week, year, etc.)
- How many units can be produced at a time?
- Methods of assembly.
- Size of components.
- Size of the aircraft.
- Staging areas size.
- Doors for entry and exit.
- Manufacturing tooling, fixtures & jigs.
- Complexity of the aircraft.
- Number of components of the aircraft.

The space utilisation can be determined by applying the correct methodology. In a space utilisation case study performed for the automotive industry, it sets of by quantifying the space required in a four step methodology.

The Four step methodology:

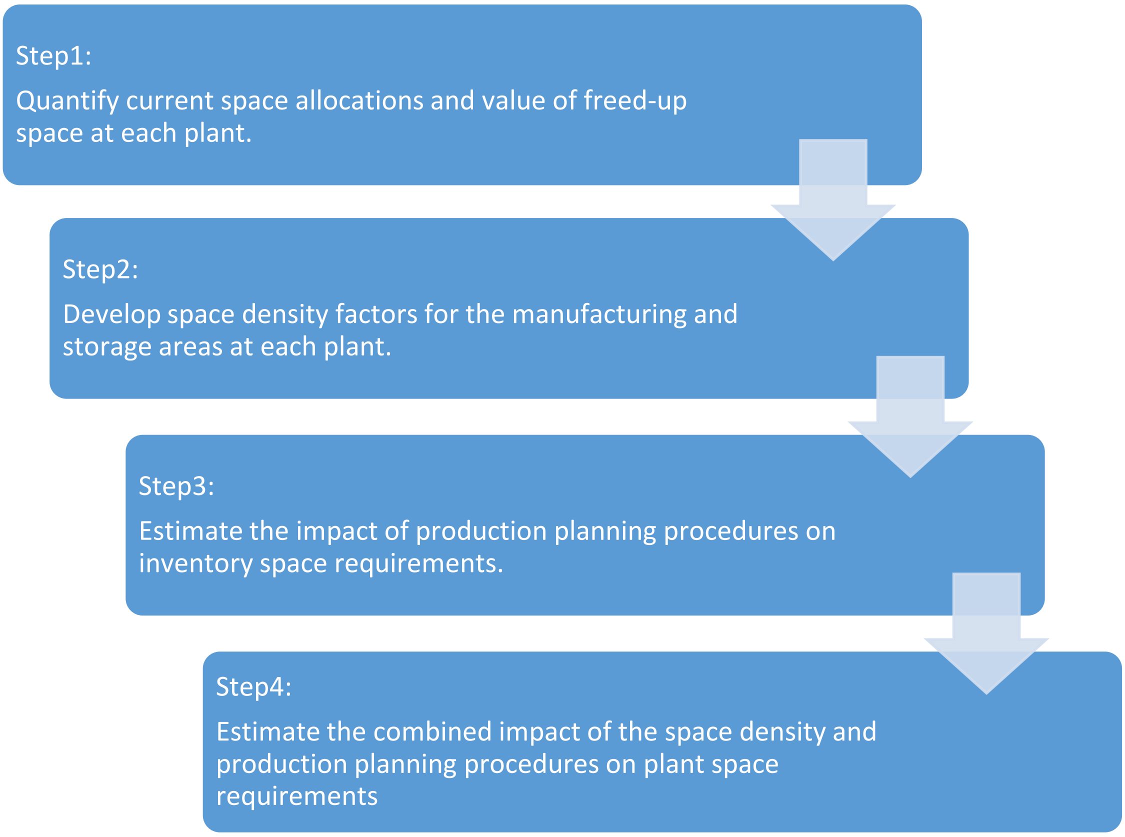


Figure 2:(Bozarth, Vilarinho) Four step methodology for space requirements

The first step involves quantifying current space allocations and the cost of floor space at each plant. The second step is where the variable, space density factors are introduced and implemented. Space density factors are defined as the percentage of currently allocated space that is not being utilised. The third step involves the estimation of the impact of production planning procedures on inventory space requirements. This step resolves around the inventory and storage areas of the plant. In the last step requires the estimation of the combined impact of current space allocations and all of the above factors such as the density factors.

However since this project is a green-field project where the assembly facility is designed from scratch along with the design of the aircraft, where the actual assembly of the aircraft will be and also which facilities Denel is going to use, are still being decided.

After decisions have been made, then this methodology can be implemented, but at this stage of the project the student will only be designing a theoretical concept that can later be applied and implemented on the SARA project.

2.2 Proposed layouts types & concepts

2.2.1 Assembly system

An assembly system is the process of collecting and merging different components together to create one product as an output. There are various assembly layouts for an assembly system.

A basic description of an assembly system is various stations where tasks are performed by operators to assemble or manufacture a component.

Below is a simple example of an assembly system as explained above.

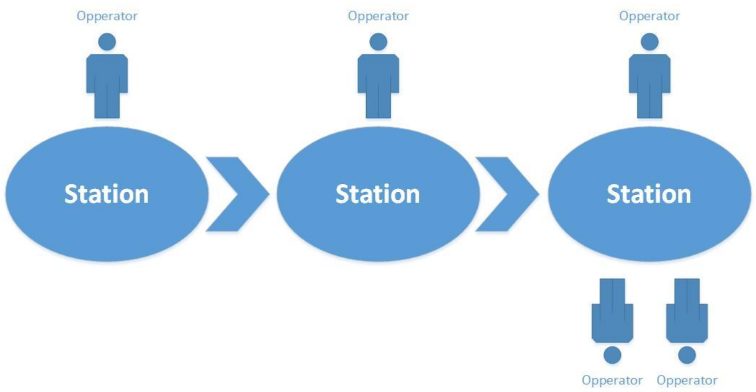


Figure 3: Example of an assembly system

2.2.2 Fishbone assembly

A Fishbone assembly is an amount of sub-assemblies connected to a main line that is the main assembly. In this case the main assembly would be the Aircraft itself and the sub-assemblies would be the wings, power plants and other aircraft components. The sub-assemblies produce different modules that are sub-systems that are merged to the main line. The figure below shows an example of a Fishbone layout.

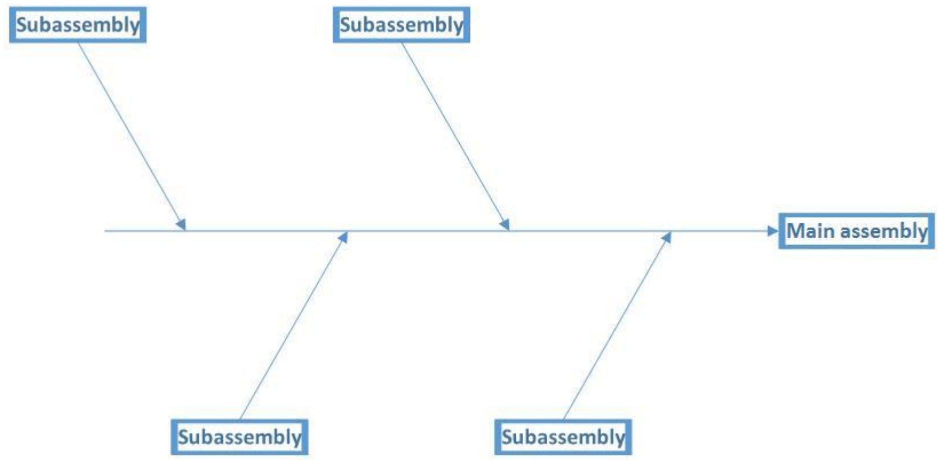


Figure 4: Fishbone layout example

2.2.3 Modularisation

Modular layouts are a combination of the fishbone assembly layout and the cellular manufacturing technique (Tompkins, Facilities planning ed. 4). It can be described as each subassembly, as indicated and explained above (*Fishbone layout example*) is an assembly module that assembles a certain component or part for the main-line product. These modules can be seen as manufacturing cells. Each manufacturing cell has its own grouping of employees, machines, materials, tooling and material handling and storage equipment to produce families of parts. In this case each cell would assemble / manufacture a component for the aircraft for example the wings, power plants, empennage, landing gear etc.

Each cell will have its own set of requirements and layout. The identification of machinery, tools and number of employees for each cell will also be an important aspect for each cell.

2.2.4 Material Flow system

This part describes the physical flow of materials between departments. In facilities planning, there is a principle of *minimising total flow* (Tompkins, Facilities planning 4 ed.) that represents the work simplification approach to material flow. The work simplification to material flow includes:

- Eliminating flow by planning for the delivery of materials, information, or people directly to the point of ultimate use and eliminating intermediate steps.
- Minimising multiple flows by planning for the flow between two consecutive points of use to take place in as few movements as possible.
- Combining flows and operations wherever possible by planning for the movement of materials, information, or people to be combined with a processing step.

Also minimising the cost of flow:

- Reduce number of manufacturing steps.
- Minimise manual handling of materials.
- Minimise travel distances.
- Minimise manual handling by mechanising or automated flow.
- Reduce flow density.

2.2.5 Flow within workstations

The most important aspects to consider for flow within a workstation are, motion studies and ergonomics (Tompkins, Facilities planning 4 ed.). Flow within a workstation should be:

- Simultaneous
- Symmetrical
- Natural
- Rhythmical
- And habitual.

Simultaneous flows implies coordination of hands, arms and feet. Hands, arms and feet should begin and end their flow together. Symmetrical flow implies the coordination of movements about the centre of the body. Natural movements are continuous, curved, and make use of momentum. Movements should be a methodical, automatic sequence of activity.

2.2.6 Flow within product and process departments with material handling considerations

The flow pattern for the assembly of an aircraft will resemble that of a *Tree flow pattern* (Tompkins, Facilities planning 4 ed.).

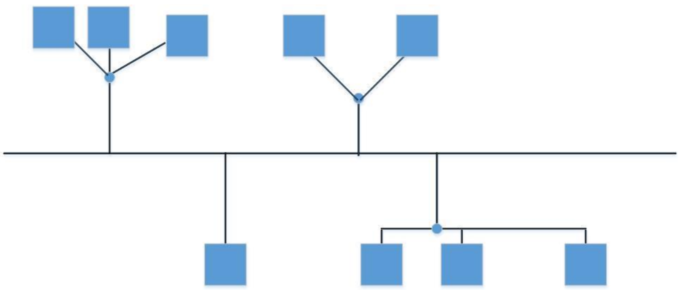


Figure 5: tree flow pattern

The tree flow pattern, as depicted in the figure above. The workstations can be positioned in a single tree or in multiple trees that are linked together to the main assembly. Each tree represents a module that assembles a different component to be married to the main product.

2.3 Simulation modelling

A Simulation model is a virtual creation of a real or possible real word scenario which is created for use instead of the real world thing. This saves time and money for you need not have to physically spend money and time to test for example alterations in the system.

A simulation model is created on simulation software using real world data and criteria. It is not always necessary to cover all factors of a real world scenario that is being simulated. The models simply needs to answer the questions that is supposed to be answered.

Why simulation:

Validated simulation models have various advantages:

- Easy to evaluate “What-if?” scenarios.
- Various different scenarios can be tested.

Simulation models may be helpful in the understanding of how a system operates.

Discrete, Event-based simulations

Discrete event simulation is a process of summarising the behaviour of a complex system as an arranged sequence of events. An event, in this context means a specific change in the system’s state in a specific point in time for example a customer arriving.

Discrete event simulation (DES) is commonly used in modelling procedures and processes in the industry such as manufacturing and assembly.

SIEMENS plant simulation is a discrete-event simulation modelling software used to create these complex system.

A Discrete event-based simulation must include the following as a minimum requirement:

- Predetermined starting and ending points
- Time keeping method
- List of discrete events that already occurred since the process began
- List of pending discrete events
- Statistical record of the function for which the discrete event simulation was built.

3 Research design methodology

3.1 Design

For this project all the data and research gathered was used to design the assembly line concept for the SARA project. The student first looked at methods and layouts other aircraft manufacturers use globally and used that information to design iterations of an assembly line process and layout that is most likely, promising and economically viable to fit SARA. These assembly line layouts were compared against each other by using simulations and other engineering tools to see which of them ultimately complies with Denel's goals and requirements for SARA.

3.2 Methodology

The main deliverables are:

- Proposed layouts
- Simulation models
- Economic analysis
- Final decision

These deliverables are met as follows:

3.2.1 Proposed layouts

The first deliverable will be to design three different concepts for an assembly line. Each concept adopting a different type of layout and method assembly.

The aim is that these concepts are developed on such a level that they can be replicated as simulation models to later on compare and see which concept will suite SARA best and reach Denel's goals and requirements for this project. These simulation models will replicate a hypothetical real world scenario where these simulation concepts are implemented and running.

The data needed for these assembly line concepts will later be acquired and estimated when the simulation models are built.

3.2.2 Simulation models methodology

Simulation models are carried by steps. These steps include:

- Problem formulation
- Model conceptualization
- Data collection
- Model building
- Verification
- Validation
- Analysis
- Documentation
- And Implementation.

(Banks 2004).

The detailed methodology is described in the following figure.

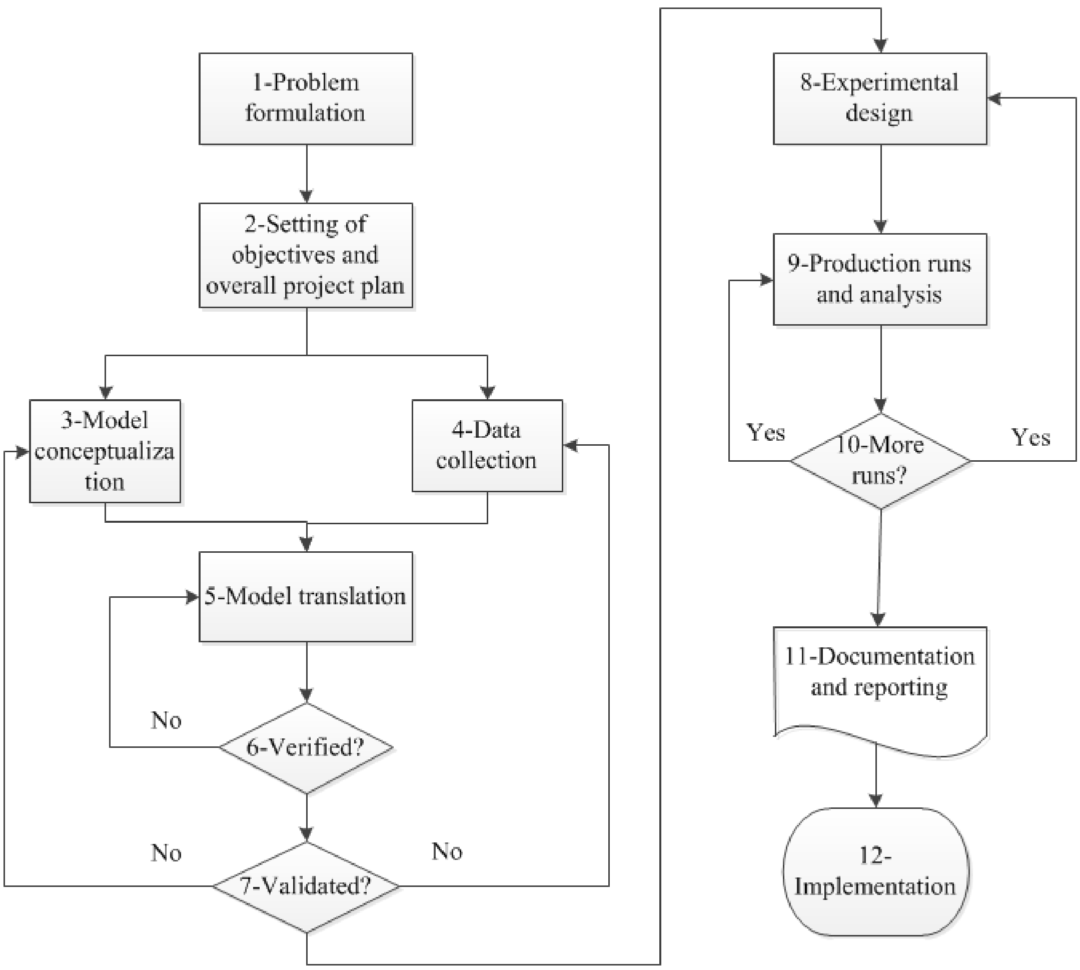


Figure 6: Methodology for discrete event simulation

In any simulation model, it starts with the Problem formulation, where the problem is identified and finding the objectives, goals and level of detail of the project. Then there needs to be a project plan set up to follow throughout the project. Thereafter data needs to be obtained regarding the system and the problem by investigation. If the model has been verified and validated, an experimental design can be analysed to see how certain factors has an effect on the model. Now the models can be run and the results analysed. All findings should be documented and presented. If all went according to plan the implementation can commence.

3.2.3 Economic analysis

An Economic analysis would also be necessary in this project due to the fact that it is a budget conscious project.

All assembly line concepts will need to be compared with monetary value added to see how economic they operate and what their respective start-up costs will be.

There are 4 economic analyses to consider:

- Cost analysis
- Fiscal impact analysis
- Cost-effectiveness analysis
- And cost-benefit analysis.

The most important economic analysis to consider for this project would be the cost-benefit analysis.

The different assembly line concepts will be compared to each other to see which is the most economically viable.

3.2.4 Final decision

For the ultimate deliverable of this project: The selection of the final assembly line concept, the analytical hierarchy process (AHP) shall be used.

AHP is a mathematical technique used to organise and analyse complex decisions. Alternatives will be weighed up against each other on a rational platform.

The goal here is to find the best solution for Denel aerostructures' SARA project.

4 Conceptual Design

The conceptual design of the assembly line designed for SARA will be inspired by the following methods of aircraft assembly used by various manufacturers across the globe.

These methods and designs will be discussed each individually and clearly state how they differ from each other. The student will then use this information to design a few iterations of assembly lines that would suite SARA best.

4.1 Proposed layouts

The following proposed layouts will be broken down to a level where only the essential process will be described for an easy transition to simulation in a later phase of the project.

4.1.1 Embraer assembly line for the E190

Figure 7: Picture of the Embraer E190

The Embraer E190 passenger jet is a narrow-body, medium range, twin engine aircraft. It was developed by the Brazilian aerospace company Embraer. It uses Pratt & Whitney PW1000G geared turbofans, fly-by-wire control with new avionics and an updated cabin.

Specifications:

- Passenger capacity: +- 114 passengers
- Flight deck crew: 2 pilots
- Length: 36.2 m
- Wingspan: 33.7 m
- Height: 11.0 m

- Max. Take-off weight: 56,200 kg
- Max. Landing weight: 48,730 kg
- Max. Payload weight: 13,080 kg
- Max. Speed: 870 km/h
- Range: 5,200 km

Based on the research done, the parts for the aircraft is manufactured and sourced and sent to the facilities that assemble the aircraft.

Assembly facilities include:

- Main fuselage preparation and assembly facility
- Facility for preparing wiring harnesses and other components
- Painting facilities
- Wing assembly facility
- Empennage and Power plant assembly/preparation facilities
- Final detail assembly facility

Main assembly components:

The Embraer E190 consists of the following components:

- Main fuselage
- Empennage
- Nose/Cockpit section
- Wing assembly
- Landing gear
- Power plants

Assembly process:

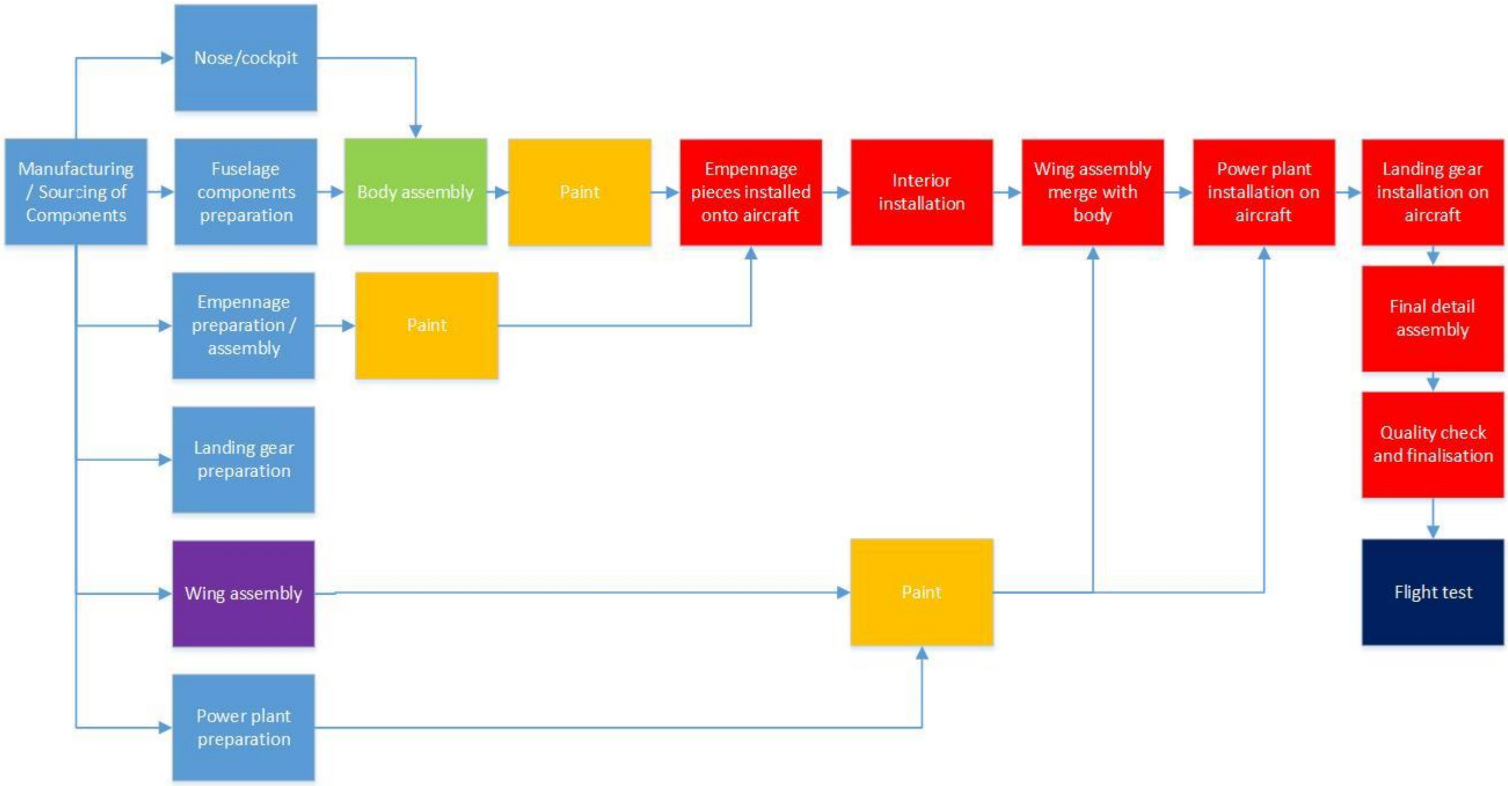


Figure 8: Assembly process for the Embraer E190

Each colour in the assembly process above represents a different facility used to perform an assembly process step:

- Body assembly facility (Green)
- Main assembly line (red)
- Wing assembly (Purple) & Wing assembly paint (Orange)
- Power plant & landing gear preparation (Blue)
- Power plant housing paint (Orange)

These facilities are not necessarily in separate buildings, however they each form part of a separate process.

The assembly process of the Embraer E190 will be discussed in detail.

Embraer uses a modular setup for their assembly process. The assembly line is designed in the form of a fishbone assembly where each sub-component is assembled in a module that links up with the main assembly to produce one ultimate product which is the aircraft.

Embraer uses a product family layout for each component of the aircraft.

Main fuselage preparation & assembly:

After the main fuselage components have been manufactured / sourced, they are staged in the main fuselage assembly facility. The components, the nose/cockpit, centre section and empennage are positioned onto a jig with an overhead crane and personnel that align them and then ultimately fastened together.

Each fuselage that is completed will be moved to a different stage in the facility where it is prepared for the main assembly of the aircraft.

Preparation includes:

- Starting phases of interior installation such as windows
- Wiring installation
- And flight systems installation such as pilot's controls.

Figure 9: Picture of the main fuselage assembly and preparation facility (https://www.youtube.com/watch?v=XmEuQk5otcg).

Systems & wiring components preparation:

Wiring harnesses, flight systems and other important systems are prepared for installation in a separate facility for each aircraft to be assembled.

Figure 10: Picture of wiring harnesses being prepared for installation (https://www.youtube.com/watch?v=XmEuQk5otcg).

Interior installation:

The interior and seating of the aircraft is installed and completed simultaneously along with the exterior of the aircraft. As the aircraft nears the end of its assembly the interior installation also gets completed.

Wing assembly:

The wing assembly follows a modular assembly where the entire wing section is assembled completely in its own facility and then transported to the main assembly facility to be fitted to the aircraft.

Figure 11: Picture of the wing assembly being fitted to the aircraft (https://www.youtube.com/watch?v=XmEuQk5otcg).

Painting facility:

Each main assembly component gets painted separately.

After the Cockpit/nose, centre piece of the fuselage and empennage have been assembled as the fuselage of the aircraft, it gets painted.

The wing assemblies and power plant covers/housings also gets painted before going onto the aircraft in the main assembly line.

The Empennage pieces such as tail fin and stabilisers are painted before going onto the aircraft as well.

Empennage & power plant preparation:

The empennage pieces and the power plants that need to be assembled onto the aircraft gets prepared for assembly in a different facility.

The tail fin and stabilisers gets assembled completely before being painted and transported to the main assembly facility to be fitted to the aircraft.

Final detail installation & Quality check:

After the completion of the aircraft, nearing the end of its assembly, it is inspected and quality checked to ensure al systems are in working order.

Final details such as trim pieces and interior detail are also completed at this stage.

Test flight:

After the complete assembly of the aircraft, it goes for a test flight to ensure that it performs up to standard.

In Conclusion:

Boeing uses a fishbone assembly method where components are sub assembled and then joint to the main assembly. Boeing uses a product family layout of its facilities where each product is assembled according to the family of products it belongs to.

4.1.2 Bombardier assembly line for the Q400

Figure 12: Picture of the Bombardier Q400

The Bombardier Q400 is a modern, twin-engine turboprop aircraft built in Canada by Bombardier aerospace.

Specifications:

- Passenger capacity: +- 78 passengers
- Flight deck crew: 2 pilots
- Length: 32.81 m
- Wingspan: 28.4 m
- Height: 8.3 m

Main assembly components:

The Bombardier Q400 consists of the following components:

- Main fuselage
- Empennage
- Nose/Cockpit section
- Wing-to-fuselage fairing
- Wing assembly
- Landing gear
- Power plants

Assembly facilities:

The assembly facilities used to assembly the Bombardier Q400 are as follow:

The colours are matched with the assembly process flow-chart (*Figure 6: Bombardier Q400 assembly process*) below.

- Body assembly facility (*Red*)
- Main assembly facility (*Green*)
- Paint facility (*Purple*)
- Final staging and interior installation facilities (*Orange*)
- Staging facilities to prepare the components for assembly (*Blue*)

Assembly process:

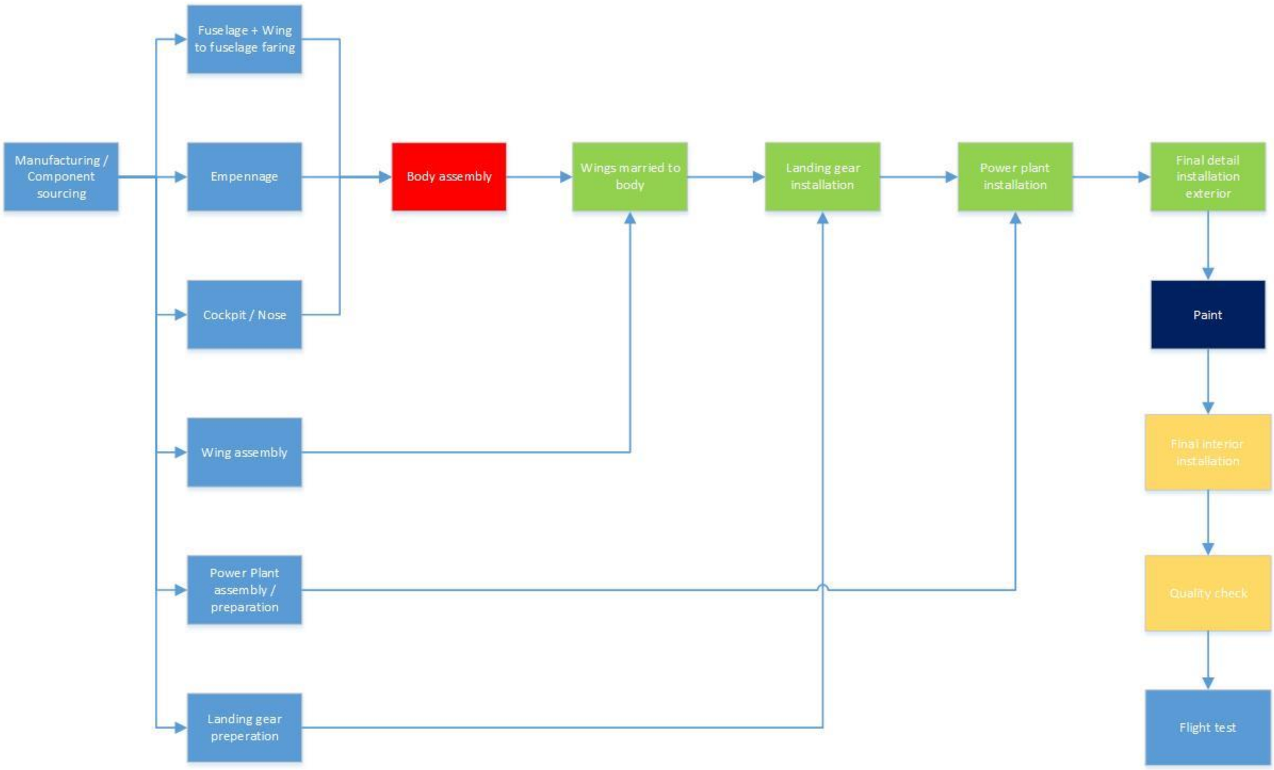


Figure 13: Bombardier Q400 assembly process

The assembly process above (*Figure 6: Bombardier Q400 assembly process*) will be discussed in detail.

The assembly of this aircraft is split up into modules that each individually assemble the main components. Each module is designed specifically for an assembly step in the assembly

process. The aircraft move through these modules as steps until it moved through all the steps towards its completion.

Bombardier uses a Process layout for the assembly of components where similar processes are grouped together in facilities.

Staging and component preparation:

In the staging facilities, the components of the aircraft are stored and prepared for assembly. This includes wiring harness preparations that will be installed in the main fuselage and other technical components to be installed.

Larger parts such as the empennage, fuselage, cockpit and nose cone will take up most of the space.

Preparation includes:

- Installing doors on the main fuselage
- Getting the empennage ready for mounting on the fuselage
- Getting the cockpit ready for mounting on the fuselage
- Etc.

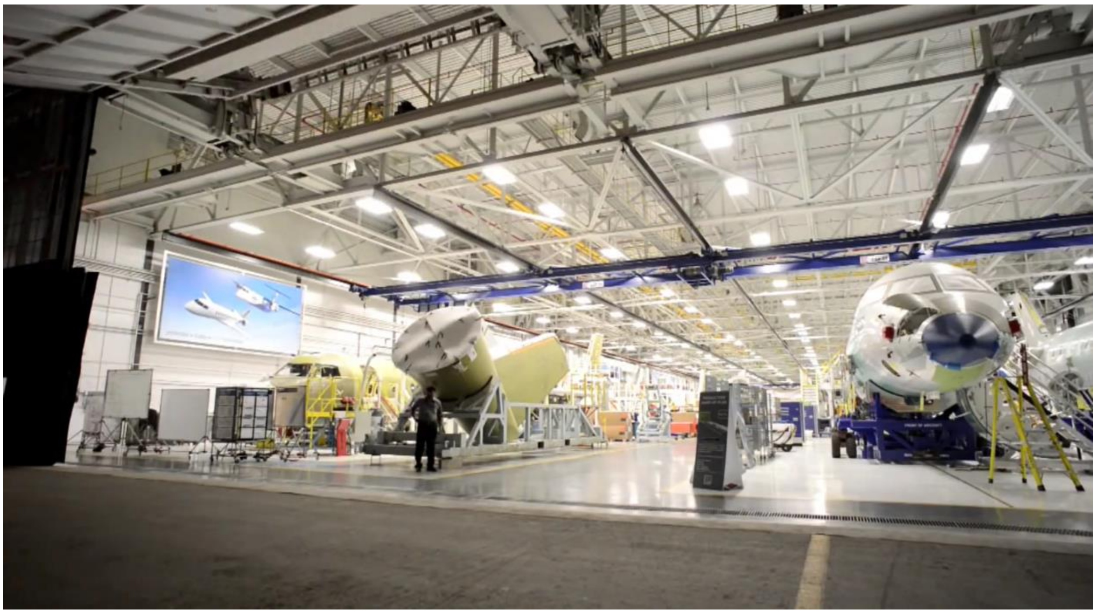


Figure 14: Picture of the staging and component prep facility (https://www.youtube.com/watch?v=3u8HHSquHWg).

Body Assembly:

In the body assembly stage, parts form storage come together to form the main body of the aircraft.

The fuselage, empennage, cockpit and nose cone are assembled by using ceiling mounted cranes to move them into position and then riveted together. The body is assembled in a large jig. After the body is assembled it is put onto a large moving trolley for transportation to the main assembly facility.

Figure 15: Picture of the fuselage sections being moved by overhead crane (https://www.youtube.com/watch?v=3u8HHSquHWg).

Figure 16: Picture of the Q400 body assemblies (https://www.youtube.com/watch?v=3u8HHSquHWg).

Wing assembly, power plant & landing gear preparation:

The wing assemblies is assembled in a different facility and afterwards they are transported to the main assembly facility.

The same counts for the power plants and landing gear. After they are sourced or assembled they are transported form their staging areas to the main assembly facility.

Figure 17: Picture of the wing assembly being assembled (https://www.youtube.com/watch?v=3u8HHSquHWg).

Main Assembly stages:

The main assembly phase is split up into 3 stages, each performing an assembly task on an aircraft. Each stage has its own facilities and is specifically designed for specific assembly tasks to aid the workers assembling the aircraft. Once an aircraft leaves a stage another replaces it and so on.

In the first stage, the aircraft wing assembly is married to the aircraft body assembly (depicted in *Figure 19: Picture of the wing assembly being married to the body assembly*). In this stage the aircraft rests on stands that are fixed to a position and the wing assembly is put onto a lowering jig that aligns the assemblies and marry them.

In the second stage, the landing gear is assembled to the aircraft and can now roll on its own without the need of a trolley (depicted in *Figure 18: Picture of landing gear being assembled onto the aircraft*).

In the third and final stage of the main assembly phase, the power plants are mounted onto the aircraft. The final components that finishes the aircraft is also installed here:

- Propellers
- Controlled surfaces
- Flaps

- Panels

- Etc.

Figure 19: Picture of the wing assembly being lowered onto the fuselage (https://www.youtube.com/watch?v=3u8HHSquHWg).

Figure 18: Picture of the landing gear being fitted (https://www.youtube.com/watch?v=3u8HHSquHWg).

Figure 21: Picture of aircraft rolling out of stage 2 onto stage 3 (https://www.youtube.com/watch?v=3u8HHSquHWg).

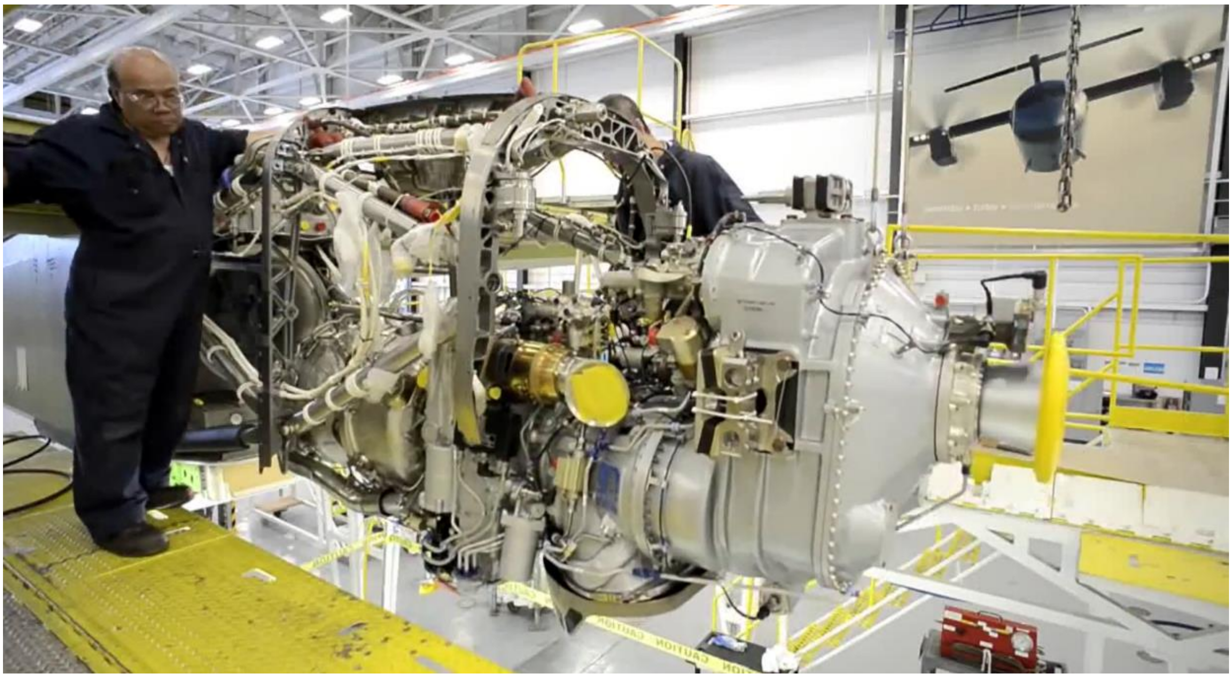


Figure 20: Picture of Power plant being mounted onto aircraft (https://www.youtube.com/watch?v=3u8HHSquHWg).

Paint:

After the aircraft is assembled at the main assembly facility it is transported to the painting facility. Here, each aircraft gets its livery based on what the customer wants. The aircraft is sprayed by hand and scaffolding is used to access difficult to reach areas of the aircraft.

Figure 22: Picture of the Q400 in the painting facility (https://www.youtube.com/watch?v=3u8HHSquHWg).

Final detail and interior installation:

In this stage, the final smaller detail components is installed to the aircraft as well as its interior and seating. The aircraft goes through a thorough systems inspection to assure quality.

Figure 23: picture of the interior being installed (https://www.youtube.com/watch?v=3u8HHSquHWg).

Test flight:

After the complete assembly of the aircraft, it goes for a test flight to ensure that it performs up to standard.

Figure 24: picture of the Q400 test flight

In conclusion:

Bombardier uses a fishbone assembly method where components are sub assembled and then joint to the main assembly. The assembly line is set up into modules that each perform a specific task of the assembly process. This is a very effective and cost-efficient assembly line that produces aircraft for the commercial market on a global scale.

It uses basic tools and equipment that are inexpensive compared to more modern, automated machinery some companies use.

4.1.3 Boeing assembly line for the 777:

Figure 25: picture of the Boeing 777

The Boeing 777 is a twin-engine, modern wide-body passenger jet airliner capable of long-range air travel. It is developed and manufactured by Boeing in the United States.

Specifications:

- Passenger capacity: +- 314 passengers
- Flight deck crew: 2 pilots
- Length: 63.7 m
- Wingspan: 60.9 m
- Height: 18.5 m

Main assembly components:

The Boeing 777 consists of the following components:

- Main fuselage
- Empennage
- Nose/Cockpit section
- Wing assemblies
- Landing gear
- Power plants

Assembly facilities:

The assembly facilities used to assembly the Boeing 777 are as follow:

The facility uses a U-shaped, moving process line. This a moving assembly line where the aircraft enters at one stage and exits as a complete product.

The colours are matched with the assembly process stations () below:

- Body assembly (Purple)
- Moving assembly line (Red)
- Wing assembly (Green)
- Power plant preparation (Green)
- Landing gear & Body part preparation (Blue)
- Paint (Orange)

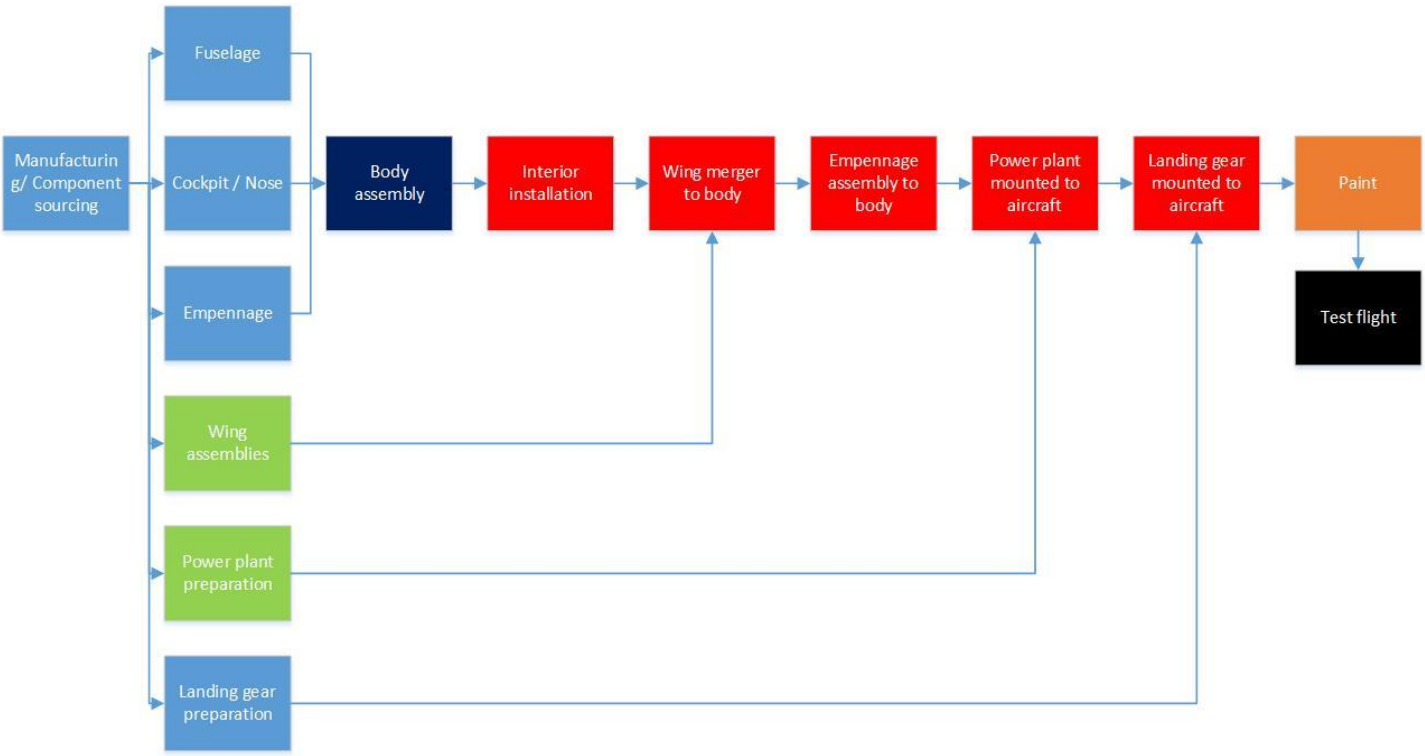


Figure 26: Assembly process for Boeing 777

The assembly process above (*Figure 26: Assembly process for Boeing 777*) will be discussed in detail.

The assembly of the Boeing 777 relies on a moving, U-shaped assembly line. This is a modern assembly technique only used by Boeing thus far. The aircraft, after body assembly including wings and empennage enter a moving assembly line where multiple assembly processes happen at once. The interior is installed while the aircraft's exterior is being finished. Quality and systems check happens while the aircraft is in the assembly line and being assembled. The assembly line moves at 4.6 cm/minute. This moving assembly line concept decreases overall assembly time from initial fuselage sections arrival to systems installation to the day it rolls out of the shop. This method cuts costs and reduces assembly time by implementing Lean principles into production.

Boeing uses a Production line layout for their assembly process of the 777.

Wing assembly:

The wings of the aircraft are assembled separately in modular assembly form. The wings are assembled totally completed so that they only need to be fitted to the aircraft.

Figure 27: picture of the 777 wing assembly (http://16749-presscdn-0-94.pagely.netdna-cdn.com/wp-content/uploads/2015/09/0101_met_BOEING-ANALYSIS_1_-1024x670.jpg).

Power plant preparation:

The power plants are prepared separately with all the connections and parts needed to go onto the aircraft.

Figure 28: picture of the 777 power plants

Moving assembly line:

Boeing uses a moving U-shaped assembly line where the whole aircraft is assembled on a moving line.

Figure 29: Picture of the 777 moving assembly line (https://www.youtube.com/watch?v=H_olh7qxCbQ).

Figure 30: picture of fuselage section of the 777

Body/fuselage assembly:

The fuselage of the aircraft consists out of various section. These sections are then moved to the moving assembly line using overhead cranes. Each section has different detail that requires a different set of assembly skill to be assembled.

Mechanics install parts and lay down wiring as the fuselage parts are being pulled across the factory floor by a tug. As the fuselage parts reach completion, they are aligned and joint into the main fuselage of the body on the factory floor.

After the entire fuselage is assembled, it first awaits its wing assemblies and empennage before it moves any further on the moving assembly line.

Wing merger to fuselage:

The complete wing assemblies are transported to aircraft on the moving assembly line. The wing assemblies are mounted and fastened to the aircraft using overhead cranes to move them and a ground team to fasten the wing to the aircraft.

Figure 31: picture of the wing assembly being merged to the fuselage (https://www.youtube.com/watch?v=H_olh7qxCbQ).

Empennage assembly:

The empennage is assembled to the aircraft piece by piece. The pieces are hoisted into position by overhead cranes and the workers access the empennage by scaffolding to fasten it.

Figure 32: picture of empennage being assembled (https://www.youtube.com/watch?v=H_olh7qxCbQ).

The following processes happen simultaneously in the moving assembly line:

- **Interior installation:**

  The interior is installed by a team moving in and out of the fuselage. Interior assembly includes wiring, controls, pilot's consoles, seating, interior panels, etc.

Figure 33: picture of the interior being installed (https://www.youtube.com/watch?v=H_olh7qxCbQ).

- **Power plants mounted to aircraft:**

  The completed power plant units are transported to the aircraft by using trolleys that carry and hoist them into place and installed on the aircraft.

Figure 34: picture of the power plant being fitted onto the aircraft (https://www.youtube.com/watch?v=H_olh7qxCbQ).

- **Landing gear mounted to aircraft:**

  The completed landing gear units are transported to the aircraft to its position in the moving assembly line and installed.

Figure 35: picture of the landing gear being fitted (https://www.youtube.com/watch?v=H_olh7qxCbQ).

- **Smaller detail components installation:**

  Smaller details such as wiring and small, secondary components are also installed in the time that the aircraft is on the moving assembly line.

- **Material handling:**

The materials and tools needed for the assembly of the aircraft are setup in carts that can be moved along to designated spots with each aircraft in the assembly line. This eliminates the time a worker would use to move and fetch the tool or part he/she needed.

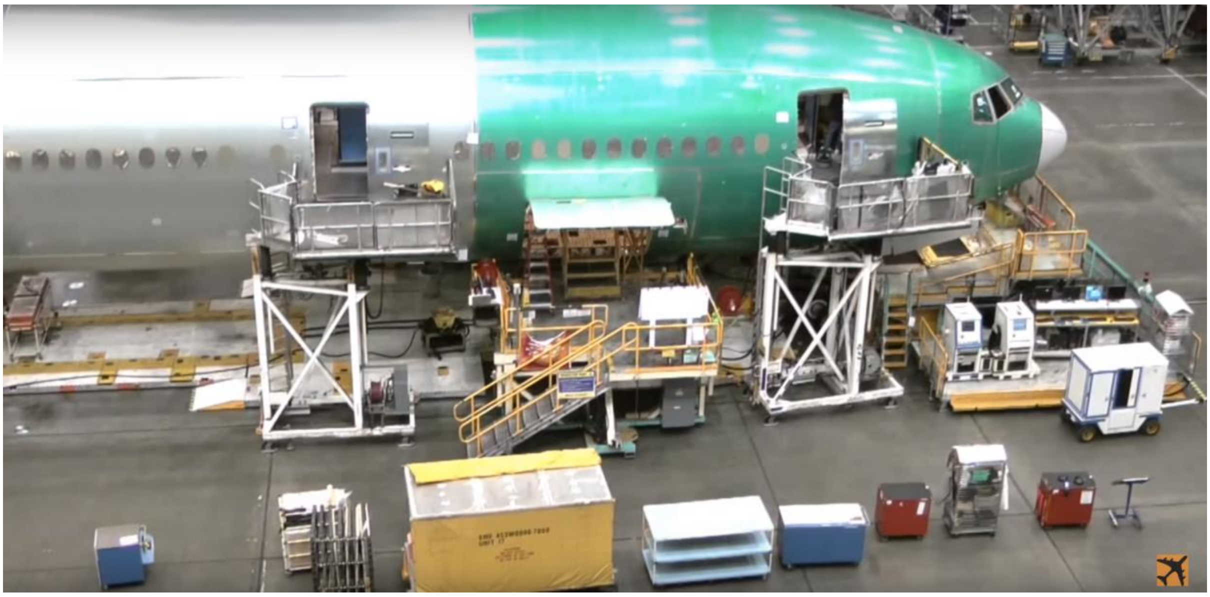


Figure 36: picture of carts for tooling and material handling (https://www.youtube.com/watch?v=H_olh7qxCbQ).

Paint:

After the aircraft is assembled it is transported to the painting facility. Here, each aircraft gets its livery based on what the customer wants. The aircraft is sprayed by hand and scaffolding is used to access difficult to reach areas of the aircraft.

Figure 37: picture of the 777 being painted (https://www.youtube.com/watch?v=H_olh7qxCbQ)

Test flight:

The aircraft is tested in flight to make sure all systems are working and that the customer receives a safe, quality product.

Figure 38: picture of the 777 test flight.

In conclusion:

Boeing uses a modern, moving assembly line to assemble the Boeing 777. This modern technique improves efficiency immensely and eliminates waste by implementing lean principles into the assembly process.

However this method is more expensive than previous mentioned methods, it is most likely the most efficient method for an aircraft of this calibre.

4.2 Summary of Proposed layouts

Figure 39: Summary of three different assembly lines

Assembly line	Embraer E190	Bombardier Q400	Boeing 777
Layout used	Product family layout	Process layout	Production line layout
Layout definition	Machines, equipment, materials, tooling, personnel, and material and storage handling required to produce the family part are grouped together.	Combine identical workstations into initial planning departments and attempt to combine similar initial planning departments without obscuring important interrelationships within the department.	Combine all workstation required into a process to produce the product.
Pros		Relatively affordable.	Highly efficient. Low usage of space.
Cons	High usage of space.		Expensive modern technology. Potential high start-up investment.

(Tompkins et al. 2010)

4.3 Concepts for SARA assembly line

The following assembly line concepts for SARA will be based of the methods other companies use to assemble their commercial aircraft.

These concepts will each include a different basic layout type and different method of assembly process so that they can later be compared against each other using engineering techniques to see which concept will suite SARA and Denel's goals and requirements best.

These concepts will only include the core assembly process that will later be built into a simulation model.

SARA:

The aircraft to be assembled consist out of the following main assembly components:

Figure 40: Main assembly components of SARA

The components mentioned above will be used in the assembly concepts. These components will be regarded as the main assembly components although there are many other components revolving around these main assembly components that are also assembled to the final aircraft. These other, finer detailed components will not be included in these concepts, however they will be considered into the assembly times, calculations and simulation models in a later phase of the project.

Illustrations of main assembly components:

Each assembly layout / assembly process will be depicted and described visually using floor layouts drawn in MS Visio. In these layouts the assembly components will be depicted as follows:

- Fuselage:

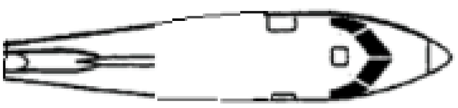


Figure 41: depiction of SARA fuselage

The Fuselage consist of the empennage, centre piece and nose/cockpit section.

- Centre piece:

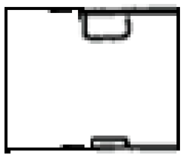


Figure 42: depiction of centre piece

Centre piece of the fuselage.

- Empennage:

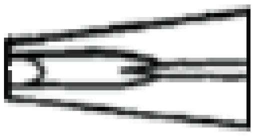


Figure 43: depiction of empennage

The empennage without its tail fin and stabilisers.

- Nose/cockpit:

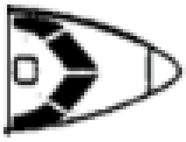


Figure 44: depiction of nose/cockpit section

- Power plant:

Figure 45: depiction of power plant

The turbo-prop engine.

- Landing gear:

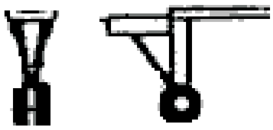


Figure 46: depiction of landing gear

- Wing assemblies:

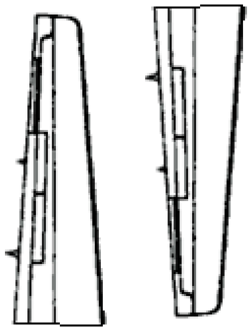


Figure 47: depiction of wing assemblies

- Interior & seating:

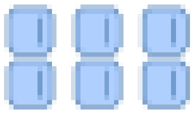


Figure 48: depiction of seating

➢ SARA:

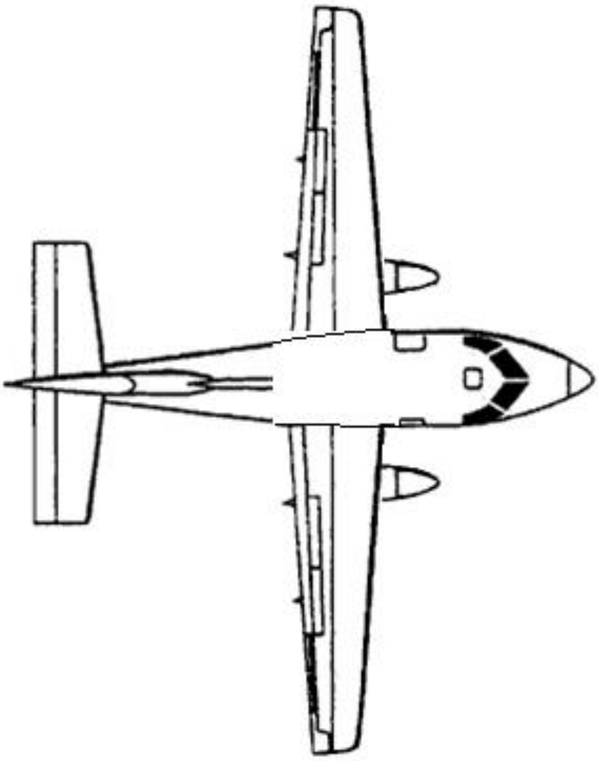


Figure 49: depiction of the complete assembly of SARA

The complete assembled aircraft.

Facility layouts:

The facility layouts will be developed in MS Visio in a generic hypothetical warehouse where each assembly line will be built in.

These Concepts can be adjusted and implemented to real world scenarios.

4.3.1 Moving assembly line (Production line layout):

The Moving assembly line concept for SARA will be inspired from Boeing's 777 assembly methods and process.

The moving assembly line concept for SARA will adopt the production line facility layout (*Tompkins et. Al 2010*) where the aircraft will be assembled on a slow-paced moving assembly line. The assembly process will also be Modular where components are sub assembled and join the main assembly on the moving assembly line.

For this concept the main assembly line is at the core of the facility and assembly line while sub-assemblies can happen in other facilities and smaller workstations are formed along the moving assembly line.

In this concept there is a team of workers assigned to each aircraft and move along with each build as it goes through the assembly process.

Material and tool handling will be done by assigning carts with all the tools and materials required that move along with the aircraft being assembled. This eliminates the time a worker would have to go and find the tool or part he/she needs in the workshop and then return to the assembling aircraft. This also eliminates the chances of parts and tools going missing and keeps an organised work environment.

Larger parts such as the wing assemblies and power plants will be moved into position for assembly by use of overhead cranes and forklifts. Smaller parts can fit in the carts mentioned previously and also be brought in by pushing trolleys.

For the actual moving of the aircraft, the aircrafts fuselage will rest on a large trolley that will be pulled at a constant calculated pace through the assembly line until it reaches the point where it can roll on its own landing gear wheels and then be pulled through the final stages.

Assembly process:

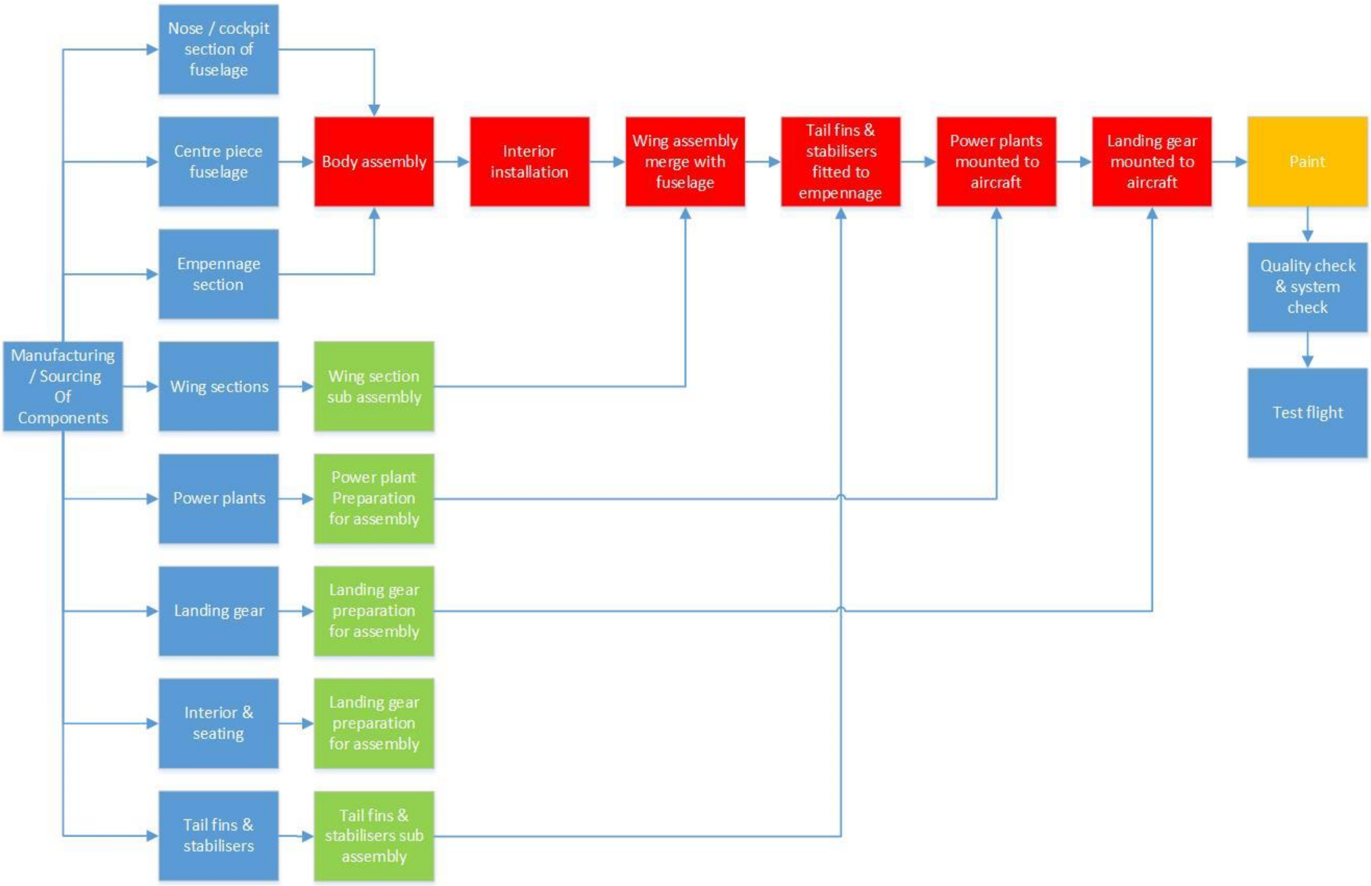


Figure 50: Assembly process for the moving assembly line concept

The assembly process above for the Moving assembly line concept for SARA will be discussed in detail.

The components and parts for the aircraft are either sourced or manufactured for the final assembly of the aircraft.

This assembly process would be at its most cost efficiency and effectiveness if it would adopt the JIT *just-in-time* production system (*Tompkins et al. 2010*). This is where components and sub-assemblies arrive where needed in the assembly line just as they are needed.

In the figure above of the assembly process for the moving assembly line concept:

- The *green* rectangles are sub-assemblies.
- The *red* rectangles indicate the moving assembly line and critical path of the assembly.
- The *orange* rectangle is the painting facility.

Facilities used:

The Moving assembly line concept for SARA mainly uses 5 facilities for the assembly process:

- A Facility for the main moving assembly line.
- A Painting facility.
- A Facility for the wing and empennage parts sub-assemblies.
- A Facility for the preparation of the power plants and landing gear.

Workstations:

The workstations are primarily around the main aircraft assembly and they move along with the aircraft going through the assembly line. The workstations change dynamically as the aircraft goes through different assembly processes.

Facility layouts & flow:

Main assembly line:

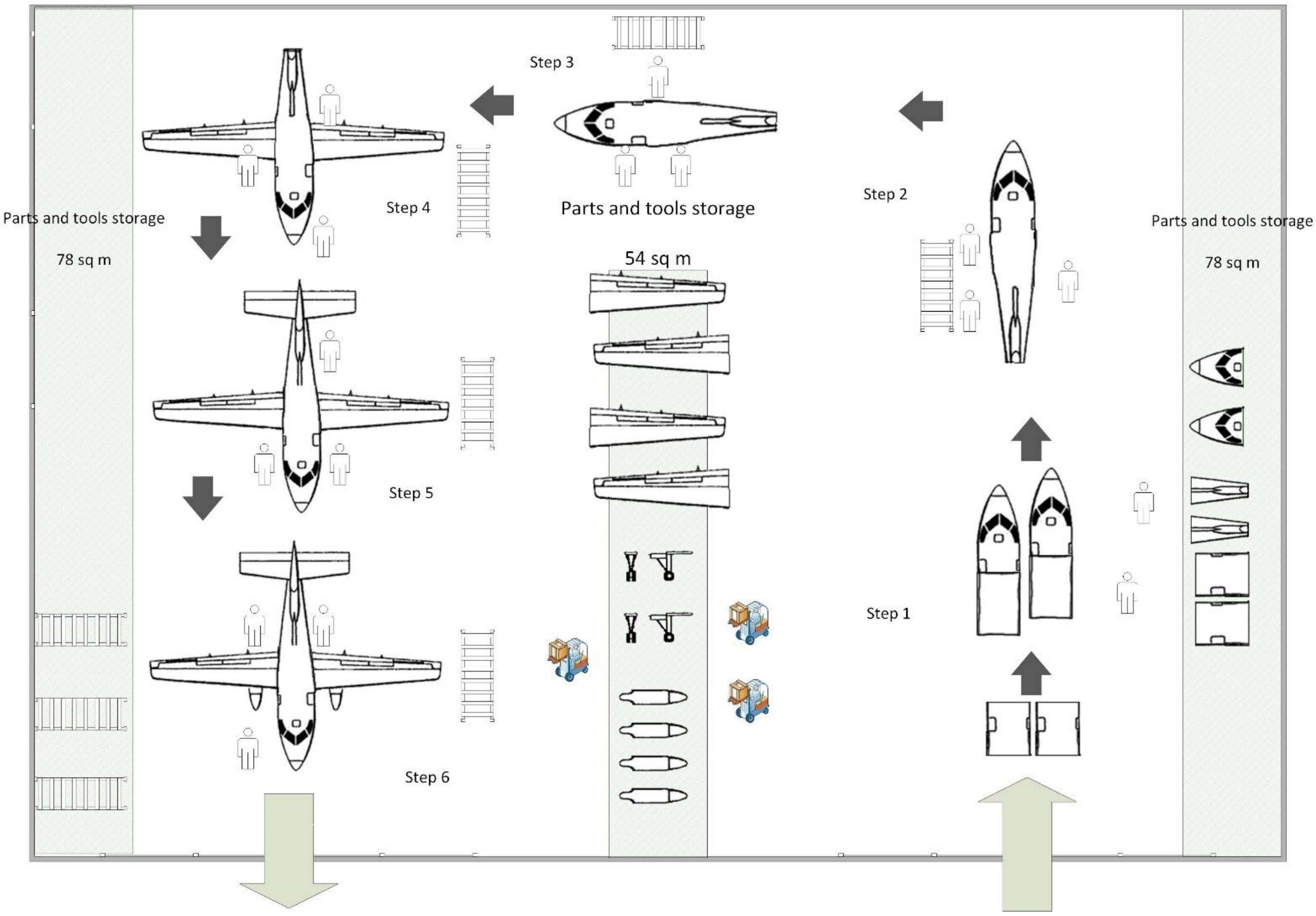


Figure 51: Layout of the moving assembly line facility

The main assembly facility houses the main moving assembly line for the SARA aircraft. Parts and components are also transported in and out of the facility using forklifts. The facility has dedicated storage areas for parts alongside the assembly line. In the figure above (), there can be seen that each aircraft has its dedicated crew assigned to it and also carts containing tools and materials for each aircraft.

The assembly of the SARA aircraft can be divided into 6 steps.

- Step 1: Body / Fuselage assembly

  The fuselage components arrive at the facility and enter the assembly line. The nose, centre and rear (empennage) sections go onto large moving trolleys so that they can move along on the assembly line.

Each component is worked on separately where smaller detailed components are installed on these sections before they are joined to form the main fuselage. They are also prepared to be joint together.

- Step 2: Main fuselage assembly

  After the nose, centre and empennage sections are completed, they are joint to form the main fuselage of the aircraft.

  This is done by aligning the 3 part's trolleys and joining them into one. The main fuselage is then moving at a certain pace throughout the assembly line on to the next process.

- Step 3: Interior installation
  In this step, the workers start to install the interior of the aircraft and also start to install flight systems, wiring and pilot's controls.

- Step 4: Wing assemblies merged to aircraft

  After the wing sub-assembly is completed and transported to the main assembly line facility, they are moved and hoisted into position to be fastened to the aircraft.

  This can be done by pulling the aircraft trolley into a certain marked, fixed position and lowering the assembly onto the aircraft. Workers will then make sure that everything goes accordingly and fasten the wing assembly.

- Step 5: Empennage assembly & landing gear attachment

  The tail fin and stabilisers are fitted to the empennage using overhead cranes to position them and workers to attach them to the aircraft.

  Landing gear is transported to the facility and allocated to each aircraft. The workers fit the landing gear onto the aircraft and the aircraft can now roll on its own.

- Step 6: Power plant installation & final details

  The power plants are mounted to the aircraft in this stage.

  After the main components are installed, the workers start assembling the more detailed, "last minute" parts. For example the propellers, nose cone, covers, etc.

  All systems of the aircraft are checked and an overall quality check is conveyed to ensure the aircraft is assembled accordingly.

Paint facility:

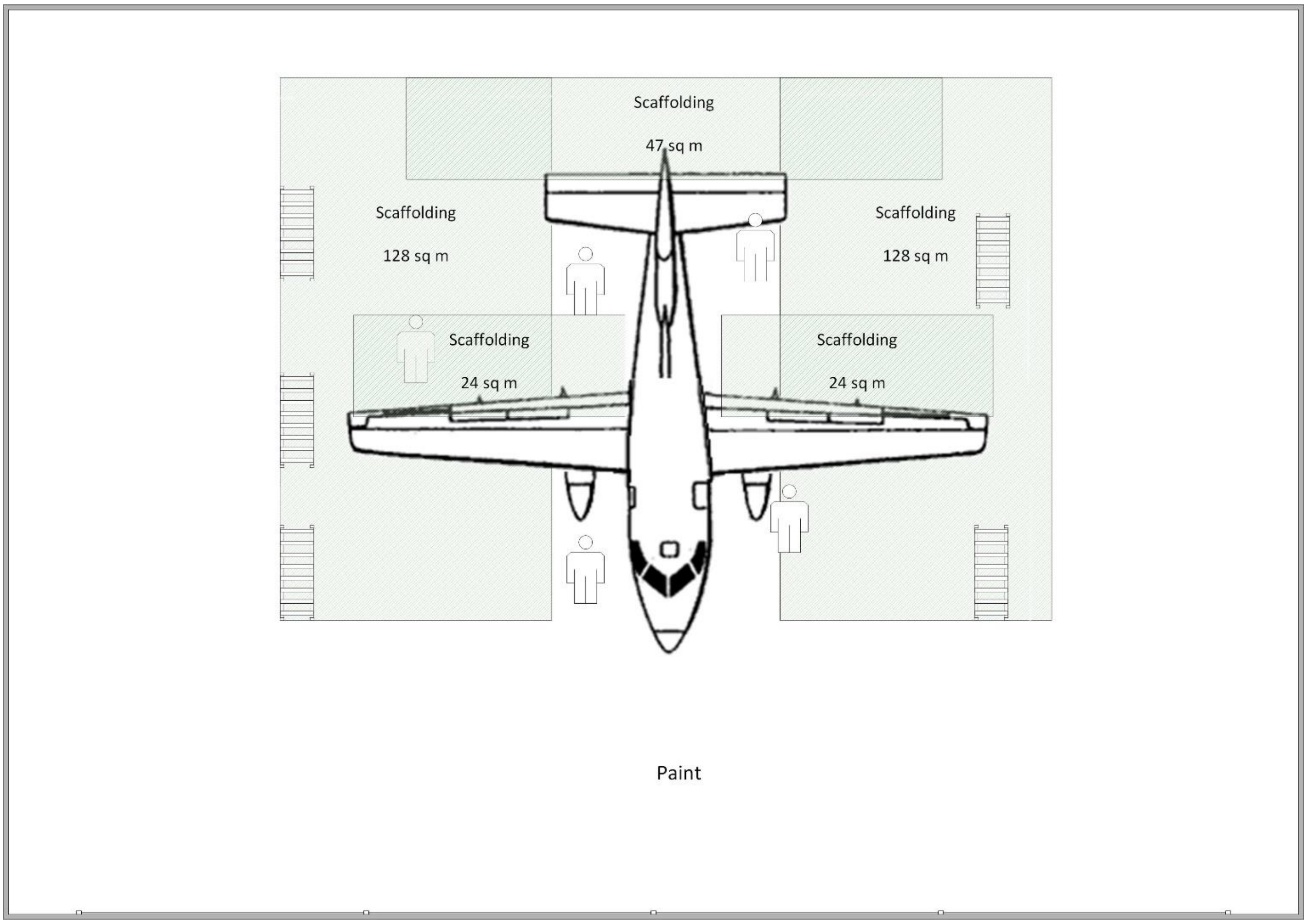


Figure 52: Painting facility layout

After the aircraft is completely assembled it is transported into the painting facility where it gets a fresh coat of paint according to what the customer wants.

The aircraft is sprayed by hand and reached via scaffolding.

Wing and empennage sub-assemblies facility:

The wings and empennage pieces are assembled completely in a different facility. They are assembled with the necessary connections so that they can simply be installed onto the aircraft.

Power plant and landing gear preparation facilities:

The power plants and landing gear are also prepared in a different facility so that they also can just be assembled onto the aircraft.

Finalising and quality check facility:

After the aircraft has been painted it is transported to a facility where final details such as interior trim pieces and seats can be installed and also a final quality and systems check before it undergoes its test flight.

4.3.2 Modular flow-line assembly (Process layout):

The modular flow-line assembly concept for SARA is an assembly process where the layout is process based. This is where the aircraft goes through stations on the assembly line each providing a different assembly process.

In the previous layout and assembly method the aircraft was continuously moving where in this version the aircraft stops at a station, awaits the assembly process to be completed and then moves to the next station to have a different assembly process be performed on it.

Each station is a module that performs one or more specific assembly tasks on the aircraft.

Larger components such as the aircraft body / fuselage and main wing parts are assembled in different facilities and transported to a main assembly facility.

Each station has its own tools and materials waiting that need to be fitted to the aircraft. Once one aircraft leaves the station, the materials needed are restocked.

Assembly Process:

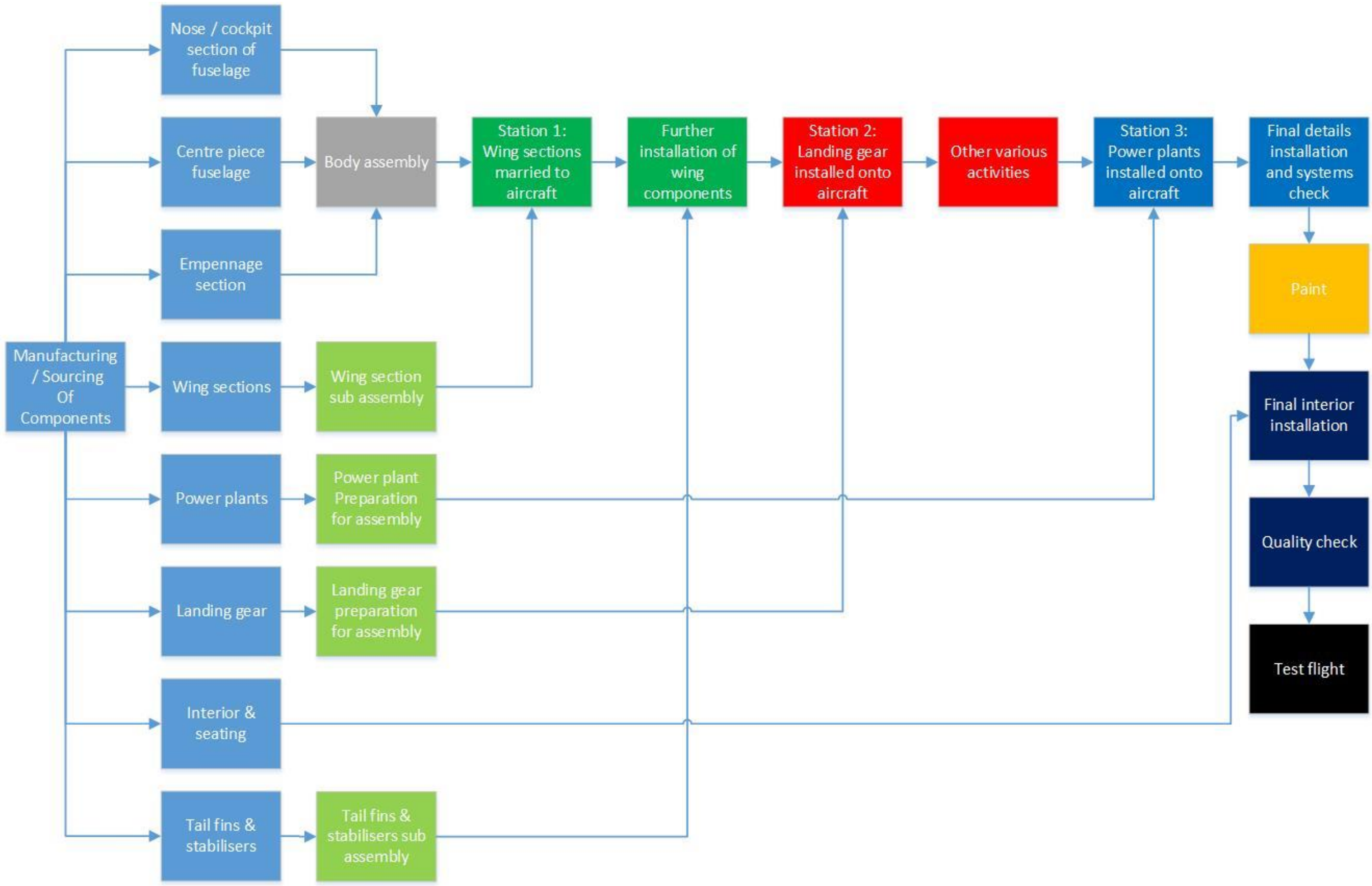


Figure 53: Assembly process for the modular process layout assembly line

The assembly process in the figure above will be described in detail.

The components and parts for the aircraft are either sourced or manufactured for the final assembly of the aircraft.

In the figure above of the assembly process for the modular process layout assembly line concept:

- The *green* rectangles are sub-assemblies.
- The *grey* rectangle represents the body assembly facility where the various fuselage sections are joint to form the main body / fuselage of the aircraft.
- The *orange* rectangle is the painting facility.
- The *Dark green* rectangle represents the first station in the main assembly facility.
- The *Red* rectangle represents the second station in the main assembly facility.
- The *Dark blue* rectangle represents the third station in the assembly facility.
- The *Dark purple* rectangle represents the final interior installation facility.

Facilities used:

The Modular process layout assembly line concept for SARA mainly uses 5 facilities for the assembly process:

- Body assembly facility.
- Main assembly facility.
- Painting facility.
- Interior installation facility.
- Wing assembly facility.

Workstations:

The workstations each has its own specialised facilities to do specific assembly tasks on the aircraft. Workers are each assigned to a different workstation and each workstation has its own tools.

Assembly layouts & flow:

Main assembly facility:

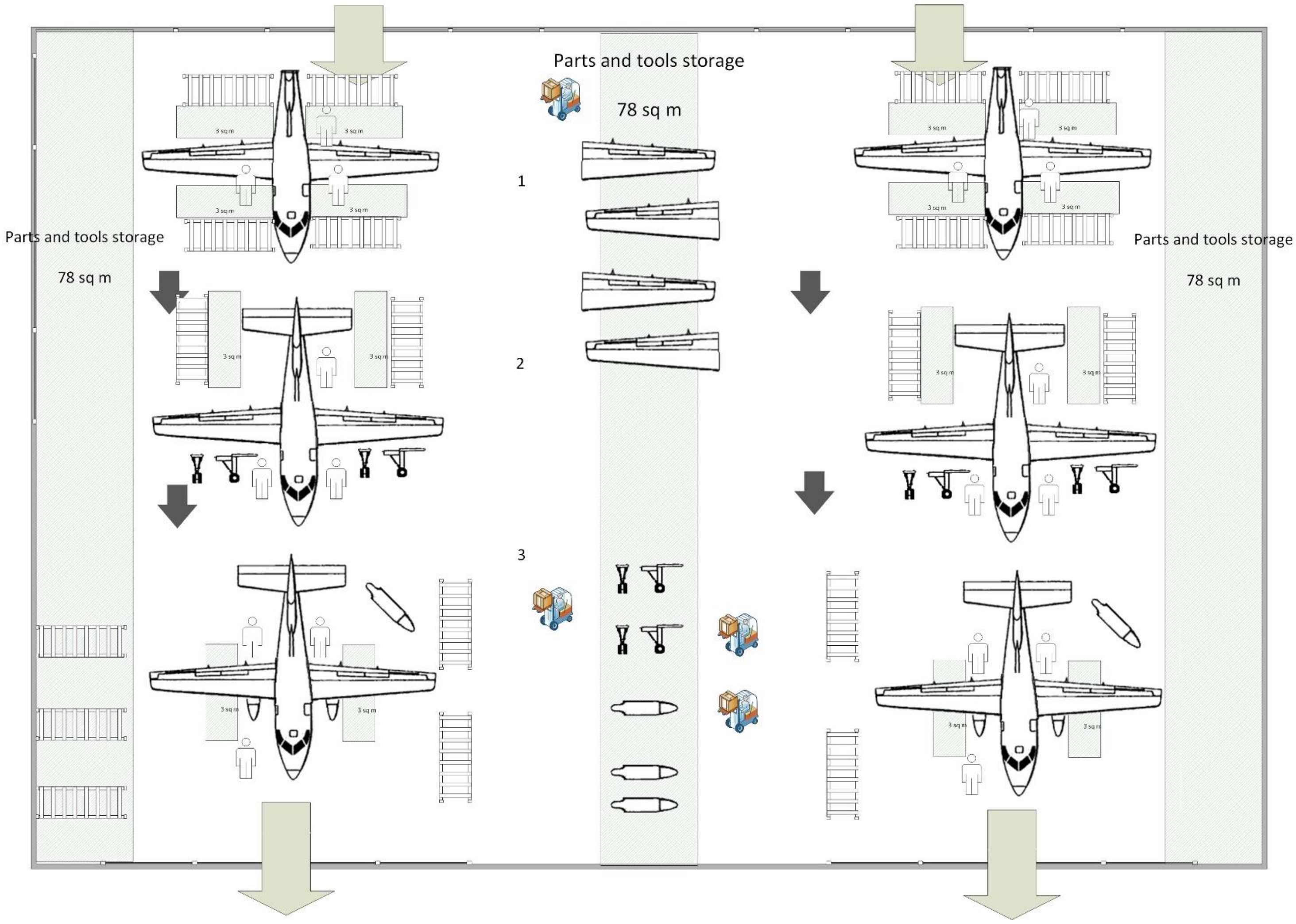


Figure 54: Layout for main assembly facility of the process layout

The main assembly process can be divided into 3 stages where each stage represents a physical assembly station in the assembly line that performs specific assembly procedures and activities on the aircraft passing through it.

- Station 1: Wing assembly to aircraft

  The wing assembly arrives from the wing assembly facility. The aircraft is secured to a fixed position while the wing assembly is hoisted into position using an overhead crane. The wing assembly is lowered onto a hydraulic jig that aligns and lowers the wing assembly onto the aircraft.

After the wing assembly is lowered onto the aircraft it is fastened by the workers at the station.

- Station 2: Landing gear installation.

  The aircraft is pulled into the next station. The crew installs the landing gear into the aircraft after it arrives.

  The tail fin and other stabilisers are also installed onto the empennage of the aircraft using overhead cranes to position and lower them into place and workers to fasten them.

  The aircraft is now ready to be lowered down onto its own weight and roll on its own wheels.

- Station 3: Power plants installed

  The aircraft is pulled, now on its own wheels to the next station.

  At this station the power plants are installed onto the aircraft using hoists and workers fitting them into place.

  The final details are also assembled at this stage such as propellers, covers, and final exterior and system details.

  The aircraft is almost finished and is now ready for the paint facility.

Body assembly facility:

In this instance, there is a separate facility used for the body / fuselage of the aircraft.

The body sections are assembled into the main fuselage. The installation of wiring harnesses as well as the beginning stages of the interior and flight systems are also installed in this facility.

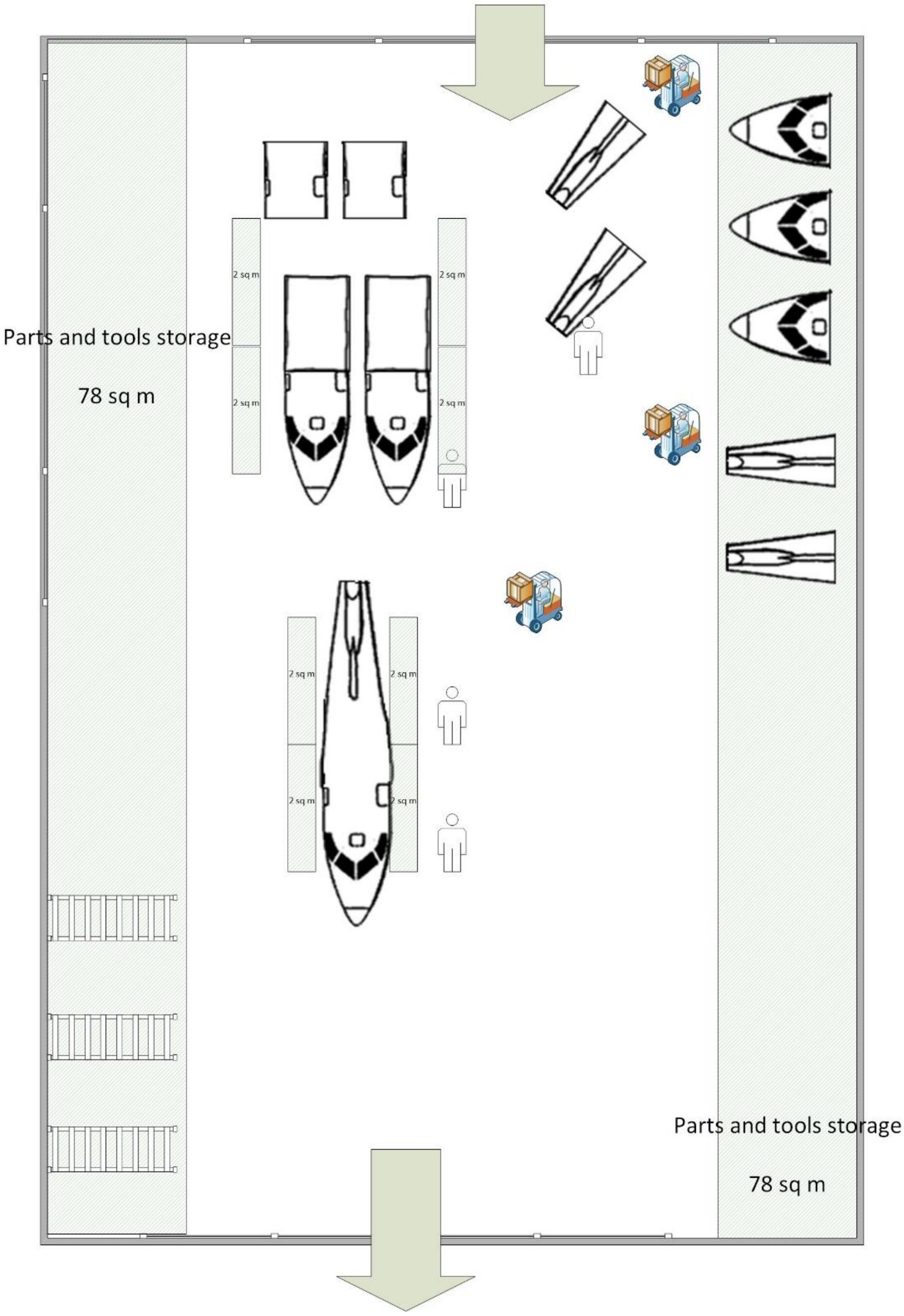


Figure 55: Layout of the body assembly facility

Wing assembly facility:

The wings and empennage pieces are assembled completely in a different facility. They are assembled with the necessary connections so that they can simply be installed onto the aircraft.

Paint:

The painting procedure is the same here as before and uses the same type of facility and layout.

After the aircraft is completely assembled it is transported into the painting facility where it gets a fresh coat of paint according to what the customer wants.

The aircraft is sprayed by hand and reached via scaffolding.

Interior installation facility:

In this stage, the final smaller detail components is installed to the aircraft as well as its interior and seating. The aircraft goes through a thorough systems inspection to assure quality.

Afterwards the aircraft is ready for its test flight.

4.3.3 Modular flow-line assembly (Product family layout):

The Modular Product family layout assembly line concept for SARA is an assembly process that groups assembly processes together based on similar manufacturing operations.

Machines, equipment, materials, tooling, personnel, and material and storage handling required to produce the family part are grouped together in one facility thus creating a *cell* – Cellular manufacturing (Tompkins et al. 2010).

JIT *just-in-time* production system (*Tompkins et al. 2010*) and lean manufacturing concepts and techniques apply to this method of assembly layout.

In this concept each major assembly component will be assembled in a dedicated facility and then brought together to form the main assembly.

Thus each component will be assembled 100% completed including paint before it is joint to the main assembly.

Assembly Process:

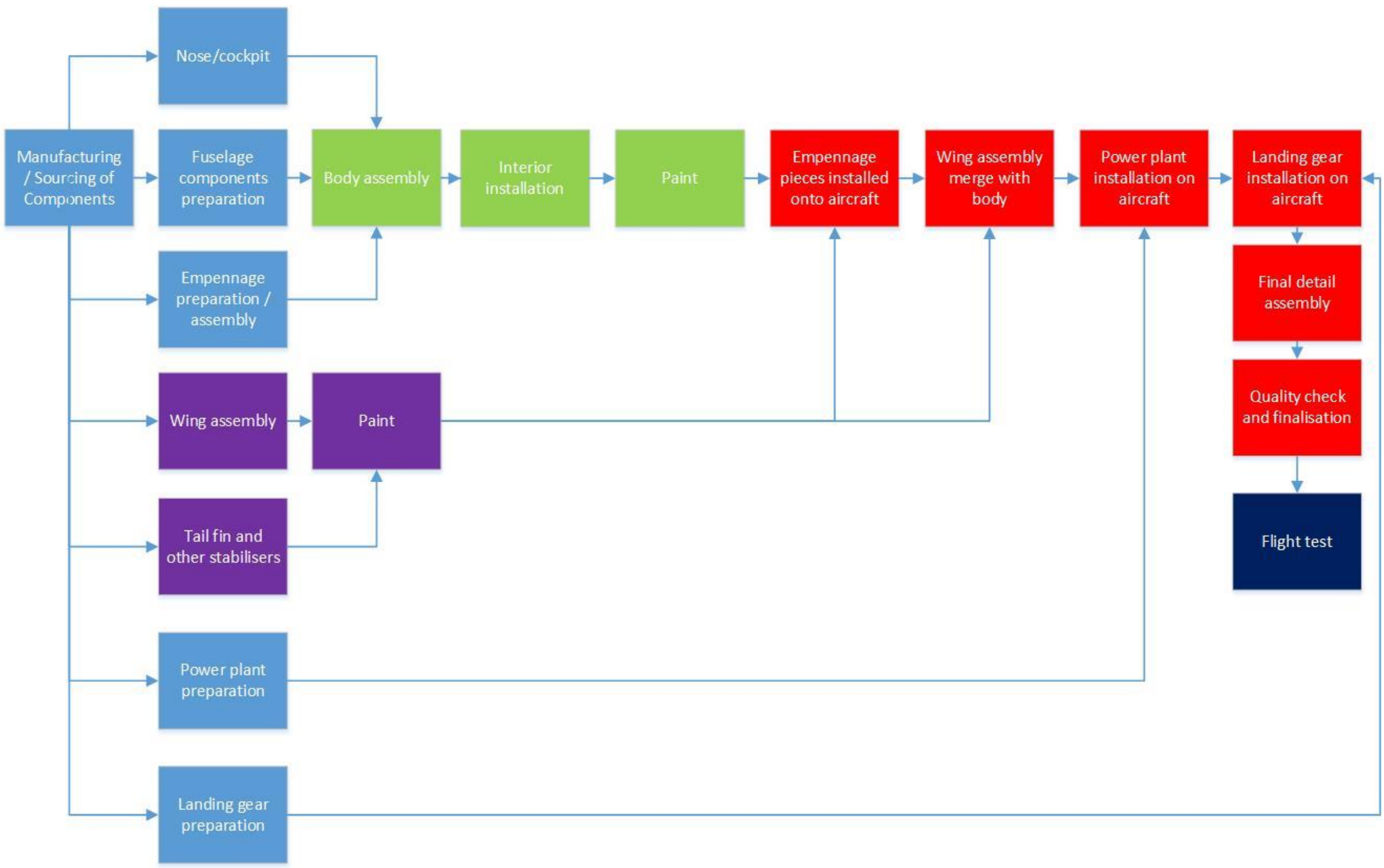


Figure 56: Assembly process for the product family layout assembly line

The assembly process in the figure above will be described in detail.

The components and parts for the aircraft are either sourced or manufactured for the final assembly of the aircraft.

In the figure above of the assembly process for the product family layout assembly line concept:

- The *green* rectangles the body assembly / fuselage family.
- The *purple* rectangle represents the wing assembly and winglet assemblies for the empennage family.
- The *red* rectangle is the main assembly facility where all product families come together to form the aircraft.
- The *blue* rectangles represents the mechanical family parts such as the landing gear, power plants and manufacturing of parts.

Facilities used:

The Modular product family layout assembly line concept for SARA mainly uses 4 facilities for the assembly process:

- Body assembly facility.
- Main assembly facility.
- Wing assembly facility.
- Landing gear and power plant preparation assembly.

Workstations:

The workstations will be allocated according to what machines, equipment, materials, tooling, personnel, and material and storage handling methods required to assemble each component in their respective facility.

Assembly layouts & flow:

Body assembly facility:

The body assembly facility would look exactly like the previous concept's layout. *(Figure 57: Layout of the body assembly facility)*.

The body sections are assembled into the main fuselage. The installation of wiring harnesses as well as the beginning stages of the interior and flight systems are also installed in this facility.

After the interior is completely installed with all its systems, the fuselage is painted to the customer's specification before it is transported to the main assembly facility.

Main assembly facility:

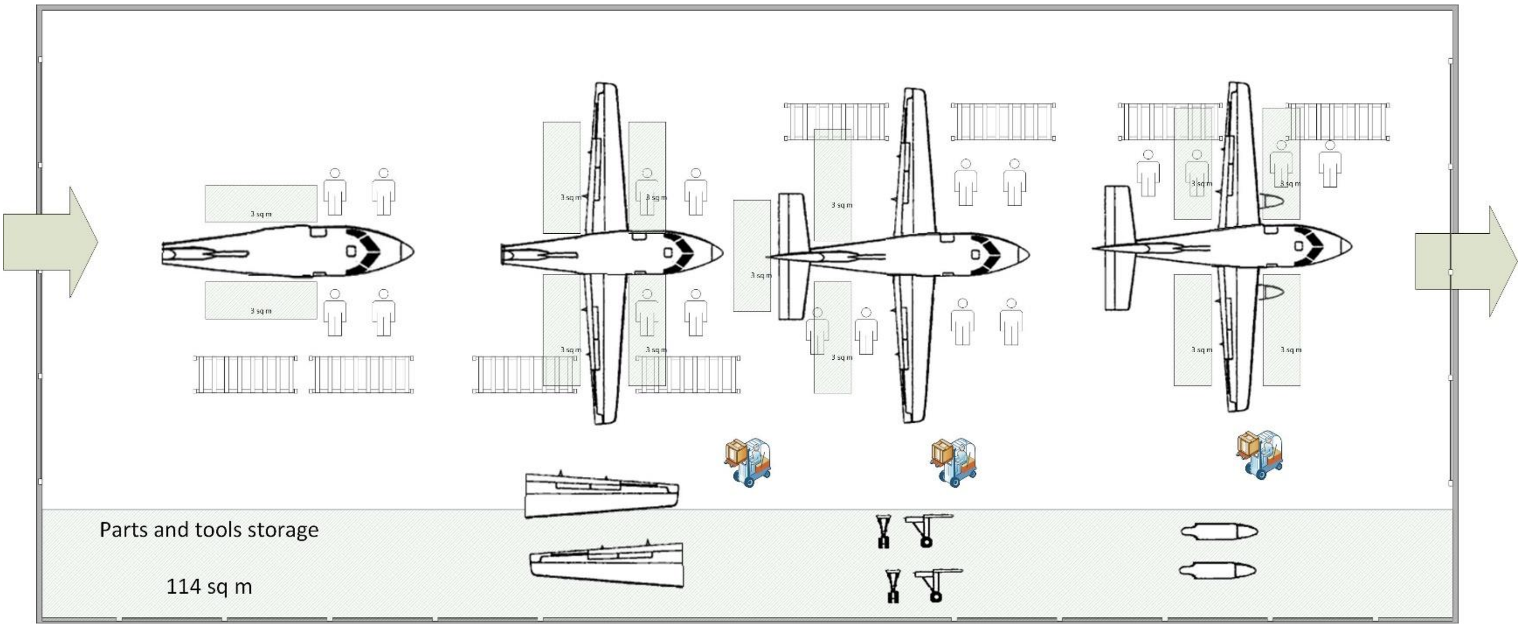


Figure 58: Layout of the main assembly facility of the product family layout

After each component has been assembled and painted till 100 % completion, it is sent to the main assembly facility where they are assembled into the main aircraft.

This procedure can be divided into 3 steps:

- Step 1: Wing assembly merger to fuselage
  The wing assembly arrives from the wing assembly facility. The aircraft is secured to a fixed position while the wing assembly is hoisted into position using an overhead crane. The wing assembly is lowered onto a hydraulic jig that aligns and lowers the wing assembly onto the aircraft.
  After the wing assembly is lowered onto the aircraft it is fastened by the workers at the station.
  This is the exact same procedure as before.

- Step 2: Tail pieces assembled to empennage & landing gear installation

  The tail fin and other stabilisers are also installed onto the empennage of the aircraft using overhead cranes to position and lower them into place and workers to fasten them.

  The landing gear is also fitted to the aircraft. The aircraft can roll on its own wheels.

- Step 3: Power plant installation & finalisation
  The aircraft is pulled, now on its own wheels to the next station.
  At this station the power plants are installed onto the aircraft using hoists and workers fitting them into place.

The final details are also assembled at this stage such as propellers, covers, and final exterior and system details.
Final system and quality checks are done to ensure a quality product for the customer.

Wing assembly facility:

The wings and empennage pieces are assembled completely in a different facility. They are assembled with the necessary connections so that they can simply be installed onto the aircraft.

After they are assembled and completed, they are painted according to the customer's specification and sent to the main assembly facility.

Landing gear & power plant preparation facility:

The landing gear and power plants are prepared for installation for each aircraft in this facility.

5 Project Implementation

The project's planning and procedure for implementation was covered in detail in the previous chapters. In this part of the document, the simulation models built to test each layout concept will be discussed and reviewed.

The first part of this chapter was researching data on time studies and cycle times when it comes to the assembly of aircrafts. The data was estimated by using distributions to generate time studies and cycle times that would mimic other assembly processes for aircraft and applied to this project.

This is a green field project, as stated previously thus the concepts where designed from scratch on a macro-level so that only the essence of aircraft assembly can be simulated for each layout concept.

The critical path for assembling the aircraft with estimated times are as follow:

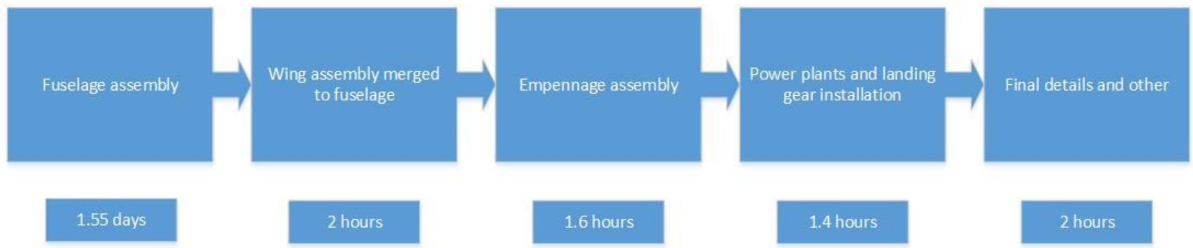


Figure 59: Critical path with approximated times

The aircraft is completed in the following sequence:

- Fuselage / wing assembly / Empennage pieces / Power plant & landing gear preparations
- Wing assembly merger to aircraft
- Empennage installation
- Power plant and landing gear mounting

Each sub-assembly is joined together in the main assembly facility of each layout and each concept follows this critical path and method.

Inter-arrival times should not affect the production rate directly, but rather the buffer sizes. Buffer sizes are directly relate to the storage of abundant parts.

The simulations are run for 365 days following a shift calendar where employees work from 8:00 – 16:45.

According to the project sponsor of this project, a good aim for a demand would be 100 aircraft per year.

5.1 Simulation Models

The simulation models where built in Siemens Plant simulation, software provided by ESTEQ. Each model represents a facility layout concept from where to start the detailed design of the facility and assembly process later on.

These simulation models are tested against each other and their end results are compared. Based on the results and further calculations, a layout concept will be selected as the final result or a mixture of layouts.

The arrival and assembly times used in the models will be estimated based on research mentioned in previous sections and past projects, since the current project is still in design phase and the end result is only a concept to work from.

The number of facilities used differ from simulation model, however each layout uses a main assembly facility where the aircraft is completed.

The moving track length used for the moving assembly line concept is 240m long. Thus to fit the track, the main assembly facility size used for all 3 concepts is 150x70m

Facilities used for concepts:

- Moving Assembly line concept:
  - Main assembly facility containing u-shaped moving line.
  - Wing assembly facility (Assembles main wing assembly along with other wing related parts used for empennage).
  - Power plants and landing gear staging facility (also for other parts used on micro-level).
- Product family layout concept:
  - Main assembly facility that can fit 2 assembly lines.
  - Body assembly facility where the aircraft fuselage is completed.
  - Wing assembly facility (Assembles main wing assembly along with other wing related parts used for empennage).
  - Power plants and landing gear staging facility (also for other parts used on micro-level).
- Fixed position layout concept:
  - Main assembly facility that can house 4 fixed layout positions.
  - Wing assembly facility (Assembles main wing assembly along with other wing related parts used for empennage).
  - Power plants and landing gear staging facility (also for other parts used on micro-level).

5.1.1 Proposed Siemens Plantsimulation models

The following are screenshots of each layout concept:

- Moving Assembly line concept:
    - Main assembly facility:

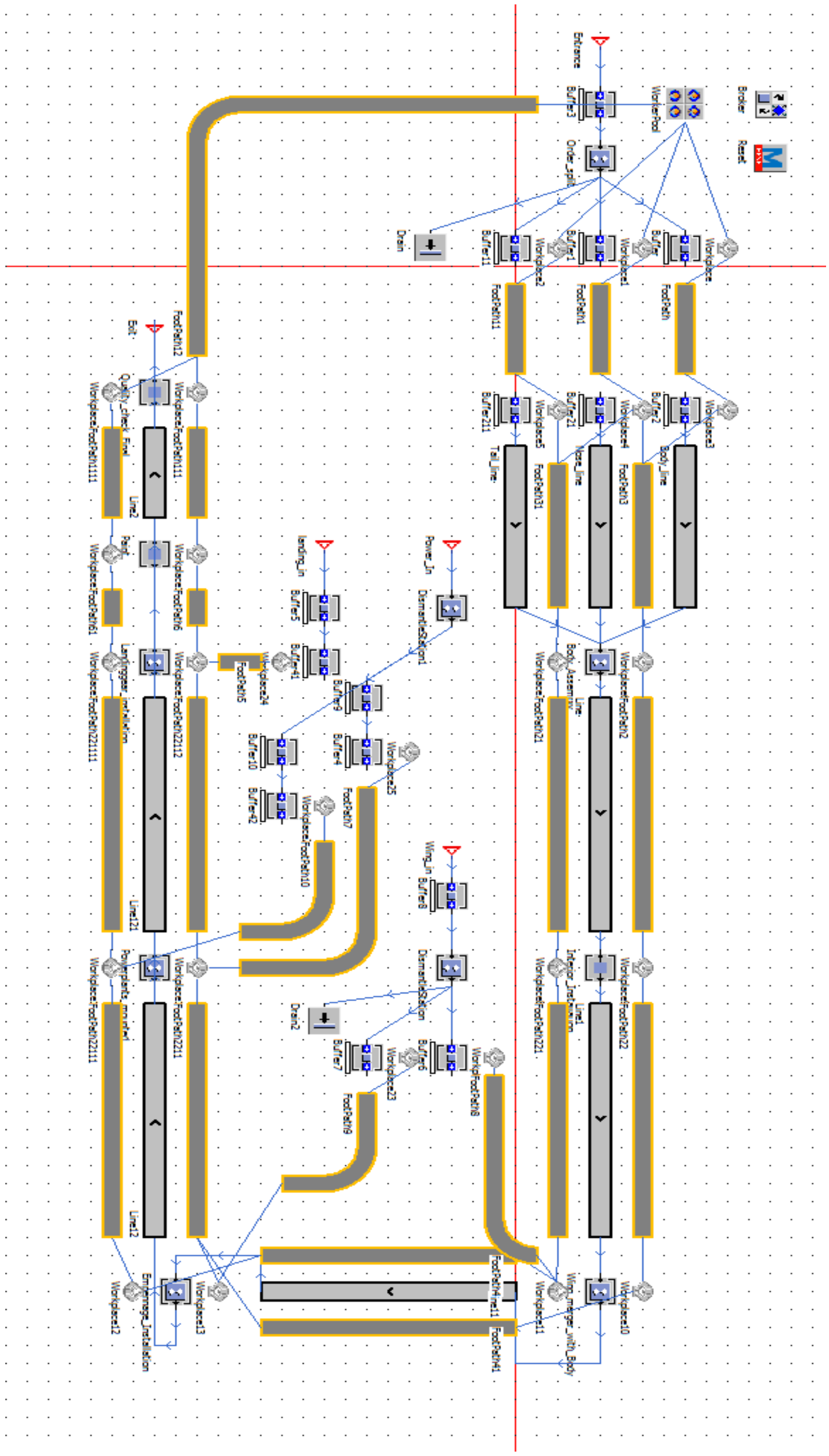


Figure 60: Main assembly line for the Assembly line layout concept simulation model.

- Moving assembly line concept:

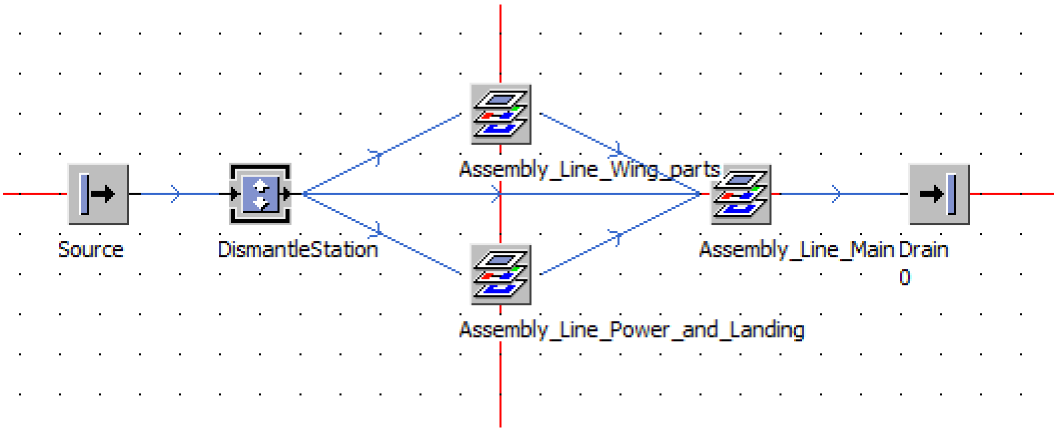


Figure 61: Moving assembly line layout concept: All facilities with connections

- Wing assembly facility:

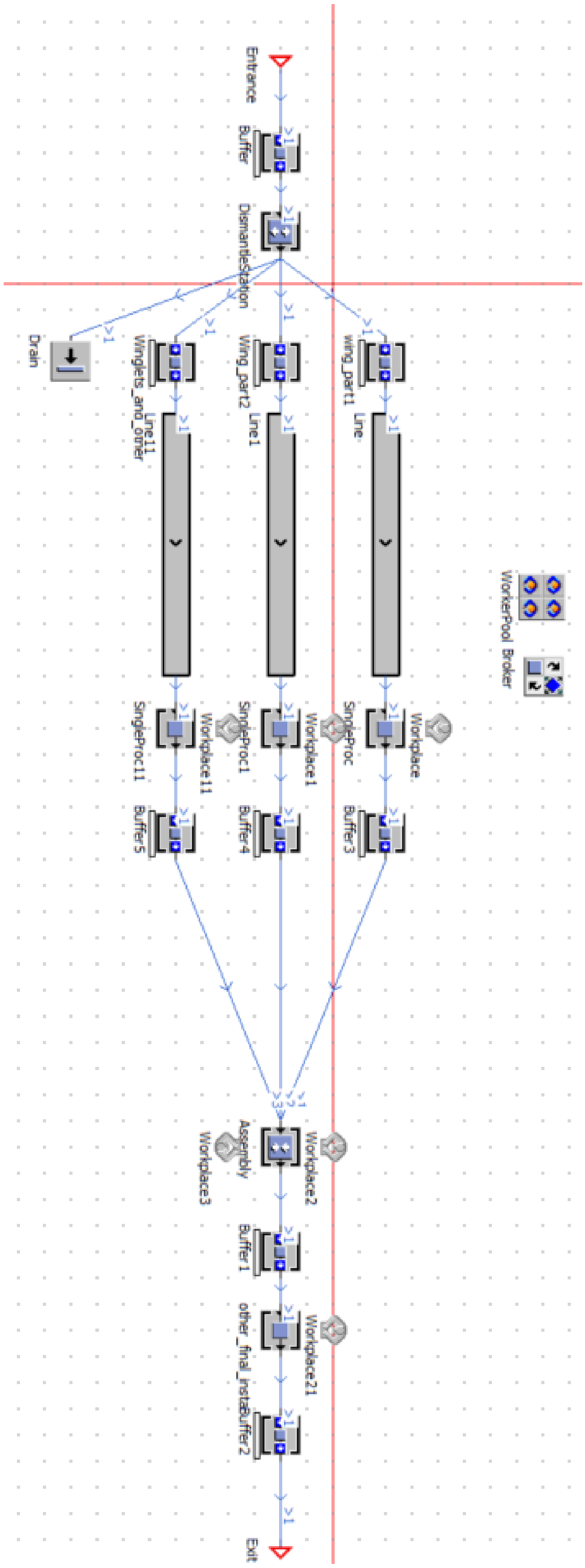


Figure 62: Wing assembly facility used for Moving assembly line concept

- Power and landing gear preparation:

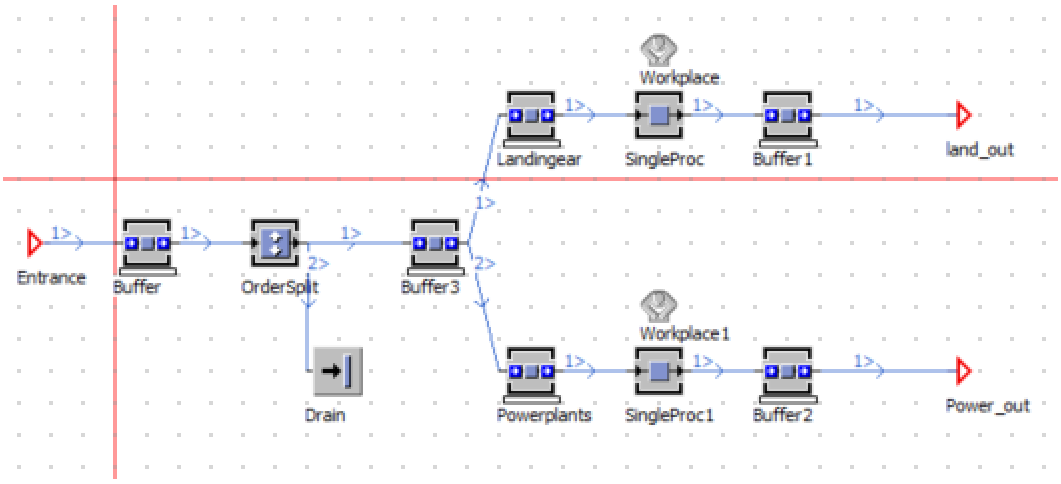


Figure 63: Power and landing gear preparation facility used in the moving assembly line layout concept

- Product family layout concept:
    - Main assembly facility:

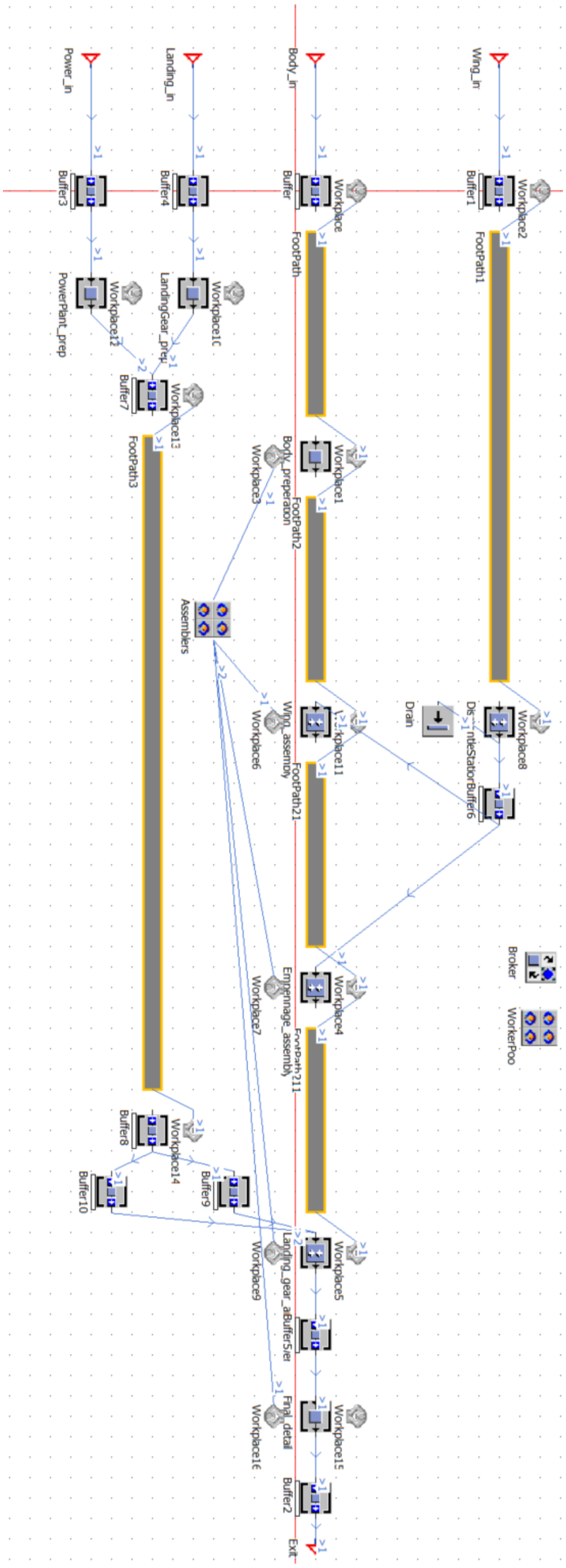


Figure 64: Product family layout concept main assembly facility.

- Product family layout concept:

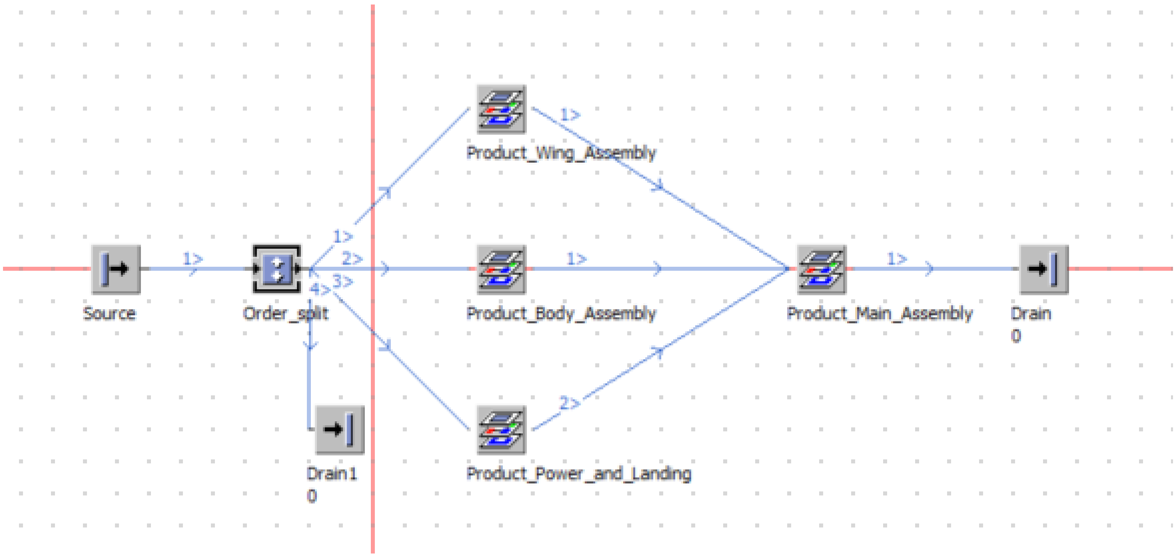


Figure 65: Product family layout concept: All facilities with connections

- Body assembly facility:

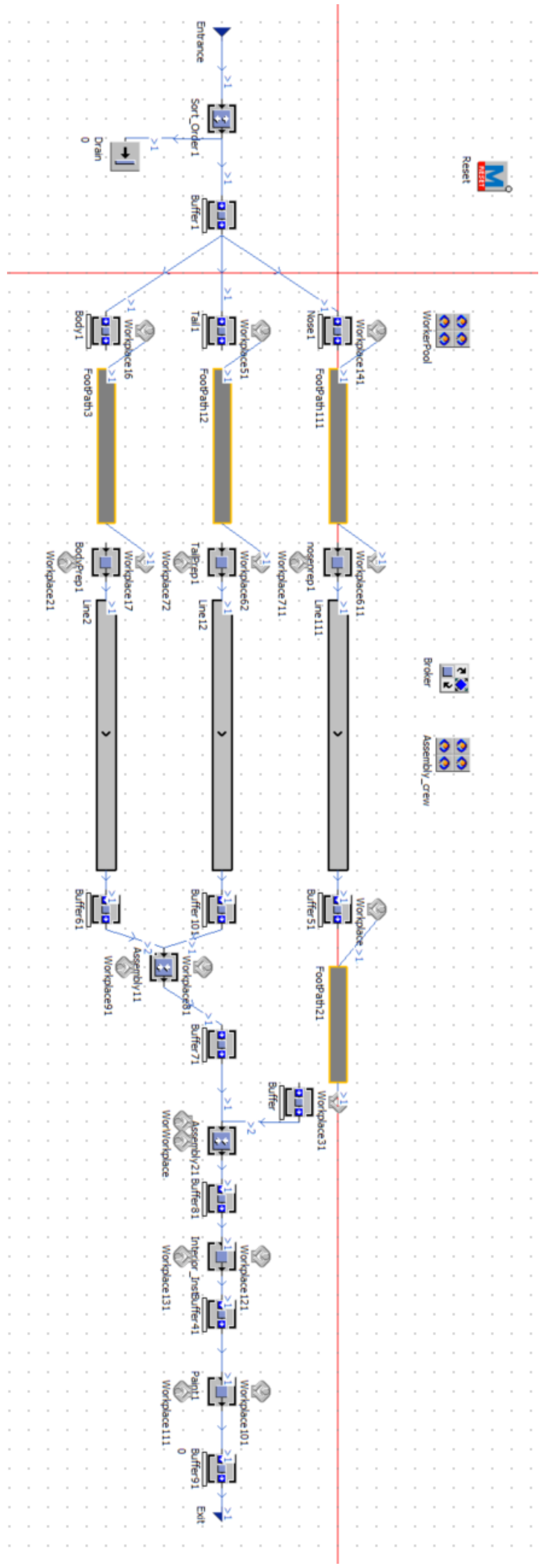


Figure 66: Body assembly facility used in the product family layout concept

- Wing assembly facility:

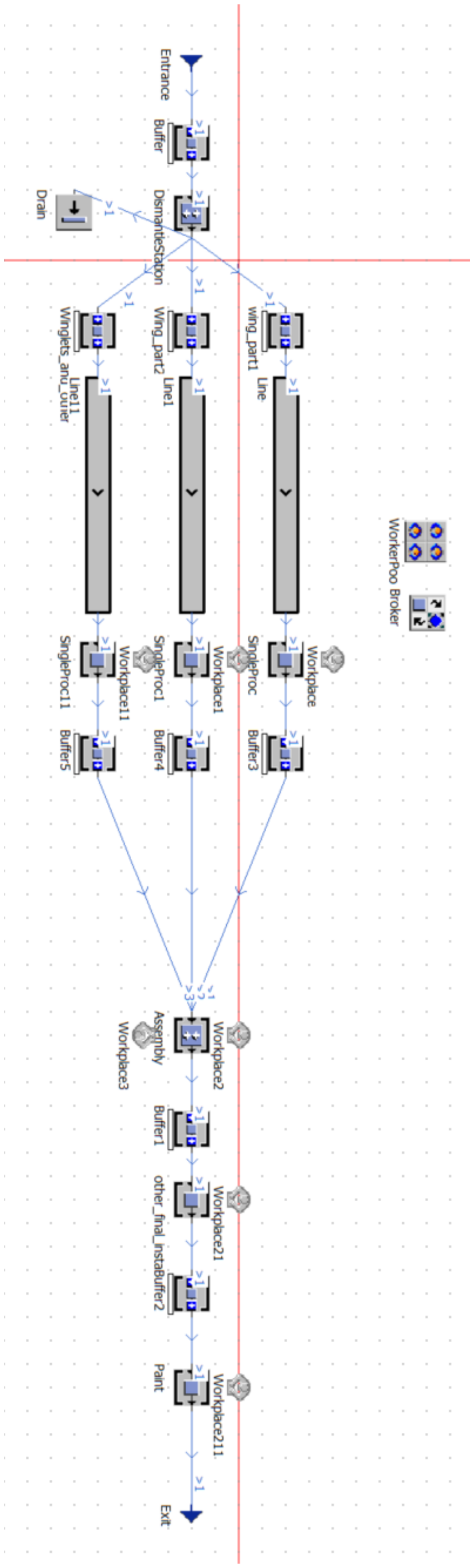


Figure 67: Wing assembly facility used in the product family layout concept

- Power plant and landing gear preparation facility:

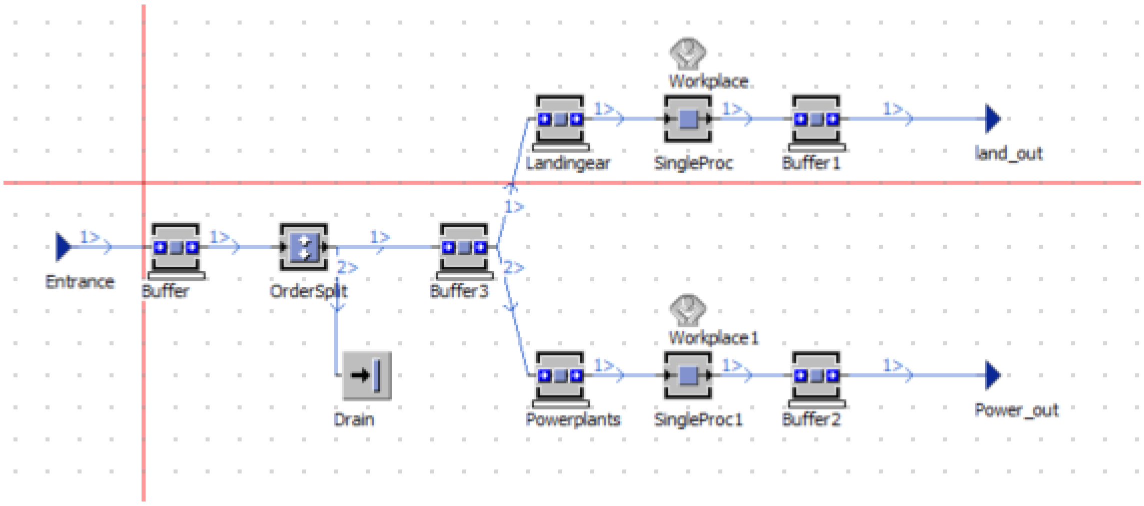


Figure 68: Power plant and landing gear preparation facility used in product family layout concept

- Fixed position layout concept:
    - Main assembly facility: Showcasing one fixed position aircraft assembly

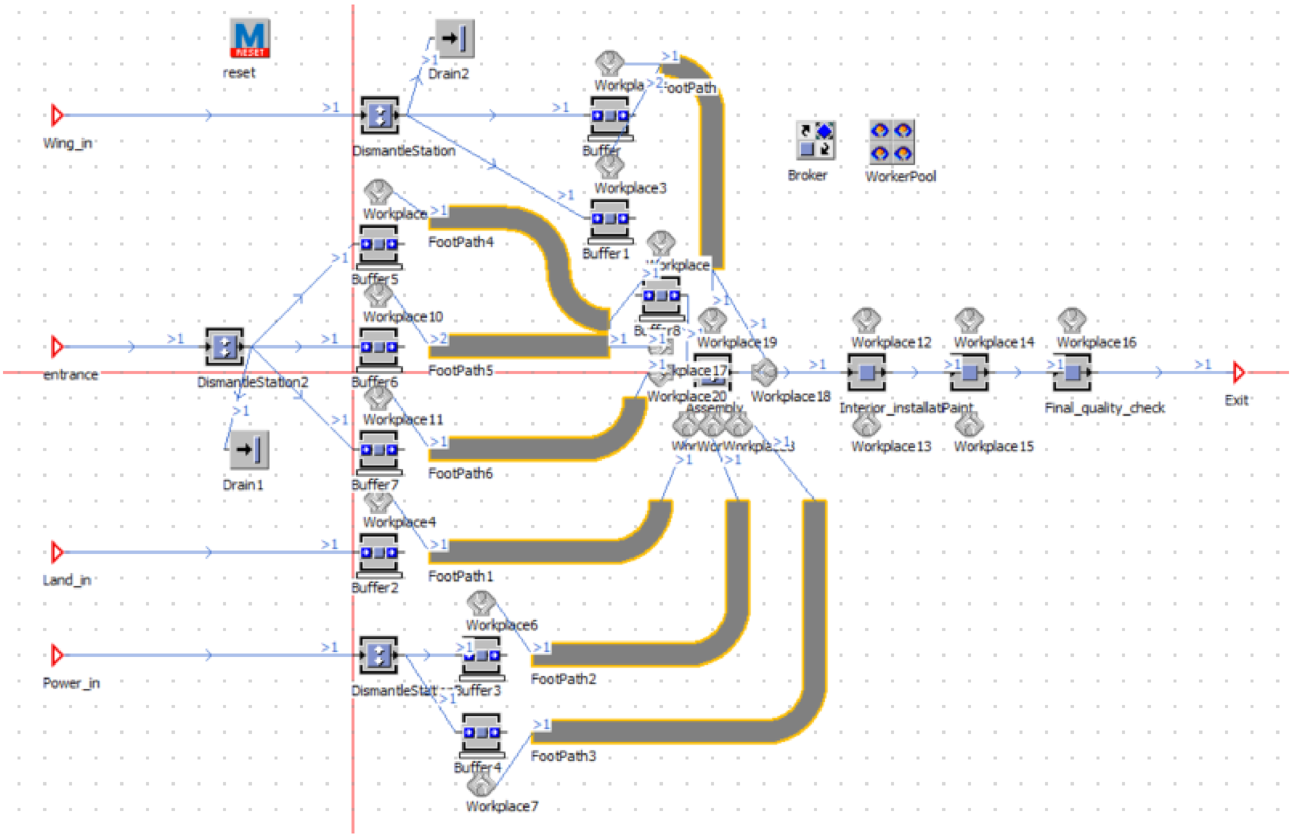


Figure 69: Fixed position layout concept main assembly

- Fixed position layout concept:

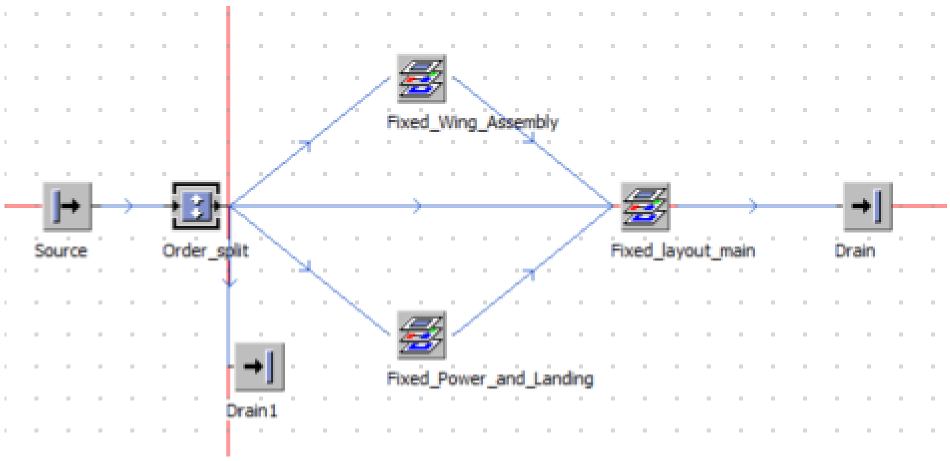


Figure 70: Fixed position layout concept including all connections between facilities

- Wing assembly facility: The same as the facility used for the assembly line layout concept in figure 62.

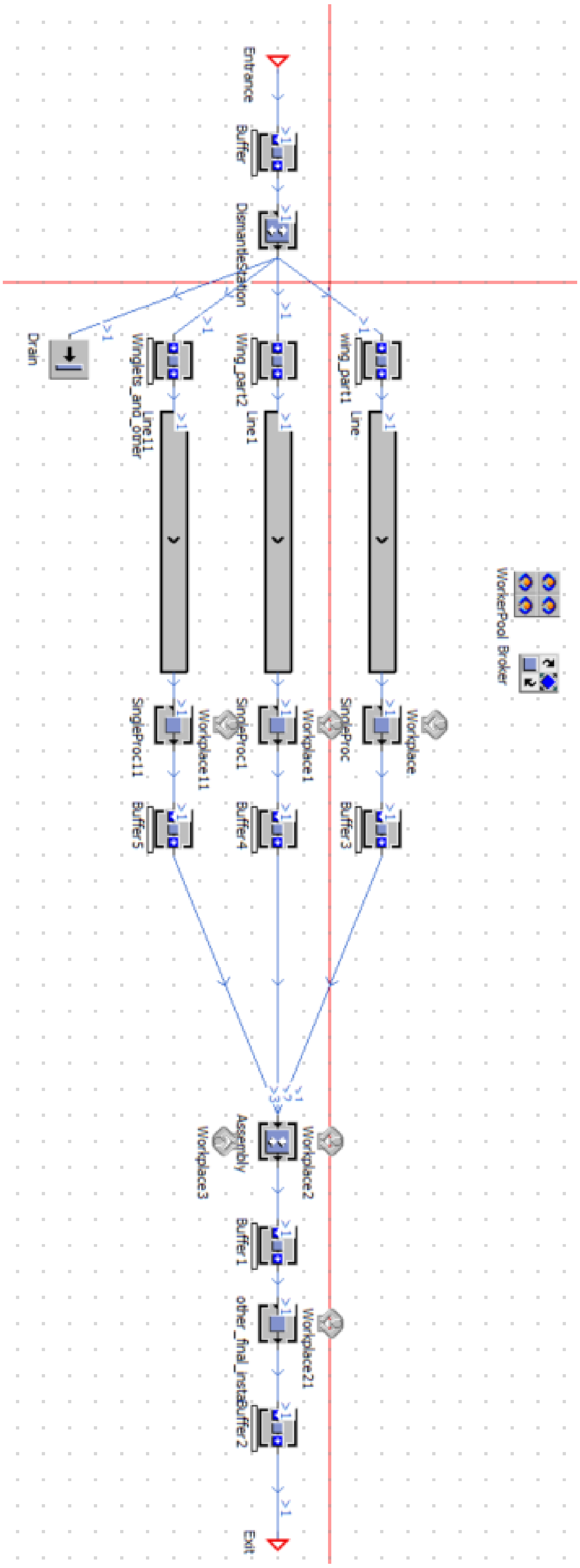


Figure 71: Wing assembly facility used for the fixed position layout concept

- Power and landing gear preparation facility:

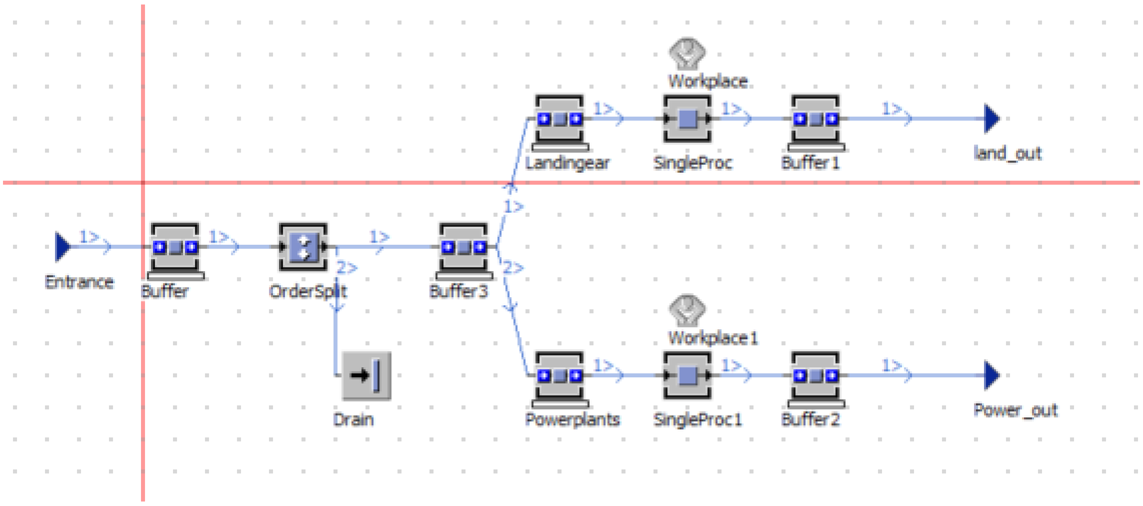


Figure 72: Power and landing gear preparations facility used for the fixed position layout concept.

5.1.2 Model Experiments & Results

5.1.2.1 Experiment design

After each simulation model was built using Siemens Plant simulation software, they were tested in their ability to accurately simulate each layout. Each model is tested to see how many aircraft can be assembled within a certain time frame using the least amount of resources. The models' results will also be compared to an estimated demand for the aircraft per year to see if the layout will achieve that goal. The optimal amount of workers have been calculated for each layout prior to this result. The moving assembly line concept's optimal efficiency stays constant since the throughput is directly related to the speed of the line. The models will be tested in five steps.

Step 1:

In Step one the models will have the following constants:

- There is a constant inflow of orders with no interval between them.
- There are an abundance of workers available.
- Each order will generate the parts needed for that order.
- 1 entity of parts per aircraft order.

The following will be tested:

- Throughput for 365 days.
- Time to complete 100 aircraft.
- The time 1 aircraft is in the system is also recorded.

This step follows a "manufacture-to-order" recipe.

The first step tests the following:

- The simulation model's optimal performance
- It tests if the layout concept reaches at least a demand of 100 aircraft per year
- And it also tests how effectively it produces 100 aircraft and how long it would take.

Results:

Product family layout:

Table 1: Table showing the phase 1 testing of the Product family layout concept.

Phase 1 testing:	Manufacture-to-order	
Product family layout:		Average time in system
Throughput 365 days	693 aircraft	4 days
time to complete 100 aircraft	47 days	2 days

Moving Assembly line layout:

Table 2: Table showing the phase 1 testing of the Moving assembly line layout concept.

Phase 1 testing:		Manufacture-to-order
Moving assembly line layout:		Average time in system
Throughput 365 days	2099	5 days
time to complete 100 aircraft	17 days	5 days

Fixed position layout:

Table 3: Table showing the phase 1 testing the fixed position assembly layout concept.

Phase 1 testing:		Manufacture-to-order
Fixed position layout:		Average time in system
Throughput 365 days	392	6 days
time to complete 100 aircraft	94 days	6 days

Summary:

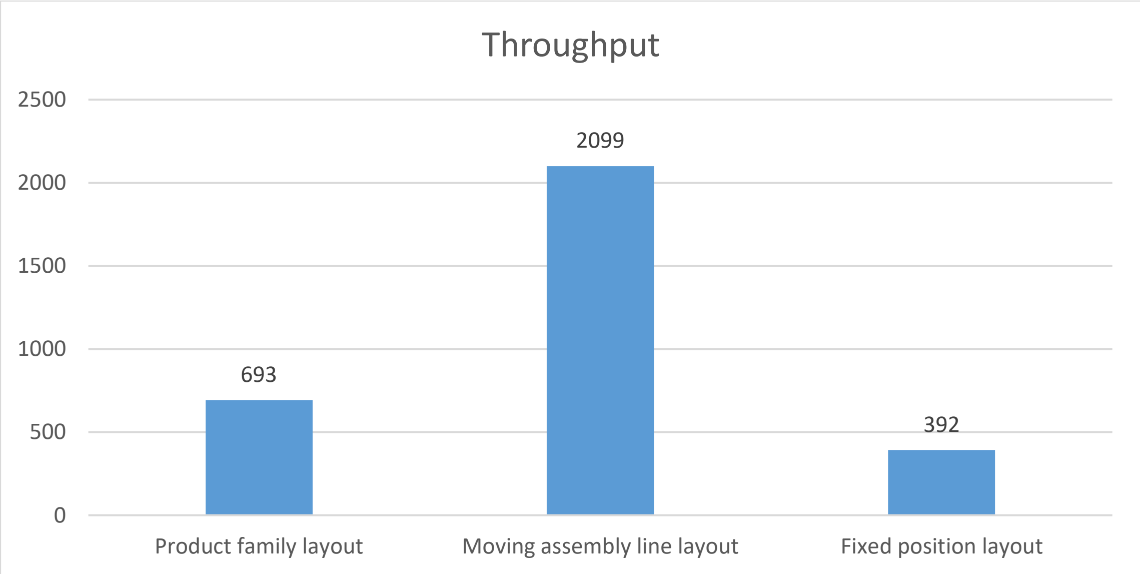


Figure 73: Graph showing the total throughputs of each layout resulting phase 1 testing.

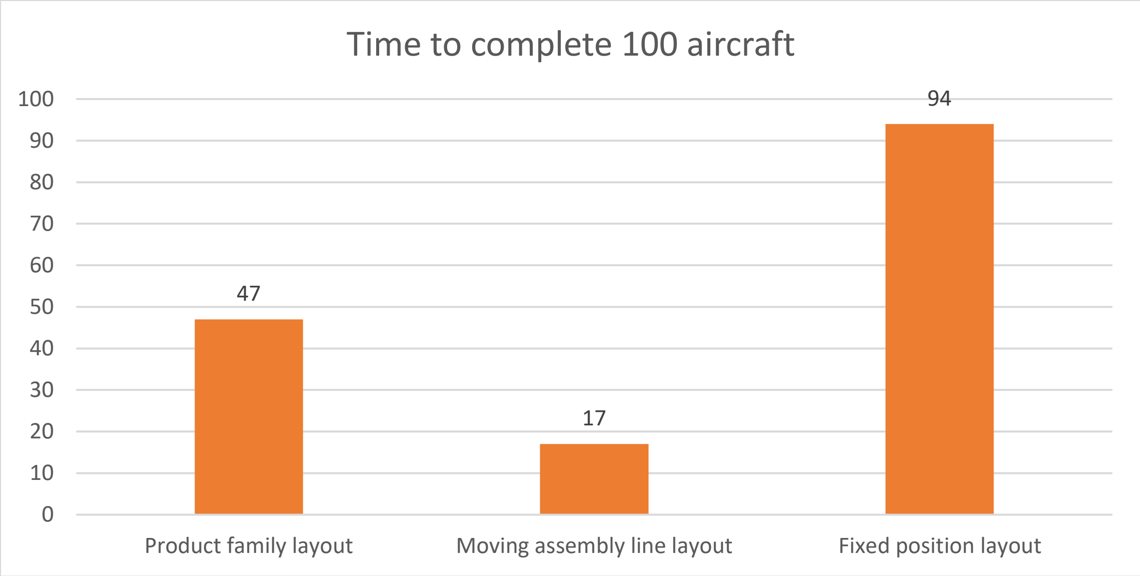


Figure 74: Graph showing the time each layout takes to complete 100 aircraft resulting phase 1 testing.

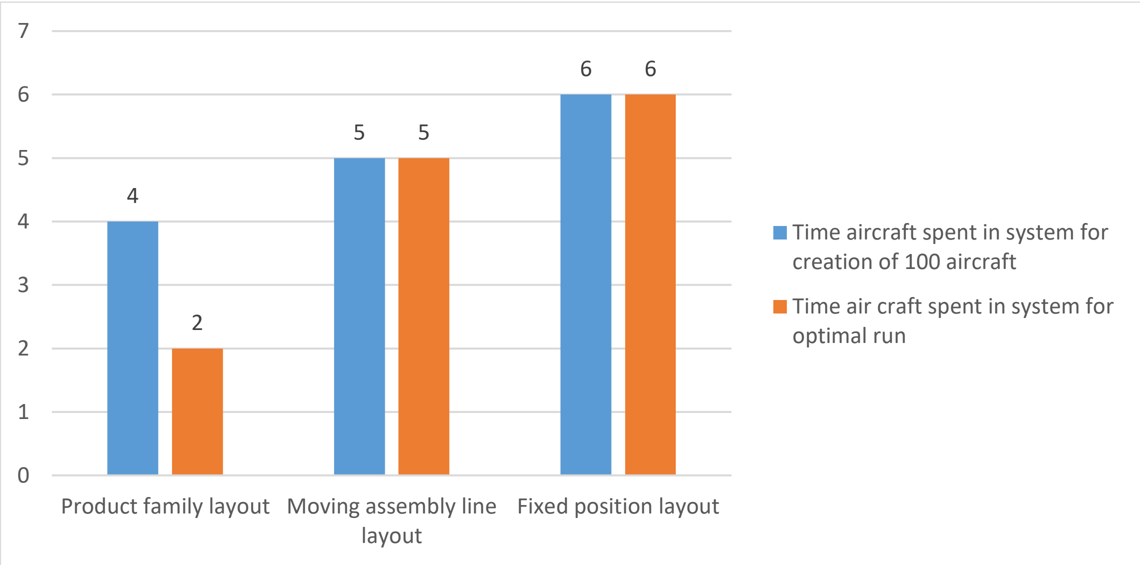


Figure 75: Graph showing the time each aircraft spends in each layout resulting phase 1 testing.

We can clearly see that the Moving assembly lines optimal performance stands out from the other two.

Step 2:

In the second step the models have the following constants:

- Each simulation model is run for 600 days.
- There are 2 workers at a station.
- Orders arrive at a triangular distribution of between 30 – 40 days.
- Each order size is of 10 aircraft.

In this step the batch sizes of parts for the aircraft will be altered for each run to see how it affects the following:

- The overall throughput.
- The time the aircraft spends in the system.
- What is the optimum batch size for parts for each layout?

Results:

Product family layout:

Table 4: Product family layout concept phase 2 results.

Results:		Batch size ordering
Phase 2 testing:		
Product family layout:		
Batch size of parts per order	Throughput	Time in system
1	260	5 days
2	516	6 days
3	766	8 days
4	1009	11 days
5	1206	13 days
6	1339	21 days
7	1356	23 days
8	1363	23 days
9	1366	23 days
10	1365	23 days

Moving Assembly line layout:

Table 5: Moving assembly line layout concept phase2 results.

Results:		Batch size ordering
Phase 2 testing:		
Moving assembly line layout:		
Batch size of parts per order	Throughput	Time in system
1	270	1 day
2	540	2 days
3	810	3 days
4	1078	4 days
5	1338	4 days
6	1598	4 days
7	1858	5 days
8	2118	5 days
9	2378	5 days
10	2638	5 days

Fixed Position Layout:

Table 6: Fixed position assembly layout concept phase 2 results.

Results:		Batch size ordering
Phase 2 testing:		
Fixed position layout:		
Batch size of parts per order	Throughput	Time in system
1	259	4 days
2	508	7 days
3	644	9 days
4	644	10 days
5	644	10 days
6	644	11 days

The optimal batch sizes are highlighted in green as seen above.

Step 3:

Based on the optimal batch size calculated above, the models are tested on how long it takes each layout to complete 100 aircraft arriving at a triangular distribution of 10 orders every 30-40 days.

Results:

Table 7: Results on time each layout takes to complete 100 aircraft using optimal batch sizes.

Layout concept:	Batch size	Time to complete 100 aircraft
Product family layout	6	43,02 days
Moving assembly line layout	10	25,03 days
Fixed position layout	4	94,06 days

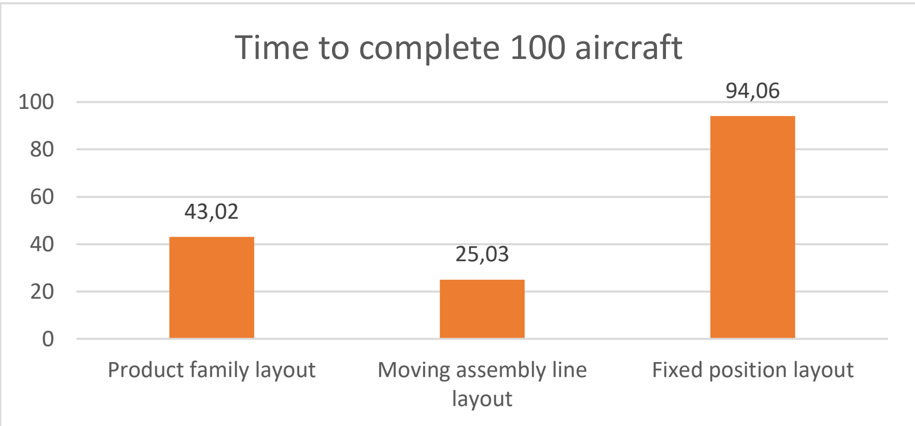


Figure 76: Graph showing results on time each layout takes to complete 100 aircraft using optimal batch sizes.

Step 4:

In step 4 the number of optimal workers calculated to run each layout efficiently are simply compared:

Table 8: Optimal number of workers for each layout concept.

Layout concept:	Assemblers	Standard	Painting	Interior	Total
Product family layout	45	25	25	15	110
Moving assembly line layout	60	35	25	15	135
Fixed position layout	30	20	25	15	90

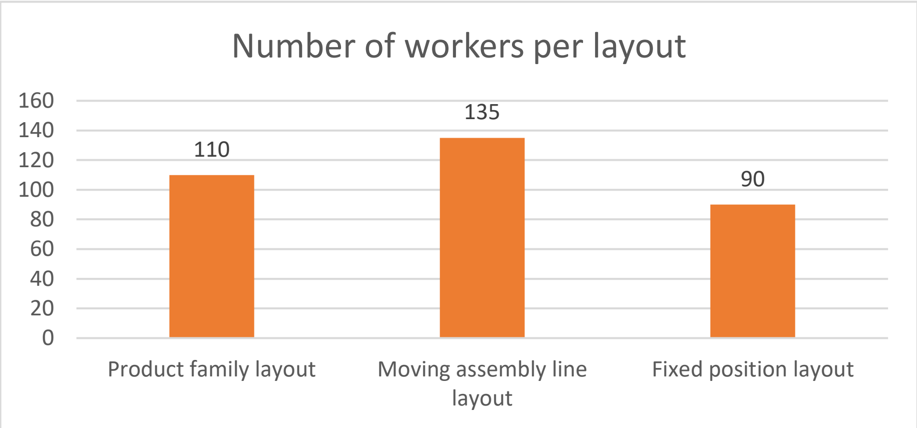


Figure 77: Graph showing optimal number of workers for each layout concept.

Step 5:

Kanban Implementation:

Kanban is used as a scheduling system for controlling inventory and WIP to ultimately control the supply chain. Kanban is most commonly used for lean-manufacturing or just-in-time manufacturing.

It ultimately improves efficiency and streamlines the manufacturing process by reducing buffer sizes, avoiding overloading manufacturing system and other benefits such as:

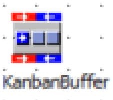
- Reduces waste and scrap.
- Reduces inventory and product obsolescence.
- Increases Output.
- Reduces total cost.

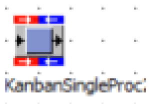
The simulation models where altered using Kanban tools provided in the Siemens software packet. Each of the 3 layouts where altered in two stages:

- In the first stage the entire system, including the incoming orders where included in the Kanban process. This was done to confirm the optimal throughputs calculated in the previous steps and also minimise buffer sizes to an optimal size throughout the layouts.
- In the second stage, only the parts needed to build the aircraft was included as a Kanban implementation, while the orders arrived as in the previous steps.

Kanban elements:

- Source: Sourcing parts and orders into the system. 

- Buffer: 

- Singleproc: a Kanban process pulling orders and components. 

Kanban layouts:

Stage 1:

Product family layout concept with Kanban Implementation:

- Body / Fuselage Assembly facility:

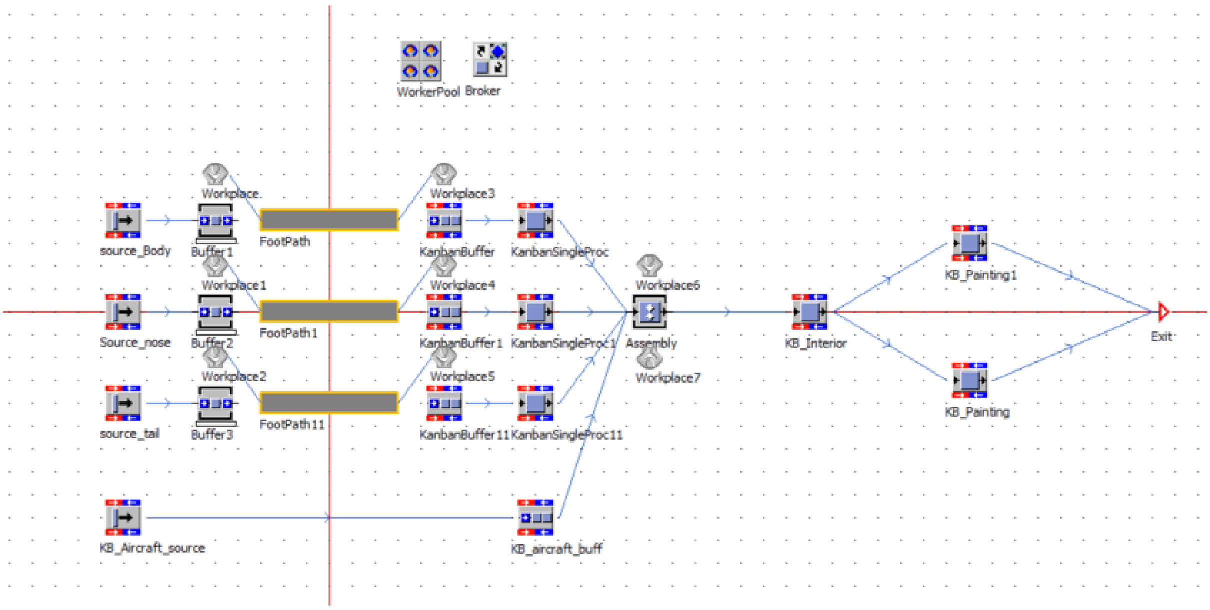


Figure 78: Product Family Layout concept Body assembly facility with Kanban implementation.

- Main Assembly facility:

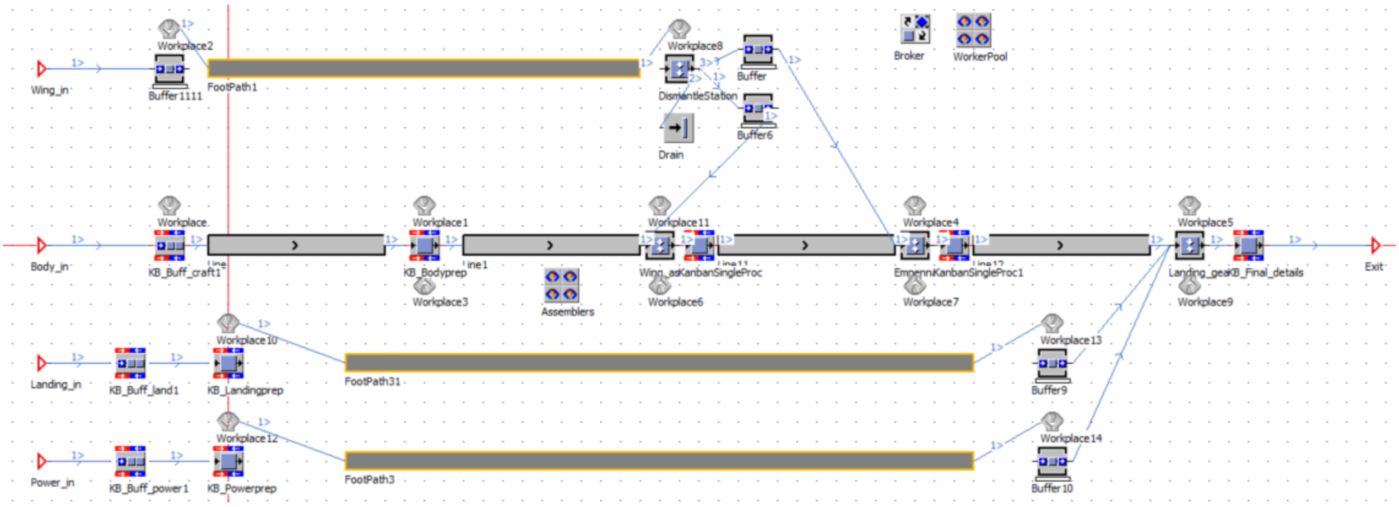


Figure 79: Product Family Layout concept Main assembly facility with Kanban implementation.

- Wing Assembly facility:

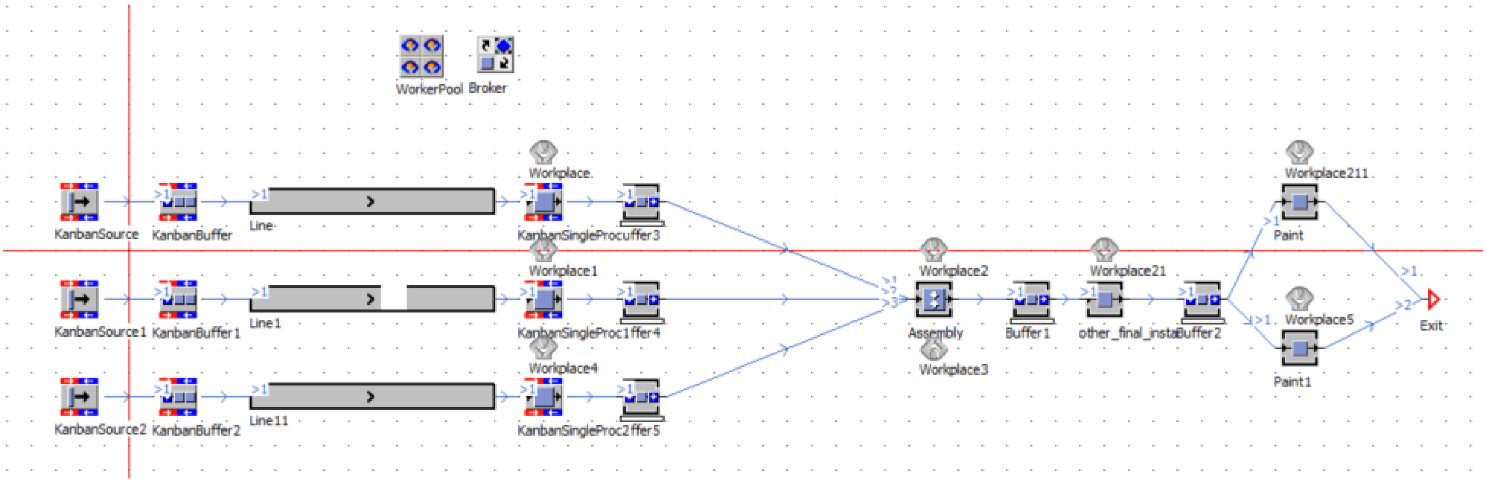


Figure 80: Product family Layout Wing assembly facility with Kanban implementation.

- Power plant and Landing gear prep facility:

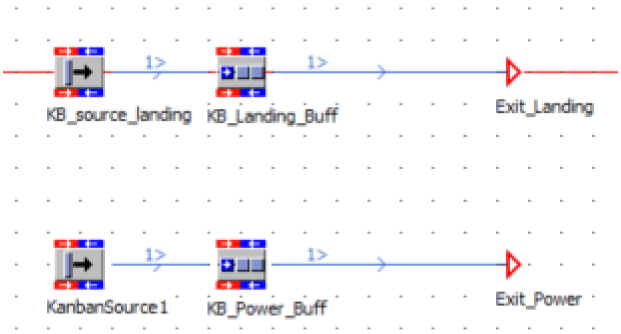


Figure 81: Product Family Layout Power plant and landing gear prep facility with Kanban.

Moving Assembly line layout concept with Kanban Implementation:

- Main Assembly line:

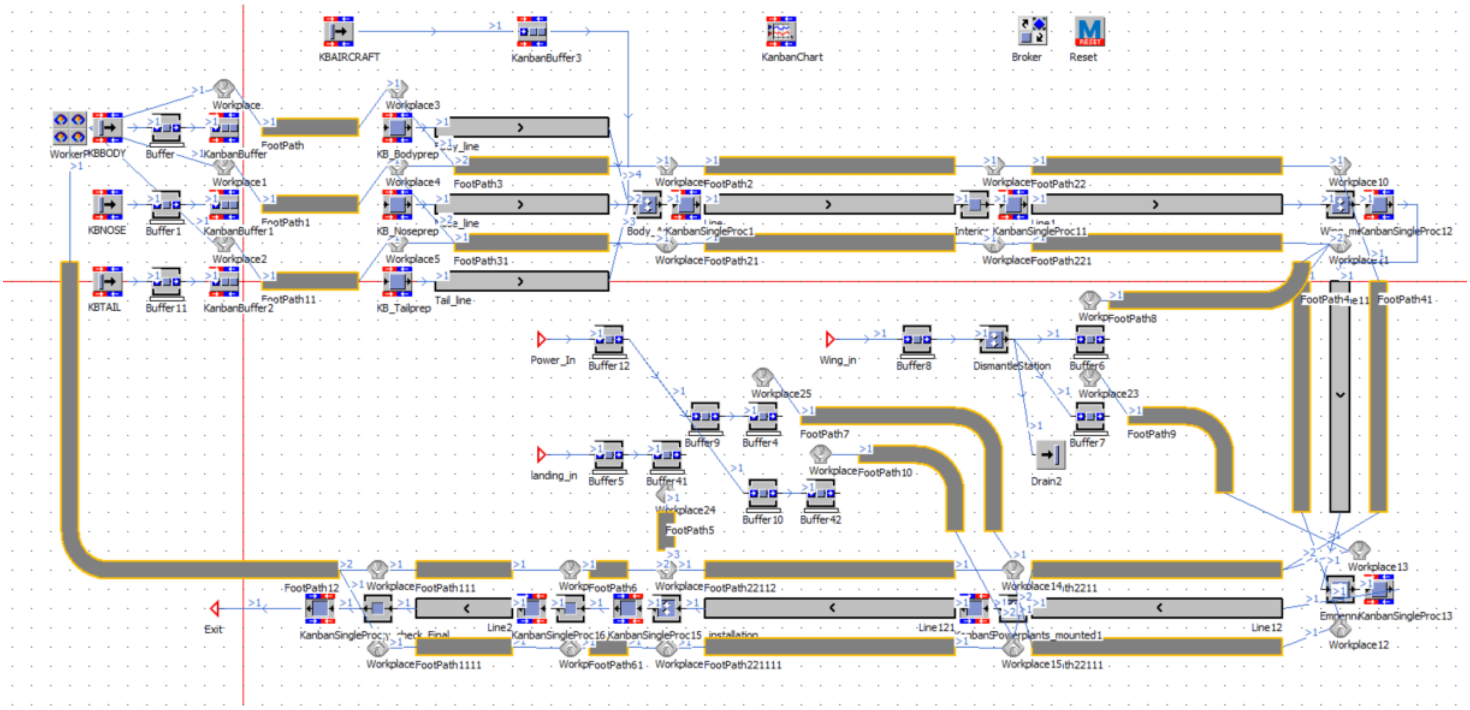


Figure 82: Moving assembly line layout Main assembly line with Kanban implementation.

- Wing assembly facility:

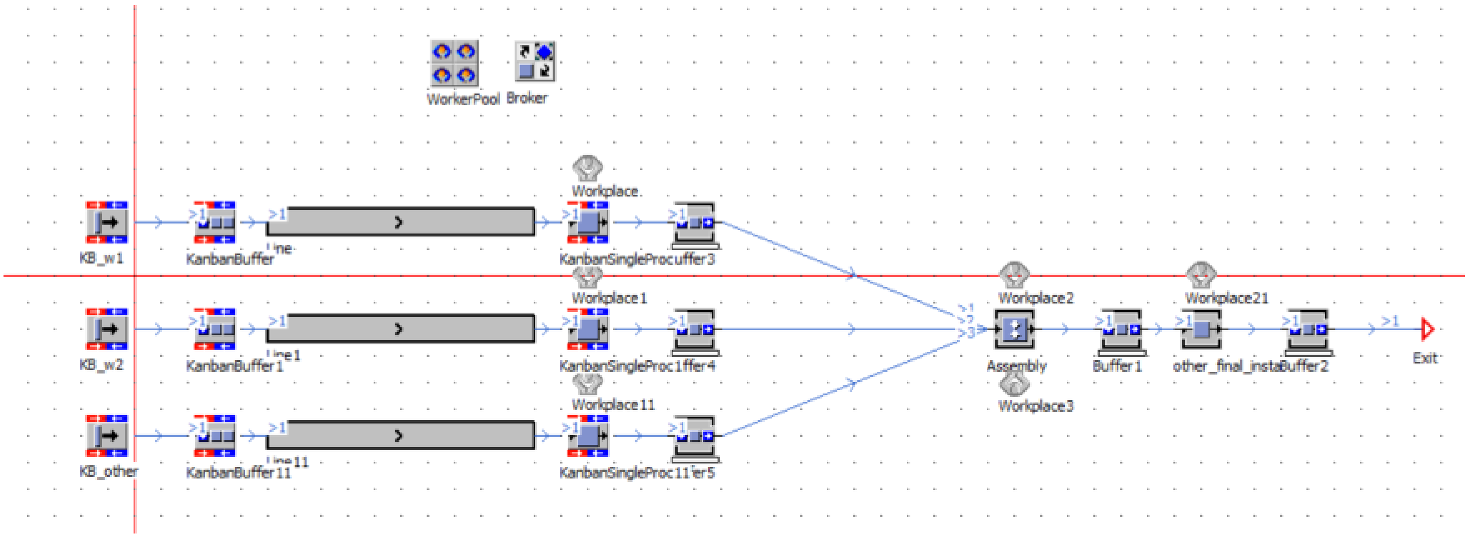


Figure 83: Moving Assembly line concept wing assembly facility with Kanban implementation

➢ Power and landing gear preparation facility:

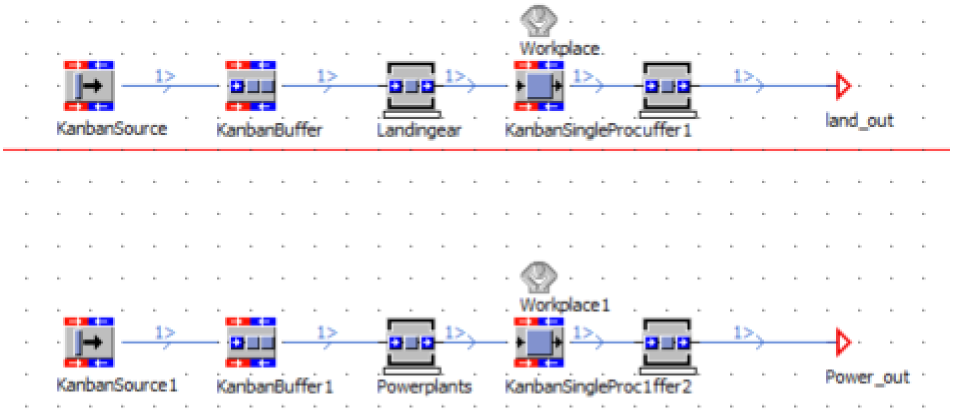


Figure 84: Moving assembly line layout power and landing gear facility with Kanban implementation.

Fixed Position Assembly layout concept with Kanban Implementation:

➢ Main assembly facility:

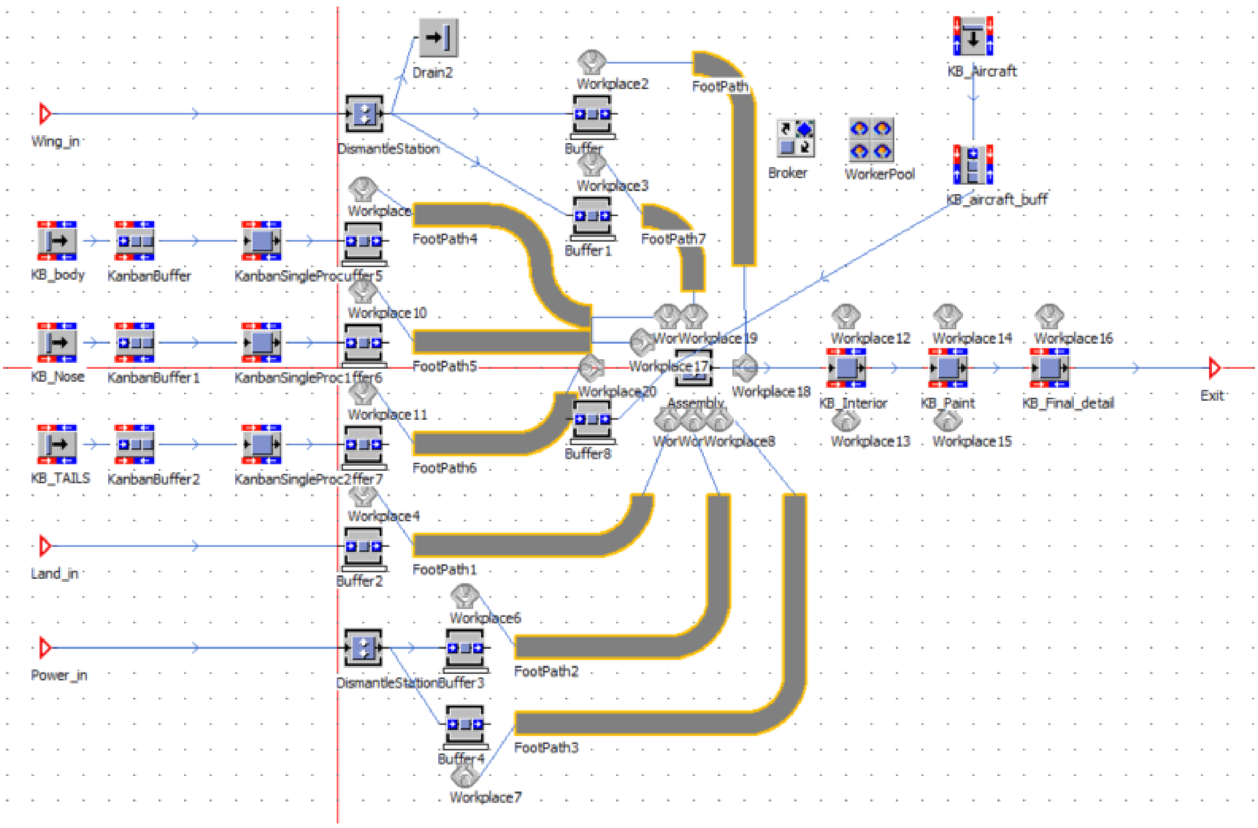


Figure 85: Fixed position assembly layout main assembly with Kanban implementation.

➢ Wing assembly facility:

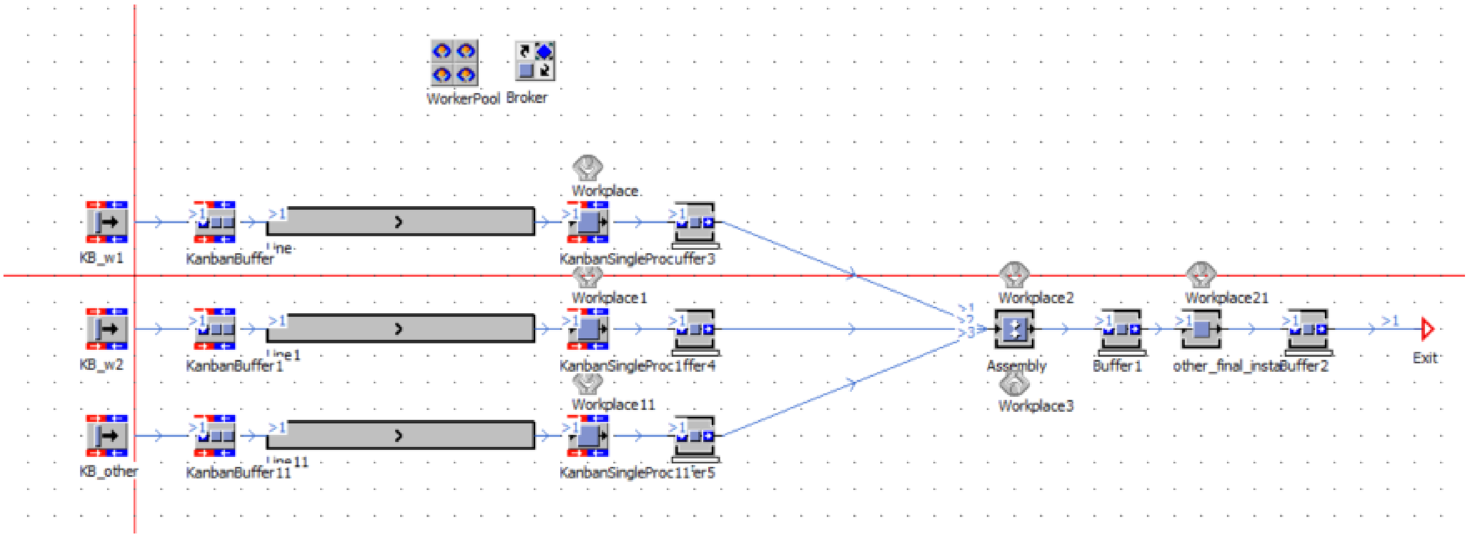


Figure 86: Fixed position assembly layout wing assembly facility with Kanban implementation.

➢ Power and landing gear prep facility:

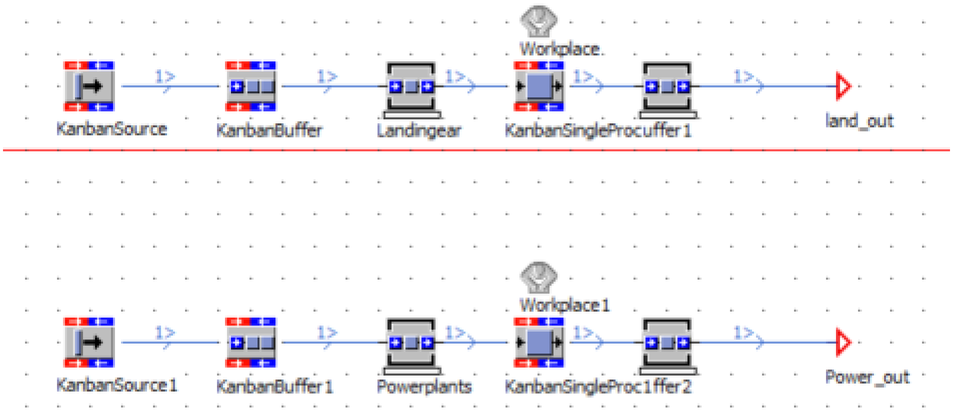


Figure 87: Fixed position assembly layout power and landing gear prep facility with Kanban implementation.

In the figures above, there can be observed how the layouts were altered by implementing Kanban in each facility of the assembly concept layout. In stage 1 of the Kanban implementation, the orders were "pulled" into the system as if they were part of the Kanban process to confirm the optimal throughput of each layout.

The painting facilities in the Product family assembly concept have been doubled in the wing and body assembly facilities due to the fact that they were the biggest bottleneck in the system.

Kanban stage 1 results:

The following assumptions can be made:

- Assume instant availability of parts and orders.
- Optimal number of workers already calculated in previous steps, stays the same.

The results of each layout's throughput, running for 365 days:

Table 9: Results of each Layout's throughput running for 365 days.

Layout concept:	Total throughput / 365 days	Avg. Time Aircraft spent in system (days)
Product Family layout concept	1608	2.16
Moving assembly line layout concept	2094	1.04
Fixed position assembly layout concept	392	3.08

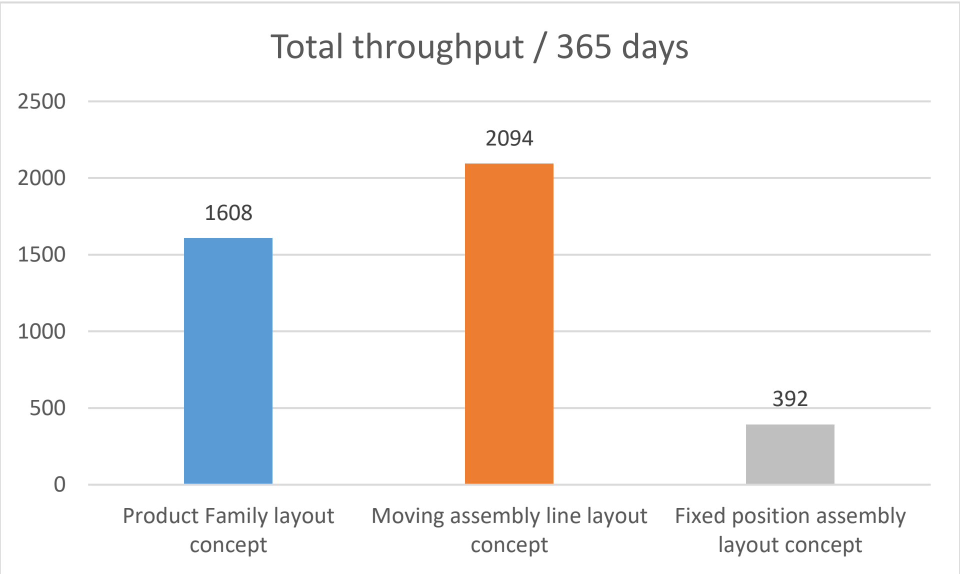


Figure 88: Graph showing Total throughput of each layout with Kanban stage 1 implementation.

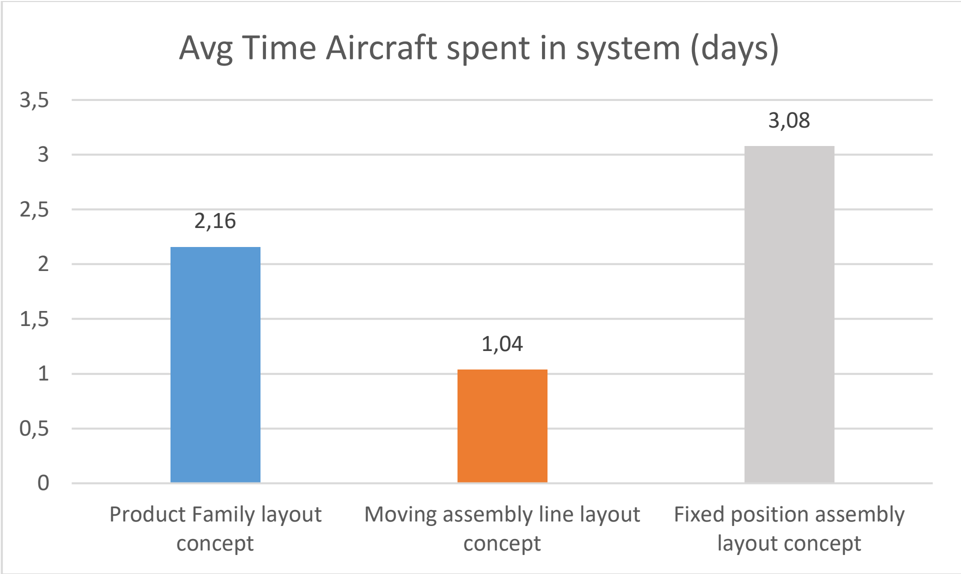


Figure 89: Graph showing number of day's aircraft spends in system for each layout with Kanban implementation stage 1.

It is clear that the optimal throughput of each layout running for 365 days, were correct. The Moving assembly line concept still rises above the other two layouts when it comes to throughput and the time one craft spends in the system.

Stage 2:

In this stage, the Kanban system has only been implemented on the parts being sourced for the building of each aircraft, thus orders for aircraft are sourced as in the previous steps. Only the parts needed for the construction of the aircraft are pulled into the assembly system as they are needed.

In stage 2 of the Kanban implementation, the Kanban implementation that was done on the sourcing of the orders was switched back to normal sourcing as in the previous steps.

Assumptions for this was:

- Constant orders for aircraft coming in to the system.
- Instant availability of parts.

Results:

The following results shown below, is the results of how long it takes each layout concept to process and assembly 100 aircraft and also how long each aircraft spent in the system.

Table 10: Results of each layout producing 100 aircraft.

Layout concept:	Avg. Time Aircraft spent in system	Time to complete 100 orders
Product Family layout concept	3,02 days	23,16 days
Moving assembly line layout concept	2,05 days	17,23 days
Fixed position assembly layout concept	9,11 days	93,18 days

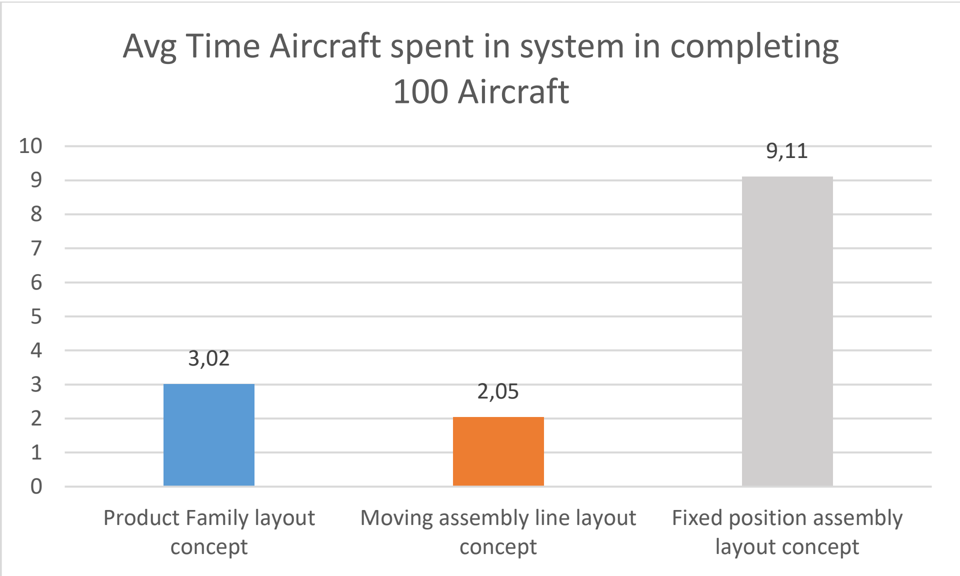


Figure 90: Graph showing the times of an aircraft spending in each layout concept when producing 100 aircraft.

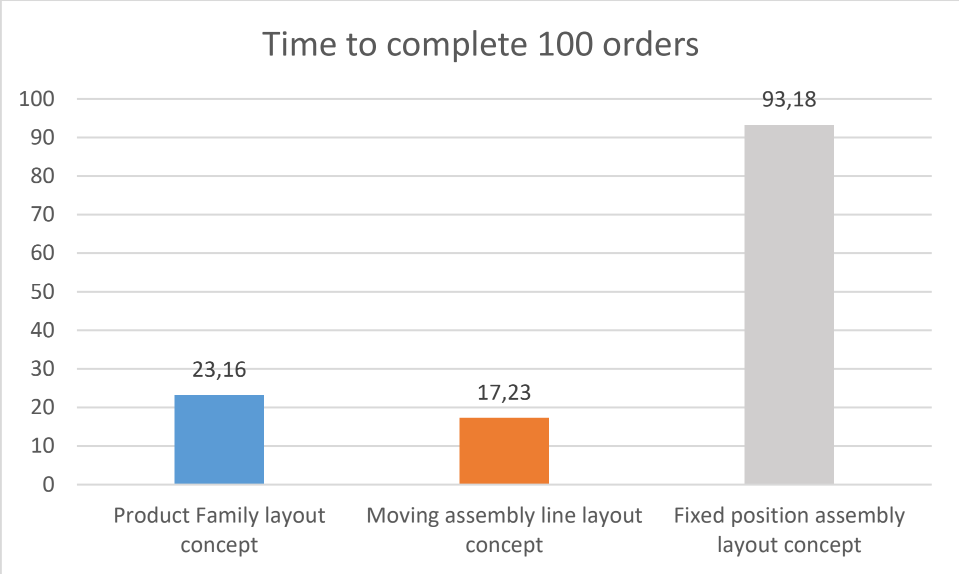


Figure 91: Graph showing the number of days it takes each layout concept to complete 100 aircraft.

As seen in the figures and tables above, the fixed position assembly layout clearly takes the longest, with 93 days in completing the order of 100 aircraft, while the Moving assembly line takes the shortest with 17 days.

Adjusted Models with realistic order times and delays:

In this part of stage 2 of the Kanban Implementation, the Assembly layout concept's order arrival times and delays were set to more realistic numbers that follows triangular distributions:

Table 11: Table showing the Order delay times as well as the delays for ordering of parts.

Layout concept:	Order arrival times following triangular distribution	Wing part order delays following triangular dist.	Body section parts order delays following triangular dist.	Power plants and landing gear order delay following triangular dist.
Product Family layout concept	30 - 40 days	3 days	3 days	4 days
Moving assembly line layout concept	30 - 40 days	3 days	3 days	4 days
Fixed position assembly layout concept	30 - 40 days	3 days	3 days	4 days

After the models order arrival times and parts arrival delays were set, the models were ran for various iterations of order sizes to see how the amount of aircraft ordered at a time would affect the systems load, throughput and times.

The following results, are the result of changing the order size from 10 aircraft per order every 30-40 days triangular distributed up to 1000 aircraft per order as the extreme case. The data shows how each model performs at low loads and also shows how each model handles more aircraft at a time.

Results:

Table 12: Triangular dist. Of 1 order of 10 aircraft every 30-40 days.

Layout concept:	Total throughput / 365 days	Avg. Time Aircraft spent in system
Product Family layout concept	120	1,22 days
Moving assembly line layout concept	130	1,08 days
Fixed position assembly layout concept	130	5,17 days

It is clear that each model can clearly handle more than 10 aircraft per order since the throughput of each model is extremely close to one another.

Table 13: Triangular dist. Of 1 order of 20 aircraft every 30-40 days.

Layout concept:	Total throughput / 365 days	Avg. Time Aircraft spent in system
Product Family layout concept	240	3,02 days
Moving assembly line layout concept	260	2,05 days
Fixed position assembly layout concept	254	10,05 days

Table 14: Triangular dist. Of 1 order of 30 aircraft every 30-40 days.

Layout concept:	Total throughput / 365 days	Avg. Time Aircraft spent in system
Product Family layout concept	360	4,05 days
Moving assembly line layout concept	382	3,01 days
Fixed position assembly layout concept	374	19,05 days

Table 15: Triangular dist. Of 1 order of 40 aircraft every 30-40 days.

Layout concept:	Total throughput / 365 days	Avg. Time Aircraft spent in system
Product Family layout concept	480	5,08 days
Moving assembly line layout concept	502	3,21 days
Fixed position assembly layout concept	392	26,21 days

Table 16: Triangular dist. Of 1 order of 100 aircraft every 30-40 days.

Layout concept:	Total throughput / 365 days	Avg. Time Aircraft spent in system
Product Family layout concept	1141	11,01 days
Moving assembly line layout concept	1222	9,01 days
Fixed position assembly layout concept	392	52,23 days

Table 17: Triangular dist. Of 1 order of 1000 aircraft every 30-40 days.

Layout concept:	Total throughput / 365 days	Avg. Time Aircraft spent in system
Product Family layout concept	1608	98,07 days
Moving assembly line layout concept	2094	84,08 days
Fixed position assembly layout concept	392	183,03 days

After the order number was changed to 40 aircraft per order, the fixed position layout met its maximum theoretical throughput for these delays and arrival times.

At the extreme level, where 1000 aircrafts are ordered per order, the aircraft entities have to wait long before they are processed through the model thus explaining the ridiculous long number of days it spends in the system. These values are calculated by the software.

The following graphs shows the models competing against each other. The models start of at the same performance when the aircraft per order number is low and then start to deviate as the number increases and so increases the load on each model. Each models' performance differs as seen in the graphs below.

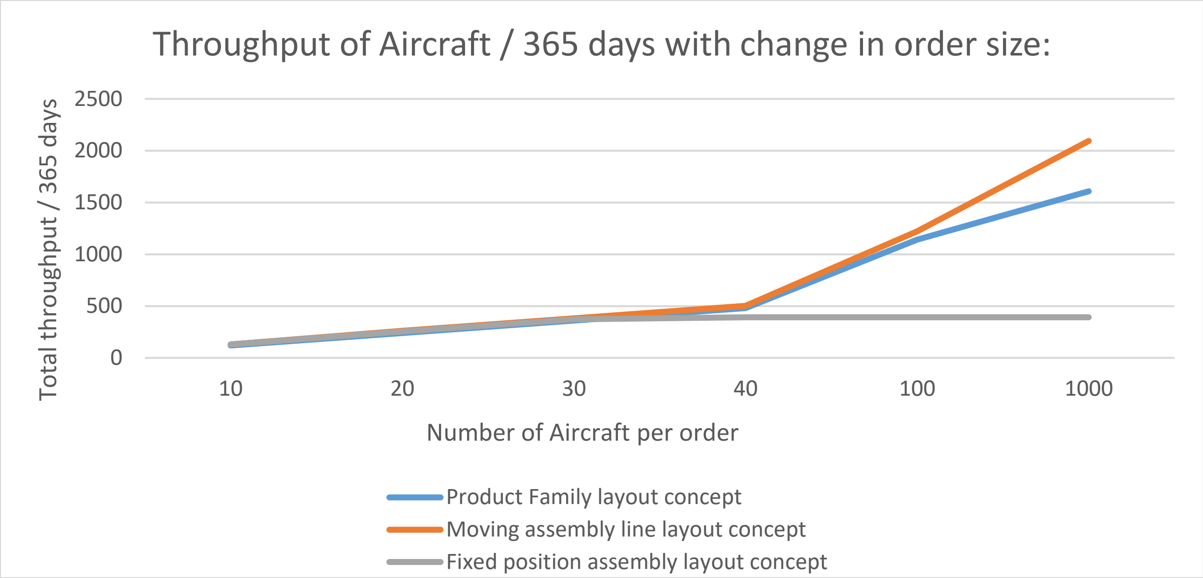


Figure 92: Graph showing the total throughput of each model running for 365 days when delay times and order arrival times are set.

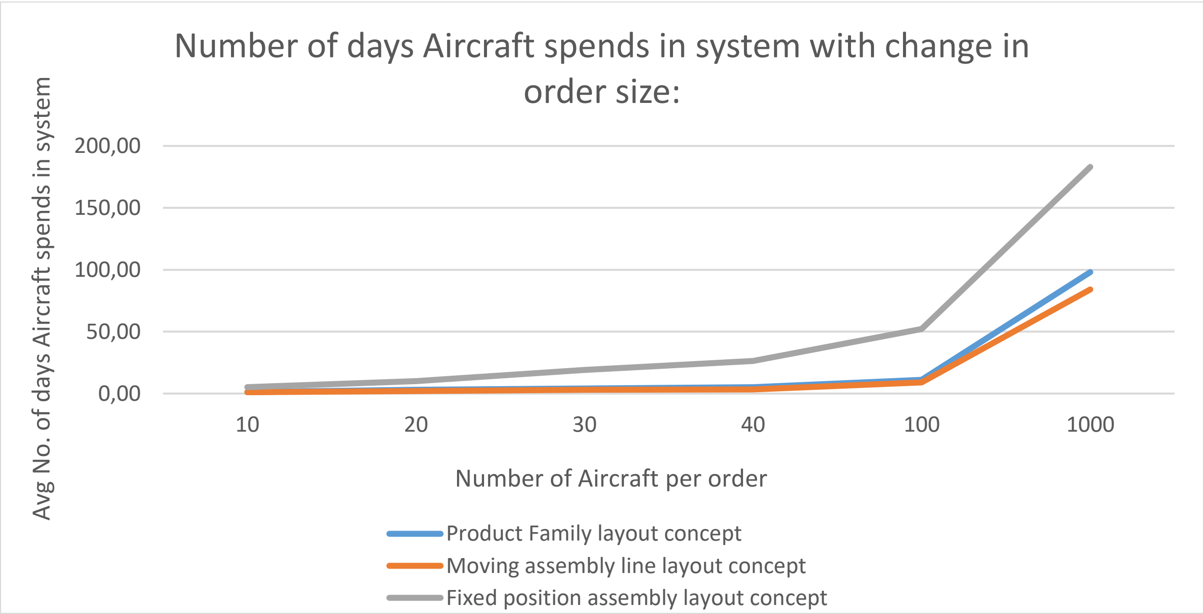


Figure 93: Graph showing the number of days an aircraft spends in the system of each model running for 365 days when delay times and order arrival times are set.

It is clear when looking at the data and graphs above, that the Moving assembly line concept can handle the largest load when it comes to order processing. The Fixed position assembly layout has the largest lead time.

Results conclusion:

Clearly from the data documented above, the Moving assembly layout has the best throughput and efficiency but it uses up an entire facility and the initial cost to build the assembly loop with the rolling floor is very expensive in comparison to the other options.

The product family layout is a good option for medium system loads.

More than one fixed position layout is also a god option as it is very competitive at low system loads compared to the other two models and also cheaper. Implementing 2-4 of these layouts in the same facility space could be a very competitive option for medium system loads and would compete strongly against the product family assembly layout concept.

5.2 Economic Analysis

5.2.1 Cost Benefit analysis

A Cost benefit analysis was done using data estimated and based on what the project sponsor mentioned, researching the industry, and processing via Excel. The analysis was done on all three layouts.

Each layout was evaluated based on:

- Direct and indirect costs
- Benefits
- Depreciation
- Inflation and prime rates
- NPV (net present values)
- Time period: 10 years

Costs

All costs are based on estimates and industry research.

- Initial costs: Both the product family layout and the fixed position layout has more or less the same initial start-up cost, however the moving assembly line layout requires the rolling floor and necessary equipment which is much more expensive in comparison.
- Utilities and peripherals cost are excluded from the calculation due to the fact that all 3 layouts would use the same amount.

Initial costs

Initial costs include:

- Facility equipment, such as jigs, clamps, specialised equipment for certain tasks and etc.
- Cranes for the movement of large assembly parts from station to station.
- Tools: average tools used by workers and assemblers.
- Machinery.
- Painting equipment.
- Aircraft transporting trolleys.
- The initial cost for the Rolling floor used for the Moving assembly line concept layout.

Table 18: Table showing the different costs associated with each layout concept.

Layout concept:	Product family layout	Moving assembly line layout	Fixed position layout
Facility equipment	R12 000 000,00	R80 000 000,00	R8 000 000,00
Cranes	R11 760 000,00	R10 080 000,00	R11 760 000,00
Tools	R12 000 000,00	R14 000 000,00	R10 000 000,00
Machinery	R90 000 000,00	R78 000 000,00	R54 000 000,00
Painting equipment	R24 000 000,00	R8 000 000,00	R8 000 000,00
Aircraft transport trolleys	R8 000 000,00	R16 000 000,00	R2 000 000,00
Rolling floor U-shaped Assembly line		R2 000 000 000,00	
Total	R157 760 000,00	R2 206 080 000,00	R93 760 000,00

The Moving assembly line concept has an additional cost of the rolling floor that needs to be built in the facility and this makes the total initial cost for the Moving assembly line concept very expensive.

Financing:

- Loan repayable 10 years
- Current South African Prime lending rate = **10.50%** (According to Standard Bank).

Loan repayments for each design for 10 years:

Figure 94: Graph showing different monthly repayments for each layout concept.

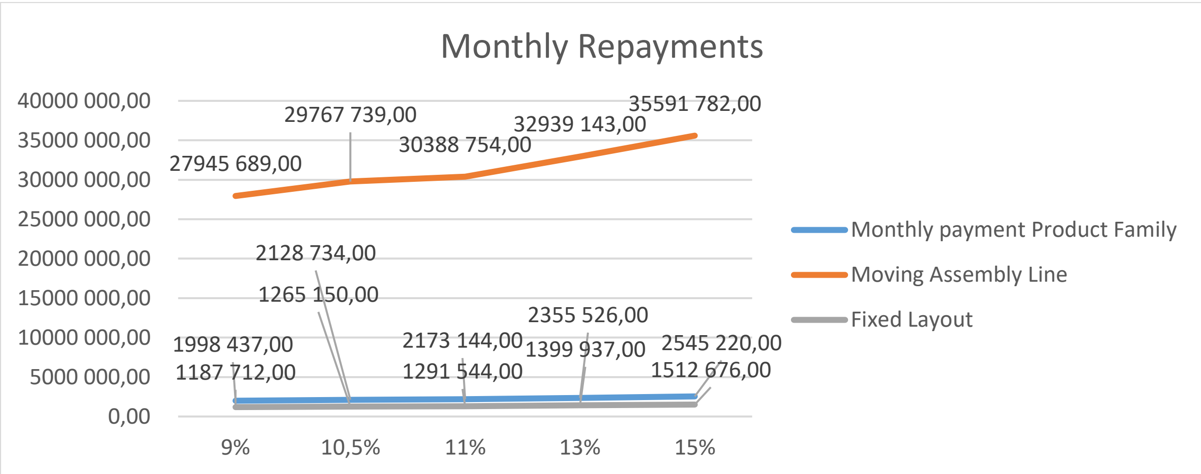


Table 19: table showing annual loan repayments for each layout concept on the prime rate of 10.5 %

Layout concept:	Annual loan repayments
Product family layout	R25 544 808,00
Moving assembly line layout	R357 212 868,00
Fixed position layout	R15 181 800,00

Annual costs

The annual costs will include:

- Wages of employees.
- Loan repayments.
- Manufacturing cost.

Wages were estimated based on the minimum wage for a factory worker doing highly skilled tasks. Furthermore for the sake of this project it was said that there is 1 engineer working per 10 factory workers on the project and their wages were also estimated. Admin expenses where not considered due to the fact that they would be more or less the same for each layout concept. The number of workers for each layout was used for the calculation as determined in the previous segment of the simulation models.

Maintenance and the replacement of tools where both considered in the Manufacturing costs.

Raw materials used for the aircraft and the selling price of each aircraft remains constant throughout all 3 layouts. These values where estimated based of research.

All data was calculated in Microsoft Excel.

Annual Benefits

The only benefits included in this cost/benefit analysis are the yearly sales each layout procures and the estimated salvage value on each layout after 10 years.

The salvage value was taken as 20% of the initial investment for all 3 layout concepts.

Results

The results of the cost / benefit analysis where summarised in the form of Net present value (NPV) calculations for each concept layout using a range of different discount rates. The discount rates can be seen in the summary of this section on Table 30.

The monetary values used in the NPV calculations are estimates based on industry research and are used comparative reasons between the 3 layout concepts.

Each layout is represented below along with the associated data.

Moving Assembly Line concept:

Table 20: Table showing annual wages cost for the moving assembly line concept.

Station	No of workers	Cost per employee	Total Employee cost [per Hour]	Total Hours per year	Total labor cost
Body assembly	50	50,4	2520	1920	R4 838 400,00
Wing assembly	30	50,4	1512	1920	R2 903 040,00
Power & landing gear staging	5	50,4	252	1920	R483 840,00
Main assembly	50	50,4	2520	1920	R4 838 400,00
Engineers	13	400	5200	1920	R9 984 000,00
	148			Total Annual cost	R23 047 680,00

Table 21: Table showing Cost elements for calculating manufacturing costs.

Cost Element	Value
Raw Material*	R5 200 000,00
Raw Material for 100 aircraft	R520 000 000,00
Facility Running Cost*	R9 700 000,00
Monthly Running Cost	R9 700 000,00
Annual Running Cost	R116 400 000,00

Table 22: Table showing Manufacturing costs.

Manufacturing Cost	
Cost per unit (variable)	R520 000 000,00
Cost (fixed)/year	R116 400 000,00
Total Cost/year	R636 400 000,00

Table 23: Table showing the Revenue per annum when selling 100 aircraft.

Revenue / Plane	
Total Planes sold/year	100
Selling Price*	R10 750 000,00
Revenue/year	R1 075 000 000,00

Table 24: Table showing Cash flows for Moving assembly line concept NPV calculation.

Cash Flows: Moving Assembly line	Loan	Annual Loan repayment	Manufacturing costs	Wages	Sales	Salvage	Total
0	R2 206 080 000						R2 206 080 000
1		-R357 212 868	-R636 400 000	-R23 047 680	R1 075 000 000		R58 339 452
2		-R357 212 868	-R636 400 000	-R23 047 680	R1 075 000 000		R58 339 452
3		-R357 212 868	-R636 400 000	-R23 047 680	R1 075 000 000		R58 339 452
4		-R357 212 868	-R636 400 000	-R23 047 680	R1 075 000 000		R58 339 452
5		-R357 212 868	-R636 400 000	-R23 047 680	R1 075 000 000		R58 339 452
6		-R357 212 868	-R636 400 000	-R23 047 680	R1 075 000 000		R58 339 452
7		-R357 212 868	-R636 400 000	-R23 047 680	R1 075 000 000		R58 339 452
8		-R357 212 868	-R636 400 000	-R23 047 680	R1 075 000 000		R58 339 452
9		-R357 212 868	-R636 400 000	-R23 047 680	R1 075 000 000		R58 339 452
10		-R357 212 868	-R636 400 000	-R23 047 680	R1 075 000 000	R441 216 000	R499 555 452

Table 25: Table showing the Net Present Value for different discount rates for the Moving assembly line concept.

Discount rate	Net Present Value
10	R201 083 085,93
15	R138 123 081,05
20	R105 190 332,03
25	R84 938 983,77
30	R71 226 601,56

Product Family layout concept:

Table 26: Table showing annual wages cost for the Product family layout concept.

Station	No of workers	Cost per employee	Total Employee cost [per Hour]	Total Hours per year	Total labor cost
Body assembly	40	50,4	2016	1920	R3 870 720,00
Wing assembly	20	50,4	1008	1920	R1 935 360,00
Power & landing gear staging	2	50,4	100,8	1920	R193 536,00
Main assembly	50	50,4	2520	1920	R4 838 400,00
Engineers	11	400	4400	1920	R8 448 000,00
	123			Total Annual cost	R19 286 016,00

Table 27: Table showing Cost elements for calculating manufacturing costs.

Cost Element	Value
Raw Material*	R5 200 000,00
Raw Material for 100 aircraft	R520 000 000,00
Facility Running Cost*	R6 500 000,00
Monthly Running Cost	R6 500 000,00
Annual Running Cost	R78 000 000,00

Table 28: Table showing Manufacturing costs.

Manufacturing Cost	
Cost per unit (variable)	R520 000 000,00
Cost (fixed)/year	R78 000 000,00
Total Cost/year	R598 000 000,00

Table 29: Table showing the Revenue per annum when selling 100 aircraft.

Revenue / Plane	
Total Planes sold/year	100
Selling Price*	R10 750 000,00
Revenue/year	R1 075 000 000,00

Table 30: Table showing Cash flows for Product Family layout concept NPV calculation.

Cash Flows: Product Family layout	Loan	Annual Loan repayment	Manufacturing costs	Wages	Sales	Salvage	Total
0	R157 760 000						R157 760 000
1		-R25 544 808	-R598 000 000	-R19 286 016	R1 075 000 000		R432 169 176
2		-R25 544 808	-R598 000 000	-R19 286 016	R1 075 000 000		R432 169 176
3		-R25 544 808	-R598 000 000	-R19 286 016	R1 075 000 000		R432 169 176
4		-R25 544 808	-R598 000 000	-R19 286 016	R1 075 000 000		R432 169 176
5		-R25 544 808	-R598 000 000	-R19 286 016	R1 075 000 000		R432 169 176
6		-R25 544 808	-R598 000 000	-R19 286 016	R1 075 000 000		R432 169 176
7		-R25 544 808	-R598 000 000	-R19 286 016	R1 075 000 000		R432 169 176
8		-R25 544 808	-R598 000 000	-R19 286 016	R1 075 000 000		R432 169 176
9		-R25 544 808	-R598 000 000	-R19 286 016	R1 075 000 000		R432 169 176
10		-R25 544 808	-R598 000 000	-R19 286 016	R1 075 000 000	R31 552 000	R463 721 176

Table 31: Table showing the Net Present Value for different discount rates for the Product family layout concept.

Discount rate	Net Present Value
10	R18 270 628,87
15	R11 660 704,90
20	R8 541 355,18
25	R6 732 567,96
30	R5 553 730,30

Fixed assembly layout concept:

Table 32: Table showing annual wages cost for the fixed assembly layout concept.

Station	No of workers	Cost per employee	Total Employee cost [per Hour]	Total Hours per year	Total labor cost
Body assembly	34	50,4	1713,6	1920	R3 290 112,00
Wing assembly	26	50,4	1310,4	1920	R2 515 968,00
Power & landing gear staging	2	50,4	100,8	1920	R193 536,00
Main assembly	28	50,4	1411,2	1920	R2 709 504,00
Engineers	9	400	3600	1920	R6 912 000,00
	99			Total Annual cost	R15 621 120,00

Table 33: Table showing Cost elements for calculating manufacturing costs.

Cost Element	Value
Raw Material*	R5 200 000,00
Raw Material for 100 aircraft	R520 000 000,00
Facility Running Cost*	R3 500 000,00
Monthly Running Cost	R3 500 000,00
Annual Running Cost	R42 000 000,00

Table 34: Table showing Manufacturing costs.

Manufacturing Cost	
Cost per unit (variable)	R520 000 000,00
Cost (fixed)/year	R42 000 000,00
Total Cost/year	R562 000 000,00

Table 35: Table showing the Revenue per annum when selling 100 aircraft.

Revenue / Plane	
Total Planes sold/year	100
Selling Price*	R10 750 000,00
Revenue/year	R1 075 000 000,00

Table 36: Table showing Cash flows for fixed assembly layout concept NPV calculation.

Cash Flows: Fixed assembly layout	Loan	Annual Loan repayment	Manufacturing costs	Wages	Sales	Salvage	Total
0	R93 760 000						R93 760 000
1		-R15 181 800	-R562 000 000	-R15 621 120	R1 075 000 000		R482 197 080
2		-R15 181 800	-R562 000 000	-R15 621 120	R1 075 000 000		R482 197 080
3		-R15 181 800	-R562 000 000	-R15 621 120	R1 075 000 000		R482 197 080
4		-R15 181 800	-R562 000 000	-R15 621 120	R1 075 000 000		R482 197 080
5		-R15 181 800	-R562 000 000	-R15 621 120	R1 075 000 000		R482 197 080
6		-R15 181 800	-R562 000 000	-R15 621 120	R1 075 000 000		R482 197 080
7		-R15 181 800	-R562 000 000	-R15 621 120	R1 075 000 000		R482 197 080
8		-R15 181 800	-R562 000 000	-R15 621 120	R1 075 000 000		R482 197 080
9		-R15 181 800	-R562 000 000	-R15 621 120	R1 075 000 000		R482 197 080
10		-R15 181 800	-R562 000 000	-R15 621 120	R1 075 000 000	R18 752 000	R500 949 080

Table 37: Table showing the Net Present Value for different discount rates for the fixed position layout concept.

Discount rate	Net Present Value
10	R12 907 246,18
15	R7 869 154,50
20	R5 612 850,19
25	R4 347 995,51
30	R3 543 007,61

Summary:

Every concepts layouts returns a positive NPV value, with the Moving assembly line layout's NPV values starting the highest and thus proving that it would be financially the most suitable option. The other two layouts, Product family layout and the fixed position assembly layout's NPV values are extremely close in comparison.

This projects main focus is only on designing an assembly line concept and thus only focusses on the assembly part of the value chain. Each layout might have different aspects further up the value chain and this might influence the NPV values negatively.

Table 38: Table showing the summary of all 3 layout concepts NPV values at different discount rates.

Net Present Value			
Discount rate	Moving Assembly Layout	Product family Layout	Fixed position Layout
10	R201 083 085,93	R18 270 628,87	R12 907 246,18
15	R138 123 081,05	R11 660 704,90	R7 869 154,50
20	R105 190 332,03	R8 541 355,18	R5 612 850,19
25	R84 938 983,77	R6 732 567,96	R4 347 995,51
30	R71 226 601,56	R5 553 730,30	R3 543 007,61

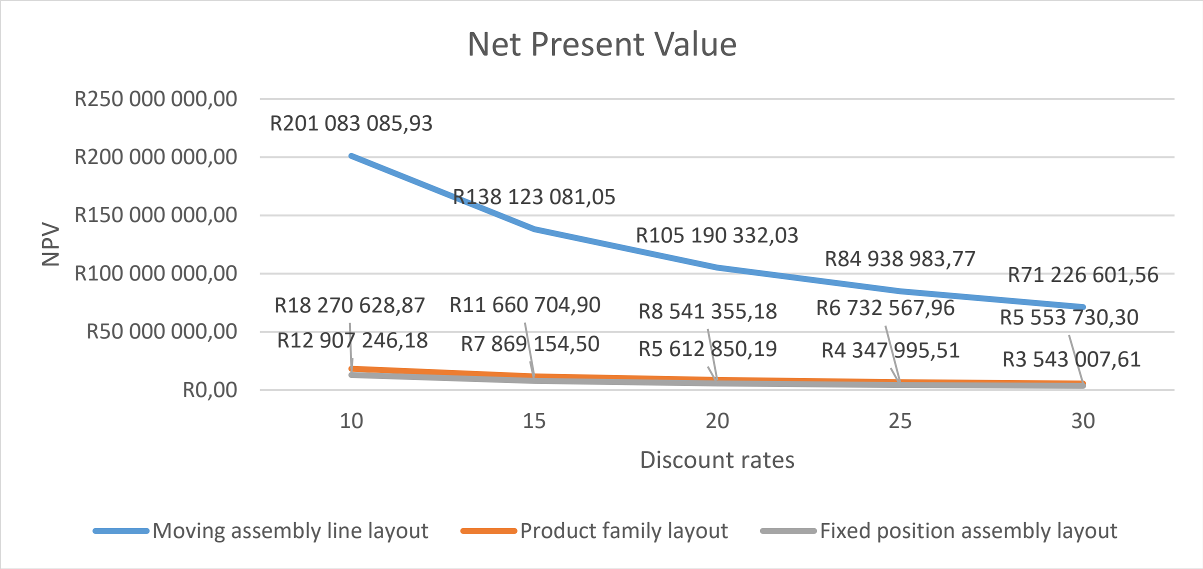


Figure 95: Graph displaying the NPV values for each layout concept over a range of different discount rates.

5.3 Final Decision

Analytical Hierarchy Process:

The Analytical Hierarchy Process (AHP) is a process used for making multi-criteria decisions. The process was used to make a decision between the 3 layout concepts due to the fact that there are multiple criteria to keep in mind while making a decision on what layout would work the best.

It is absolutely clear that the Moving assembly line concept rises above the rest when it comes to raw throughput and efficiency, however its initial cost is extremely expensive and that brings the other two concept into play when it comes to deciding on a single concept.

The criteria is compared using pairwise comparisons where a certain criteria is assigned with a weight relating to its importance. The factors are as follows:

- 1 = equal
- 3 = moderate
- 5 = strong
- 7 = very strong
- 9 = extreme

The criteria tested on each of the 3 layouts are:

- Time of completing 100 aircraft
- Cost
- Adaptability
- Throughput

Higher weights are assigned to the time and cost of each layout due to the fact that cost the cost and production goal of each layout is of much importance. Throughput and adaptability follows where the throughput of each layout is slightly more important than its adaptability.

Table illustrating the weight assigned to each criteria:

	Time	Cost	Throughput	Adaptability
Time	1	5	7	4
Cost	0.20	1	4	3
Throughput	0.14	0.25	1	2
Adaptability	0.25	0.33	0.50	1

Normalising the weights:

- w T = 0.624
- w C = 0.217
- w Th = 0.083
- w A = 0.074

Layout weights relative to Time:

	Moving	Product	fixed
Moving	1	3	7
Product	0.33	1	3
fixed	0.14	0.33	1

Normalising the weights:

- w M/T = 0.67
- w P/T = 0.24
- w F/T = 0.086

Layout weights relative to Cost:

	Moving	Product	fixed
Moving	1	0.25	0.14
Product	5	1	0.25
fixed	7	2	1

Normalising the weights:

- w M/C = 0.083
- w P/C= 0.3
- w F/C = 0.61

Layout weights relative to Throughput:

	Moving	Product	fixed
Moving	1	3	5
Product	0.33	1	1.5
fixed	0.25	0.66	1

Normalising the weights:

- w M/Tp = 0.65
- w P/Tp = 0.21
- w F/Tp = 0.14

Layout weights relative to adaptability:

	Moving	Product	fixed
Moving	1	0.25	0.14
Product	5	1	0.33
fixed	7	3	1

Normalising the weights:

- w M/A = 0.0737

- w P/A = 0.276
- w F/A = 0.6495

Moving Assembly line layout score:

= w T*w M/T + w C*w M/C + w Th*w M/Th + w A*w M/A

= (0.624)*(0.67) + (0.217)*(0.083) + (0.083)*(0.65) + (0.074)*(0.0737)

= 0.495 ≈ 0.5

Product family layout score:

= w T*w P/T + w C*w P/C + w Th*w P/Th + w A*w P/A

= (0.624)*(0.24) + (0.217)*(0.3) + (0.083)*(0.21) + (0.074)*(0.276)

=0.2527 ≈ 0.25

Fixed position layout score:

= w T*w F/T + w C*w F/C + w Th*w F/Th + w A*w F/A

= (0.624)*(0.086) + (0.217)*(0.61) + (0.083)*(0.14) + (0.074)*(0.6495)

=0.2456 ≈ 0.25

Conclusion:

From the results above, we can see that the moving assembly line is the best option for this project.

5.4 Further Implementation

5.4.1 Verification & Validation

Verification tests if the solution is compliant to the internal specifications and validation tests whether the customer's needs have been satisfied. Thus Verification and validation tests if the external and internal requirements have been met with the solution of the outcome of the projects.

Requirement:

- A concept for an assembly line layout that would produce at least 100 aircraft per year efficiently and cost effective.

Solution:

- The selected layout was the Moving assembly line layout concept.

This layout also meets the requirement for the aircraft to go into mass production. The layout was simulated and tested and met the demand in the time frame. The model performed better than the other two contenders in all factors.

5.4.2 Recommendations

If the project would be picked up later on, Using Kanban simulation modelling and designing your layouts accordingly using the Kanban system, would ultimately make your life a lot easier. The Kanban simulation models will produce more accurate results with less effort. The Kanban's ticket system allows the simulation to push and pull production of parts needed and in so doing, it optimises the number of units in the system cutting storage and WIP costs down to a minimum.

Another thing to be considered is testing combinations of layouts and how they would perform in the long run. For example implementing the fixed position layout first and later the moving assembly line concept.

6 Conclusion

Problem:

- The need for an assembly line concept: The assembly line concept design was completed in 3 stages, where the student did research on the industry, found 3 possible layouts, built simulation models to test their performance against one another and did an economic analysis to check the feasibility of the design.
- The design should at least meet the requirement for the demand of 100 aircraft per year.

Research:

- The student did research on various companies in the industry to see how they assemble aircraft for the commercial market.

3 Layouts:

- Product family layout concept: In this layout concept, the aircraft sub-assemblies are each completed separately before joint together to form the aircraft.
- Moving assembly line concept: In this layout concept, the main assembly facility is fitted with a moving U-shaped assembly line.
- Fixed position layout concept: In this concept, the aircraft is built and assembled on a fixed position in the main assembly facility and moves up a spot when completed.
- Each layout's requirements, advantages and disadvantages were also presented.

Simulations:

- Simulation models where built for each layout concept using Siemens Plant simulation software. The models where then tested to see what their optimum throughput and efficiency is.

Economic analysis:

- In the Economic analysis, various economic calculations where done on the project feasibility for each layout. Cost feasibility, Capital needed for each design, Benefit analysis, Net present value and depreciation calculations where done.

Results:

- In the end, the moving Assembly line concept proved to be the best choice.
- This decision was made using an analytical hierarchy process.

Solution to Problem:

- The need was fulfilled with an assembly line concept that would be fit for mass production of a small African regional aircraft in the commercial market.

Appendix

A: Industry sponsorship form

ESTEQ
PASSION | PEOPLE | TECHNOLOGY

Hermias Hendrikse
Digital Manufacturing Engineer

079 490 4623 | h.hendrikse@esteq.com

ndustrial & Systems Engineering
inal Year Projects
Responsibility of Project Sponsors

Final Year Projects may be published by the University of Pretoria on *UPSpace* and may thus be freely available on the Internet. These publications portray the quality of education at the University, but they have the potential of exposing sensitive company information. It is important that both students and company representatives or sponsors are aware of such implications.

Key responsibilities of Project Sponsors:

A project sponsor is the key contact person within the company. This person should thus be able to provide guidance to the student throughout the project. The sponsor is also very likely to gain from the success of the project. The project sponsor has the following important responsibilities:

1. Confirm his/her role as project sponsor, duly authorised by the company. Multiple sponsors can be appointed, but this is not advised. The duly completed form will considered as acceptance of sponsor role.
2. Review and approve the Project Proposal, ensuring that it clearly defines the problem to be investigated by the student and that the project aim, scope, deliverables and approach is acceptable from the company's perspective.
3. Review the Final Project Report (delivered during the second semester), ensuring that information is accurate and that the solution addresses the problems and/or design requirements of the defined project.
4. Acknowledges the intended publication of the Project Report on UP Space.
5. Ensures that any sensitive, confidential information or intellectual property of the company is not disclosed in the Final Project Report.

Project Sponsor Details:

Company:	ESTEQ Engineering (Pty) Ltd
Project Description:	Developing a modern final assembly line for a small african regional aircraft.
Student Name:	JHB du Toit (Boshoff)
Student number:	12023095
Student Signature:	[signature]
Sponsor Name:	Hermias Hendrikse
Designation:	Digital Manufacturing Engineer
E-mail:	h.hendrikse@esteq.com
Tel No:	012 809 9500
Cell No:	0794904623
Fax No:	
Sponsor Signature:	[signature]

References

Esteq:

https://esteq.co.za/about/ [Accessed 20 March 2016]

Denel aerostructures:

http://www.denelaerostructures.com/ [Accessed 20 March 2016]

About SARA:

http://www.defenceweb.co.za/index.php?option=com_content&view=article&id=36331:denel-promotes-new-regional-aircraft-&catid=35:Aerospace&Itemid=107/ [Accessed 20 March 2016]

Tompkins, J, 2010. Facilities planning. 4th ed. United States of America. John Wiley & Sons Inc.

Banks, J., Carson, J. S., Nelson, B. L., and Nicol, D. M., (2004), Discrete-Event System

Simulation 4th ed. Upper Saddle River, New Jersey: Prentice-Hall Incorporated

Banks, J., Carson, J.S., Nelson, B.L., Nicol, D.M. (2010), Discrete-Event System Simulation.

5th ed. Upper Saddle River, New Jersey: Prentice-Hall, Inc.

Boeing:

www.boeing.com/news/frontiers/archive/2010/april/i_ca01.pdf

www.**boeing**.com/ [Accessed May 2016].

Bombardier:

www.**bombardier**.com/ [Accessed May 2016].

Embraer:

www.**embraer**.com.br/ [Accessed May 2016].

Discrete event simulation:

www.whatis.techtarget.com/definition/discrete-event-simulation-DES