Reducing production lead time at Zodiac Galleys Europe

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Colophon

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Preface

This thesis is about reducing the production lead time at Zodiac Galleys Europe. This thesis is performed in completion of the master study Industrial Engineering Management with a specialisation in Production and Logistic Management of the University of Twente.

After the internships of my bachelor study Business Engineering at the Fontys University of Applied Sciences Eindhoven, this graduation internship was a new challenge for me. The challenge to optimise a production line in terms of cost, quality and on time delivery, is in line with my interest. With the new gained in-depth knowledge of the past two years, I was able to successfully fulfil my master thesis project.

I, Ilse van Merrienboer, would like to thank the employees of Zodiac Galleys Europe for their efforts in assisting me during my research. A special word of thanks to Olivier Baudry, director of Operations, and Marco Wagendorp, director of Engineering, for their time, support and valuable input during this graduation project. I also would like to thank my supervisors Matthieu van der Heijden and Leo van der Wegen from the University of Twente for their guidance and valuable feedback during the entire project. At last I would like to express my gratitude towards my family and Simon Janssen, for their unlimited support, and believe in my capabilities.

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Management summary

Zodiac Galley Europe (ZGEU) wants to reduce the lead time of the production of a galley, because of the increasing demand of their main customer Airbus and the contractual agreement with Airbus to decrease the sales price each year. Thus, to handle the demand with minimum amount of capacity, the production lead time needs to be reduced such that more products can be made in a fixed time period. For this reason ZGEU has started this research. This research provides an analysis to find the root cause of the too long lead time and gives a solution to reduce the production lead time of ZGEU.

Currently the total production lead time is 19 days. From all production processes Final assembly (FA) is the bottleneck process. The FA process exist out of two flows. One for the structure assembly and one for systems assembly. It has a lead time of eight days, with two employees. On average 68% of the eight days is waste time due to searching and waiting for parts.

Further research to the bottleneck process FA gives that there are different causes of the too long lead time at FA. We have done a survey to rank these causes, the results of the survey give that the two main causes of the too long lead time at FA are:

- ‘missing parts on the car from warehouse’;
- ‘wrong parts on the car from warehouse’.

The root cause of these two main causes is that ‘the process of FA is not standardised’.

To standardise the process of FA the activities need to be sequenced, this is a scheduling problem. The best fitted scheduling problem is the parallel machine scheduling problem with precedence constraints, sequence dependent tool change times and activities that cannot be done in parallel. This problem can best be solved with the Variable Neighbourhood Search heuristic. We have modelled this heuristic with Excel. From the sensitivity analysis we conclude that the best setting for the parameter ‘number of iterations’ is 500, independently of the number of employees. Further, the best setting for the parameter ‘number of employees’ is two or three, this depends on the desired balance between efficiency and a shorter lead time. We have chosen with ZGEU to stay with two employees.

The outcome of the model, which we have gained with the parameter ‘number of employees’ set to 2 and ‘number of iterations’ set to 500, gives a lead time of 2.7 days. To gain these times in practice the following conditions have to be met, because of the assumptions that were made to programme the model:

- work days of 8 hours;
- both employees can perform all activities;
- tool change times are symmetric;
- all parts are available.

Thus, by solving the root cause ‘the process of FA is not standardised’ by implementing the sequence outcome of the VNS heuristic as the new standard for FA according to the implementation plan, ZGEU can reduce the lead time of FA for the G1 galleys with 66% compared to the current situation. If we translate this reduction to the total lead time, which was 19 days, ZGEU can reduce the production lead time with 28%. The condition ‘all parts are available’ is the biggest barrier for ZGEU to achieve this reduction. But even if this condition is not met, ZGEU can reduce the lead time of FA with 20 to 30% by implementing the sequence outcome of the model.

Solving the root cause ‘process of FA is not standardised’ gives the following advantages for ZGEU:

- reduction of the lead time;
- the process of FA will be a controllable process, which means that ZGEU can start with continuous improvement of the FA process;
- it is possible to structure the car of warehouse better for the employees of FA, for example ordering the parts in the sequence of assembly and/or deliver the parts per day;
- the points mentioned above will reduce the number of missing and wrong parts during assembly.

We recommend the following points to follow up this research:

- make a planning for the implementation of the sequence outcome of the model;
- initiate an improvement project to increase the on time delivery of parts to FA, parallel to the implementation of the new standard at FA;
- initiate an improvement project to optimise the structure of the car after the implementation of the new standard at FA;
- after the implementation start with continuous improvement of FA by keeping track of the flaws at FA with a Pareto analysis;
- repeat the work done for FA for the other processes to gain an extra significant reduction in the production lead time.

Content

1. Introduction

This chapter gives a first expression of Zodiac Galleys Europe, the reasoning why this research is valuable for Zodiac Galleys Europe, the outline of the research and the outline of this report.

1.1 Zodiac Aerospace Europe

Zodiac Aerospace is world leader in aerospace equipment and systems on board of commercial, regional and business aircrafts as well as helicopters. Zodiac Aerospace is also a key player in air safety. Zodiac Aerospace is grouped into five business segments:

- Zodiac Cabin & Structures;
- Zodiac Seats;
- Zodiac Galleys & Equipment;
- Zodiac Aircraft Systems;
- Zodiac Aerosafety.

This research takes place in the business segment Zodiac Galleys & Equipment at Zodiac Galleys Europe, a subsidiary of Zodiac Aerospace. Zodiac Galleys Europe is located in the Czech Republic with approximately 850 employees.

Zodiac Galleys Europe (ZGEU) is specialised in designing, manufacturing, certifying and marketing high quality galleys, as well as stowages and crew rests. A galley is a closet (frame) that can hold various inserts (trolleys, ovens, containers, water boiler, coffeemaker etc.). Figure 1 shows illustrations of a galley.

Figure 1: Zodiac Galley (Zodiac Galleys Europe [ZGEU], 2015a)

Organisation

Figure 2 gives the organisation chart of ZGEU. This project takes place at the department Operations, Figure 3 gives a more detailed organization chart of Operations. Below an explanation follows about the abbreviations in the figures:

- HR – Human Resources;
- BU – Business Unit;
- QA – Quality;
- SA – Single Aisle, this manager concerns his-/herself about the galley types which can be placed in single aisle airplanes;
- LR – Long Range, this manager concerns his-/herself about the galley types which can be placed in airplanes with more aisles mostly airplanes for long distance flights.

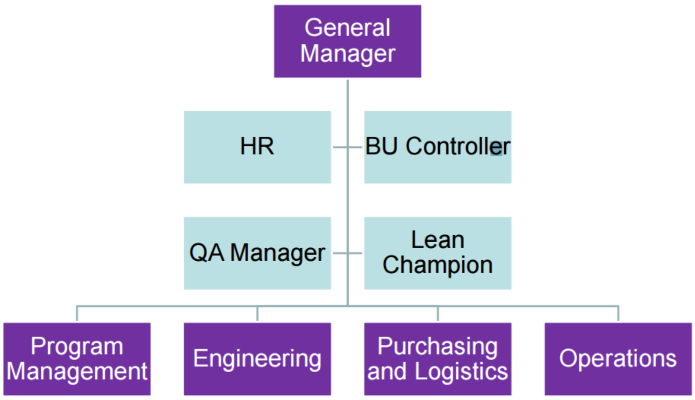


Figure 2: Organisation chart Zodiac Galleys Europe {ZGEU, 2015e)

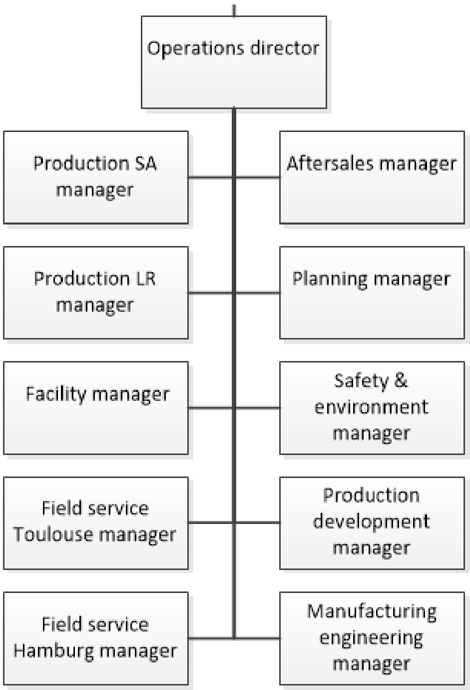


Figure 3: Organisation chart Operations department (ZGEU, 2015e)

ZGEU experienced a huge growth over the last few years due to the increasing sales, from 23 million euros in 2009 to 85 million euros in 2014. In consequence ZGEU has grown from 250 full time employees (FTEs) in 2009 to 710 FTEs in 2014 and has increased the production area from 7,300 m^2 in 2009 to 11,200 m^2 in 2013.

Product types

ZGEU produces a number of different galleys, which can be categorised into two main streams:

- SFE – Supplier Furnished Equipment, in this stream the customer is an airplane producer. It can select a galley from a catalogue and select additional features for the galley;
- BFE – Buyer Furnished Equipment, in this stream the customer is an airline company. Mostly these customers design and make the galley being built to their own specific wishes.

In general ZGEU produces the following standard types of galleys, G1, G2, G3, G4, G5. Each type of galley has a different position in the airplane, Figure 4 shows the different places of the galley types. G5 is the biggest galley, it covers the whole back of the airplane.

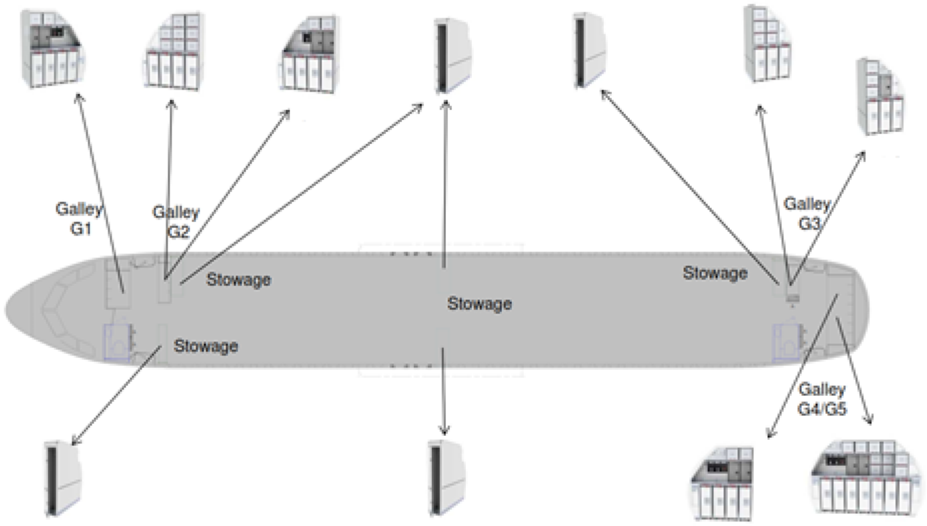


Figure 4: Locations of different galleys within an airplane (ZGEU, 2015a)

From all these types it is possible to get a ‘dry’ or a ‘wet’ version. A dry type is one without any water connections. The wet version is the opposite. In this version, for example, it is possible to place a sink. For each type of galley the customer can decide him-/herself what kind of kits he/she wants. Kits are the parts which can be placed in a galley, for example a coffeemaker, microwave or an ice drawer. The kits are not installed at ZGEU, but ZGEU has to prepare the galley to connect the kits.

ZGEU also makes stowages and crew rests as stated before, but in this research these products are out of scope.

Customers

The main customer of ZGEU is Airbus, it provides 75% of ZGEU’s production. This is a SFE customer. The other 25% comes from BFE customers like Delta and AirAsia. Currently, ZGEU has a market share of 78.6%.

Lean production

Top management of the Zodiac group wants that each subsidiary works according to the lean methodology. The CEO of Zodiac group stated “the Zodiac Aerospace Lean System is built around a set of continuously improving practices, methods and tools with a single goal: to proactively manage and improve our performance across all processes including design, sourcing, production and services” (ZGEU, 2015c, slide 5).

For production this means that all processes need to be linked in a smooth flow without detours to generate the shortest lead time, highest quality, and lowest cost (ZGEU, 2015c). To improve the processes within the production according to the lean principles ZGEU Operations department plans several ‘kaizen weeks’. Within these kaizen weeks data will be collected, Value Stream Maps (VSM) will be made and solutions will be generated with a selected team. Within ZGEU the Manufacturing Engineering department has the responsibility to improve the production processes.

1.2 Core problem
Zodiac Galleys Europe wants to reduce the lead time of the production of a galley. We define lead time as follows: “total time for a product to pass through the whole production process from start to finish” (Brook, 2006, p.36). The goal is set to reduce the lead time by 20%[1]. ZGEU needs to reduce production lead time because of two reasons. The first reason is the increasing demand of their main customer Airbus. To handle the demand with minimum amount of capacity, the production lead time needs to be reduced such that more products can be made in a fixed time period. The second reason is that ZGEU has agreed in the contract with Airbus that ZGEU reduces its sales price each year. This price composes approximately of 75% material costs and 25% handling costs. The past years, the focus of ZGEU has been on the reduction of material costs. But ZGEU also wants to reduce the handling costs, which is possible by reducing the lead time.

Core problem:
At Zodiac Galleys Europe, the production lead time of a galley needs to be reduced by 20%.

1.3 Problem statement
This research will provide a solution for the core problem. Therefore, this research answers the following problem statement:

How can the production lead time at Zodiac Galleys Europe be reduced?

1.4 Objective
Company’s objective
The company’s goal is to meet the increasing demand of its customers. ZGEU wants to achieve this by improving its production processes.

Research objective
The research goal is to develop a solution to reduce the production lead time of ZGEU. We analyse the organisation to attain a successful implementation.

1.5 Methods of research
This research follows the Managerial Problem-Solving Method (MPSM) of Heerkens (2004) to maintain overall control of the project. This method consist of the following phases:
1. identifying the problem;
2. planning the problem-solving process;
3. analysing the problem;
4. generating alternative solutions;
5. choosing a solution;
6. implementing the solution;
7. evaluating the solution.

The previous sections have given the elaboration of Phase one. This section and Section 1.6 are the elaboration of Phase two of the MPSM. This section explains the other phases by linking them to one or more research questions except for Phase six and seven. Phases six and seven are out of scope, due to time limitations. The descriptions between the brackets below show to

[1] Zodiac Galleys Europe wants to reduce the lead time by 20%. This is an indication which they think is possible to reach out of experience from other optimisation projects.

which phase the research question belongs. Further, this section gives the reasoning why we use the selected different models.

Research questions

1. *What is the current lead time of the production process and what is the bottleneck process? (Problem analysis)*
   This research question describes the current situation by making a high level overview of the production processes, the processing time of each step and the current total lead time. Because of a limited amount of data about the production processes and gathering good quantitative data of all production processes takes too much time, we limit ourselves to the bottleneck process. "The bottleneck is the resource that affects the performance of a system in the strongest manner, that is, the resource that for a given differential increment of change, has the largest influence on system performance" (Betterton & Silver, 2012, p.4159). This makes it possible to measure the process and conduct a good quantitative and qualitative, narrowed down, research. Otherwise the research would be very general and full of assumptions. Therefore, after the selection of the bottleneck process the process from above repeats itself but then on a lower level, we zoom in on the bottleneck process. This means that this research question also maps the process steps of the bottleneck process, the processing time of each step and the current lead time of the bottleneck process.
2. *How to create acceptance in the organisation for this change project? (Problem analysis)*
   Around 70% of change projects fail because of the resistance within the organisation (Burnes, 2015). To create acceptance for the solution to improve the lead time within the organisation, it is important that the solution fits within the organisation culture. Therefore, before generating solutions, it is important to look at the organisation culture of ZGEU. Besides the organisation culture a closer look at the stakeholders is necessary. Some stakeholders have the power to make or break the implementation of the solution. To create acceptance it is important to communicate with and involve the stakeholders directly from the start of the project. Therefore, the stakeholder analysis must be done before the problem identification, such that we can involve the main stakeholders in the process of finding the bottleneck of the critical process. When the stakeholders are accepting the generated solution the implementation has less resistance, so it will have a higher chance to succeed. The power to make or break the solution determines the level of involvement within this research.
3. *What is the root cause of the long lead time of the bottleneck process? (Problem analysis)*
   Within this research question we trace the causes of the current long lead time of the bottleneck process. Thereafter, we determine the impact of each cause on the lead time. The cause with the largest impact is the root cause of the bottleneck process. By solving the root cause, the largest reduction of the lead time of the bottleneck process can be obtained. Before generating a solution we reassess the stakeholder analysis, because the found root cause that needs to be solved can have impact on not yet mentioned persons or groups. We also do this because the levels of power and interest can change as a result of the narrowed scope.
4. *How can the root cause of the long lead time of the bottleneck process be eliminated? (Generating alternative solutions and choosing a solution)*
   The next phase of the method is generating a solution to solve the root cause of the bottleneck process. By performing a literature study we research different methods to solve the root cause. We select one method to generate a solution. Further, we research

the effect of the solution on the bottleneck process lead time and the total production lead time.

5. *Which steps are needed to implement the solution to eliminate the root cause and to reduce the total lead time? (Implementation of the solution)*
   This question results in an implementation plan. This implementation plan describes how the solution can be implemented. Because of time limitation the implementation itself will not be done in this project.

Models

We use different models to answer the research questions and as a result the problem statement. Figure 5 gives an overview of the models. We explain below why these models fit within this project.

Current situation

We map the current situation by making a system drawing. A system drawing gives an overview of all streams within the set boundaries (Veld, 2007). This model fits well in the beginning of this research, because it creates an overview of all processes and the physical streams between the processes. It ensures that nothing will be missed in the research and boundaries are clear for everyone. The inclusion of boundaries is the reason why we prefer a system drawing instead of another method, for example a flowchart. To make this system drawing we use the organisation chart to select the employees which have knowledge about the entire production process. Additionally we interview the team leaders during a visit to the production to verify the system drawing and gain extra information about the current situation of their processes. Besides the interviews we also gain input from available flowcharts and value stream maps of ZGEU. Thereafter it is important to quantify the current situation. The ERP system of ZGEU provides data from previous measurements within the production. To create a current state of the bottleneck process we make a system drawing again. To quantify the current state of the bottleneck process we use the data of the monitoring moments and estimations by employees.

Acceptance

To make sure that the organisation accepts the changes needed to improve the lead time, we carry out a stakeholder analysis and fill in the 7s model of McKinsey (Marcus & van Dam, 2009). We use the stakeholder analysis given by Burnes (2015), the analysis focuses on the influence and importance of individuals and groups to a change project and helps to identify which persons we should involve in the research. It is a simple and quick analysis which provides enough depth for this change project. We choose the 7s model since it analyses the performance of an organisation and it contains all internal factors an organisation can influence and their mutual interaction. The 7s model ensures that the effects on the other factors are taken into consideration (Marcus & van Dam, 2009).

Root cause

The Ishikawa diagram gives an overview of all causes that have effect on the lead time in a negative way. Because of the six deviations it ensures that no causes are left out. In addition it provides the stakeholders a clear overview of the causes, which enhances their involvement and understanding. We rank the identified causes according to their influence on the lead time with number one being the cause that effects the lead time the most. The ranking is based on monitoring data and the opinions of the employees.

Solution

First, we describe the problem that needs to be solved more specifically. By performing a literature study we research possible methods to solve the problem and select the best suited method for the problem at ZGEU. By elaborating the selected method we gain a solution. We gather the input for the model by measuring the process and organise brainstorm sessions with important stakeholders. We determine the effect of the solution on the lead time of the bottleneck process by comparing it with the current lead time of the bottleneck process. We also determine the effect on the total production lead time. We do so by calculating the reduction percentage the solution has on the total production lead time, by comparing the gained lead time reduction at the bottleneck process to the total production lead time.

Implementation

We elaborate an implementation plan for the found solution to eliminate the root cause and to reduce the lead time. The 'Eight Step Change model' gives assistance to the implementation plan, by providing a roadmap to implement a change into the business successfully (Kotter & Rathgeber, 2006). By elaborating these steps for the solution we ensure that the implementation plan covers all aspects to succeed.

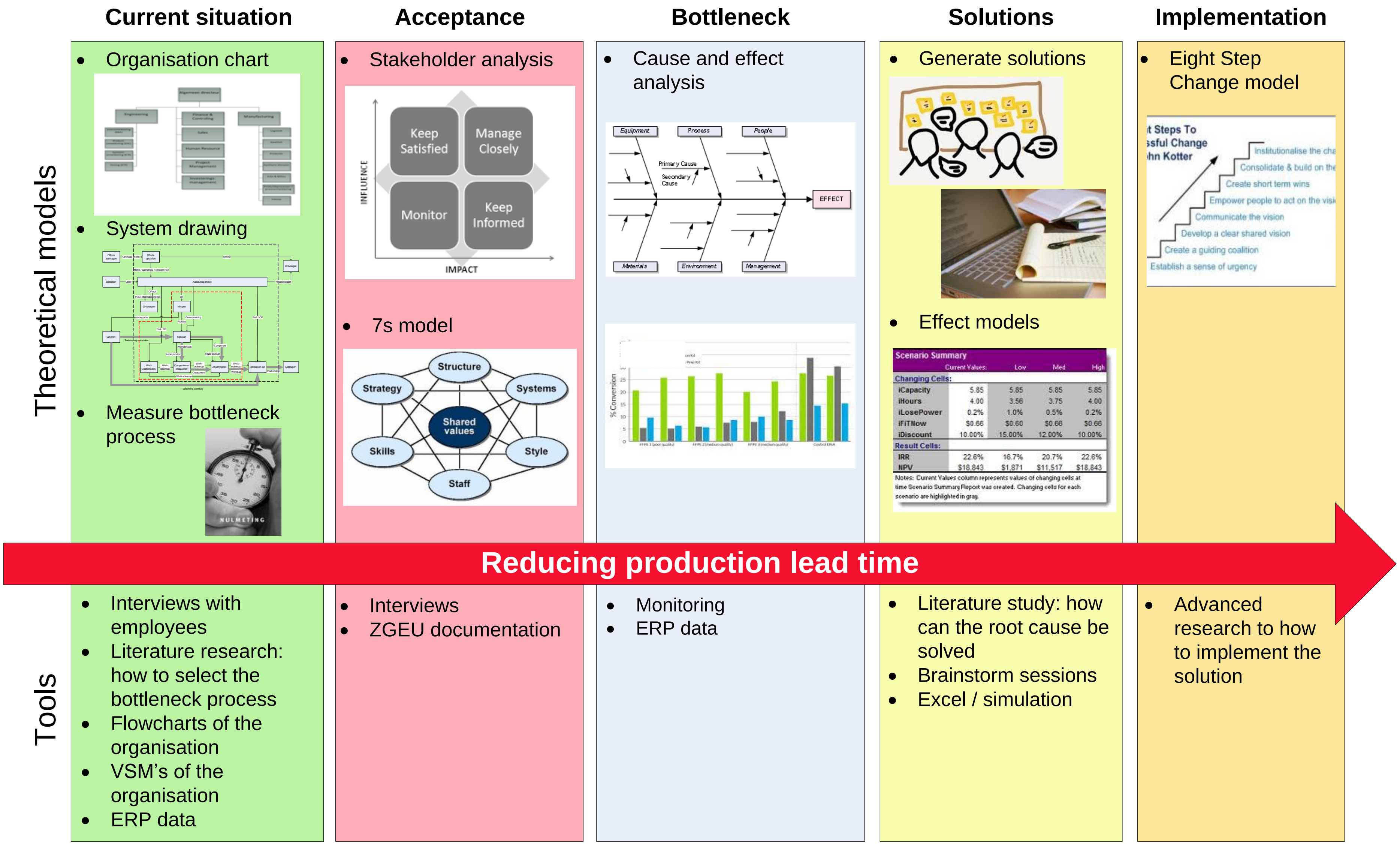


Figure 5: Method of research

1.6 Scope

The project takes place with the following limitations:
We have limited this research to the determined bottleneck process, because of the limited amount of data about the production process, which is needed to perform a good quantitative research. It is possible to determine the bottleneck process with the limited data, but for further analyses there is not enough data available. Gathering all required data of each process takes too much time. We can gain enough data for one process step, within the set time, by monitoring the bottleneck process to gain quantitative data and interview the employees for qualitative data. Further, we limit the benefits of this research to the percentage of reduction of the production lead time instead of cost savings. We do this because the research objective is to develop a solution to reduce the production lead time of ZGEU.

1.7 Outline report

We have given the background and described the purpose of this research in this first chapter. In Chapter two we describe the current situation of the production process of Zodiac Galleys Europe, determine the bottleneck process and describe the current states of the identified bottleneck process. Chapter 3 gives insight into the organisation culture and provides the important stakeholders, which need to be involved during this research. Chapter 4 describes the causes of the too long lead of the bottleneck process and detects the bottleneck of the bottleneck process. We also give the in-depth analysis of the detected bottleneck to determine the root cause of it in Chapter 4. Chapter 5 provides a method how the root cause can be solved and thereby reducing the appearance of the bottleneck of the critical process. It also mentions the possible gains for Zodiac Galleys Europe when the gained solution shall be implemented. Chapter 6 contains an implementation plan to implement the solution at Zodiac Galleys Europe after this research. The last chapter gives the conclusions of this research and recommendations for Zodiac Galleys Europe. The appendices give further in-depth information on the subjects of the chapters above.

2. Current situation

This chapter describes the current situation of ZGEU. The first section explains the production process. The second section gives the current state of the production process in figures and detects the bottleneck process. The third and fourth section describe the process steps of the bottleneck process ‘final assembly’ and its current state.

2.1 Production processes

Figure 6 shows the production process. The dotted line represents the boundaries of this research with regard to the production process. Now we can give a more specific definition of the production lead time at ZGEU, namely the total time for a galley to pass through the whole production process from ‘Making panels’ to ‘Inspection’. The current lead time is 19 days (ZGEU, 2015b). The description below describes the production process, as well as the information flows.

<u>Making panels</u> – The production starts with sawing the honeycomb blocks into slides if it does not have the standard thickness, otherwise the supplier delivers honeycomb slides. Honeycomb is the core material where the panels are made of. Thereafter, the workers cover both sides of the honeycomb slide with 2 layers of prepreg material and a layer of tedlar. ZGEU uses prepreg to make the panel stronger and uses tedlar to make it possible to paint the panel. The panel press heats the honeycomb with the layers while it presses this package between metal plates. The panel press heats the prepreg such that it melts and fills the gaps in the honeycomb. After this the panel press cools down which makes the prepreg solid and stick on the honeycomb as well as the tedlar.

<u>Routering panels</u> – After the panels are cooled the workers move the panels to the next machine, the router. The router cuts the panels into smaller panels and makes the needed holes, according to the needs of the project. All these panels get a sticker with information, for example the name of the project. After the router, the workers at the router station deburr the panel’s sides and holes.

<u>Preparing panels</u> – At this process workers manually fill the holes with inserts and fasteners. They also finish the sides with a foam. This is necessary to connect the different panels to each other, because honeycomb does not stick on other honeycomb material.

<u>Bonding structure</u> – The workers at bonding put the different panels together with glue to one structure. ZGEU has moulds where the panels can be put in during the curing time. The curing time of the glue is 24 hours.

<u>Decorating structure</u> – The decorating workers brush the structure to get a surface without any bumps and if necessary they plaster some parts, to get a flat surface. After this the workers manually decorate the structure to the wishes of the customer. They only decorate the places which are visible when the galley is placed into the airplane. This station also decorates doors as well as other panels that need to be assembled at subassembly or final assembly. When we look at Figure 6 we see a loop from final assembly to decorating structure. This is because ZGEU decorates some types of galleys for just 90% the first time. The workers are decorating the other 10% after the assembly. ZGEU chooses to do this because the decoration of different galleys got repeatedly damaged on the same place during the assembly process, which leads to too much rework.

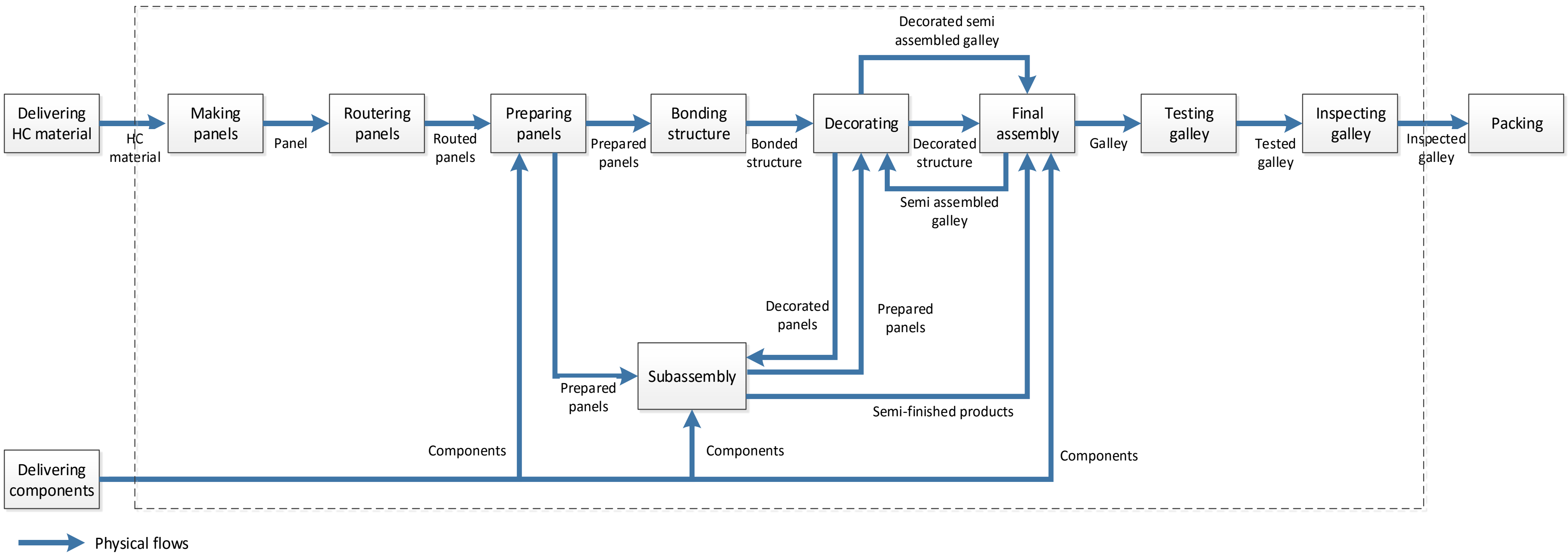


Figure 6: System drawing

Subassembly – At the workstation subassembly ZGEU makes its semi-finished products, for example doors or work decks. When the panels for the semi-finished products need to be decorated, subassembly sends them to the area of decoration. Thereafter, the workers of subassembly assemble the necessary items, for example a door handle, on the decorated panels to create the semi-finished products.

Final assembly – This workstation assembles the galley. A few assembly parts are for example the structure, electric wires, water tubes and doors.

Testing – This functional test examines the following aspects:

- weight of the galley;
- the water systems;
- bonding;
- insulation breakdown and resistance;
- electrical continuity;
- refrigeration system;
- individual air system;
- ventilation system.

Inspecting – An inspector examines the galley and if necessary he/she repairs it. The inspector examines the following aspects for each type of galley:

- documentation;
- identification of galley, placards and part marking;
- water and air;
- complete finish (sealing, paint and glue);
- electrical systems;
- operation of doors;
- sliding table;
- decorative trim and paint.

Besides this general inspection list, there is also a galley type specific inspection list. This list consists of the items which have a failure at the customer repeatedly. The worker inspects these items extra to make sure the failure will not occur at the customer again.

Packing – The workers pack the galley and make it ready for shipment.

Information flows within the production process – Each workstation in the production process receives a planning from the planning department with the projects and the dates when the station needs to work on it. Each workstation also receives a drawing of the engineering department, these are workstation specific. Further, there is a peer book for each project that goes through the whole process. This peer book is meant to add information about the progress of the project. It contains a Bill Of Material (BOM), checklist for inspection, status of the assembly and other documents to document the progress of the project. The workstation where the final inspection takes place also receives information from the quality department about the failures which have happened at the customers.

2.2 Bottleneck process detection

Literature gives all kinds of different methods to detect bottleneck processes. The most common industry bottleneck detection methods are according to Roser, Lorentzen & Deuse (2014) the following four approaches:

- Process time approach – this approach uses the processing times to detect the bottleneck. It is a simple and fast method to detect the bottleneck, but this approach only detects the static bottleneck. This means it detects the bottleneck that occurs when the system works under perfect conditions, no machine failures or other causes of temporary delay are taken into account. This method works only for manufacturing systems that are static, so there are no losses within the process. If we look at ZGEU there are a lot of human activities which makes the system dynamic. This means that, when we use this approach, we have a chance that we do not detect the primary bottleneck.
- Utilisation approach – this approach uses the difference between the net production time and the lead time. To determine the gap it uses averages. This approach works best for manufacturing systems which have a low/ high mix of products, low number of stations and low fluctuation (Lima, Chwif & Barreto, 2008). ZGEU has a high mix of products, high number of stations and high fluctuation, so this approach is not good to detect the bottleneck at ZGEU.
- Simulation – this method simulates the processes in a software model. This approach requires a lot of data and the data quality needs to be precise to detect the primary bottleneck. The required data is often difficult to obtain and therefore many assumptions need to be made, which causes that the data quality is of insufficient level of precision. Roser, Lorentzen & Deuse (2014) therefore exclude simulation as a basis for a detection method. ZGEU does not have enough data of good quality for this approach, so this approach is not suitable.
- Active period method – this method measures the time a process is working without interruptions by waiting for parts or transport. The process with the longest average active period is the bottleneck. This approach also works best for manufacturing systems which have a low/ high mix of products, low number of stations and low fluctuation (Lima, Chwif & Barreto, 2008). Again ZGEU has a high mix of products, high number of stations and high fluctuation, so this approach is not good to select the bottleneck at ZGEU. This approach also requires a lot of data, which is not available at ZGEU.

Roser, Lorentzen & Deuse (2014) give another approach to detect the bottleneck instead of these common approaches, the bottleneck walk. The bottleneck walk selects the bottleneck by observing the different processes (waiting for parts or waiting to transport parts) and inventory states (full or empty) during a walk along the flow line. Because ZGEU produces a part of the production in Tunisia, the bottleneck walk is not possible. There are a lot more methods to detect the bottleneck process, but ZGEU currently does not have enough detailed data of each process which most of these other methods require to detect the primary bottleneck. ZGEU has the processing time of each process in their ERP system. The processing time is the lead time of an individual process, where lead time means the total time for a product/ batch or service to pass through the whole process from arrival until departure of the process (Brook, 2006). Therefore, we can use the process time approach to detect the bottleneck process. We state that this approach does not 100% guarantee it detects the primary bottleneck, so to verify its correctness we also interview employees of ZGEU. In this interview we ask them which process they indicate as the bottleneck process.

The shop floor workers have measured the processing times of each process 60 times, except the process ‘Inspecting galley’, of the galley type G1 from April until September 2015. The shop floor workers have clocked in and out for a galley per process. From the clocking system the planning department has obtained the processing times. This means that the shop floor workers were not aware of the measurements directly, because they always are clocking for a galley. The processing time of FA does not include the return loop to decorating, because the employees clock out before the galley goes to decorating and clock in again when the galley returns to FA. The 60 measurements give the average processing times of each process in hours. Figure 7 shows these average processing times, if one employee works on the galley (ZGEU, 2015b).

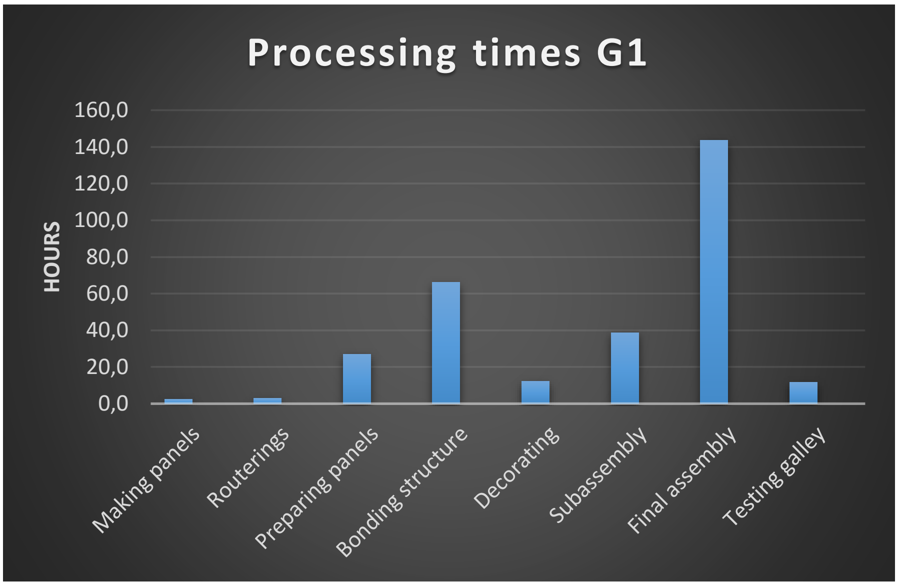


Figure 7: Processing times (ZGEU, 2015b)

As stated by Roser, Lorentzen & Deuse (2014), the process time approach does not include any losses and therefore it sometimes does not detect the real bottleneck. But because ZGEU works according to the lean principles, the bottleneck process can be detected with a higher degree of correctness by the process time approach. This is because the lean principles are eliminating losses. The lean principles are as follows (Symbol, 2014, p.35):

- “value – define what is of value to the customer;
- value stream – identify the value stream / eliminate waste;
- flow – create a constant flow;
- pull – produce on customer demand in the part downstream of customer order decoupling point;
- perfection – continuous improvement.”

According to the process time approach, the process which has the longest processing time is the bottleneck process. Thus, with the process time approach final assembly (FA) is the bottleneck process. FA has the longest average processing time, see Figure 7. The process time approach detects the actual bottleneck process in this case. More certainty that FA is the primary bottleneck process is given by the interviews with director of Operations, production SA manager and production supervisor, who are detecting FA as the current bottleneck process as well. Appendix A gives the interviews with the director of Operations, production SA manager and production supervisor.

2.3 Final assembly process steps

Figure 8 shows the process of FA which has a lead time of 8 days. There are two flows, one for structure assembly (blue blocks) and one for systems assembly (yellow blocks). Both are done in parallel. This means that there are two workers responsible to assemble the galley. One works on the structure of the galley and the other concerns him-/herself with the systems that need to be assembled. The sequence in Figure 8 has been obtained by monitoring the process of a G1 galley. Known is that there is no standardisation of the sequence for both flows. How a G1 type or any type is built depends on the skills of the workers. The description below describes each process step within the process of FA. During the whole process the worker has to do an auto check. This means he/she constantly controls his/her work on mistakes (for the purpose of readability we will hereafter refer to he and his regardless the gender). Further, a sealing specialist seals the galley and checks the already sealed places. The specialist seals different galleys during a day, so he comes and goes during the whole process of one galley. Sealing is left out because the sealing specialist works on different galleys in one shift.

Install extrusions/profiles – The structure worker files the structure and covers the ledges with aluminium extrusions/ profiles by gluing them on the structure. These parts need to harden for 24 hours.

Install removable shelfs – FA receives shelfs from subassembly. The structure worker assembles the shelfs on the galley. The shelfs are removable, so the customer can change the height of the shelf within the galley.

Install retainers – The structure worker places retainers. These retainers keep the kits and trolleys within the galley during the flights.

Install pull out table – If requested by the customer the structure worker will place a pull out table, a table which can be pulled out and pushed in after use for extra work deck space.

Install rub strips/fillers – The structure worker places rub strips/ fillers within the galley. The rub strips/ fillers will keep the kits at their place within the galley.

Install work deck – The structure worker installs the work deck. The customer can request a sink. The worker installs this as part of the work deck.

Install dividers – FA receives dividers from subassembly which the structure worker installs on the galley. A divider is a vertical panel to make more boxes within the galley. After this process the galley returns to decoration to decorate the remaining parts. This is only for a few types of galleys to prevent rework.

Install doors – The structure worker installs the doors that he receives from subassembly after the galley is completely decorated.

Making subparts – The systems worker first assembles different subparts of systems. For example the air conditioning cover and the electrical installation.

Install water systems – The systems worker installs the water systems on the galley, this exists off the potable water system and ventilation.

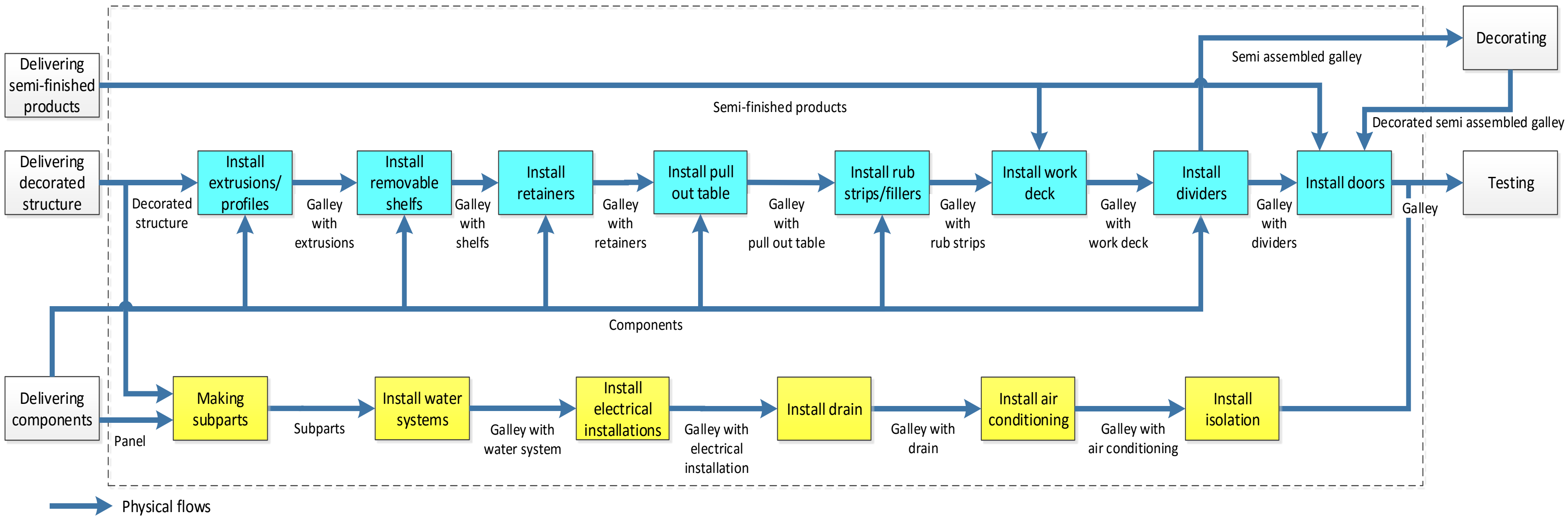


Figure 8: Final assembly

Install electrical installations – The systems worker installs the electrical installations on the galley and secures all wires.

Install drain – The systems worker installs the drain, and the required tubes with it, on the galley.

Install air conditioning – The systems worker places the air conditioning cover and connects all tubes and secures them.

Install isolation – The systems worker installs the isolation around the water tubes.

2.4 Current states final assembly

The total processing time of FA for the galley type G1 is 114 hours, if one employee works on the galley (Figure 7). As stated before FA has one worker for the structure assembly and one for systems assembly per galley. Table 1 gives the detailed distribution of the 114 hours per work specialty.

Table 1: Time per work specialty (ZGEU, 2015b)

Work specialty	Time	
	Hours	Days
Structure assembly	59	7.3
Systems assembly	55	6.9

With this number of workers the current lead time of FA is 8 days. One shift at ZGEU is 8 hours. To obtain the 20% reduction of the total lead time of 19 days, FA must reduce its lead time to 4 days. When ZGEU has reduced the processing time of FA by 50% it is still the process with the longest processing time. Thus, the objective to reduce the lead time with 20% can be obtained by only improving the FA process. Figure 9 gives the average processing time of each process step within the FA except sealing.

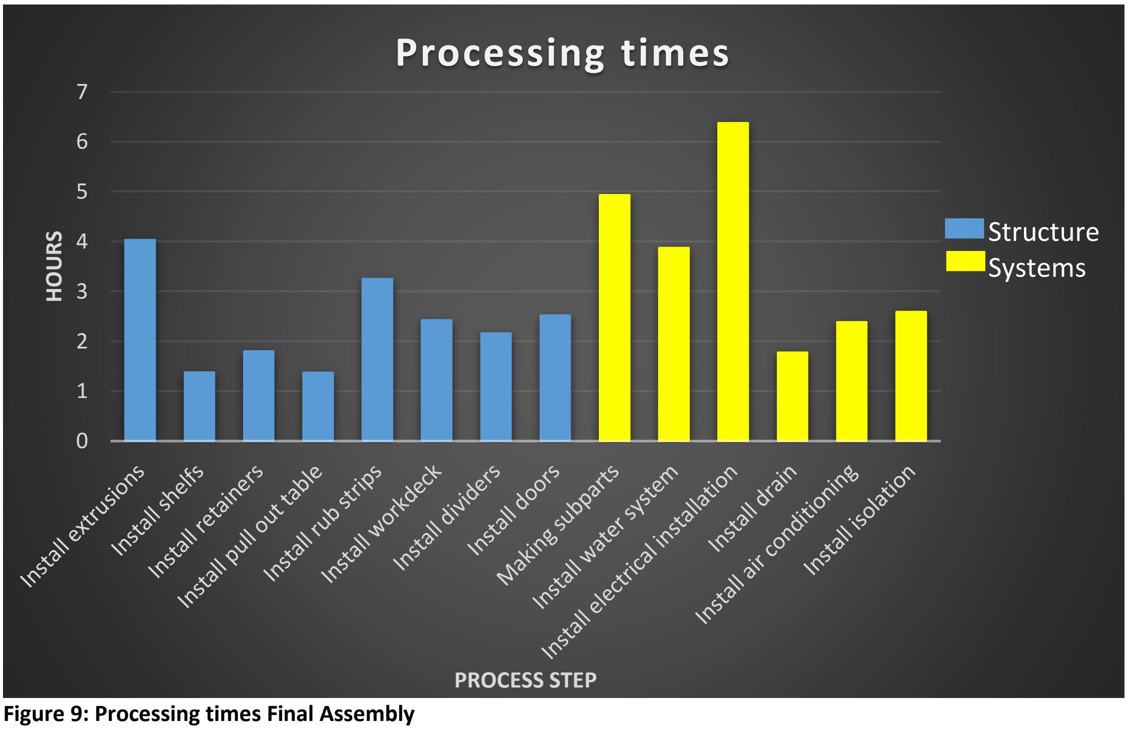


Figure 9: Processing times Final Assembly

We have obtained these processing times by using the following data:

- data from the first monitoring of the FA, a worker from the ME team has measured the processing times of this monitoring;
- data from the second monitoring of the FA, we have measured the times of the second monitoring ourselves;
- time estimation by the workers of FA, 15 workers and two team leaders of FA have estimated the processing times.

Table 2 gives the processing times gained by the measurements described above and the average processing times which we also illustrate in Figure 9.

Table 2: Processing times per measurement

Processing time					
	Monitoring 1	Monitoring 2	Employees FA average	Employees FA STDV	Average
Factor	0.449	0.333	0.218		1.00
Structure					
Install extrusions	3.0	3.9	6.4	1.99	4.0
Install shelfs	1.0	0.2	3.9	1.66	1.4
Install retainers	2.0	0.9	2.8	1.56	1.8
Install pull out table	1.0	*	2.1	0.64	1.4
Install rub strips	4.0	1.0	5.1	0.99	3.3
Install work deck	2.5	0.6	5.0	1.69	2.4
Install dividers	2.0	2.1	2.6	1.05	2.2
Install doors	2.0	2.0	4.4	1.18	2.5
Systems					
Making subparts	3.0	6.4	6.8	1.92	4.9
Install water system	4.0	2.7	5.4	1.93	3.9
Install electrical installation	8.0	3.8	7.0	2.18	6.4
Install drain	2.0	1.3	2.0	1.56	1.8
Install air conditioning	3.0	0.8	3.6	2.69	2.4
Install isolation	2.0	1.7	5.1	2.09	2.6

* The G1 galley monitored during monitoring 2 did not require a pull out table, so the installation time for the pull out table is not measured.

Table 2 shows that there is a large difference between the measurements. Let us explain these differences.

- Monitoring 2 gives lower processing times then monitoring 1. This is because the ME team has prepared monitoring 2, so they have eliminated losses such as the time to get the right tool or right part. So we interpret the processing times of monitoring 2 as the minimum processing times of the galley type G1. We see that monitoring 2 sometimes has higher times than monitoring 1, this is because of the difference between the requirements of the galley type 601850-001601 of monitoring 1 and the galley type 601850-002501 of monitoring 2.
- The processing times estimated by the employees of FA are very large compared to the data of monitoring 1 and 2. And the STDV of the estimations of the employees indicates that the employees are not aligned with each other. Reasons for these differences are the following:

- Workers can be influenced by the presence of the employees which were monitoring the process. Employees are working harder than normal during a monitoring which explains the lower times at the monitoring measurements (Schwartz, Fischhoff, Krishnamurti & Sowell, 2013).
- Employees are estimating the times too high, because they are afraid for new standards for the processing times. As Pihir, Konecki & Tomicic-Pupek (2015) state employees over-rate in most cases their human manual activities working time.
- There are different types of G1 galleys. For example, the G1 galley of the second monitoring has no pull out table which reduces the number of retainers.
- Because currently no process steps are defined, the employees can have misinterpreted the steps defined by this research. This can explain the value of the STDV's. 'Install extrusions' for example, can be interpreted as the time needed to install the extrusions plus the cure time, or just the installation time of the extrusions.
- From the questioned employees 30% has recently started at ZGEU, so their experience is low. Therefore, their estimation can be different of the experienced employees which explains the value of the STDV.

Because of these differences we give each measurement a weight factor. A weight factor presents how good the data of that measurement reflects the real processing times compared to the other measurements. The weight factor determines the amount of leverage the data of that measurement has on the average processing times. Because we do not have the real processing times we need to compare the measurements to each other by subjective criteria.

A suitable method for this multi criteria evaluation problem is the Analytic Hierarchy Process (AHP). "The AHP is a systematic procedure for representing the element of any problem. It organises the basic rationality by breaking down a problem into its smaller constituent parts and then calls for only simple pairwise comparison judgments to develop priorities in each hierarchic level." (Cho, 2002, p.1102). The AHP method suits here well because it is possible to compare the measurements with each other on the same scale based on subjective criteria. It uses a ratio scale so it quantifies the gap between the measurements. The applications of the AHP method are numerous, it is for example applicable for resource allocation problems and organisation priority settings (Saaty, 2013).

We want to compare the measurements with each other and prioritise them in order which measurement reflects the real processing times the best. We choose to prioritise with the following criteria:

- accuracy of the measurement method:
    - monitoring
    - estimation
- who measured the data:
    - ME team
    - researcher
    - employees of FA
- preparation level:
    - well prepared
    - not prepared

Together with the manager of the ME team and an employee of ME team we have judged the level of dominance of one criterion over another criterion with the AHP scale. After this, we determine the weight factors for each measurement with the AHP method. Because the AHP method uses a ratio scale the weight factors of the AHP method can be used as the percentages of leverage the data of each measurement must have on the average processing times. The calculated weight factors are as follows:

- Monitoring 1: 0.499
- Monitoring 2: 0.333
- Estimation by the employees of FA: 0.218

Appendix B gives further insight of the calculation of the weight factors and the average processing times.

We conclude from Figure 9 and Table 2 that the total average processing time of the structure assembly is 19 hours, which equals 2.4 days. The current lead time is 8 days so 30% of the time is added value for structure assembly. The average processing time of systems assembly is 21.9 hours, or 2.7 days. This means 34% of the time is added value for systems assembly. A remark here is that currently the systems worker always finishes earlier than the structure worker. Conclusion is that structure assembly has most impact on the current 8 days lead time of the galley at FA.

2.5 Conclusion

The production process of ZGEU exists out of different processes. These processes and their processing times are given in Figure 7 in Section 2.2. From these processes, currently FA is likely to be the bottleneck process, because it has the longest processing time. Also, employees of ZGEU are indicating FA as the bottleneck process. The process FA exists out of two flows. One for the structure assembly and one for systems assembly. Figure 9 in Section 2.4 gives the process steps within FA and their processing times. The process steps happen disorderly at both flows, because there is no standard for the sequence of the process steps.

The average total processing time of the structure assembly is 2.4 days, which gives that 30% of the total lead time of 8 days is added value. The average total processing time of the systems assembly is 2.7 days which gives a percentage of added value of 34%. Looking at the minimum processing time of the second monitoring the added value of the structure assembly is 17% of the total lead time of 8 days and 26% added value of the systems assembly. Remark, this is specifically for the galley type 601850-002501 without any losses. Thus, reducing the lead time at FA with 4 days to reduce the total lead time with 20% should be possible.

Many change projects fail because of the resistance within the organisation. Therefore, before analysing the process of FA further we need to know the main stakeholders and be aware of the organisation culture to decrease the resistance during the project and the implementation of the solution.

3. Acceptance by the organisation

To make sure that the organisation accepts the changes needed to improve the lead time, we perform a stakeholder analysis to know who we need to involve and we fill in the 7s model of McKinsey for ZGEU to gain information about the organisation culture. But first we explain the importance of these analyses.

3.1 Resistance of an organisation

Around 70% of change projects fail because of the resistance within the organisation (Burnes, 2015). Burnes (2015) gives four theories why employees resist to changes:

1. Level of cognitive dissonance. Workers are consistent in their attitudes and behaviour. If an inconsistency occurs between two or more attitudes or between attitude and behaviour, workers feel frustrated and uncomfortable with the situation (dissonance). They want to keep a low level of dissonance and therefore resist to changes.
2. The depth of intervention. Currently, employees do not get involved enough during change projects. Therefore, the changes come out of the blue for them, which can lead to resistance. The involvement of the worker with the change project and a participative style of leadership, leads to higher readiness and acceptance of the change.
3. Changes of psychological contract. The employee has expectations of factors like payment, hours, promotion prospects and training. The employer also has expectations like work effort, commitment, loyalty and responsibility. These expectations can be written down or unwritten, like the business culture. If the balance of the expectations of the employee and employer changes because of the change project, resistance and conflicts may arise.
4. Employees level of dispositional resistance. Each person has a different level of dispositional resistance. The above three aspects are organisational, dispositional resistance is a personal aspect. Each individual reacts different to changes, the level of dispositional resistance is the degree to which an employee tends to accept or resist a change. A worker with a high level of dispositional resistance has the most tendency to reject a change.

Thus, it is important to involve the employees into the change project as soon as possible to create acceptance within the organisation. This will decrease the level of dissonance, gives the employees time to acclimate and employees have the opportunity to give their opinion over the change project also in terms of the psychological contract. Because the psychological contract can be written but also unwritten it is important to understand the organisation culture. The fourth aspect ‘level of dispositional resistance’ is an aspect that cannot be changed by the leaders of the change project, but they can take it into account. This can be done by emphasising the importance of the change to the employees with a high level of dispositional resistance.

3.2 Stakeholder analysis

Some stakeholders have the power to make or break the implementation of a solution. To create acceptance, which is needed to reach the optimal outcome of the solution, it is important to communicate with and involve the stakeholders directly from the start of the project. The power and interest to make or break the solution determines the level of involvement. This stakeholder analysis creates an overview of the importance and influence of individuals and groups to the change initiative (Shirey, 2012). Figure 10 summarises the outcome of this analysis.

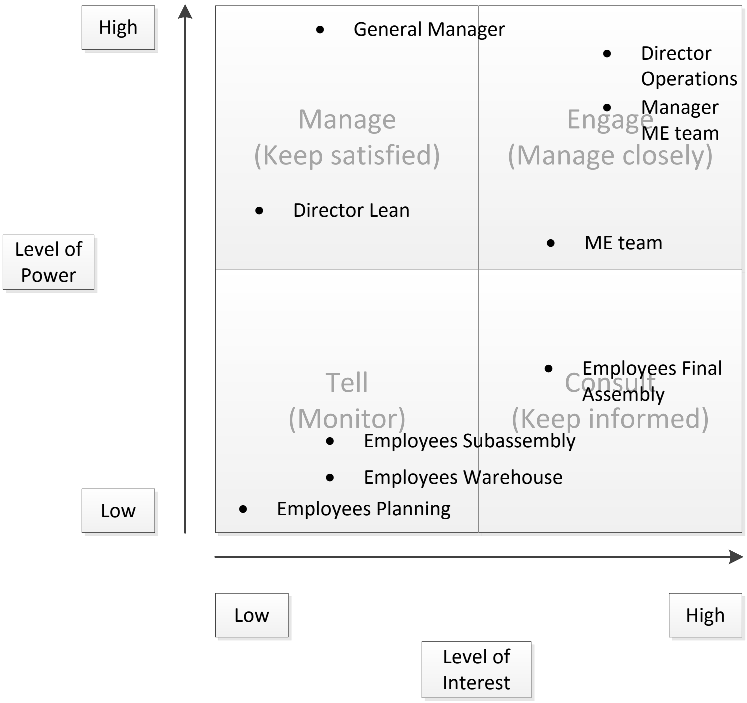


Figure 10: Outcome stakeholder analysis

This stakeholder analysis provides a framework of how to involve the different stakeholders. The stakeholders in the upper left quadrant (manage quadrant) are powerful and busy people. Therefore, the communication about the project toward these stakeholders is short and concise, exists of summaries and brief one-on-one conversations (Shirey, 2012). According to Gambles (2009) these stakeholders are the most dangerous. We inform the stakeholders in the upper right quadrant (engage quadrant) frequently and in more detail. According to Shirey (2012) a good way to inform this group is holding regular meetings, developing reports and give presentations. Therefore, every two weeks a meeting with the director of Operations and manager of ME team takes place to discuss the progress. We also invite these stakeholders to participate with brainstorm sessions, for example. The bottom left quadrant is the tell quadrant, we inform these stakeholders only about the important subjects that affects them. A one way communication is preferred for this quadrant (Shirey, 2012). The remaining quadrant is the consult quadrant. We inform the employees of FA during the whole project, feedback from this group is important. A good way to communicate with these stakeholders is a two way communication (Shirey, 2012). Appendix C describes the establishing of this stakeholder analysis in more detail.

3.3 7s model

To create acceptance for the solution to improve the lead time within the organisation, it is important that the solution fits within the organisation culture, as Section 3.1 states. Therefore, before generating solutions it is important to look at the organisation culture of ZGEU. The 7s framework of McKinsey is a management model that describes seven factors to organise a company in an all-embracing and effective way (Marcus & van Dam, 2009). Together, these factors describe the way an organisation operates. The factors are all interdependent as shown in Figure 11, so if a company fails to give proper attention to one of them, this will affect all others as well. On top of that, the relative importance of each factor may vary over time.

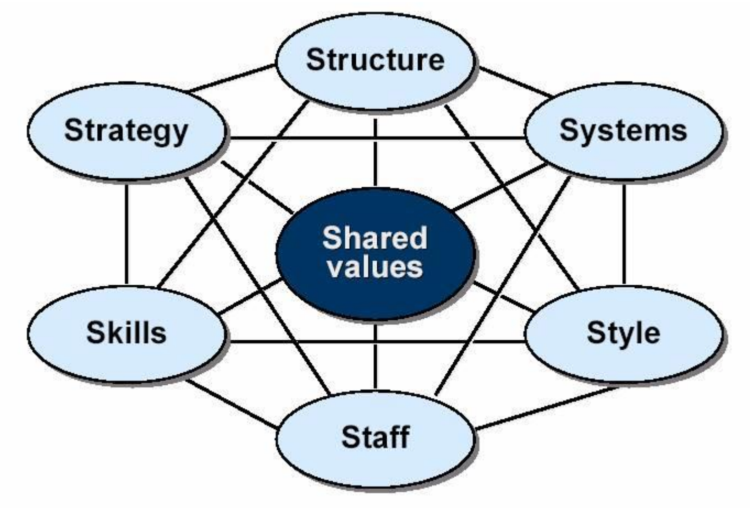


Figure 11: 7s model (Marcus & van Dam, 2009)

Below we describe shortly each factor of the 7s model:

1. ‘Shared values’ McKinsey places this factor in the centre. It contains the business conception, business culture, identity of the company and the vision. The reason for the central positioning is that this factor ensures consistency of and controls the other factors.
2. ‘Strategy’ indicates the intended actions of the organisation. Which goals are set, are possible and how can these goals be reached? The strategy is the bridge between the mission statement of the company and the needed resources. A strategic plan presents the choices which are made for the whole organisation, and it describes what is expected of the departments to contribute to the success of the company.
3. ‘Structure’ refers to the organisation structure (levels, roles, coordination, line organisation, staff organisation and functional organisation).
4. ‘Systems’ includes all formal and informal methods, procedures and communication flows, both internally and externally.
5. ‘Style’ refers to the management style, the way the management treats the staff and the way people interact. A good way of leadership generally provides a good result. If there is an enjoyable ethos in the company, employees come to work with pleasure.
6. 'Staff' focuses on the question ‘What are the competences of the managers and the employees, now and in the future?’.
7. 'Skills' focuses on the core competences of the organisation, that are needed now and in the future.

Appendix D gives the elaboration of each factor for ZGEU. The description below gives a summary of the 7s model for ZGEU.

ZGEU has a clear vision for the company, “be the preferred business partner for galleys and monuments, be recognized as the leader and the pioneer in our business and be a company of commitment and well-being” (ZGEU, 2014, slide 4). The strategy of ZGEU focuses on protecting the current market share by improving the KPIs: on time delivery, cost and quality. By improving these KPIs ZGEU wants to outperform its competitors. The KPIs will improve if ZGEU reduces the lead time, according to the director of Operations. The new plant in Tunisia is also a part of the execution of this strategy. The plant in Tunisia has started the production at the beginning of 2015, this means it is still learning the processes. Therefore, the strategy of the Operation department is to create an alignment between the plant in Tunisia and the plant in the Czech Republic.

Management describes the business culture as closed and formal, but the general manager states that the organisation is open to customers and suppliers. ZGEU wants to change the business culture to an open culture. The values are supporting the change to an open culture. Also the weekly and daily meetings on different levels in the organisation encourage an open culture, because these meetings are not only meant to inform others but also to gain feedback from other departments. The general manger supports an open culture by ‘show by example’. The director of Operations applies the democratic leadership style to create an open culture. Democratic leadership style “involves others in deliberations and arrive at decisions through majority rule” (Trask, Rice, Anchors & Lilieholm, 2009, p.30).

In accordance with the theory of Mintzberg (Marcus & van Dam, 2009) ZGEU is an adhocracy and a little bit a machine bureaucracy organisation. The organisation is standardising the work processes at the shop floor, has a functional alignment but at the shop floor there is a market alignment, is selective decentralising decisions and provides trainings to employees. The main information system of ZGEU is the ERP system, which is advanced and automated.

The employees of the department of Operations differ from educational backgrounds. The function description gives the requirements the employee needs to fulfil. Employees have the opportunity to grow in the organisation by following trainings, which ZGEU provides. The commitment of the employees is not only offering the right salary, but also creating a good social environment at the workplace, according to the director of Operations. The organisation needs employees who are proactive, cautious and interested in their work and the product, and the organisation needs knowledge about the ins and outs of a galley to be successful in the market.

3.4 Conclusion

It is important to involve the employees into the change project as soon as possible to create acceptance within the organisation, because this decreases the level of dissonance. It also gives the employees time to acclimate to the change and they can give their opinion on the change project, also in terms of the psychological contract. With the stakeholder analysis and the 7s model we ensure that the solution does not fail because of the possible resistance within the organisation. We involve the main stakeholders: the director of Operations, manager of ME team, ME team and the employees of FA, by for example a brainstorm session about how the lead time can be reduced. We also ask their opinion about important decision points within this research. This supports the open culture the organisation wants to achieve. From the 7s model we conclude that the solution needs to give an improvement of the lead time and so improving the KPIs on time delivery, quality and cost. An improvement of the lead time also improves the alignment with the production plant in Tunisia. Analysing the process and generating alternative solutions is a process where not only the powerful stakeholders need to be involved. A threat is that, because of the current still closed and formal culture, the less powerful stakeholders do not give their opinions and ideas. Also because of this culture, it is even more important that the powerful stakeholders support this research to gain the optimal outcome.

Now, we know which stakeholders need to be involved to make this project succeed. The next step is to detect the root cause of the long lead time of the bottleneck process FA. By involving the stakeholders in the next step they are aware of the methodology to determine the root cause, which creates support to solve the root cause.

4. Detecting the root cause of the too long lead time of final assembly

This chapter detects the bottleneck of the FA process. The first section gives all causes which are affecting the lead time. The second section ranks all causes and selects the bottleneck, the cause that affects the performance of a system in the strongest manner (Betterton & Silver, 2012). Section three gives the underlying causes of the selected bottleneck and the determination of the root cause(s).

4.1 Causes of long lead time final assembly

The Ishikawa diagram in Figure 12 gives an overview of different causes which are causing the current eight days long lead time of FA. The research to detect these causes and their underlying connections exists of the two monitoring moments of the FA, a brainstorm session with the ME team, an interview with the director of Operations and input from FA employees. These are the 'engage' and 'consult' stakeholders. The description below gives further explanation of the causes in the Ishikawa diagram.

<u>Equipment</u>

The equipment for FA leads to a longer lead time because of two causes:

- Not all tools are present. A worker needs to walk to another area for the right tools.
- According to the drawings of engineering, the current tools are not advanced enough to work precisely, which leads to rework.

<u>Process</u>

Regarding the process, different causes are having impact on the lead time:

- The structure worker first needs to file the structure of the galley before he can start with assembly. At different workstations, workers are working on the sides of the panels, for example at panel preparation or bonding. So several times in the process, ZGEU loses setup times to edit the sides of the structure, which increases the lead time.
- The systems worker makes semi-finished products for the systems. The systems worker cannot start assembling the parts before he made the semi-finished products. We would expect that the workers of subassembly makes these semi-finished products and delivers them to FA, especially because subassembly has a shorter processing time. This means there is not an optimal allocation of the activities which causes a longer lead time.
- There are a lot of unnecessary repeated handlings. An underlying cause is that materials do not fit directly. The worker first files the parts to make them fit. This means that he puts the part on the structure, gets it off, files it and puts it back on the structure. This sometimes repeats several time for one part causing an increased lead time.
- Hardening of the glue takes a lot of time, it takes 24 hours before the worker can proceed with that part of the galley.
- Process steps are not standardised. A worker decides his own sequence of assembly of a galley. Because of the variable sequence it is not possible to work in two shifts like other processes. The two employees who start at a project need to stay with that specific project, because they are the only ones who know what is already done and what remains to be done. It also causes extra delay when a worker is absent and another employee needs to take over the work of the absent employee. Because it is not known in which sequence he worked the employee who takes over, first needs to spend time to find out what is done and what is not. After this, he continuous according to his own sequence and when the absent worker is back this process repeats itself. This means ZGEU loses time twice.

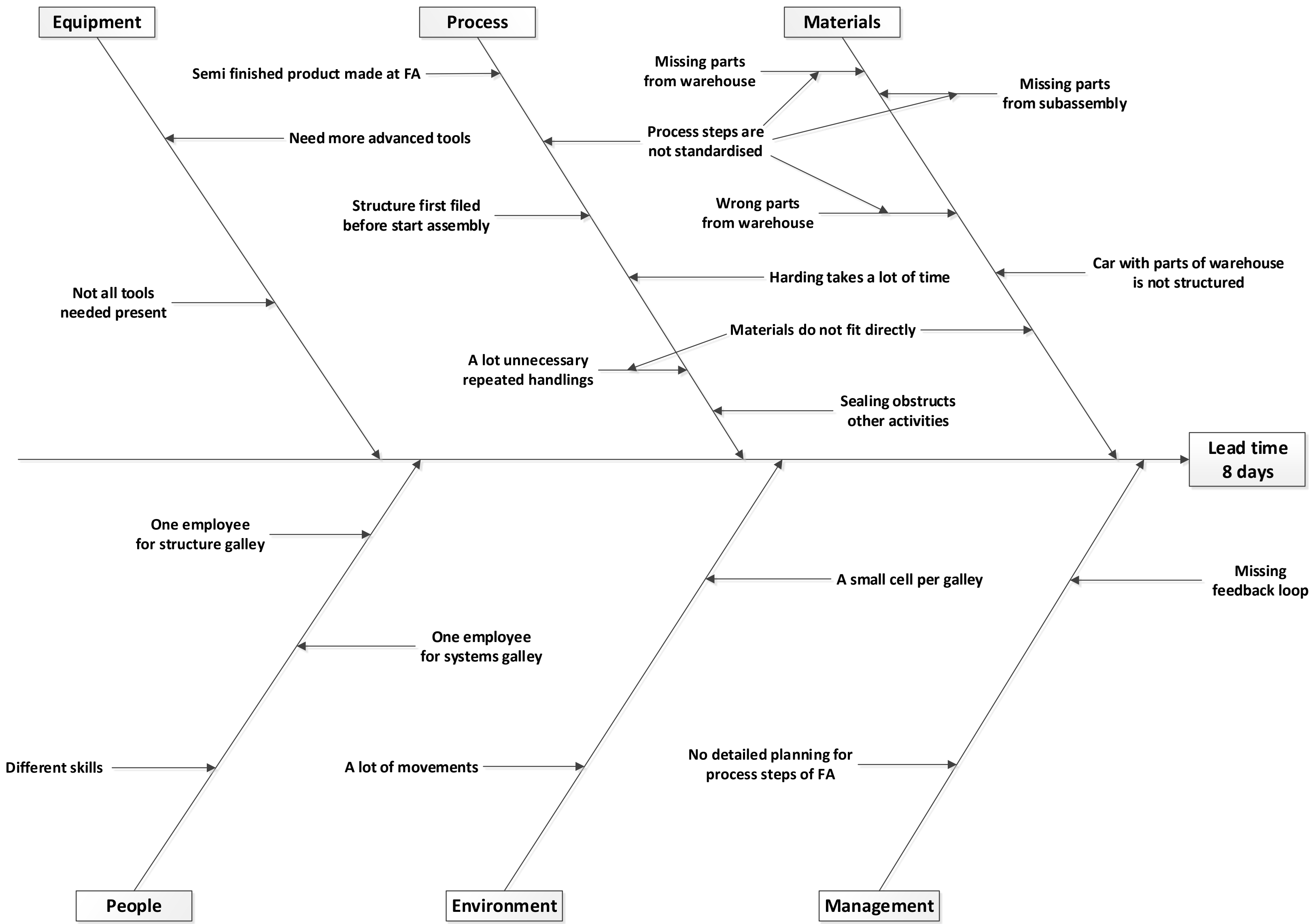


Figure 12: Causes lead time of FA

- Sealing obstructs other activities. Another worker specialised in sealing does all the sealing. The sealing worker obstructs the two other workers, because he blocks the galley. This leads to unnecessary waiting times for the structure and systems workers.

Materials

Activities around the materials are leading to a longer lead time:

- Missing parts on the car of the warehouse at the cell. This means that the worker has to wait for the missing parts before he can continue. An underlying cause can be that process steps are not standardised. The warehouse now needs to deliver all parts for FA at once (for the total eight days). For example, if the warehouse misses one part but it can deliver the part on the fourth day, it depends on the worker's sequence if the worker loses time for searching the part. Another underlying cause can be the way of order picking.
- Wrong parts on the car of the warehouse. Wrong parts are parts that are defect or wrongly picked at the warehouse. The worker needs to wait until the warehouse delivers a new or the right part. An underlying cause for the wrong picked parts can be that the process steps are not standardised. The warehouse needs to pick a lot of parts at once, which increases the chance of mistakes. Another underlying cause can be the way of order picking again.
- FA misses parts of subassembly. There are missing parts on the car by the cell, but these parts should be delivered by the process subassembly. This has the same effect as the first cause, 'the worker needs to wait for the missing parts before he can continue'. Again the underlying cause for this cause can be that the process steps are not standardised, because of the same reasoning as of 'missing parts on the car of the warehouse'.
- Materials do not fit directly on the structure of the galley. The worker often needs to file the parts and try again whether it fits. If the delivered parts fit directly the lead time can be shorter, because the worker then does not have to fit the parts several times.
- The warehouse delivers the materials on a car, which is not structured well for the workers of FA. The workers are searching for parts on the car which is an unnecessary waste of time and can cause damaged parts.

People

There is one worker specialised in assembling parts on the structure of the galley and one worker is specialised in assembling the systems on the galley. This means that each worker has different skills. But even between the workers with the same task there is a difference in skills. This influences how the worker assembles the galley. This makes the process of FA uncontrollable. The quality differs between employees, each employee makes different mistakes because of their different methods to assemble a galley. Because of the limited sharing of experience between the workers, they keep making the same mistakes, while it is quite possible that another employee has a solution for it. New employees learn the method of their senior with the same mistakes. Repairing of these mistakes at the inspection workstation leads to an unnecessary long lead time. Besides this, the speed also differs between employees depending on the skills of the employees but also on the sequence of assembly, which employees determine themselves. A not optimal sequence causes time losses, because it increases the needed time to produce a galley.

Environment
For each galley there is a small area to assemble the galley, a 'cell'. The movement space is tight around the galley, which can cause a longer lead time. Further, a lot of movements takes place around the cell, for example passing workers or galleys, which can distract the worker.

Management
The management aspect gives two causes:

- There is no feedback loop. The worker repairs the mistakes on the galley made by earlier processes, but the worker does not inform the other processes about the repair. This means that previous processes are not aware of the mistakes and therefore they cannot improve their processes which causes that the mistakes keep appearing. The employees of FA are losing time by repairing mistakes of previous processes which unnecessarily leads to a longer lead time. The worker does not inform the other processes, because there is no procedure to give feedback to other processes.
- There is no detailed planning for the process steps within FA. A detailed planning makes the process of FA more manageable. For example, with a detailed planning the suppliers of FA can better plan their activities to the planning of FA, which leads to less mistakes into the process of delivering parts. This helps to decrease the waiting time for parts at FA and therefore the lead time of FA. Also, without a detailed planning it is not visible during the process if a project gets delayed or not. Because this is only known at the end, FA cannot adjust recourses to minimise the delay.

4.2 Quantification of causes

This section determines the bottleneck of FA. The bottleneck is the cause that has the most impact on the lead time, so the cause which takes the most time. Unfortunately, it is not possible to quantify all causes in terms of time and ZGEU does not have data of the causes that are quantifiable in time. Therefore, we choose to make a score list for the causes and let the employees of FA estimate the time they lose because of a cause.

The score list works as follows. Each respondent has 100 points which he can divide over the causes, not every cause has to have points. The cause with the highest score is the main reason that the process takes longer than necessary. This is the constant sum method (Smith & Albaum, 2005). We choose this method because of its simplicity. The instruction to fill out the score list is easy and understandable for everyone, it does not take much time to fill it out, it is easy to distribute within the organisation and the method does not force the employee to select one main cause. This is important because two causes can have the same effect on the lead time. Further, this method gives insight into the relevance of the causes, the importance a respondent gives to a cause compared to the other causes. Employees of FA, members of the ME team, ME team manager, SA manager and the director of Operations have, independently from each other, filled out the score list. In total we have 19 respondents. We have asked the employees to fill the score list for the final assembly of a G1 galley. Table 3 gives the results of this score list. The causes in yellow are the main causes according to the employees of the Operations department: 'missing parts on the car from warehouse', 'wrong parts on the car from warehouse' and 'materials do not fit directly'. Appendix E gives the scores per respondent. Noticeable is that the ME team manager and the director of Operations both do not assign any points to the main causes. The ME team manager thinks 'process steps are not standardised' is the main cause. The director of Operations marks four main causes: 'missing parts from subassembly', 'car with parts of warehouse is not structured', 'a lot of movements' and 'cannot proceed because of sealing'.

We also have asked the employees of FA to estimate the time they need for each cause that is quantifiable in time. Appendix E gives the estimated times of each respondent. Table 3 summarises this, and gives the average and standard deviation per stream of FA. Some cells are empty because these causes are not quantifiable in time or do not have influence on the process of that stream.

Table 3: Ranking of the causes

Causes					
Cause	**Score (%)**	**Time (hours)**			
	Employees FA	**Structure assembly**		**Systems assembly**	
		Average	**STDV**	**Average**	**STDV**
Missing parts on the car from warehouse	25.0%	7.0	1.41	4.0	2.00
Wrong parts on the car from warehouse	18.5%	4.2	0.69	2.8	0.69
Materials do not fit directly	17.2%	3.8	1.07	2.8	0.69
Missing parts from subassembly	12.7%	7.0	1.41	4.7	1.49
Car with parts of warehouse is not structured	5.3%				
A small cell per galley	3.6%				
Process steps are not standardised	2.9%				
Missing feedback loop	2.8%				
Structure first filed before start assembly: better prepared for bonding structure	2.1%	6.3	3.20		
Cannot proceed because of sealing	1.8%				
No detailed planning for process steps of FA	1.7%				
One employee for systems galley	1.4%				
A lot of movements	1.3%				
Harding takes a lot of time	1.1%				
One employee for structure galley	0.8%				
A lot unnecessary repeated handlings	0.5%				
Semi-finished products made at FA	0.4%			6.6	1.99
Need more advanced tools	0.3%				
Not all tools are present	0.3%	2.3	0.75	1.3	0.69
Different skills	0.2%				

The estimated times between structure assembly and systems assembly are quite different as can be seen in Table 3. We conclude that structure assembly loses more time on the causes than systems assembly. The wasted time for missing parts, wrong parts from warehouse and subassembly is less at systems assembly. This is because the number of different parts for different types of G1s at systems assembly is less compared to structure assembly, which causes a lower chance to make mistakes for the workers at systems assembly.

When we only look at the time estimation for structure assembly, the two main causes are 'missing parts on the car from warehouse' and 'missing parts from subassembly'. For systems assembly the two main causes are 'semi-finished products made at FA' and 'missing parts from subassembly'. We have marked these causes blue in Table 3. Remarkable is that the time estimation gives that the cause 'semi-finished products made at FA' costs 6.6 hours. This has a large impact on the lead time for systems assembly, but from the score list this cause just received 0.4% of the total points. The explanation for this is that this activity is standard in the current FA process step, so the employees see this as a necessary process step. Before we continue we also notice that at structure assembly the cause ‘structure first filed before start assembly’ has a high standard deviation. This is because the time of this process steps depends heavily on the preparation of the steps before the FA. Currently, this cause is also seen as a standard process step of FA.

We decide to focus on the main three causes:

1. missing parts on the car from warehouse;
2. wrong parts on the car from warehouse;
3. materials do not fit directly.

We exclude the cause ‘materials do not fit directly’ because another intern is focussing on the possibilities of machines in the production process. Currently almost everything is made by hand, which leads to different deviations per galley. The different deviations are the reasons why materials do not fit directly on a galley and need to be filed to make it fit. The remaining two causes together cause a total waste time of approximately 11 hours for structure assembly and 7 hours for systems assembly, based on the average estimated time by the employees of FA. Systems assembly is always finished before structure assembly, so ZGEU can gain more than a reduction of 7 hours by eliminating the causes ‘missing parts on the car from warehouse’ and ‘wrong parts on the car from warehouse’.

4.3 Root cause of ‘missing and wrong parts on the car from warehouse’

First let us look to the process of ordering parts, receiving them in the warehouse and order picking of the parts. Procurement retrieves information from the ERP system about which and how many parts it needs to order for a bulk of projects. For certain critical parts ZGEU retains a safety stock, but for most parts ZGEU purchases the exact amount from the ERP system because of space limitation in the warehouse. After the procurement department has ordered the parts, the warehouse receives the ordered parts a few days or weeks later, depending on the supplier. Approximately 20% of the incoming different parts go through the quality inspection. The warehouse stores the remaining 80% directly in the warehouse. The warehouse receives a planning from the planning department with the date the warehouse needs to start the order picking of project X for workstation Y. The planning contains a number of production orders. A production order is a batch of parts that need to be picked. These production orders are based on the BOM. An order picking for a G1 project for the workstation FA contains approximately 10 production orders and 300 parts. Figure 13 gives a summary of the process of ordering parts, receiving them in the warehouse and order picking the parts.

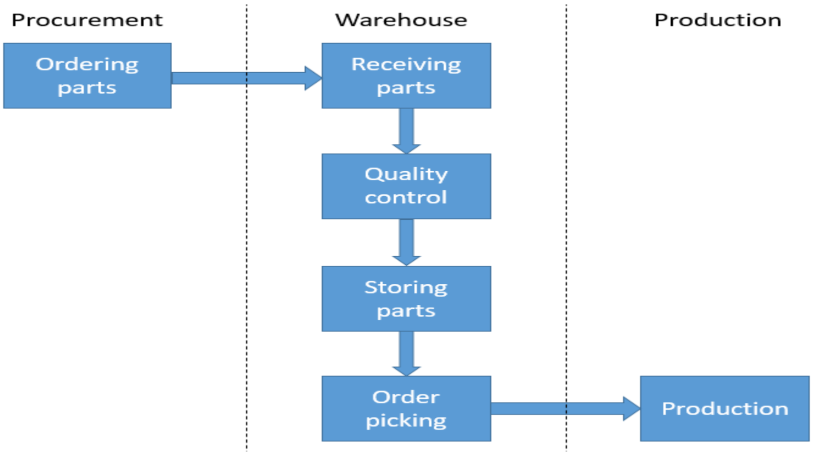


Figure 13: Order process

Now the process is clear, we can analyse the underlying causes of missing and wrong parts on the car of the warehouse. During the order picking the employees of the warehouse are the first ones who can notice parts are missing. If a part is missing or damaged they report the part on the backorder list of that order pick. The employees of the warehouse attach this list on the car, such that the shop floor employees know which parts are missing on the car. Further, the employees of the warehouse notify the procurement department to reorder the parts. Reasons why the parts are missing during the order picking are:

- A mistake in the amount of parts needed in the ERP system, therefore procurement ordered too little. According to the director of Purchasing and logistics this is minimal.
- Parts are scrapped, because they did not fulfil the requirements at the incoming quality inspection. On yearly basis this is 2% of the parts which get inspected.
- Suppliers did not deliver the correct number of parts, or they delivered too late.

The warehouse delivers the parts on the backorder list to production as soon as it receives the parts in the warehouse. The first two causes can be excluded of this research because they have limited impact on 'missing and wrong parts on the car of warehouse'. The third cause can be split in two streams of suppliers, external and internal suppliers. Internal suppliers are suppliers within the Zodiac Group. The external suppliers have a percentage of 96% on time delivery (OTD). But the internal suppliers have a poor OTD for metal parts (73%). Because the Zodiac Group obligates ZGEU to buy 50% of their budget at internal suppliers, ZGEU cannot decide to buy elsewhere. One solution ZGEU has established is its own metal shop, they make about 75% of all parts which are not delivered. But the workload is increasing, therefore ZGEU is investigating this problem. Because ZGEU is looking into this we exclude this cause from this research. But these reasons only explain why there are parts missing during the order picking. Often employees of the shop floor miss and have wrong parts on the car from the warehouse, that are not on the backorder list. Therefore, we are going to analyse the missing and wrong parts that are not on the backorder list further.

When employees notice a part is missing, or they have the wrong part on the car of the warehouse, they must report this (if the part is not on the backorder list). The warehouse saves the reports of missing and wrong parts not mentioned on the backorder list in a Production Quality Control (PQC) file. In this PQC file the reason why the part is missing or wrong and how long it took to solve it for production is described. Below, we describe the different possible reasons:

- Missing parts are named as 'lost parts SA' in PQC file, parts that employees of FA miss on the car of the warehouse and are not on the backorder list.
- Wrong parts:
    - Claim – parts that are not produced according to the drawings by the supplier. These are parts that did not go through the incoming quality control. When an employee reports this, the whole batch stored in the warehouse gets checked.
    - Rework metal shop – parts that are damaged but can be reworked by the employees of the metal shop of ZGEU. This is done for parts that are not available in the warehouse anymore and have a long delivery time.
    - Rework supplier – parts that are damaged but can be reworked by the supplier. This is done for parts that are not available in the warehouse anymore, have a long delivery time and the supplier is located nearby.
    - Scrap SA – parts that are damaged and cannot be used anymore.
- WHS (warehouse) mistake, parts that are wrongly or not order picked in the warehouse. Because this is a combination of missing and wrong parts we separate this reason from the two reasons above.

From August to November 2015 the warehouse has retrieved 908 reports from the employees of FA for the galley type G1 about missing and wrong parts. Table 4 gives the percentage of the 908 reports per reason, the average time to solve it and the impact (ZGEU, 2015d).

Table 4: Data PQC file

Reason	Percentage	Average time (hours)	Impact
Missing parts / Lost parts SA	48.9%	3.8	1.86
Wrong parts	49.8%		
Claim	*9.5%*	*19.7*	*1.87*
Rework Supplier	*1.1%*	*27.0*	*0.3*
Rework Metal shop	*2.5%*	*5.0*	*0.13*
Scrap SA	*36.7%*	*2.8*	*1.03*
WHS mistake	1.3%	6.7	0.09

Because we are not able to divide WHS mistakes into missing and wrong, we conclude from Table 4 that total missing and total wrong parts is divided approximately 50-50. We notice that 'Scrap SA' is the most common reason for wrong parts which takes on average 2.8 hours to solve, but 'claim' has most impact. The claims are a part of the research ZGEU is doing on the internal suppliers. Because ZGEU is already investigating the claims we exclude the claims from this research.

To determine the root cause(s) of the causes missing and wrong parts on the car of warehouse we have done a research to the underlying causes. Figure 14 gives an overview of all the underlying causes and their interaction with each other. We have obtained the causes by analysing the data of the PQC file and a brainstorm session with the Warehouse manager and the director of Purchasing and logistics. Below the figure we explain the causes and their interactions.

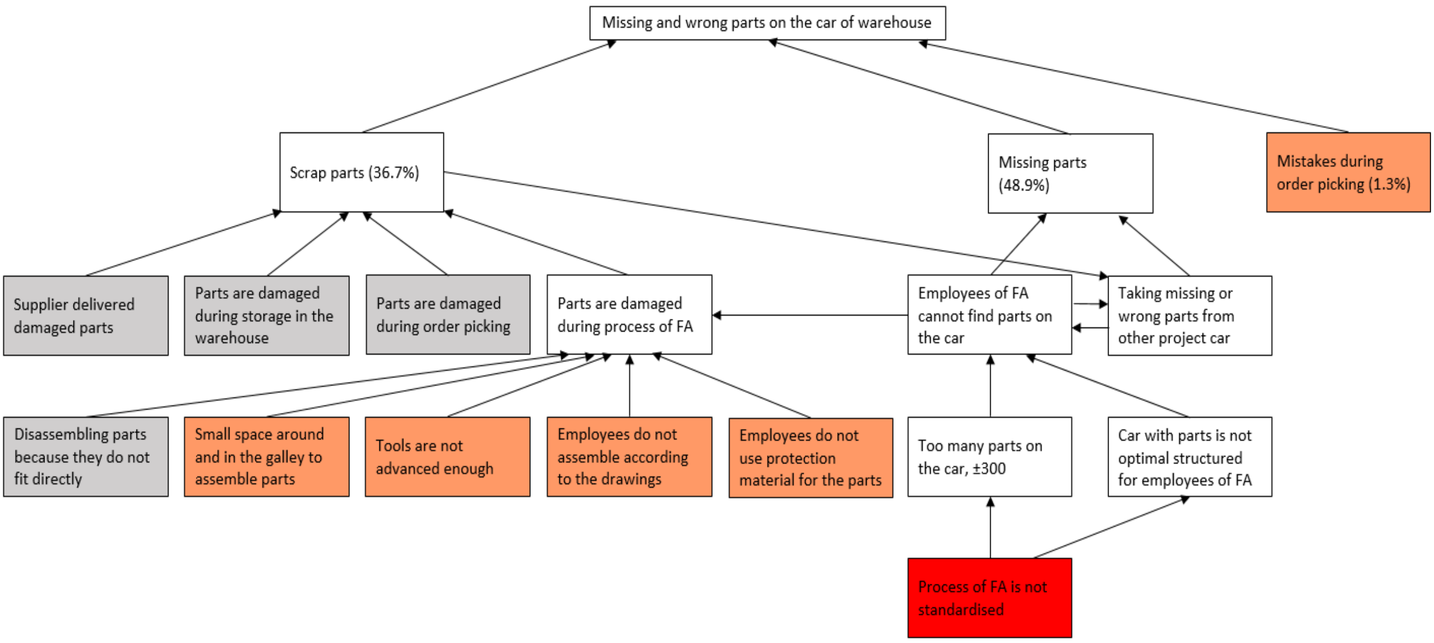


Figure 14: Underlying causes and their interactions

From Figure 14 we see that missing and wrong parts on the car of the warehouse has three underlying causes. From the data of the PQC file we have determined that defect parts is the most common reason for wrong parts (36.7%), that there are many missing parts (48.9%), and that the warehouse makes mistakes during the order picking is minimal (1.3%).

According to the Warehouse manager and the director of Purchasing and logistics, there are two main reasons why parts are missing. The first reason is that an employee cannot find a part between the approximately 300 other parts on the car of the warehouse. The employee then reports it missing. In 11.2%[2] of these reports the reported missing part is left over when the galley is finished and returns to the warehouse. This means that in most cases the part is definitely not on the car. The second reason is that if a part is missing or wrong, an employee takes the same part of another car which is meant for a different project and therefore that project will miss a part. If the employee of that project also takes a part from another project car that project is also missing a part, so it creates a domino effect of problems at FA. Employees do this mostly because of time pressure, according to the Warehouse manager and the production supervisor.

The above two reasons are also underlying reasons from each other. An employee will find the part on his car if no one took it, and an employee will not take a part of another car if he can find the part on his car. A second underlying cause of 'taking missing or wrong parts from another project car' is 'scrap parts', an employee will not take a part from another car if his part is not defect.

According to the warehouse manager and the director of Purchasing and logistics, scrap parts appear because of the following reasons:

- supplier delivered damaged parts;
- parts are damaged during storage in the warehouse;
- parts are damaged during the order picking;
- parts are damaged during the assembly.

Therefore, the above reasons are the underlying causes of 'scrap parts'. Three of these are marked grey in Figure 14. They are not in the scope of this project because ZGEU has already investigated these causes and reduced the percentage of appearance last year. The remaining cause is 'parts are damaged during the process of FA'. According to the Warehouse manager, production supervisor, team leaders of FA and noticed during the two monitoring moments by ourselves, there are different underlying reasons which cause damages during the assembly process. The largest one is moving parts on the car because the employee cannot find the right part. By moving them they damage parts, according to the production supervisor this causes 50% of the parts that get damaged during the process of FA. Therefore, the cause 'employees of FA cannot find parts on the car' is an underlying cause of 'parts are damaged during the process of FA'. Other underlying reasons why parts get damaged during the process of FA are:

- damaged during the disassembly of parts because the parts do not fit directly (5%);
- employees damage parts because of the small space around and in the galley to assemble parts (5%);
- tools are not advanced enough (10%);
- employees do not assemble according to the drawings (20%);
- employees do not use protection material for the parts (10%).

Appendix F gives further explanation and examples of the above causes.

[2] The Warehouse manager estimates that 35% of the parts that return to the warehouse are reported missing by the employees. In the period of September till November there were 315 reports about a missing part and 101 returned to the warehouse. Thus, ((0.35*101)/315*100%=) 11.2% of the missing parts are parts that were on the car but the employee did not find them and has reported them missing.

We have analysed the cause ‘employees of FA cannot find parts on the car’ further, because this cause has the largest impact. According to the Warehouse manager the large number of parts on the galley is an underlying cause why employees cannot find the right part on the car. Another underlying cause is that the car is not optimal structured for the employees of FA. According to the employees of FA the car of warehouse is not structured, but according to the Warehouse manager the car is structured. We have looked at some cars that were ready to be send to production, the cars were structured by materials of the parts. But because the employees of FA say that the car is not structured, we conclude that the car is not optimal structured for the employees of FA.

Both the causes ‘too many parts on the car’ and ‘car is not optimal structured for the employees of FA’ have the same underlying cause ‘the process of FA is not standardised’. It is an underlying reason for the cause ‘too many parts on the car’, because the warehouse cannot reduce the number of parts on the car. The warehouse cannot reduce it because each employee decides his own order of assembly and therefore all parts must be present at the start of the FA. The other cause is quite remarkable, because the warehouse department has done a research to find the best possible solution to structure the car. The outcome of their research was that the best solution is to structure the car to material of the parts. But with the current best structure of the car the employees of FA still cannot find the parts easily on the car. The question that arises is why is it not possible to structure the car such that the employees of FA can find the parts the quickest. According to Medbo (2003, p.267) the ideal structure to gain the lowest searching time for parts is “that the components are displayed next to the operator in the correct assembly sequence”. Faccio (2014) gives different good parts-feeding policies for just-in-time (JIT) assembly system like FA at ZGEU, which are all based on the set assembly sequence. Thus, there are different policies to structure the car other than to the material of the parts. But in the current situation the process of FA does not have a fixed sequence. Therefore, for the current situation structuring the car with parts to materials is the best solution. To gain another better structure for the car for the employees of FA the process of FA needs to be standardised. Thus, the cause ‘the process of FA is not standardised’ is an underlying reason of ‘the car is not optimal structured for the employees of FA’.

In Figure 14 the causes without underlying reasons are marked red. The brighter red are causes that do not have much influence on the lead time of FA. The dark red give the root cause of missing and wrong parts on the car of warehouse. This is the cause ‘the process of FA is not standardised’. From the time estimation made by the employee of FA in Section 4.2 we state that by standardising the process steps of FA, ZGEU can definitely reduce the lead time with at least 7 hours. The 7 hours is the minimum of the time reduction possible by structure assembly and the time reduction possible by systems assembly. The possible time reduction is the sum of the time estimation of the causes ‘missing parts on the car from warehouse’ and ‘wrong parts on the car from warehouse’ made in Section 4.2. Unfortunately we cannot further specify the time reduction from the other underlying causes. Therefore, a time reduction of 7 hours by solving the root cause is the most accurate time reduction we can give.

4.4 Reassess stakeholders

Because our focus is now narrowed to making a standard for the FA process, the outcome of the stakeholder analysis changes. Because of the importance that the stakeholders accept the needed changes to implement the standard in this case, we reassess the outcome of the stakeholder analysis of Section 3.2. The level of interest and power for the employees of planning both increase, because it will be possible to plan for shorter time periods. The employees must know the selected standard sequence. Their power increases, because if they do not plan it well the implementation will fail. This means the employees of planning fall within the quadrant ‘consult’, so we must communicate more frequently and ask for feedback. The employees of subassembly and warehouse will get influenced if the way of delivering parts to FA changes. Because we only focus on making a standard, the level of interest of the employees of subassembly and warehouse will be lower than first for this project. This does not change the way of communication. The rest of the stakeholder analysis stays the same.

4.5 Conclusion

The research to detect all causes which are affecting the lead time exists of the two monitoring moments of FA, a brainstorm session with the ME team, an interview with the director of Operations and input from FA employees. The causes and their underlying connections are given in Figure 12 in Section 4.1. With the survey results under the employees of Operations we have ranked the causes. The main causes are the following three:

1. missing parts on the car from warehouse;
2. wrong parts on the car from warehouse;
3. materials do not fit directly.

We exclude cause three because another intern does research into this. Thus, the bottleneck of FA is ‘missing parts on the car from warehouse’. But because the second main cause is linked closely we have researched these two bottlenecks together.

The root cause of ‘missing and wrong parts on the car from warehouse’ is that the process of FA is not standardised. Therefore, it is not possible to structure the car of the warehouse optimal for the employees and it is not possible to deliver smaller quantities of parts. Because of those reasons employees are searching for parts on the car by moving them. This causes damages on the parts and the search for parts costs time. It happens that because parts are damaged or cannot be found, employees take the same part of another project car because of time pressure. Therefore another project will miss a part, causing a domino effect of problems at FA.

We narrow the research to the root cause of the long lead time of FA ‘the process of FA is not standardised’. To solve the root cause we need to standardise the sequence of activities of the process of FA. To do this we need to find a method that can sequence activities and copes with specific constraints of the process of FA.

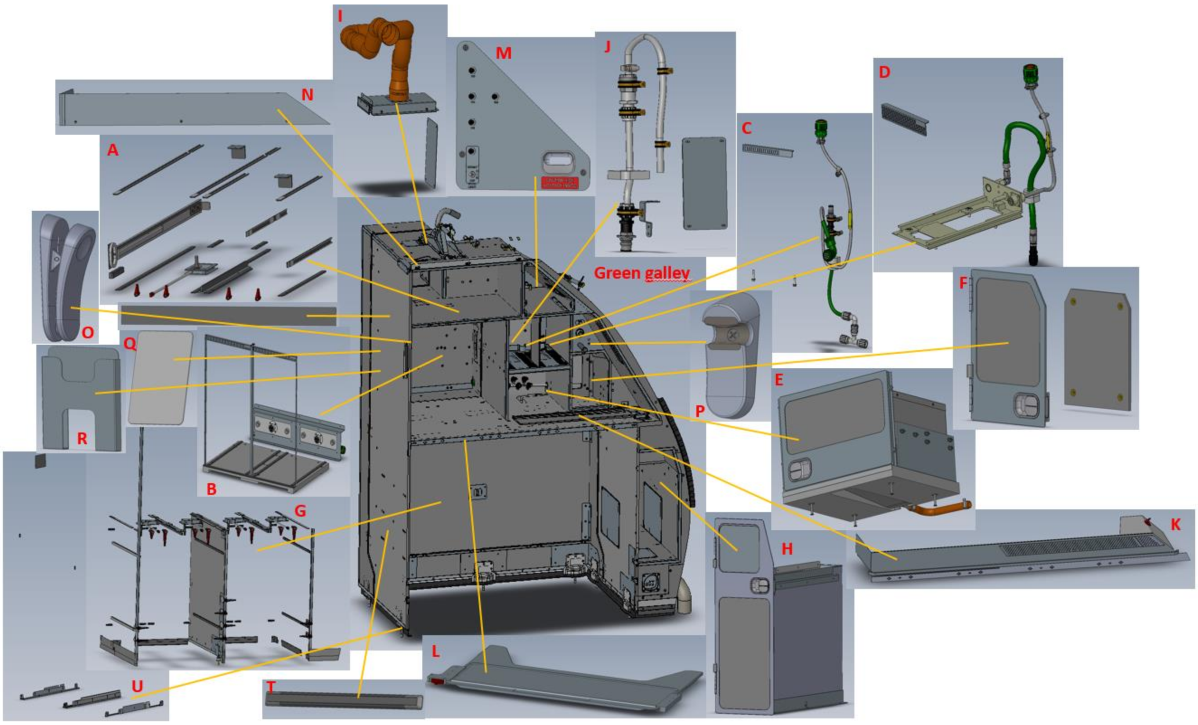
5. Standardising the process of FA

This chapter gives a solution on how to standardise the process of FA. Section one describes the problem we need to solve. The second section gives an overview of related literature. In the third section we give a model for Excel to determine a near-optimal sequence of activities, and the near-optimal sequence for ZGEU. Section four validates if the model represents the system of FA correctly. Section five summarises the possible gains for ZGEU when it implements the solution. And the last section summarises this chapter.

5.1 Problem description

The root cause of the long lead time at FA is that the process is not standardised. Thus, we need to standardise the sequence of activities of the process of FA. It is important to select a sequence that minimises the lead time. We solve this issue for the G1 601850-001801, because it is the most advanced one of all galley G1 types. But it is important that the approach can be extended for the other galley types, like the G5. Extending the approach for the other galley types does not change the essence of the problem, but the size of the problem changes because the number of activities increases for other galley types. We first describe the problem at ZGEU.

The goal of ZGEU is to minimise the lead time of the FA process. The process exist of different activities, each activity has a specific processing time independent of which employee it is assigned to. The number of activities depends on the galley type. In Section 2.3 we have split the process of FA in 14 different process steps to describe the process. For a better scheduling sequence we determine more detailed activities instead of using the general process steps of Section 2.3. We do this because the process steps of Section 2.3 present a high level of steps to give a global overview of the process. Because the process of FA does not have a fixed sequence, some employees start with installation of extrusions and profiles, but do not finish them all, then they install the retainers and afterwards install the remaining extrusions and profiles. Therefore, we want to include the possibility to generate sequences like above, by combining the process steps and the kits of a galley. This means an activity is one of the process steps for one kit. Figure 15 gives an overview of all kits of the galley G1 601850-001801, with kit number and description. The galley in the middle is the Green galley, the base for all G1 type galleys, which the plant of ZGEU in Tunisia makes. Appendix G gives an overview of which process steps a kit contains and it gives illustrations of the parts that need to be assembled per activity.



A	263101-11, Container	H	263113-41, Waste bin	O	263120-11, Paperclip
B	263103-221, Oven kits	I	263115-11, Air intrusion system	P	263120-21, Bottle opener
C	263105-61, Beverage maker	J	263116-41, No steam oven provision	Q	263120-61, Mirror
D	263106-21, Beverage maker	K	263117-31, Work deck	R	263120-91, Document holder
E	263107-31, Ice drawer	L	263119-11, Pull out table	S	263121-111, Bumper
F	263108-81, Misc stowage	M	608850-1121, Electrical panel	T	691850-1811, Placard
G	263109-71, Trolley installation	N	263118-111, Pallet installation	U	691850-1811, Customization kit

Figure 15: Kits of the G1 galley 601850-001801

The kits N, O, P, Q, R, S and T are customer specific and need to be assembled at the end of the process of FA, after the entire decoration is done. Assembling these kits takes approximately 30 minutes in total. Therefore, we do not take these kits into account to determine a standard sequence for ZGEU.

The activities have precedence relations among each other, activity i cannot be started until activity j is finished. Because ZGEU has knowledge about sequences within the process of FA, we have asked the team leaders and the production supervisor to answer the following two questions for each activity to determine the order of execution (Laperrière, 1992):

Q1 – Which activities must be done before activity X can be started?

Q2 – Which activities must be left undone such that activity X can be done?

Asking these two questions reduces the total number of questions and makes it easier to build a precedence relations diagram of the activities. This is because we group the activities in front of and after activity X. Therefore, for the next activity we only have to ask if the activities in the same group are in front of, or after the activity. This reduces the group for the next activity to be examined. By grouping the activities we only need to examine the relation of the current examined activity X with the activities in the group of activity X to determine the precedence relations, instead of all activities individually.

Figure 16 gives the precedence relations between the activities. The first node is a finished Green galley. The letter of the activity stands for the kit and the number for the process step. The arrow states that the activity in front of the arrow must be finished before the activity after the arrow can start. To give an example, activity B11 (assembly of electrical installation of oven kits) cannot start before activities B9 (making subpart of over kits) and B2 (assembly of extrusions/profiles of oven kits) are finished.

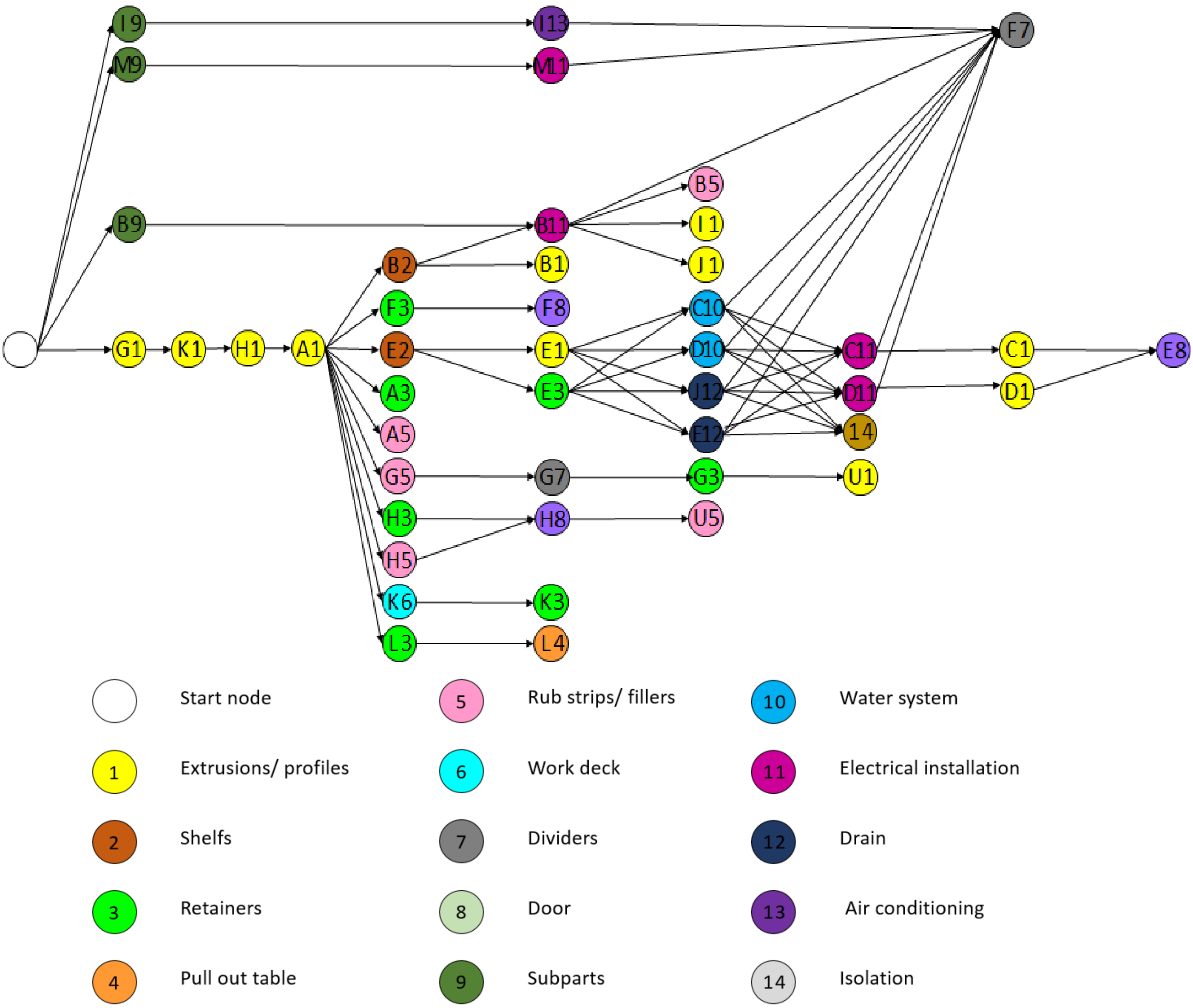


Figure 16: All activities and their relations

The process step isolation (14) is not linked to a kit. This activity can be done when all water and drain systems (C10, D10, J12 and E12) are installed.

Also, some activities cannot be done at the same time, otherwise the employees block each other. The activities of the same kit cannot be done in parallel, as well as the activities of the following kits:

- A-B-G-L (Container - Oven kits - Trolley installation - Pull out table);
- C-D-E-F-J-K (Beverage makers - Ice drawer - Misc stowage - No steam oven provision - Work deck);
- G-U (Trolley installation - Customization kit).

Appendix H gives the processing time of each activity. These processing times are estimated by the team leaders of FA and the production supervisor. The total processing times of a process step, which we have determined in Section 2.3, is divided over the activities to determine the process time of one activity. For example, installing all shelfs of the galley takes 1.4 hours, by estimation activity B2 (shelf of oven kit) takes 48 minutes and E2 (shelf of ice drawer) takes 36 minutes.

Another factor within the scheduling problem of ZGEU are the tool change times. This is the time needed to change the tools needed for an activity. For example, for installation of the extrusions/profiles of the trolley installation the employee needs a glue pistol. If the next activity is installation of the retainers of the trolley installation the employee needs a drill. The time to change from glue pistol to drill is the tool change time. The tool change time depends on the sequence of the activities. If after the installation of extrusions/profiles the activity install divider of trolley installation follows, there is no tool change necessary which means no tool change time. Further, we assume that the tool change time is independent of the prior kit. Thus, the tool change time from activity B11 to I1 is equal to the tool change time from activity B11 to J1. We also assume that the tool change times are symmetric. The team leaders and the production supervisor have agreed with the above assumptions and have estimated the tool change times, see Appendix I.

Further, ZGEU fixes the number of available employees for one galley. An employee works one 8 hour work shift a day. With the director of Operations we have chosen to assume that both employees can perform all activities, to increase the flexibility of resources. Also, we assume that all parts are available. This is an important assumption because to gain the result, when we solve this scheduling problem, in practice the supply of parts must be perfect. Currently, ZGEU has problems with the supply of parts, especially the metal parts. Thus, to gain the results of this research in practice ZGEU needs to improve the supply of parts.

5.2 Literature study

Standardisation

According to Symbol business improvement (2014, p.24) “standardised tasks and processes are the foundation for continuous improvement and employee empowerment”. Standard operating procedures are important because “it is impossible to improve a process until it is stabilised and standardised” (Symbol business improvement, 2014, p.24), like there is no improvement possible for the structure of the car of warehouse without standardising the process of FA. But what is standardisation? Standards are, according to the ISO/IEC guide (as cited in Muenstermann and Weitzel, 2008, p.4) “documents, established by consensus and approved by a recognised body, that provides, for common and repeated use, rules, guidelines or characteristics for activities or their results, aimed at the achievement of the optimum degree of order in a given context”. De Vries (as cited in Muenstermann and Weitzel, 2008, p.4) gives the following definition:

> "standardisation is the activity of establishing and recording a limited set of solutions to actual or potential matching problems directed at benefits for the party or parties involved balancing their needs and intending and expecting that these solutions will be repeatedly or continuously used during a certain period by a substantial number of parties for whom they are meant".

Muenstermann and Weitzel (2008) summarise the benefits of process standardisation, see Table 5.

Table 5: Benefits of process standardisation (Muenstermann and Weitzel, 2008, p.5)

Benefit	Description
Improved process performance	• Reduced end to end time • Reduced process costs • Improved process quality • Increased performance measurability
Enhanced readiness	• To outsourcing business processes • To merge with or buy other companies • To react to market and external change and trends by increased process flexibility
Enhanced ability to react to regulatory changes	Founded in the enhanced readiness to react to external changes companies having standardised processes can easily react to regulatory changes.
Enhanced technical interchangeability	Standardising processes, firstly, step by step detaches the processes from supporting IT and thereby, secondly, enables the use of standard hard- and software solutions.
Improved customer confidence	The more standardised processes are, the lower the probability for process driven mistakes will be. Consequently the overall quality and thereby customer confidence improves.

A scheduling problem

Within this research we need to standardise the sequence of activities of the process of FA. According to Homem de Mello and Sanderson (1991) the sequence of assembling has a large effect on the efficiency of the total assembly process. Therefore it is important to select a sequence that is optimal for ZGEU. So to make a good standard we need to solve a scheduling problem. The outcome of a scheduling problem is a "process plan for a specific design or part under the constraints of available resources on the shop floor and machining strategies" (Xu, Yuan & Li, 2008, p.162).

A scheduling problem is hard to solve, because the number of possible sequences is a factorial function of the number of components (Dini, Failli, Lazzerini & Marcelloni, 1999; Nazarian, Ko & Wang, 2010). This gives a huge amount of possible sequences, which all need to be analysed to select the best sequence. These kinds of problems are also called NP-hard (nondeterministic polynomial time problem) because they cannot be solved in polynomial time (Schutten, n.d.). Because the scheduling problem is NP-hard, a good method to obtain a near optimal solution for it is to use a heuristic (Dini et al., 1991; Nazarian et al., 2010).

Currently, in most organisations, industrial engineers are creating the process plan. But because of the huge amount of possible sequences there is no guarantee that a good assembly sequence is overlooked. Therefore, by using a systematic procedure like a heuristic, the chance to overlook a sequence decreases and it will guarantee that only feasible sequences will be generated (Homem de Mello & Sanderson, 1991).

Criteria and constraints

To select a good heuristic that fits with the problem of ZGEU we need to look at which criteria and constraints apply for ZGEU. According to Jones, Wilson and Calton (1998) encountering all constraints into a single program is impractical and the constraints are company or product specific. For this reason and because the constraints narrow the solution space (Baldwin, Abell, Lui, de Fazio & Whitney, 1991), it is important to select the ones which are important for ZGEU. Jones et al. (1998) give an overview of all kinds of criteria and constraints for assembly systems. In Section 5.1 we have described the problem that needs to be solved at ZGEU, which makes that the following criteria and constraints are important to obtain a good process plan for ZGEU. The goal of this research is to reduce the lead time, therefore we want a heuristic that uses the criteria 'minimise completion time' mentioned by Jones et al. (1998). The heuristic also must handle tool change times (Jones et al., 1998; Kanai, Takahashi & Makino, 1996) that are sequence dependent, the precedence and parallel relations among the activities (Nazarian et al., 2010) and a resource constraint (limited number of employees available) (Jones et al., 1998).

Another criterion is that the heuristic must be programmable with Excel-macros. The manager of the planning department prefers this, such that it also is usable for ZGEU after this research.

Parallel machine scheduling problem

Thus, we have a scheduling problem with tool change times, which are sequence dependent, precedence and parallel constraints. We also want to minimise the completion time. With this knowledge we can specify what kind of scheduling problem applies for the problem of ZGEU. From literature two different kinds of problems can describe the scheduling problem at ZGEU.

The first one is the parallel machine scheduling problem.

> "A classical parallel machine problem can be stated as follows: a set of independent jobs to be processed on a number of available identical parallel machines. Each machine can be process only one job at a specific time, and each job can be processed on one machine" (Tavakkoli-Moghaddam et al., 2009, p.3224).

This problem is extendable with the constraints we have mentioned before. For ZGEU this problem can be described as follows: a set of independent activities which must be done by a number of available employees. Each employee can only do one activity at a time, and each activity can be processed by one employee.

The second problem type which can describe the scheduling problem at ZGEU, is the resource constrained multi-project scheduling problem (RCMPSP) (Mejía Delgadillo & Ramírez Palencia, 2012). The article gives the sequencing of a bus body assembly line as an example. The RCMPSP problem "consists of determining the start and completion time of all activities of all projects. The activities have predefined precedence relationships and share resources" (Mejía Delgadillo & Ramírez Palencia, 2012, p.432). For ZGEU this problem can be described as follows: the employees are the resources and we only have one project, the galley.

We choose to approach the scheduling problem of ZGEU as a parallel machine scheduling problem, because extensions of this problem consider tool change times that are sequence dependent (Behnamian, Zandieh & Fatemi Ghomi, 2009; Drießel & Moench, 2009; Tavakkoli-Moghaddam et al., 2009; Vallada & Ruiz, 2011). The RCMPSP method lacks this criterion.

We can model this problem the following way:
Objective: minimise lead time.
Parameters:

- processing time per activity i (p_i);
- precedence relations $\left(Y_{ij} \begin{cases} 1, if\ activity\ i\ must\ precede\ activity\ j \\ 0, otherwise \end{cases}\right)$;
- parallel relations $\left(Z_{ij} \begin{cases} 1, if\ activity\ i\ cannot\ be\ done\ in\ parallel\ with\ activity\ j \\ 0, otherwise \end{cases}, Z_{ij} = Z_{ji}\right)$;
- tool change times of activity i to j, which are sequence dependent (t_{ij});
- number of available employees (E);
- number of activities (N).

Restrictions:

- every activity must be assigned to one employee;
- every activity has one predecessor, except the first assigned activities;
- every activity has one successor, except the last assigned activities;
- precedence relations must be satisfied;
- parallel relations must be satisfied.

Decision variables:

- $X_{eij} = \begin{cases} 1, if\ activity\ i\ immediately\ precedes\ activity\ j\ and\ both\ are\ assigned\ to\ employee\ e \\ 0, otherwise \end{cases}$;
- $C_i = Completion\ time\ of\ job\ i;$
- $V_{ij} = \begin{cases} 1, if\ C_j > C_i \\ 0, otherwise \end{cases}$, auxiliary variable to determine which activity has largest completion time if they cannot be done in parallel;
- $C_{max} = Maximum\ completion\ time = lead\ time\ of\ FA.$

This gives the following optimization problem, based on the mixed integer programming of Vallada & Ruiz (2011):
$\text{Min}(C_{max})$
Subject to

$\sum_{e=1}^{E} \sum_{i=0, i \neq j}^{N} X_{eij} = 1 \qquad j = 1 \dots N$

Ensures that every activity is assigned to exactly one employee and has exactly one predecessor, use dummy jobs 0 as X_{e0j} for all e and all j. These dummy activities are necessary, because the first assigned activity of employee e also must have one predecessor according to the constraint. Therefore the first assigned activity has a dummy activity as predecessor. If we state the constraint smaller or equal to one and do not use dummy jobs, the model will not assign all activities.

$\sum_{e=1}^{E} \sum_{j=1, i \neq j}^{N} X_{eij} \leq 1 \qquad i = 1 \dots N$

Ensures that every activity i has maximum one successor. An activity can only be assigned to one employee and there is only one unique combination ij, so X_{eij} can at most be one. We do not need dummy jobs here, because the previous constraint makes sure all activities will get assigned.

$\sum_{j=1}^{N} X_{e0j} \leq 1 \qquad e = 1 \dots E$

Limits the number of successors of the dummy activities to a maximum of one by each employee.

$\sum_{h=0,h\neq i,h\neq j}^{N} X_{ehi} \geq X_{eij} \qquad i = 1 \dots N, j = 1 \dots N, e = 1 \dots E$

Controls that each activity is assigned to an employee and has one predecessor. If activity i and activity j are processed by employee e, a predecessor h must exist by same employee. Again we use the dummy activities 0.

$C_j + M\left(1 - \sum_{e=1}^{E} X_{eij}\right) \geq C_i + p_j + t_{ij} \qquad i = 0 \dots N, j = 1 \dots N, i \neq j$

Calculates the completion times. If activity j is assigned to employee e after activity i, its completion time C_j must be greater than the completion time of activity i plus processing time j plus tool change time from activity i to activity j. If $\sum_{e=1}^{E} X_{eij} = 0$, than the big constant M renders the constraint redundant.

$(C_j - C_i) * Y_{ij} \geq p_j * Y_{ij} \qquad i = 1 \dots N, j = 1 \dots N, i \neq j$

Ensures that the precedence constraints are satisfied (Tavakkoli-Moghaddam, Taheri, Bazzari, Izadi & Sassani, 2009). The time between the completion time of activity j and the completion time of activity i must be equal or larger than the processing time of activity j, if activity i must precede activity j.

(1) $Z_{ij}\left(-C_i + C_j\right) \leq M(1 - V_{ij}) \qquad i = 1 \dots N, j = 1 \dots N, i \neq j$

(2) $Z_{ij}(-C_j + C_i) \leq MV_{ij} \qquad i = 1 \dots N, j = 1 \dots N, i \neq j$

(3) $Z_{ij}\left(1 - V_{ij}\right)(-M) \leq \left(C_i - C_j - p_i\right) \qquad i = 1 \dots N, j = 1 \dots N, i \neq j$

The above three constraints ensure that the parallel constraints are satisfied, where M is a large number. If the completion time of activity i is larger than the completion of activity j (V_{ij}=1) then the time between the completion time of activity i and the completion time of activity j minus processing time of activity i must be equal or larger than zero (3). The model checks the above constraints for all combinations. For example it checks first i=1 and j=2 and later on i=2 and j=1. Therefore, if the completion time of activity j is larger than the completion of activity i (V_{ij}=0), we want the model continue the algorithm without changing the current variables the first time with i=1 and j=2. Thus, constraint (3) must be satisfied if V_{ij}=0. To do this we use (1-V_{ij}) in the last constraint. V_{ij} gets determined by constraints (1) and (2), by determining which activity has a larger completion time. Z_{ij} ensures that these constraints only apply for activities that cannot be done in parallel.

$C_i \geq 0 \qquad i = 1 \dots N$

Set completion time for all activities to non-negative.

$C_{max} \geq C_i \qquad i = 1 \dots N$

Calculates maximum completion time.

$X_{eij} \in \{0,1\}$ (binary variable)

$V_{ij} \in \{0,1\}$ (binary variable)

$i \neq j$ (activity i is not equal to activity j)

VNS heuristic

If we want to solve the above model with 2 employees and 45 activities, this will result in a large run time. This is because it than has 5986 decision variables in total and 24120 constraints, see appendix J for the calculations. Therefore, we choose to solve the problem with a heuristic. Heuristics can solve a NP-hard problem close to optimality (Schutten, n.d.). For the parallel machine scheduling problem there are different heuristics. Sevkli and Uysal (2009) compare the heuristics Variable Neighbourhood Search (VNS), Genetic Algorithm (GA) and Longest Processing Time (LPT). The VNS heuristic outperforms the other two, since it finds the optimal solution more often, its performance is quite stable and the VNS heuristic is very efficient for large sized problems since the execution time is very small (Drießel & Moench, 2009; Sevkli & Uysal, 2009). We have stated in Section 5.1 that the model must be extendible for the other galleys, this would increase the size of the problem, making the VNS heuristic even more suitable. To be sure that this heuristic comes with a near-optimal solution for the problem described in Section 5.1, we have tested the heuristic in Excel for a small problem with the optimal solution known. The VNS heuristic gives the optimal solution for the small problem 10 out of 10 times by 10 iterations. Thus, the VNS heuristic is a good heuristic to solve the scheduling problem of ZGEU.

"The VNS heuristic is one of the most recent metaheuristics used for problem solving in which a systematic change of neighbourhood within a local search is carried out" (Sevkli & Uysal, 2009, p.108). The VNS heuristic searches in several neighbourhoods for a better solution than the obtained current solution. The VNS heuristic is able to escape from local optima because it uses a shaking procedure (Drießel & Moench, 2009). This shaking procedure is no more than that it randomly (uniform distribution) selects a neighbour solution, within the neighbourhood structure of the current solution of the selected local search. There are different variations of the VNS heuristics. Sevkli & Uysal (2009) propose a VNS heuristic where the shake function is executed before the local searches. This means it starts for each local search with the same neighbour of the current solution. Behnamian et al. (2009) propose a VNS heuristic where three types of local search are used and the shake function is done each time for a local search. The proposed VNS heuristic of Drießel & Moench (2009) uses four local searches and stops after a maximum run time instead of a maximum number of iterations. We choose to use the VNS heuristic and the local searches given by Behnamian et al. (2009). This is because, according to Rocha, Gómez Ravetti, Mateus and Pardalos (2007), the best amount of local searches used in the VNS heuristic is often three and because it is easy to program in Excel-macros without too long run time. We limit ourselves to this software package such that ZGEU can work with it.

We give the pseudo code of the selected VNS heuristic below (Behnamian et al., 2009):

1. Find an initial solution S*;
2. k $\leftarrow$ 1
3. **For** iterations $\leftarrow$ 1 to a maximum number of iterations **do**
4.   S $\leftarrow$ S*;
5.   Shake procedure: find a random solution S' ϵ N_k (S);
6.   Perform a local search on N_k (S') to find the best neighbourhood solution S'';
7.   **If** f(S'') $\leq$ f(S*) **then**
8.   S* $\leftarrow$ S'';
9.   k$\leftarrow$1;
10.   **End if**
11.   k $\leftarrow$ k+1;
12. **End for**

Abbreviations:
S* = S = current solution
k = local search k
S' = random selected solution in the neighbourhood of S
N_k (S) = neighbourhood structure accessible with local search k of S
N_k (S') = neighbourhood structure accessible with local search k of S'
S'' = a solution in the neighbourhood of S'
f(S'') = completion time of S''
f(S*) = completion time of S*

The first step of the VNS heuristic is to generate an initial solution and assign the solution to the variable current solution S* (1). The heuristic starts with applying local search one (2). It randomly (uniform distribution) selects a neighbourhood solution S' of the current solution S (5). This neighbourhood structure of the current solution exists only of solutions that are obtainable with the selected local search. Then, it applies the selected local search on the random selected neighbourhood solution S' (6). The solution obtained is S''. If the completion time (lead time) of S'' is lower or equal than the completion time of the current solution then (7) the heuristic replaces the current solution (S*) with the solution of S'' (8). If it finds a better solution and the heuristic has not reached the maximum number of iterations, it repeats steps 4, 5, 6, 7, and 8 with local search one (9). If the heuristic does not find a lower completion time, it repeats steps 4, 5, 6, 7, and 8 with the next local search (11). The heuristic stops when it reaches the maximum number of iterations.

The three local searches Behnamian et al. (2009) use are:

- k=1: job swaps at one employee
  "This local search analyses every possible swap on one machine" (Behnamian et al., 2009, p.9639). In terms of the problem at ZGEU this local search analyses all possible swaps at one employee. For example, if the current solution gives the following solution:
  Employee A: 1-2-3
  Employee B: 4-5
  The local search only swaps two activities. In this case it can swap the activities 1-2-3 with each other or 4-5. The local search analyses the following neighbourhood structure in the example:
  1) A: 2-1-3, B: 4-5
  2) A: 1-3-2, B; 4-5
  3) A: 3-2-1, B: 4-5
  4) A: 1-2-3, B: 5-4
  The neighbourhood solution with the lowest completion time gets compared with the completion time of the current solution.
- k=2: job swaps between different employees
  "All job swaps between jobs belonging to different machines are evaluated" (Behnamian et al., 2009, p.9640). This local search analyses all possible swaps between two employees. If we take the same example as above, this local search analyses the following neighbourhood structure:
  1) A: 4-2-3, B: 1-5
  2) A: 1-4-3, B: 2-5
  3) A: 1-2-4, B; 3-5
  4) A: 5-2-3, B: 4-1
  5) A: 1-5-3, B: 4-2
  6) A: 1-2-5, B; 4-3

The best neighbourhood solution gets compared with the completion time of the current solution.

- <u>k=3: job insertion</u>
"This procedure searches for new solutions transferring jobs from the machine with the highest make span to the machine with the lowest one" (Behnamian et al., 2009, p.9640). Let us take the same example as before and say that the completion time to do activities 1-2-3 is 2 hours and for the activities 4-5 this is 1.5 hours. Then this local search analyses the following neighbourhood structure:
    1) A: 2-3, B: 1-4-5
    2) A: 2-3, B: 4-1-5
    3) A: 2-3, B: 4-5-1
    4) A: 1-3, B: 2-4-5
    5) A: 1-3, B: 4-2-5
    6) A: 1-3, B: 4-5-2
    7) A: 1-2, B; 3-4-5
    8) A: 1-2, B; 4-3-5
    9) A: 1-2, B; 4-5-3

  Again the best neighbourhood solution gets compared with the completion time of the current solution.

To determine a feasible initial solution, we choose to apply the dispatching rule longest path based on the heuristic of Kim and Posner (2010). By using this rule we take the precedence constraints into account. The calculation for the longest path for an activity is the processing time of the activity plus the maximum longest path of the possible immediate successors of the activity. We start the calculation for the activities which do not have any immediate successors. After this, we select the job with the longest path. This job will be planned on the first available machine. We remove this job out of the list and repeat the process until all jobs are scheduled.

5.3 Results VNS heuristic

The stakeholders of the planning department want the programming of the VNS heuristic in Excel. The maximum number of employees working on the galley is four. According to the planning manager, more than four employees working on one galley has a negative effect on the lead time. Then, the employees cannot move properly around the galley anymore to grab a tool or assemble parts on the galley. For the galley G1 601850-001801 we run the VNS heuristic several times with each time different settings of number of employees and number of iterations. We have summarised the outcomes in Appendix K. Appendix K gives that the best setting for the number of iterations is 500, independently of the number of employees. Except when we run the model with 1 employee, then 10 iterations is enough. This is because in this case two of the three local searches are not possible. Table 6 gives the best completion times for different settings of number of employees out of Appendix K, by 500 iterations. Figure 17 gives the influence of the number of employees on the completion time as well as on the percentage of waste time.

Table 6: Best completion times

Number of employees	Number of iterations	Completion time (days)
1	10	5.3
2	500	2.7
3	500	2.1
4	500	1.8

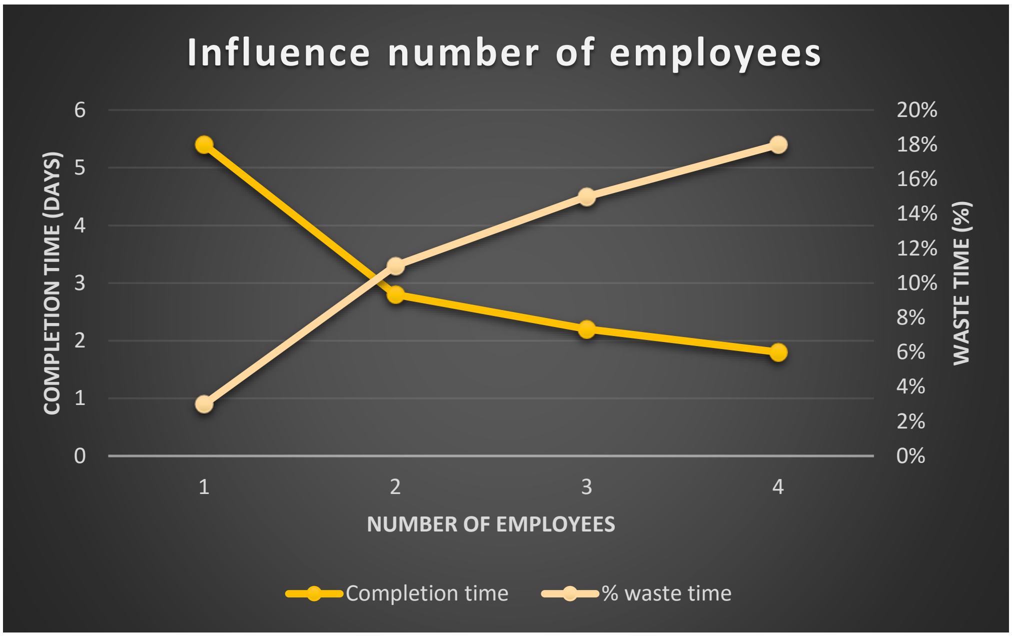


Figure 17: Influence number of employees

Currently, ZGEU assigns two employees to one G1 galley. From Figure 17 we see that if we add an extra employee the percentage of waste time increases, because employees possibly block each other. This means that we need to find a balance between the efficiency and a shorter lead time. We have chosen with ZGEU to stay with the two employees, because of the small possible gain in lead time with a third employee related to the increase in the percentage of waste time and considering the space around the galley. Appendix K gives detailed information about this parameter 'number of employees'.

Figure 18 shows the best sequence for two employees, which we have gained by 500 iterations. Appendix L gives a detailed time schedule of the sequence in Figure 18.

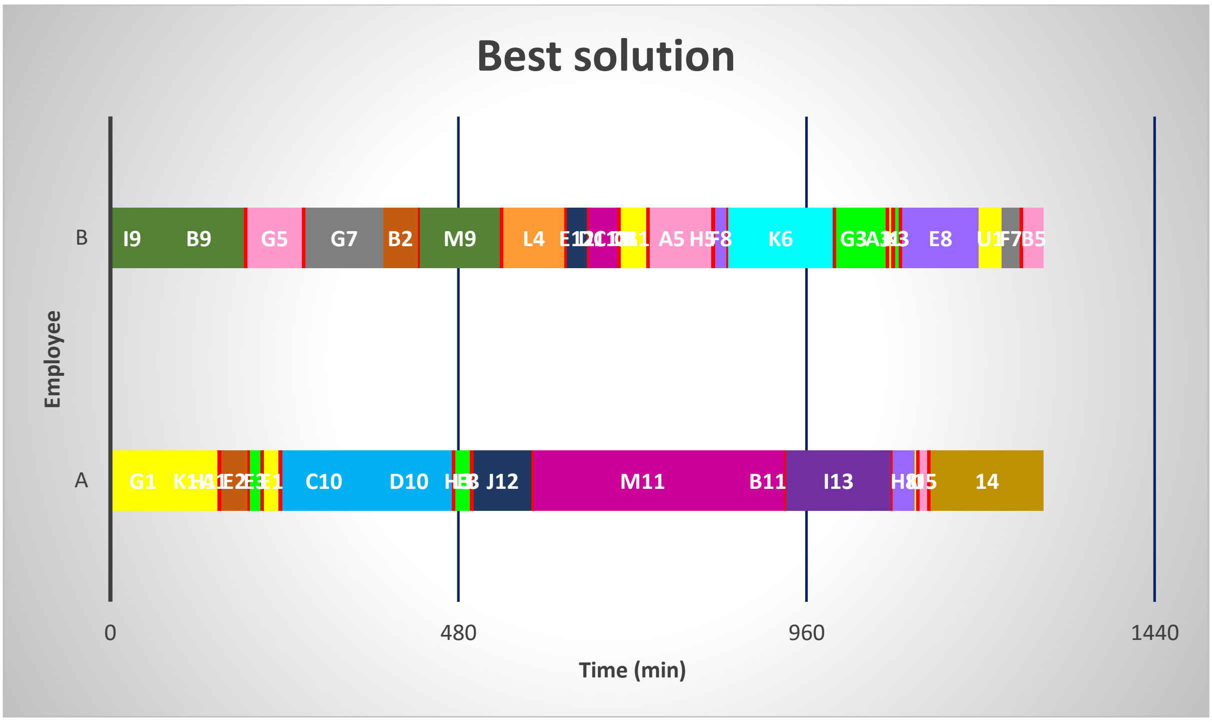


Figure 18: Best sequence with 2 employees

We have excluded the kits: pallet installation, paperclip, bottle opener, mirror, document holder, bumper and placard (N, O, P, Q, R, S and T). We have excluded these because these kits are customer specific and need to be assembled at the end of the process of FA after the entire decoration is done. In Figure 18 and the mentioned completion times, the time to install the excluded kits is not taken into account. Therefore, we must add 30 minutes to the completion times. The total completion time of the sequence in Figure 18 and Appendix L is 1317 minutes. Table 7 gives that 9% of the completion time is non-added value for the customer.

Table 7: Best completion time with 2 employees, with excluded kits

2 employees – G1	Minutes	Days
Completion time	1317	2.7
Total tool change time	114	0.2
Total waiting time	0	0.0
Total waste time	114	0.2
Total waste time (%)		9%

To gain these times in practice the following conditions have to be met, because of the assumptions that were made to programme the model:

- work days of 8 hours;
- both employees can perform all activities;
- tool change times are symmetric;
- all parts are available.

The condition ‘all parts are available’ is the biggest barrier for ZGEU to achieve the lead time of the sequence. But even if this condition is not met, the director of Operations estimates that ZGEU can reduce the lead time of FA with 20 to 30% by implementing the sequence outcome of the model.

5.4 Validation of model

According to Law (2015), determining the validation of a model is one of the most difficult problems in modelling, where validation is described as the determination of how accurate the model represents the actual system that is studied. Three important terms to determine if the model is valid are verification, validation and credibility. Law (2015) defines verification as the debugging of the program. As we have stated above, the validation of the model entails the determination of how accurate the model represents the actual system that is studied. Law (2015) describes models as credible if the model is perceived correct by the manager and other key personnel.

Law (2015) gives eight techniques to debug the computer program. We have used four of these techniques, because the other four are specifically for simulations models. The four techniques of Law (2015) we have used for debugging the model are the following:

- program the model in modules or subprograms;
- check the models output for plausibility by running the model several times with various values of the input parameters;
- control the state of the system during the run, check the variables after each event and perform hand calculations to check if the program is operating as intended;
- run the model under simplified assumption where we know the true characteristics of or which can be computed in an easy way.

Further Law (2015) gives six classes of techniques to increase the validity and credibility:

- "Collect high-quality information and data on the system" (Law, 2015, p.256). We used the following techniques of Law to collect the right data:
    - Observations of the system – we have monitored the system two times to determine the input data processing times;
    - Conversations with Subject-Matter Experts – Subject-Matter Experts (SME) are the stakeholders in the 'consult' and 'engage' quadrants (employees of FA, employees of planning, ME team, ME team manager and director of Operations). We have used their knowledge about the system to determine the input data processing times, tool change times and precedence relations.
- "Interact with the manager on a regular basis" (Law, 2015, p.257). This increases the chance that the model will be used in the decision-making process. We have informed the director of Operations approximately every two weeks about the developments.
- "Maintain a written assumptions document and perform a structured walk-through" (Law, 2015, p.258). We have chosen to describe all of the assumptions and explanation of the algorithm in the previous sections. We have not done a structured walk-through as Law (2015) describes, but we have organised regular meetings with the important stakeholders.
- "Validate components of the model by using quantitative techniques" (Law, 2015, p.260). It is important to know how the settings of the model influence the outcome. For the VNS heuristic, the parameter 'number of iterations' influences the outcome of the model. Therefore, we have determined the best value for it in Appendix K, with a sensitive analysis.
- "Validate the output from the model" (Law, 2015, p.262). Here we establish if the output data of the model closely resembles the output data that would be expected from the actual system. Law (2015) gives three comparisons:
    - comparison with an existing system;
    - comparison with expert opinion;
    - comparison with another model.

  The ME team has monitored the final assembly to optimise the working instructions (description how employees need to assemble a part on the galley). These working instructions are written per kit. To check the working instructions easily, the ME team has determined a fixed sequence of kits for the monitoring (they have checked the work instruction per kit). The monitoring had a lead time of 4.5 days with two employees. Comparing this monitoring of an existing system with the model outcome, which also gives 4.5 days completion time for this sequence, indicates that the model gives a valid outcome. We can also apply a comparison with an expert opinion. The team leaders of FA, the production supervisor and the director of Operations all agreed that the outcome of the model will be possible in practice. But they state that to come to the same results ZGEU needs to improve the delivery of internal suppliers of metal parts first and the employees must get trained. Which means that the model gives a valid and credible outcome. Comparison with another model is not possible, because there is no other model available to compare it with.
- Use animations in the model. Because we have programmed the model in Excel, animations are not possible. The possibility in Excel is to look how the programme switches the jobs on the sheets, which we have used during the verification. We have chosen to not show the screen updates, because this substantially increases the run time.

Thus, we have evaluated the verification, validation and credibility of the model. We conclude that the model is valid for FA at ZGEU.

5.5 Possible gains for FA

Table 8 compares the current situation of ZGEU with the outcome of the VNS heuristic for two employees. We only compare the situation with two employees, because in the current situation ZGEU assigns two employees to one G1 galley. In this comparison the waste time of the current situation includes missing parts caused by suppliers which is not included in the calculations of the model. Thus, to gain the results of the model in practice ZGEU needs to improve the supply of parts.

Table 8: Comparison between current situation and outcome model

	Current situation		Outcome model	
	Minutes	Days	Minutes	Days
Lead time	3840	8	1317	2.7
Waste time	2592	5.4	114	0.2
Waste time (%)	68%		9%	

We conclude from Table 8 that it is possible for ZGEU to reduce the lead time with 66% $\left(\frac{current\ lead\ time\ FA\ [days] - outcome\ model\ lead\ time\ [days]}{current\ lead\ time\ FA\ [days]} * 100\%\right)$. at FA for the G1 galleys. If we translate this reduction to the total lead time, which was 19 days, ZGEU can reduce the production lead time with 28% $\left(\frac{current\ lead\ time\ FA\ [days] - outcome\ model\ lead\ time\ [days]}{total\ production\ lead\ time\ [days]} * 100\%\right)$. Again recall that this is only possible if the conditions we have given in Section 5.3 are met.

When the root cause ‘process of FA is not standardised’ is solved, this will give the following advantages for ZGEU:

- reduction of the lead time;
- the process of FA will be a controllable process, which means that ZGEU can start with continuous improvement of the FA process;
- it is possible to structure the car of warehouse better for the employees of FA, for example ordering the parts in the sequence of assembly and/or deliver the parts per day;
- the above points together will reduce the number of missing and wrong parts during assembly, because the causes ‘car with parts is not optimal structured for employees of FA’ ,‘too many parts on the car’ and ‘employees of FA cannot find parts on the car’ will be solved. Therefore the appearance of the causes ‘parts are damaged during process of FA’ and ‘taking missing or wrong parts from other project car’ reduce as well.

5.6 Conclusion

We eliminate the root cause ‘the process of FA is not standardised’, by solving a scheduling problem. There are different scheduling problems, but the parallel machine scheduling problem describes the problem at ZGEU best. We solve the parallel machine scheduling problem with Variable Neighbourhood Search (VNS) heuristic. We have chosen to solve the problem with the VNS heuristic, because it finds the optimal solution often and its performance is quite stable. We have controlled this with test runs of a small problem, 10 out of 10 times the optimal solution was gained. Further, the VNS heuristic is very efficient for large sized problem since the execution time is very small, which is important to extend the model for other galley types.

For the VNS heuristic we have determined the activities necessary to assemble a G1 galley. An activity is one of the process steps for one kit. We have determined the values of the parameters (processing times, precedence relations, tool change times and which activities cannot be done in parallel) with the team leaders and the production supervisor. The best setting for the parameter ‘number of iterations’ is 500, independently of the number of employees. Further, the best setting for the parameter ‘number of employees’ is two or three, this depends on the wanted balance between the efficiency and a shorter lead time. We have chosen with ZGEU to stay with two employees.

Currently ZGEU assigns two employees to a galley at FA, therefore we compare the current situation with the model outcome. The model gives a lead time of 2.7 days. To gain these times in practice the following assumptions have to be true:

- work days of 8 hours;
- both employees can perform all activities;
- tool change times are symmetric;
- all parts are available.

Thus, by solving the root cause ‘the process of FA is not standardised’ by implementing the sequence outcome of the VNS heuristic as the new standard for FA according to the implementation plan, ZGEU can reduce the lead time of FA for the G1 galleys with 66% compared to the current situation. If we translate this reduction to the total lead time, which was 19 days, ZGEU can reduce the production lead time with 28%.

6. Implementation of standard in FA

In this chapter we describe an implementation plan to implement the gained standard in FA. We use the Eight Step Change model of Kotter as framework of this implementation plan. Each section describes a step of the Eight Step Change model.

6.1 Step 1 – Create a sense of urgency

"Help others feel a gut-level determination to move and win, *now*" (Kotter, 2012, "Step 1", subscript).

Kotter (2012, "Step 1") stated that about 50% of the change projects fail because most organisations do not pay attention to this step. This step is important because employees resist changes if they are not aware of the urgency of those changes. Leaders of the organisation are responsible for creating awareness by the employees, but they often fail to do so.

To create a sense of urgency it is important to let the stakeholders know what the benefits are of the new standard. In Section 5.5 we have described the possible gains for ZGEU. Each stakeholder has his own perception on which gains are most important and which are not important for him. This will depend on the stakeholders interests and goals. For example, to create a sense of urgency by the employees of FA we can refer back to the ranking list of Section 4.2. For the employees of FA the reduction of missing and damaged parts is an important benefit. But the main benefit for example, for the director of Operations is reduction of the lead time. We recommend to mention all benefits, but the order of mentioning depends on the stakeholder.

Communicating the urgency is possible in different ways. Because of the top-down culture at ZGEU we recommend to start with a presentation for the management, "leaders who understand the importance of a sense of urgency are good at taking the pulse of their company and determining whether the state of the organisation is" Kotter (2012, "Step 1", para. 2.). In this presentation the urgency of the standard, the benefits and the implementation plan must be made clear. After the presentation the advice is to give handouts of the presentation to the managers to read it again. It is optional that the managers read this report for more details. After a week a second meeting has to be scheduled to make sure a sense of urgency is created by the management and everything is clear to them. After this, we create the sense of urgency by the other stakeholders, with support of the management. This can be done the same way, but the focus of the gains should be adapted to the stakeholder.

6.2 Step 2 – Create a guiding coalition

"Putting together a group with enough power to lead the change" (Kotter, 2012, "Step 2", subscript).

Kotter (2012, "Step 2") stated that one person, no matter how competent, is not capable to change an organisation. So to successfully lead a change project, it is critical to form the right coalition of people. This coalition must have a high level of trust and the persons of the coalition must have shared objectives among each other. For ZGEU this objective would be minimising the lead time of FA. In order to form an effective guiding coalition, the guiding coalition must reflect the four qualities below as stated by Kotter (2012, "Step 2", para. 3):

- "Position power: enough key players should be on board so that those left out cannot block progress.

- Expertise: all relevant points of view should be on represented so that informed intelligent decisions can be made.
- Credibility: the group should be seen and respected by the rest of the organisation so that the group' pronouncements will be taken seriously by other employees.
- Leadership: the group should have enough proven leaders to be able to drive the change process."

For the team it is important to create shared goals and a level of trust in the organisation to make the needed changes happen. At ZGEU this guiding coalition can be formed out of the ME team. The ME team already is standardising the process of FA on a lower level, namely the working instructions (description how employees need to assemble a part on the galley). The combination of the working instructions and the gained sequence by the VNS heuristic provide a good standard for the process of FA.

6.3 Step 3 – Develop a change vision

"Clarify how the future will be different from the past" (Kotter, 2012, "Step 3", subscript).

Kotter (2012, "Step 3") stated that it is important to develop a clear change vision because of three reasons. It helps in making detailed decisions, it helps to motivate people to take steps in the right direction and it serves as a fast and efficient method to steer actions of different people. Further Kotter (2012, "Step 3", para. 1) gives that "a clear and powerful vision will do far more than an authoritarian decree or micromanagement can ever hope to accomplish".

According to Kotter (2012, "Step 3", para. 5) an effective vision has six key characteristics:
- "**Imaginable**: it conveys a clear picture of what the future will look like.
- **Desirable**: it appeals to the long term interest of those who have a stake in the enterprise.
- **Feasible**: it contains realistic and attainable goals.
- **Focused**: it is clear enough to provide guidance in decision making.
- **Flexible**: it allows individual initiative and alternative responses in light of changing conditions.
- **Communicable**: it is easy to communicate and can be explained quickly."

A clear change vision for this project 'implementation of a standard in FA' is:

> Implement the standard at FA to create a controllable process. A standardised FA process decreases the lead time of the production process. In this way ZGEU can satisfy its customers' demand.

6.4 Step 4 – Communicate the vision for buy-in

"Ensuring that as many people as possible understand and accept the vision" (Kotter, 2012, "Step 4", subscript).

Kotter (2012, "Step 4") states that organisations often make the mistake to not communicate their vision enough. Often organisations just communicate their vision for the change project through a memo or a couple of speeches by the CEO or the guiding coalition. This is not enough to have an effective change project. To increase the effectiveness, every opportunity (for example, memos, speeches, presentations, emails and meetings) must be used to communicate the vision.

It is important to create a vision, but this vision also needs to be communicated frequently and powerfully so people will remember it. Talk about the vision at every opportunity instead of only telling it a meeting, like the TOP 5 meeting of ZGEU. It is also important to 'walk the talk', what is done is more important than what is said. Leaders who transform their organisation 'walk to talk' will be seeking to become a living example of the new corporate culture that the vision aspires to.

6.5 Step 5 – Empower broad-based action

"Removing as many barriers as possible and unleashing people to do their best work" (Kotter, 2012, "Step 5", subscript).

Kotter (2012, "Step 5") stated that the internal structures of organisations often do not align with the change project vision. This creates barriers that make it impossible to obtain the best outcome for the change project. In order to achieve the best outcome for the change project, the barriers need to be solved.

To gain the result of 66% lead time reduction at FA, some barriers must be solved during the implementation process. Below we give the barriers and we give recommendations to solve these barriers.

- <u>Resistance of the organisation</u> – Make sure that the standardisation is a good baseline for continuous improvement. This is important because the level of resistance of an organisation depends on the impact of the change. It is better to take the time to determine a good standard. For the employees this would mean one large change, with small change impacts (continuous improvements) after implementation. If we implement earlier and change large parts of the standard after a couple of months, these have a large change impact. This leads to a high level of resistance, because of the higher level of dissonance and the decrease of credibility of the changes pushed by the organisation. To create a good baseline it is best to test the gained sequence on the model line and optimize the model by improving the found flaws of the tested sequence before elaborating further steps. Gaining more exact data like processing times and tool change times for the model will also improve the sequence. Currently, the ME team elaborated work instructions per kit. We recommend to reorganise these work instructions to the standard sequence, such that the work instructions include the sequence and employees can follow the sequence and work instruction easily.
- <u>Supply of parts is not sufficient</u> – The supply of parts can be improved by placing the sequence in the ERP system with connections to the needed parts per day. This is such that the purchasing department knows more exact when a part must be in production, warehouse can adapt their order picking to the new sequence and subassembly can adapt their supply to the new sequence.
- <u>An employee cannot perform all activities</u> – The model to determine the sequence is based on the assumptions that an employee can perform all activities (as requested by the director of Operations). Thus, to adapt the sequence in practice ZGEU needs to train the employees of FA, such that an employee can perform all activities. By training the employees ZGEU creates more flexibility.
- <u>The car of warehouse is not optimal structured</u> – Start an improvement project to optimize the structure of the car of warehouse to decrease the search time to parts. As we have stated at recommendation four, the warehouse can adapt their order picking to the new sequence, if it knows the standard sequence. The parts can be sequenced on the car according the sequence of FA and/or provide a car every day with parts for just that day.

- Not all parts are available – Start a second improvement project to increase the on time delivery of metal parts. This project is important because, if the production misses parts it cannot follow the time schedule of the standard to gain the wanted lead time. The on time delivery level of metal parts is the lowest. Because of the constraint that ZGEU must purchase 50% at internal suppliers of the Zodiac group, this improvement project must be focussing on how to select and divide the budget over external and internal suppliers to minimise the number of missing parts in production.

6.6 Step 6 – Generate short term wins

"Creating visible, unambiguous success as soon as possible" (Kotter, 2012, "Step 6", subscript).

According to Kotter (2012, "Step 6") leaders in a long term change project should identify significant short term improvements. By tracking the short term wins, the stakeholders get insight in the progress of the change project, which keeps them motivated and supportive. Further, it gives the guiding coalition information if the chosen approach needs to be adjusted to come to the desired outcome of the change project. This ensures that the change project will be successful.

To ensure success, short term wins must be visible and unambiguous. The wins must also be clearly related to the change effort. By measuring the KPI 'lead time' of the tests on the model line, the guiding coalition can make the short term wins visible of this implementation project. Short term wins also can be shown by giving the progress of the implementation project (which goals are already achieved). For example, the progress in the training of employees. It is important to communicate these short term wins to the stakeholders, such that they know the project is progressing well.

6.7 Step 7 – Do not let up

"Consolidating gains and producing more change" (Kotter, 2012, "Step 7", subscript).

According to Kotter (2012, "Step 7") it is very dangerous to let up the change project. Stopping the change project, when it is not finished yet, results in losing the momentum of changing and will eventually lead to regression. It is so important to keep the momentum because it is nearly impossible to restart implementation once regression begins.

It is important to keep the stakeholders motivated and confident in the project, such that everyone wants to continue. The guiding coalition has the responsibility to keep all the stakeholders involved. For example, the employees of FA need to be motivated to follow the trainings needed to implement the standard. Also, the management needs to keep faith in the implementation such that they do not want to cancel it halfway. If the implementation would be cancelled halfway or employees lose motivation and stop trainings the implementation fails and an unnecessary waste of resources is created. The guiding coalition can motivatedthe stakeholders by keeping track of the improvements and sharing these with the stakeholders increases the motivation to go through, 'walk the talk'.

6.8 Step 8 – Make it stick

“Anchoring new approaches in the culture for sustained change” (Kotter, 2012, “Step 8”, subscript).

Kotter (2012, “Step 8”) stated that new practices as a result of the change project, must be kept attached to the culture of the organisation. This is hard because of the norms of behaviour and shared values, which are incredibly strong forces in the culture of an organisation. Therefore, it is important to follow the seven steps above and stick to them.

This is an important step when the standard gets implemented for the whole FA of the G1 type. The guiding coalition must ensure the continuity of the standard. The employees of FA must follow the standard and therefore need guidance. By supporting the employees of FA to follow the standard, it can be faster adapted into the culture of the organisation. The guiding coalition can support them by being visible and available at the shop floor of FA, such that the guiding coalition than can answer any questions, give instructions and award them. Again, keep track of the improvements and share the results with the stakeholders to increase the acceptation of the change.

7. Conclusions and recommendations

In this chapter we answer the problem statement 'How can the production lead time at Zodiac Galleys Europe be reduced?'. The first section gives the conclusions of this research and the second section gives recommendations to follow up this research.

7.1 Conclusions

The core problem of ZGEU is that the production lead time of a galley needs to be reduced by 20%. The outcome of this research gives a method how ZGEU can reduce the production lead time with 28%. Namely by solving the root cause 'process of FA is not standardised' with the VNS heuristic.

Below, we summarise the main conclusions of this research.

- Current production lead time is 19 days.
- FA is the bottleneck process, because it has the longest processing time. Currently, it has a lead time of eight days with two employees. On average 68% of the eight days is waste time due to searching and waiting for parts.
- The main stakeholders for this research are the director of Operations, manager of ME team, ME team and the employees of FA. As the culture of ZGEU is closed and formal, it is important to anticipate on the threat that the less powerful stakeholders do not give their opinions and ideas. Also because of this culture, it is important that the powerful stakeholders support this research to gain the optimal outcome.
- The bottleneck of FA is 'missing parts on the car from warehouse'. Because the second main cause 'wrong parts on the car from warehouse' is linked closely, we have researched these causes together. Further research to these bottlenecks of FA gives that the root cause of the long lead time of FA is that 'the process of FA is not standardised'.
- To solve the root cause a scheduling problem needs to be solved. The best fitted scheduling problem is the parallel machine scheduling problem with precedence constraints, sequence dependent tool change times and activities that cannot be done in parallel.
- We have solved the parallel machine scheduling problem with the Variable Neighbourhood Search heuristic.
    - The best setting for the parameter 'number of iterations' is 500, independently of the number of employees.
    - The best setting for the parameter 'number of employees' is two or three, this depends on the wanted balance between the efficiency and a shorter lead time. We have chosen with ZGEU to stay with two employees.
- The outcome of the heuristic, which we have gained with the parameter 'number of employees' set to 2 and 'number of iterations' set to 500, gives a lead time of 2.7 days. To gain these times in practice the following conditions have to be met, because of the assumptions that were made to programme the model:
    - work days of 8 hours;
    - both employees can perform all activities;
    - tool change times are symmetric;
    - all parts are available.
- The steps that need to be taken to implement the solution to eliminate the root cause 'the process of FA is not standardised' are:
    1. Create a sense of urgency
    2. Create a guiding coalition
    3. Develop a change vision

4. Communicate the vision for buy-in
5. Empower broad-based action
6. Generate short term wins
7. Do not let up
8. Make it stick

Thus, by solving the root cause ‘the process of FA is not standardised’ by implementing the sequence outcome of the VNS heuristic as the new standard for FA according to the implementation plan, ZGEU can reduce the lead time of FA for the G1 galleys with 66% compared to the current situation. If we translate this reduction to the total lead time, which was 19 days, ZGEU can reduce the production lead time with 28%.

7.2 Recommendations

We recommend the following points to follow up this research.

1. Make a planning of the implementation. The appointed guiding coalition should elaborate each step of the implementation plan in smaller activities, assign tasks and responsibilities and make a milestone planning for it.
2. Initiate an improvement project to increase the on time delivery of parts from suppliers. As stated before a barrier to gain the results of this research is that not all parts are available. Currently, the on time delivery of metal parts is the poorest. Therefore, we recommend to focus on the suppliers of metal parts. This improvement project can be done in parallel with the implementation of this research. We recommend that the procurement and logistics department takes responsibility and control of this improvement project, because it is related to the suppliers.
3. Initiate an improvement project to optimise the car of the warehouse to the new standard. We recommend to do this after implementation of the new standard, with the same guiding coalition plus stakeholders of the warehouse. This is because the guiding coalition is familiar with the new standard. Stakeholders of the warehouse need to be added, because of the possible limitations in the warehouse which the guiding coalition is not aware of and gaining support of the employees of the warehouse.
4. After the implementation, start with continuous improvement of FA by keeping track of the flaws at FA with a Pareto analysis and solve these flaws. A Pareto analysis gives an overview of the largest flaws, where ZGEU can obtain the largest improvements. Besides, it forces the organisation to gather data about the process and gives direction for continuous improvement of the process.
5. We have limited the scope of this research to the bottleneck process, therefore other processes have not been researched. However, we expect that by researching the other processes with the same approach of this research at FA, an extra significant reduction in the production lead time can be gained.

References

Baldwin, D.F., Abell, T.E., Lui, M.M., Fazio, T.L. de, & Whitney, D.E. (1991). An integrated computer aid for generating and evaluating assembly sequences for mechanical products. *IEEE TRANSACTIONS ON ROBOTICS AND AUTOMATION*, *7*(1), 78-94.

Behnamian, J., Zandieh, M., & Fatemi Ghomi, S.M.T. (2009). Parallel-machine scheduling problems with sequence-dependent setup times using an ACO, SA and VNS hybrid algorithm. *Expert Systems with Applications*, *36*, 9637-9644.

Betterton, C.E., & Silver, S.J. (2012). Detecting bottlenecks in serial production line – a focus on interdeparture time variance. *International Journal of Production Research*, *50*(15), 4158-4174.

Brook, Q. (2006). Lean Six Sigma and Minitab. Hampshire: OPEX Resources Ltd.

Burnes, B. (2015). Understanding resistance to change- building on Coch and French. *Journal of Change Management*, *15*(2), 92-116.

Cho, K.T. (2002). Multicriteria decision methods: an attempt to evaluate and unify. *Mathematical and computer modelling*, *37*, 1099-1119

Dini, G., Failli, F., Lazzerini, B., & Marcelloni, F. (1991). Generation of optimized assembly sequences using genetic algorithms. *Annals of the CIRP*, *48*(1), 17-20.

Drießel, R., & Moench, L. (2009). Scheduling jobs on parallel machines with sequence-dependent setup times, precedence constraints and ready times using Variable Neighborhood Search. *IEEE*, 273-278.

Faccio, M. (2014). The impact of production mix variations and models varieties on the parts-feeding policy selection in a JIT assembly system. *Int J Adv Manuf Technol*, *72*, 543-560.

Gambles, I. (2009). Making the business case: proposals that succeed for projects that work. Bodmin: MPG Books Ltd.

Heerkens, H. (2004). A methodological checklist for the high-tech marketing project. Retrieved at 22 September, 2014 from <https://blackboard.utwente.nl/webapps/blackboard/content/listContent.jsp?course_id=_18197_1&content_id=_747664_1>

Homem de Mello, L.S., & Sanderson, A.C. (1991). A correct and complete algorithm for the generation of mechanical assembly sequences. *IEEE TRANSACTIONS ON ROBOTICS AND AUTOMATION*, *7*(2), 228-240.

Ingham, A.G. (1974). The Ringelmann effect: studies of group size and group performance. *Journal of experimental social psychology*, *10*, 371-384

Jones, R.E., Wilson, R.H. & Calton, T.L. (1998). On constraints in assembly planning. *IEEE TRANSACTIONS ON ROBOTICS AND AUTOMATION*, *14*(6), 849-863.

Kanai, S., & Makino, H. (1996). ASPEN: computer-aided assembly sequence planning and evaluation system based on predetermined time standard. *Annals of the CIRP*, *45*(1), 35-39.

Kim, E., & Posner, M.E. (2010). Parallel machine scheduling with s-precedence constraints. *IIE Transactions*, *42*(7), 525-537.

Kotter, J. (2012) The 8-Step Process for Leading Change. Retrieved from Kotter Internatonal: <http://nextgen.kotterinternational.com/our-principles/changesteps>

Laperrière, L. (1992). Generative assembly process planning (thesis for doctor of philosophy). Mechanical Engineering, McMater University, Hamilton, Ontario.

Law, A.M. (2015). Simulation modelling and analysis. 5th edition. New York: McGraw-JJill Education.

Lima, E., Chwif, L., & Barreto, M.R.P. (2008). Methodology for selecting the best suitable bottleneck. In S.J. Mason, R.R. Hill, L. Mönch, O. Rose, T. Jefferson and J.W. Fowler (Eds.), *2008 Winter Simulation Conference* (1746-1751). IEEE.

Marcus, J., & Dam, N. van (2009). Een praktijkgerichte benadering van organisatie en Management. 6th edition. Groningen: Noordhoff.

Medbo, L. (2003). Assembly work execution and materials kit functionality in parallel flow assembly systems. *International Journal of Industrial Ergonomics*, *31*, 263-281.

Mehta, A. (2000). Smart modelling – basic methodology and advanced tools. In J.A. Joines, R.R. Barton, K. Kang and P.A. Fishwick (Eds.), *2000 Winter Simulation Conference* (241-245).

Münstermann, B., & Weitzel, T. (2008). What is process standardization?. *International Conference on Information Resources Management 2008 proceedings.* Paper 64. <http://aisel.aisnet.org/confirm2008/64>

Nazarian, E., Ko, J., & Wang, H. (2010). Design of multi-product manufacturing lines with the consideration of product change dependent inter-task times, reduced changeover and machine flexibility. *Journal of Manufacturing Systems*, *29*, 35-46.

Pietersma, P. et al. (2006). Het strategie boek een veranderend speelveld/ Berenschot. Den Haag: Sdu Uitgevers bv.

Pihir, I., Konecki, M., & Tomicic-Pupek, K. (2015). How measurement and analysis of business processes impact employees?. International Academic Conference on Social Sciences and Humanities, Proceedings of IAC-SSaH 2015 (258-263). CIAE: Prague.

Ramírez Palencia, A.E., & Mejía Delgadillo, G.E. (2012). A computer application for a bus body assembly line using genetic algorithms. *International Journal Production Economics*, *140*, 431-438.

Rocha, M., Gómez Ravetti, M., Mateus, G.R., & Pardalos, P.M. (2007). Solving parallel machines scheduling problems with sequence-dependent setup times using Variable Neighborhood Search. *IMA Journal of Management Mathematics*, *18*, 101-115.

Roser, C., Lorentzen, K., & Deuse, J. (2014). Reliable shop floor bottleneck detection for flow lines through process and inventory observations. *Procedia CIRP*, *19*, 63-68.

Saaty, T.L. (2013). The modern science of multicriteria decision making and its practical applications: the AHP/ANP approach. *Operation Research*, *61*(5), 1101-1118.

Schutten, M. (n.d.). dobp-sheets1UK [PowerPoint slides]. Retrieved from <https://blackboard.utwente.nl/webapps/blackboard/content/listContent.jsp?course_id=_17871_1&content_id=_736395_1>

Schwartz, D., Fischhoff, B., Krishnamurti, T., & Sowell, F. (2013). The Hawthorne effect and energy awareness. *PNAS*, *110*(38), 15242-15246.

Sevkli, M., & Uysal, H. (2009). A modified Variable Neighborhood Search for minimizing the makespan on identical parallel machines. *IEEE*, 108-111.

Shirey, M.R. (2012). Stakeholder analysis and mapping as targeted communication strategy. *JONA*, *42*(9), 399-403.

Smith, S.M., & Albaum, G.S. (2005). Fundamentals of Marketing research. California: Sage Publications Inc.

Symbol business improvement (2014). Lean six sigma green belt training. Retrieved from University of Twente.

Tavakkoli-Moghaddam, R., Taheri, F., Bazzazi, M., Izadi, M., & Sassani, F. (2009). Design of a genetic algorithm for bi-objective unrelated parallel machines scheduling with sequence-dependent setup times and precedence constraints. *Computer & Operations Research*, *36*, 3224-3230.

Trask, K.M., Rice, R.W., Anchors, S., & Lilieholm, R.J. (2009). Management styles of lumber mill managers in the northern United States. *Forest Products Journal*, *59*(3), 29-34.

Vallada, E., & Ruiz, R. (2011). A genetic algorithm for the unrelated parallel machine scheduling problem with sequence dependent setup times. *European Journal of Operational Research*, *211*, 612-622.

Veld, J. in ‘t (2007). Analyse van bedrijfsprocessen. 9th edition. Groningen: Noordhoff.

Xu, H., Yuan, M., & Li, D. (2009). A novel process planning schema based on process knowledge customization. *International Journal of Advanced Manufacturing Technology*, *44*, 161-172.

Zodiac Galleys Europe (2015a). A320 SFE Galleys and Stowages [PowerPoint slides]. Retrieved at 29 June, 2015 from Zodiac Galleys Europe.

Zodiac Galleys Europe (2015b). Hours new standard [Excel spreadsheet]. Retrieved at 8 September, 2015 from Zodiac Galleys Europe.

Zodiac Galleys Europe (2015c). LEAN - BASIC TRAINING [PowerPoint slides]. Retrieved at 10 September, 2015 from Zodiac Galleys Europe.

Zodiac Galleys Europe (2015d). Export PQC hlaseni [Excel spreadsheet]. Retrieved at 20 November, 2015 from Zodiac Galleys Europe.

Zodiac Galleys Europe (2015e). ZGEU ORG CHART [PowerPoint slides]. Retrieved at 12 August, 2015 from Zodiac Galleys Europe.

Zodiac Galleys Europe (2014). ZGEU suppliers day [PowerPoint slides]. Retrieved at 18 September, 2014 from Zodiac Galleys Europe.

Appendix

A. Interviews detecting bottleneck process

Director of Operations

According to the director of Operations, FA is the bottleneck process. FA has the longest lead time of all processes. The shift of moving the production processes, until FA of the G1 galley, to Tunisia creates a longer total lead time because of shipment. This needs to be balanced by shortening a process. The plant in Tunisia just started producing at the start of 2015, this means it is still learning the processes. When the plant in Tunisia is familiar with the processes, FA will even be a bigger bottleneck process, because Tunisia can produce more galleys in the same time. Currently, with the rework required for the galleys the plant in Tunisia supplies just in time to FA in the Czech Republic. So in approximately one year the plant in Tunisia has reduced its rework because it is then familiar with the processes and therefore delivers quicker. If the process and the capacity of FA stays the same a queue will emerge in front of the FA which is a sign that the FA is the bottleneck process.

Production SA manager

FA has the longest lead time, this means FA is the bottleneck process. ZGEU is moving the process bonding to the plant in Tunisia. This creates space within the plant of Plzen, the plan is to use this space to increase the capacity of FA. But this is a future plan, so currently the space for FA is limited and ZGEU cannot increase the capacity of FA, which also suggest that FA is the bottleneck process. Besides FA, the processes making panels and routering panels need attention. If the machines in these processes break down there is no buffer of (routered) panels, because ZGEU only produces on customer demand.

Production supervisor

Because FA takes the most time it is the bottleneck process, according to the production supervisor. FA works at maximum capacity, in case of illness or holidays FA does not have enough employees. Currently, it is not possible to work in two shifts currently because there is no fixed sequence of work for all employees. Thus, each employee decides for him-/ herself, the order in which the galley is assembled. Because they decide the sequence other employees cannot continue on the same galley without explanation of the employee who worked on it before. If FA is better controlled, the process subassembly can also be better controlled. Now subassembly needs to deliver all parts for all 8 days at the start of FA. If this can be divided to for example, each day, subassembly can spread the work better. If the process gets smoother, the quality of the parts will increase on the long term, according to the production supervisor.

B. Calculation average processing times

We calculate the average processing times with data we have gained during the monitoring measurements and the time estimations of the workers of FA. A worker from the ME team has measured the processing times of the first monitoring and we have measured the times of the second monitoring ourselves. Table A gives the time estimation per worker of FA.

Table A: Estimations processing times per worker of FA

Process step/ Respondent	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Team leader 1	Team leader 2	Average	STDV
Structure assembly																		
Install extrusions		8			6	6		4	4	0.75		10			7		6.4	1.99
Install shelfs		2			2	4		6	6	0.5		2.5			5		3.9	1.66
Install retainers		2			4	4		5	1	0.15		0.5			3		2.8	1.56
Install pull out table		2			3	2		3	2	0.2		1			2		2.1	0.64
Install rub strips		6			6	4		6	4	1		4			6		5.1	0.99
Install work deck		4			4	3		7	4	0.2		8			5		5.0	1.69
Install dividers		4			2	2		3	2	0.2		1			4		2.6	1.05
Install doors		6			4	4		6	3	0.1		3			5		4.4	1.18
Systems assembly																		
Making subparts	4		8	7			8				8		3	8		8	6.8	1.92
Install water system	6		10	4			4				4		4	5		6	5.4	1.93
Install electrical installation	8		10	4			6				10		5	5		8	7.0	2.18
Install drain	0.5		4	1			0.5				4		1	1		4	2.0	1.56
Install air conditioning	2		10	1			1				4		3	4		3.5	3.6	2.69
Install isolation	4		10	3			4				4		6	6		4	5.1	2.09

Respondent 10 gives very low values which is strange when we compare them with the other respondents. Therefore we exclude respondent 10 in our calculation for the average processing times and standard deviation.

Figure A gives an overview of the data of the processing times compared to the calculated average processing times.

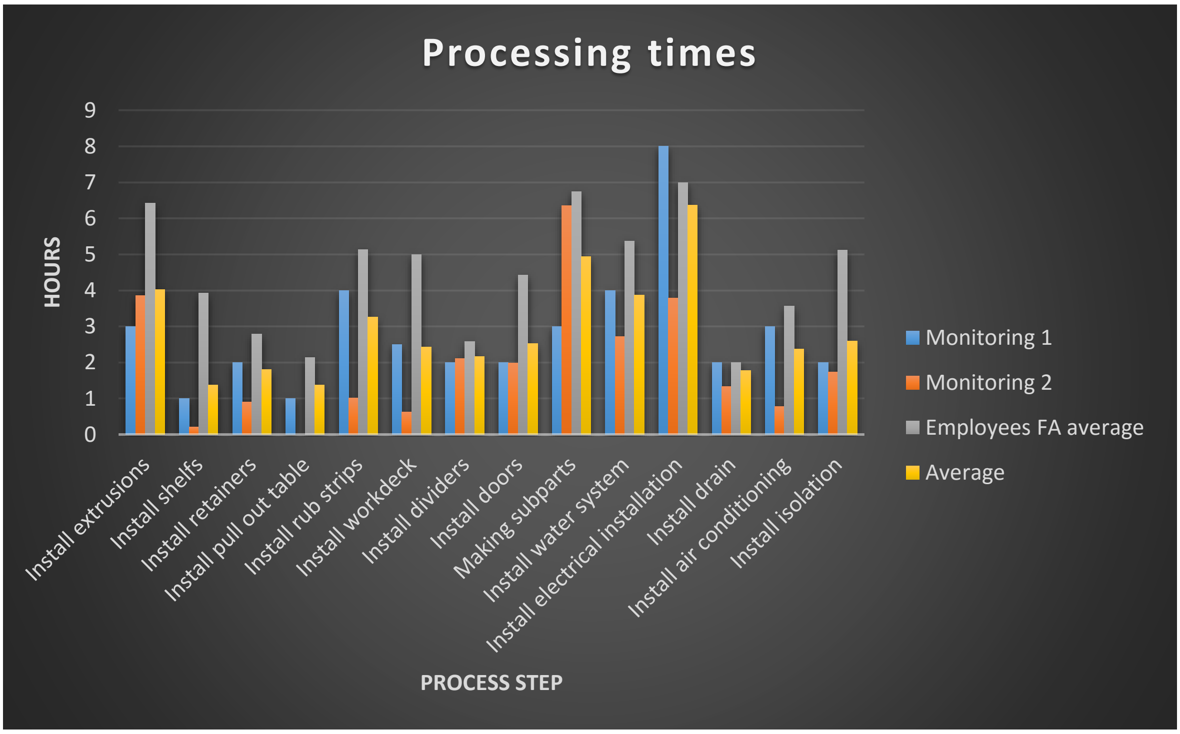


Figure A: Overview measured processing times

We use weight factors to calculate the average processing times. We use the AHP method to determine the weight factors. The first step is to define the criteria where we want to judge the measurements on. Figure B gives the criteria we use to prioritise the measurements.

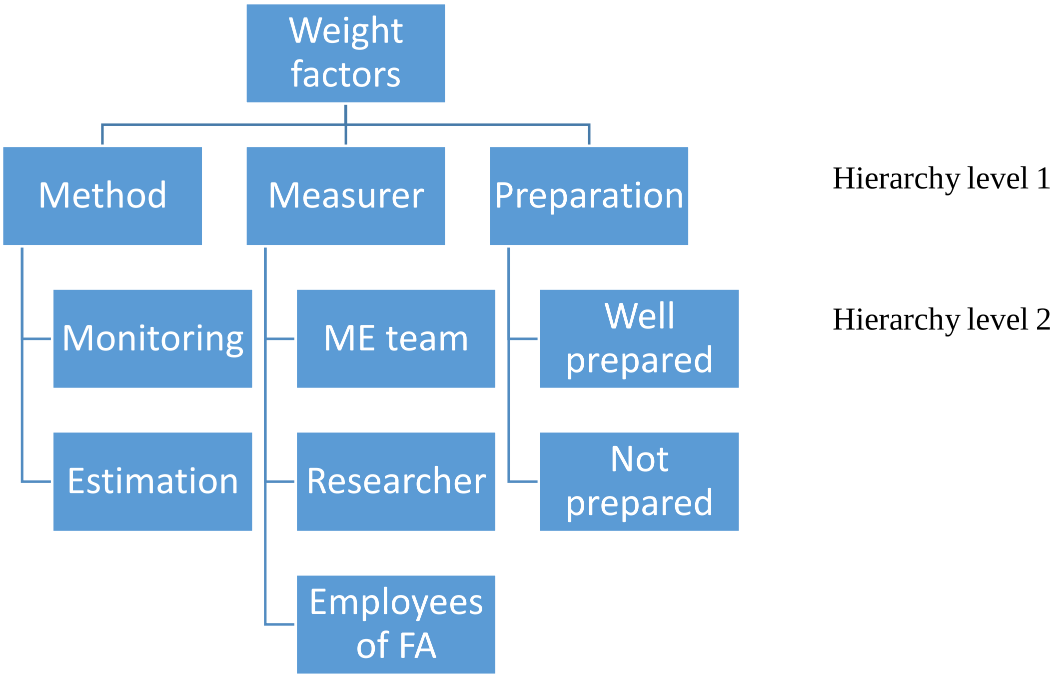


Figure B: prioritisation criteria

Together with the manager of the ME team we have judged the level of dominance of one criterion over another criterion with the AHP scale. The AHP scale is an absolute scale of numerical values:

(1) equal dominance;
(3) moderate dominance;
(5) strong dominance;
(7) very strong dominance;
(9) extreme dominance;
and the integers between for compromise (Saaty, 2013).

Tables B, C, D and E give the values of the paired comparisons determined with the manager of the ME team and an employee of the ME team. To give an example, in Table B the method is 4 times more important than who measured the data and in Table D the ME team is 2 times less precise than the researcher.

Table B: Pairwise comparison hierarchy level 1

Criteria	Method	Measurer	Preparation
Method	1.00	4.00	2.00
Measurer	0.25	1.00	0.25
Preparation	0.50	4.00	1.00

Table C: Pairwise comparison Method

Method	Monitoring	Estimation
Monitoring	1.00	6.00
Estimation	0.17	1.00

Table D: Pairwise comparison Measurer

Measurer	ME-team	Researcher	Employees FA
ME-team	1.00	0.50	3.00
Researcher	2.00	1.00	5.00
Employees FA	0.33	0.20	1.00

Table E: Pairwise comparison Preparation

Preparation	Well prepared	Not prepared
Well prepared	1.00	0.11
Not prepared	9.00	1.00

With the values of the pairwise comparisons we calculate the weight of each criterion. First, we calculate the weight of the hierarchy level 1: method, measurer and preparation, see Tables F and G for the calculations.

Table F: Summation of the values of pairwise comparison hierarchy level 1

Criteria	Method	Measurer	Preparation
Method	1.00	4.00	2.00
Measurer	0.25	1.00	0.25
Preparation	0.50	4.00	1.00
Sum	1.75	9.00	3.25

Table G: Determination weight hierarchy level 1

Criteria	Method	Measurer	Preparation	Weight
Method	1.00/1.75= 0.57	4.00/9.00= 0.44	0.62	(0.57+0.44+0.62)/3 * 100%= 54.4%
Measurer	0.14	0.11	0.08	11.0%
Preparation	0.29	0.44	0.31	34.6%

For the second hierarchy level we translate the pairwise comparison values to the measurements. If we look at Table H monitoring 1 is 6 times better than employees FA, the pairwise comparison value out of Table C (monitoring against estimation). Then again we take the sum of the columns and use the calculations from above, see Tables H and I.

Table H: Summation of values of pairwise comparison Method

Method	Monitoring 1	Monitoring 2	Employees FA
Monitoring 1	1.00	1.00	6.00
Monitoring 2	1.00	1.00	6.00
Employees FA	0.17	0.17	1.00
Sum	2.17	2.17	13.00

Table I: Determination weight hierarchy level 2

Method	Monitoring 1	Monitoring 2	Employees FA	Weight
Monitoring 1	1.00/2.17= 0.46	0.46	0.46	(0.46+0.46+0.46)/3 * 100%= 46.2%
Monitoring 2	0.46	0.46	0.46	46.2%
Employees FA	0.08	0.08	0.08	7.7%

We do this in the same way for the other criteria measurer and preparation. This gives the following weights for hierarchy level 2, see Table J.

Table J: Weight values hierarchy level 2

Weight hierarchy level 2 (%)	Method	Measurer	Preparation
Monitoring 1	46.2	30.9	47.4
Monitoring 2	46.2	58.1	5.3
Employees FA	7.7	11.0	47.4

With these weights we can calculate the weights factor for each measurement that we use to calculate the average processing times. We multiply the weight factor of hierarchy level 2 of a measurement with the criteria weight factor of hierarchy level 1 for each criterion of hierarchy level 1 and sum these outcomes. For monitoring 1 we gain the following equation:

$$Weight\ factor\ monitoring\ 1 = 46.2\% * 54.4\% + 30.9\% * 11.0\% + 47.4\% * 34.6\% = 44.9\%$$

We do this for each measurement, Table K gives the outcomes.

Table K: Weight factor per measurement

Measurement	Weight factor
Monitoring 1	44.9%
Monitoring 2	33.3%
Employees FA	21.8%

Then the average processing time is calculated as follows, ‘Install extrusions’ is taken as an example here:

$$Average\ processing\ time = 0.449 * 3 + 0.333 * 3.9 + 0.218 * 6.4 = 4.0\ hours$$

C. Establishment of the stakeholder analysis

The stakeholder analysis starts with making an overview of all persons/groups that will be affected by this research. Secondly, we estimate the influence of these stakeholders (power). Thirdly, we also estimate the interest of the affected stakeholders. Table L gives the affected stakeholders and the reasoning of their scores in Section 3.2.

Table L: Stakeholders scores

Stakeholder	Power	Interest
Director Operations	High: decides which improvements will be implemented	High: goal is to decrease the lead time, which can be obtained with this research
Manager ME team	High: needs to manage the implementation of the solution	High: goal is to decrease the lead time, which can be obtained with this research
ME team	Mid: needs to implement the solution well, but cannot decide to stop the implementation	High: wants to improve the production processes and needs to implement the solution
Employees of FA	Low: will not decide if the results of the research will be implemented	High: outcome will influence their way of working directly
General Manager	High: decides which improvements will be implemented	Low: not close to the project, delegated to Director Operations
Director Lean	Mid: the outcome must fit within the lean principles	Low: not close to the project, will not be influenced directly only when the outcome does not fit within the lean principles
Employees Planning	Low: will not decide if the outcome of the research will be implemented	Low: will not be influenced directly, but outcome can result in small changes for example the planned duration for FA
Employees Warehouse	Low: will not decide if the outcome of the research will be implemented	Low: will not be influenced directly, but outcome can result in small changes for example when to deliver the components
Employees Subassembly	Low: will not decide if the outcome of the research will be implemented	Low: will not be influenced directly, but outcome can result in small changes for example when to deliver the semi-finished products

D. Elaboration of 7s model for ZGEU

Shared values

The vision of ZGEU is: “be the preferred business partner for galleys and monuments, be recognized as the leader and the pioneer in our business and be a company of commitment and well-being” (ZGEU, 2014, slide 4). To achieve this vision ZGEU has the following mission:

- “deliver added value to the customers throughout the aircraft industry value chain;
- provide reliability and quality in everything ZGEU does;
- bring innovation to the customers to be their long term preferred partner;
- continuously strive for cost leadership to generate superior profitability on the market;
- strive for excellence through development of ZGEU’s people to their ultimate potential;
- create an open and safe environment where people can go for it and enjoy” (ZGEU, 2014, slide 4).

According to the director of Operations, ZGEU will produce more products in the plant of Tunisia in ten years. The production processes panel preparation and bonding will be completely outsourced to the plant in Tunisia. The process final assembly will still be in the Czech Republic. The general manager of ZGEU states that they have to keep protecting ZGEU’s market share the coming years, by staying best in class by increasing the capability of its products.

Further, the Zodiac Group values are “humility, realism, an entrepreneurial spirit and respect” (ZGEU, 2014, slide 4). The behaviour values are “communicate, cooperate, commitment = commitment, go for it and enjoy” (ZGEU, 2014, slide 4). The business culture within ZGEU is, according to the director of Operations, still closed and formal. Nevertheless ZGEU tries to create a more open culture, top-down and down-top. An obstacle is the number of hierarchical levels in the organisation structure. The general manager agrees with the director of Operations, but also states that the openness to ZGEU’s customers is high and the openness to its suppliers is mediate.

Strategy

The strategy of the Zodiac Group is to increase the sales and operation capacity. For ZGEU this strategy means that it has to protect its current market share by keeping performing on the KPIs: on time delivery, cost and quality. A threat currently is that the supply chain strategy of Airbus, ZGEU’s main customer, wants to have double source suppliers. This means ZGEU will lose market share because it is now the only supplier of galleys to Airbus. Thus, ZGEU needs to outperform its competitors. Therefore, the strategy of the operation department is to create an alignment between the plant in Tunisia and the plant in the Czech Republic and reducing the lead time of the production process. This leads to better performance on the requested KPIs and increases operation capacity.

The general manager communicates the strategy for the coming 1-2 years every 2-3 months within a meeting with all employees. The general manager then also shows the current status of the company and gives the opportunity to have an open discussion with the employees.

Structure

The structure of the organisation is mainly functional, as shown in the organisation chart in Figure C (ZGEU, 2015d). The employees are located by department. The sizes of a section differs per department. On middle management level, on average 20 employees are under one manager. The current structure of the company ensures that the lines between management and middle management are short, this encourages communication and collaboration among the various levels of the organisation. This is also encouraged by the weekly or daily meetings on different levels in the organisation. At the department of Operations, for example, there is a daily TOP 5 meeting. Here all the managers within the Operation department present their key performance indicators (KPIs). Besides, a manager can share the issues he is dealing with currently. Then the other managers can give input to solve the issue. Further, there is a management meeting on top management level every month. Here all heads of the different departments each show the status of their department. Here, input of the other participants is encouraged as well. On an even higher level, there is a meeting every quartile with a CEO of the Zodiac Group, of course on a monthly basis the status of the subsidiary is send through. All these kind of meetings are supporting the collaboration between departments.

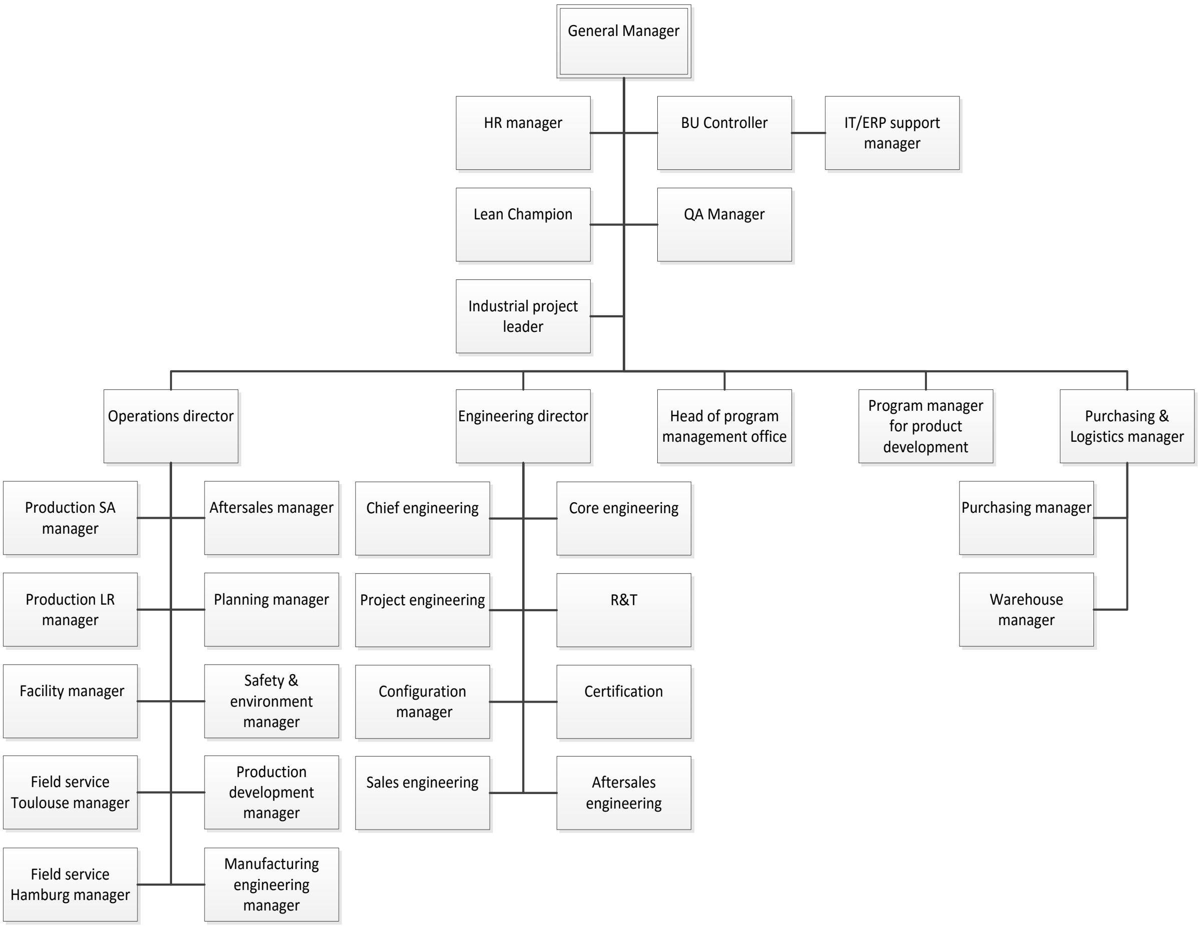


Figure C: Organisation chart (ZGEU, 2015d)

Table M: Organisation structures according to Mintzberg (Marcus & Van Dam, 2009)

Configuration	Contingencies/ situational factors	Design parameters	Coordination mechanism	Culture
Simple structure	Environment: simple, turbulent Technical system: simple, not regulating Age: young Size: small	Task-, function specialisation; not present. Formalisation of behaviour is not an issue. Few organisational units and when they exist, they are small. Systems for planning and control are barely present. Strong centralisation.	Direct supervision	Power culture
Machine bureaucracy	Environment: simple, stable Technical system: regulating, not automated Age: old Size: big	Formalisation of behaviour, vertical and horizontal specialisation of tasks, functional alignment, big operating units, vertical centralisation and limited horizontal decentralisation, action planning	Standardisation of work processes	Role culture
Professional bureaucracy	Environment: complex, stable Technical system: not regulating, not high quality Age: divers Size: divers	Training, horizontal specialisation of tasks, vertical and horizontal decentralisation. Functional- and market alignment.	Standardisation of skills	Person culture
Divisionalised structure	Environment: diversified markets Technical system: - Age: old Size: big	Market alignment, systems for monitoring results, limited vertical decentralisation	Standardisation of outputs	-
Adhocracy	Environment: complex, dynamic Technical system: advanced, automated Age: young Size: depends on project	Connection, organisational structure, selective decentralisation, horizontal specialisation of tasks, training, combined functional and market alignment.	Mutual adjustment	Task culture

In accordance with the theory of Mintzberg (Marcus & Van Dam, 2009), see Table M, ZGEU is an adhocracy and a little bit a machine bureaucracy organisation. This is because ZGEU has the following organisational characteristics:

- The product of ZGEU is a complex product, it is difficult to make and the product needs to be of high quality.
- The market is stable, because the customers' requirements are not changing frequently.
- Within ZGEU some meetings take place at fixed moments with fixed group, but communication can also be stepping by the office of an employee.
- In the organisation the different types of decisions are selective decentralised.
- Training programs and courses are held to upgrade the skills of the staff.
- The structure of the organisation is mainly functional. Within this functional group there is also a market oriented alignment.
- The behaviour in the organisation is going toward formal, the work that has to be done is more and more described in procedures and guidelines.
- Coordination mechanisms, within ZGEU, are standardisation of output and mutual adjustment. But it goes toward standardisation of work processes within the production.
- The culture at ZGEU is characterised as a task culture, task oriented and focused on results.

All the above mentioned organisational characteristics suggest that ZGEU is a configuration adhocracy and a little bit a machine bureaucracy.

Systems

The main information system ZGEU uses is an ERP system. From this system, departments can retrieve the information they need. Each department knows the date of delivery of a project to the customer this way and they can anticipate on that. Further, information is stored on the drives of the intranet of ZGEU, where everyone of ZGEU can search on.

Style

Important decisions are discussed in the monthly meetings with the directors of all departments and the general manager. In this meeting the directors will inform the other departments about the status of their department and the internal matters of the department. The directors communicate the important information to his department. Further, the director or a manager communicates directly to an employee if there are any questions or if it relates to personal information.

The general manager states that the hierarchy is still important in the organisation. He wants to create a bottom-up approach instead of top-down. He wants to do this by 'show by example'. Further, it is possible to give workshops where employees can give their opinions, which can motivate the employees too.

According to the director of Operations, the leadership style is democratic, "involve others in deliberations and arrive at decisions through majority rule" (Trask, Rice, Anchors & Lilieholm, 2009, p.30). The director of Operations gives tasks to the managers, the managers can choose themselves how they fulfil their tasks. Input from other managers can be gained during meetings like the TOP 5. The director of Operations wants to coach instead of obligate his employees and encourages teamwork within the department. For changes within the organisation the director needs to use the top-down approach, authoritarian leadership, "makes all of the decisions" (Trask et al., 2009, p.30). He then needs to push the change into the organisation, because the nature of people is to turn down changes at first. When the employees see the benefits of the change, the director switches back to the democratic leadership style.

Staff

The employees in the department of Operations differ from educational backgrounds. Employees on the shop floor need to be very practical and think logical to build the galley. Managers need to be result orientated, following the budget and their KPIs. ZGEU gives each employee the possibility to grow in the organisation. An employee can ask for a training but it is also possible that the supervisor of the employee proposes a training to improve his skills. Which training is eligible to the employee depends on the competence and character of the employee.

The opinion of the director of Operations about how to commit the employees, is not only offering the right salary, but also creating a good social environment at the workplace. This can be done by keeping, for example, an open day where employees can bring their family and have a drink with colleagues. It does not always have to be about work.

Skills

Of course, knowledge about the ins and outs of a galley is necessary for being successful in the market. Furthermore, it is important to know the customer requirements to adapt to this.

In this industry ZGEU needs reactive and cautious people who are interested in their work and the product. The interest will automatically lead to a better performance of their job. People need to be reactive to occurring problems, like a shop floor worker, who needs to be able to work on all types of galleys. Further, ZGEU prefers caution because a galley is an expensive product. This is really important at the shop floor because there is a lot of movement with and around the galleys.

E. Quantification of causes

First, Table N gives the scores of all respondents separated and the total scores.

Table N: Scores given by respondents

	Employees FA														ME team		ME team manager	SA manager	Operations director		
Cause/ Repondent	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	**Total**	**Precentage**
Not all tools are present														5						5	0.3%
Need more advanced tools												5		1						6	0.3%
Missing parts from warehouse	40	40	15	40	40	20	20	30	30	20	20	30	40	20	20	10		40		475	25.0%
Missing parts from subassembly		30		40	20					10	20	30	10	2	10	10		40	20	242	12.7%
Wrong parts from warehouse	40	20			10	40	40	30	30	40	30	30		2	10	20		10		352	18.5%
Car with parts of warehouse is not structured					20							3		3	10	5	30	10	20	101	5.3%
Materials do not fit directly		10	50	20		40	40	30	40	20	20	2		5	10	40				327	17.2%
Structure first filed before start assembly										10	10			5		5			10	40	2.1%
Semi-finished product made at FA														2		5				7	0.4%
A lot unnecessary repeated handlings														10						10	0.5%
Harding takes a lot of time														5	10	5				20	1.1%
Process steps are not standardised														6			50			56	2.9%
One employee for structure galley					10									6						16	0.8%
One employee for systems galley														6			20			26	1.4%
Different skills														3						3	0.2%
A small cell per galley	20		35										10	3						68	3.6%
A lot of movements														5					20	25	1.3%
Missing feedback loop													30	3	10				10	53	2.8%
No detailed planning for process steps of FA													10	3	20					33	1.7%
Cannot proceed because of sealing								10						5					20	35	1.8%

Second, Table O gives the estimated time of delay of the causes, that are possible to measure in time, per respondent.

Table O: Estimated time of delay by employees of FA

Cause/ Respondent	1	2	3	4	5	6	7	Average	STDV
Structure assembly									
Not all tools are present	3	3	1	3	3	2	2	2.3	0.745
Missing parts from warehouse	5	8	5	8	16	8	8	7.0	1.414
Missing parts from subassembly	5	8	5	8	16	8	8	7.0	1.414
Wrong parts from warehouse	5	4	3	4	20	5	4	4.2	0.687
Materials do not fit directly	4	2	3	4	5	5	5	3.8	1.067
Structure first filed before start assembly	1	8	8	8	4	3	10	6.3	3.197
Systems assembly									
Not all tools are present	2	2	2	0.5	1	0.5	1	1.3	0.687
Missing parts from warehouse	2	8	4	2	4	4	0.5	4.0	2.000
Missing parts from subassembly	4	8	4	4	4	4	1	4.7	1.491
Wrong parts from warehouse	2	4	3	2	3	3	0.5	2.8	0.687
Materials do not fit directly	2	4	3	2	3	3	1	2.8	0.687

We eliminate respondent 5 from structure assembly and respondent 7 of systems assembly because the time estimations are extreme compared to the others and that will have a negative influence to a representative average.

F. Underlying causes 'parts are damaged during process of FA'

- Employees of FA cannot find parts on the car (50%). Employees are moving the parts on the car a lot when they are searching for another part. By moving them they damage parts.
- Damaged during the disassembly of parts because the parts do not fit directly (5%). Because the parts do not fit directly the employees file the extrusions, which also can cause damages on the parts.
- Employees damage parts because of the small space around and in the galley to assemble parts (5%). For example, during the installation of a door the employee touches the other side with the screwdriver and them damage an extrusion or divider.
- Tools are not advanced enough (10%). Figure D gives an example of this cause. During drilling the extrusions on the galley can get damaged. ZGEU has some specific tools but there are not enough pieces of it for the entire production.

Figure D: Tools are not advanced enough

- Employees do not assemble according to the drawings (20%). Employees assemble the galleys from experience. Therefore, if engineering changes something in the drawings a lot of employees do not notice the change and assemble like they have done before. For example, the employees of FA drill a hole on the wrong place or assemble the mirror on the wrong place.
- Employees do not use protection material for the parts (10%). For some parts ZGEU has extra protection material which the employees must use during the assembly of these parts. But most employees do not use this protection material, because they see this as a waste of time.

G. Activities FA

Table P gives an overview of which process steps a kit contains. The kits N, O, P, Q, R, S and T are customer specific. A customer can choose whether he wants these kits or not, even when he orders a catalogue galley. The assembly time of these parts is just 30 minutes in total, these kits just need to be pasted on the galley. Therefore, these kits cannot be appointed to a process step which we defined in Chapter 2. Further, these kits will always be assembled at the end of the process of FA, after the entire decoration is done. Because of that we do not take them into account for the possible sequences of the process of FA. Remark that the process step isolation is not linked to a kit. This activity can only be done when all water and drain systems are installed.

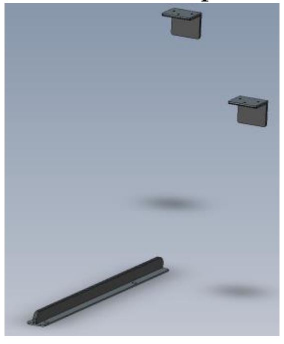
Table P: Process steps per kit

Project 601850-001801																
		Process step	Extrusions	Shelfs	Retainers	Pull out table	Rub strips	Work deck	Dividers	Doors	Subparts	Water system	Electrical installation	Drain	Air conditioning	Isolation
Kit		Description														
A	263101-11	Container														
B	263103-221	Oven kit 2x														
C	263105-61	Beverage maker/ espresso/water heater														
D	263106-21	Beverage maker/ espresso/water heater														
E	263107-31	Ice drawer														
F	263108-81	Misc stowage														
G	263109-71	Trolley installation														
H	263113-41	Waste bin														
I	263115-11	Air intrusion system														
J	263116-41	No steam oven provision														
K	263117-31	Work deck														
L	263119-11	Pull out table														
M	608850-1121	Electrical panel														
N	263118-111	Pallet installation														

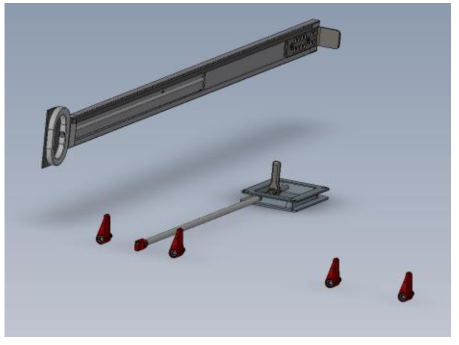
O	263120-11	Paperclip														
P	263120-21	Bottle opener														
Q	263120-61	Mirror														
R	263120-91	Document holder														
S	263121-111	Bumper														
T	691850-1811	Placard installation														
U	691850-1811	Customization kit (protection)														

Below, we give illustrations of the parts that get assembled during an activity, an activity is a process step of a kit.

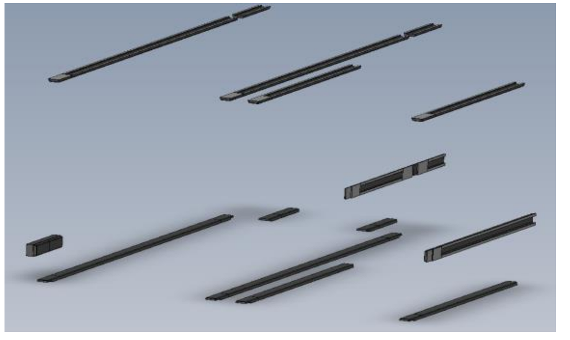
A- Extrusions/ profiles



A- Retainers

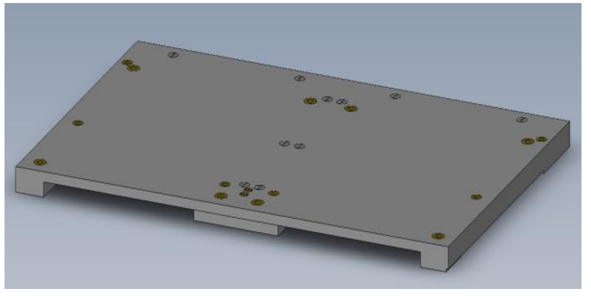


A- Rub strips/ filters

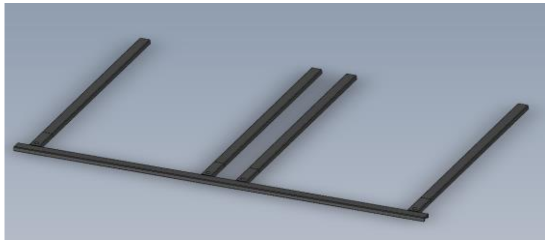


B- Extrusions/ profiles

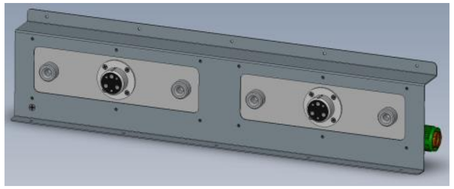
B- Shelf



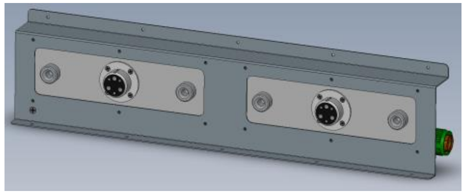
B- Rub strips/ fillers



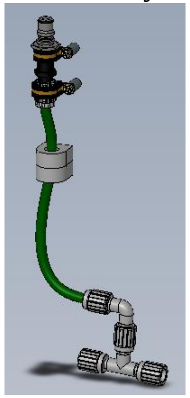
B- Subpart



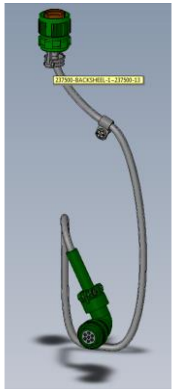
B- Electrical installation



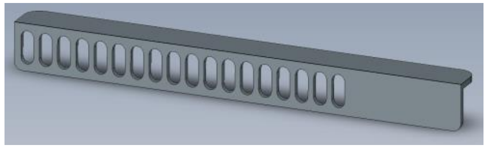
C- Water system



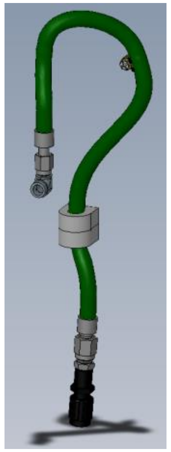
C- Electrical system



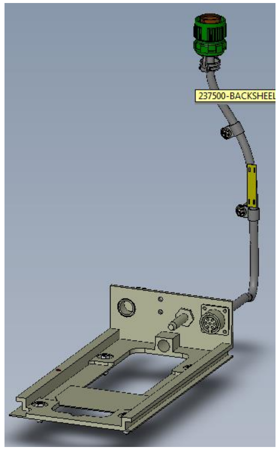
C- Extrusions/ profiles



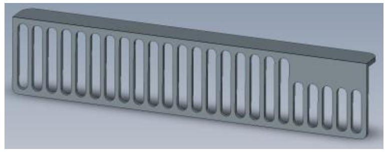
D- Water



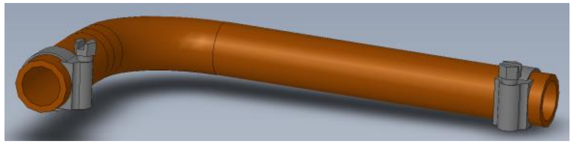
D- Electric



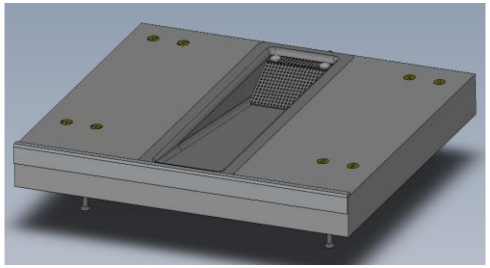
D- Extrusions



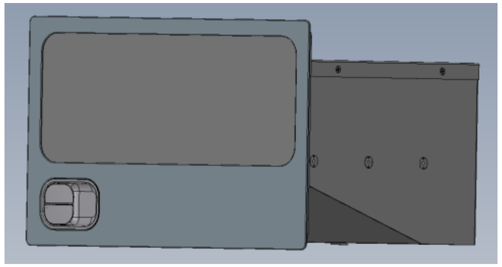
E- Drain



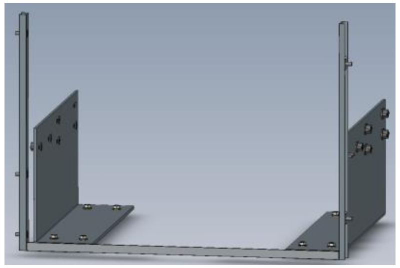
E- Shelf



E- Door

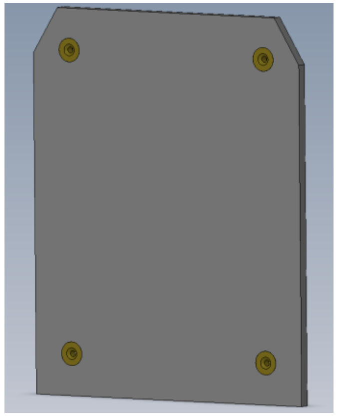


E- Extrusions

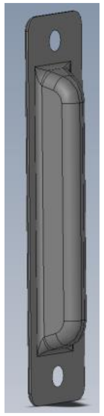


E- Retainers

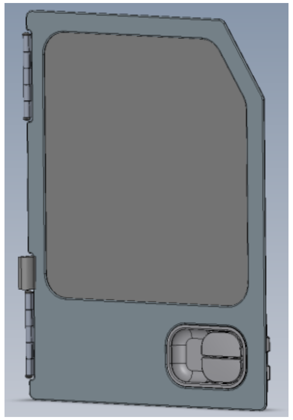
F- Divider



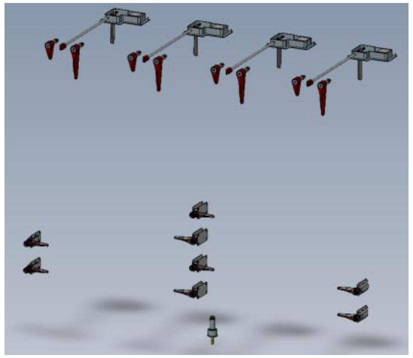
F- Retainer



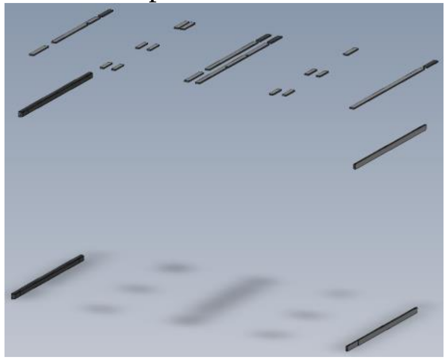
F- Door



G- Retainers

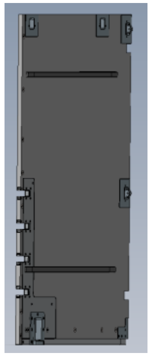


G- Rub strips

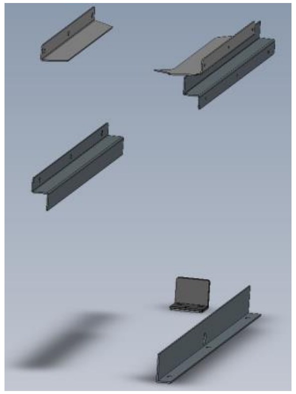


G- Extrusions

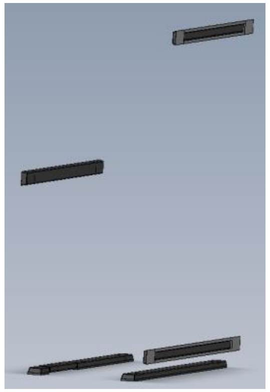
G- Divider



H- Extrusions

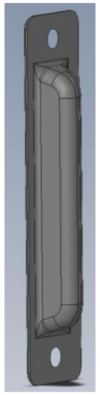


H- Rub strips

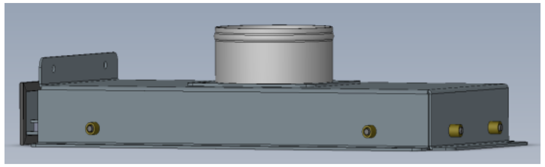


H- Door

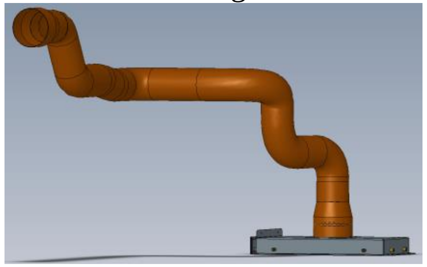
H- Retainer



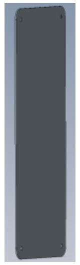
I- Subpart



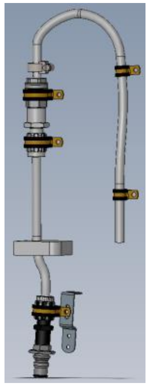
I- Air conditioning



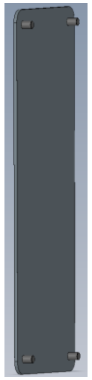
I- Extrusions



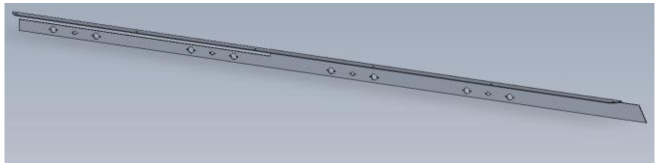
J- drain



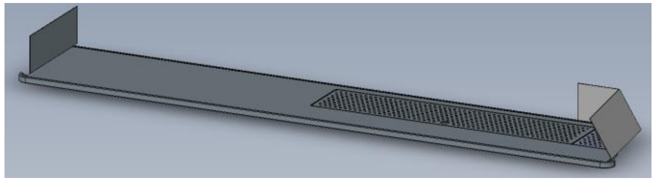
J- Extrusion



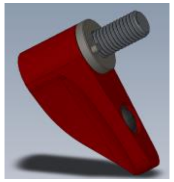
K- Extrusion



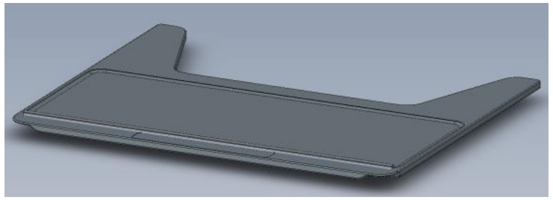
K- Work deck



K- Retainer

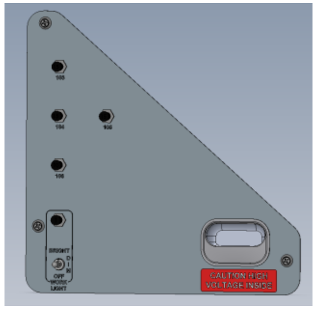


L- Pull out table



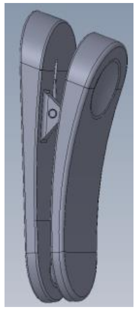
L- Retainers

M

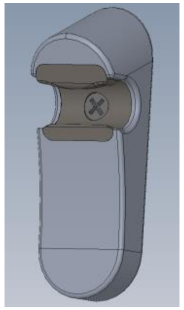


N

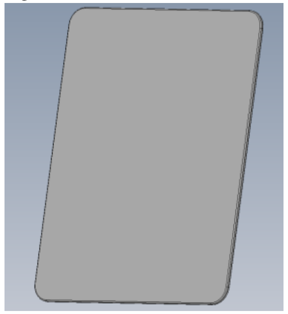
O



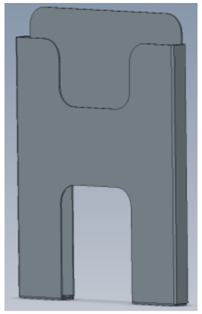
P



Q



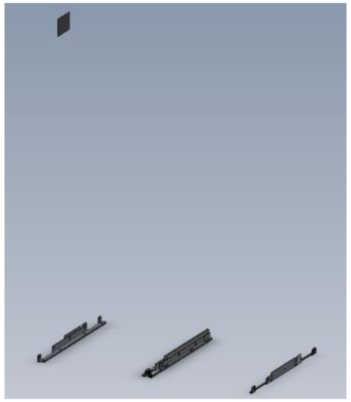
R



S

T

U- Extrusions



U- Rub strips

H. Processing times activities FA

Table Q gives the processing times of all activities at FA in minutes. The processing times of the activities are estimated by the team leaders and the production supervisor. The total processing times of a process step, determined in Section 2.3, is divided over the activities to determine the process time of one activity. For example, installing all shelfs of the galley takes 1.4 hours, by estimation the activity install shelf of oven kit takes 48 minutes and install shelf of ice drawer takes 36 minutes.

Table Q: Processing times activities FA

Process	Kit	Processing time (min)
Install extrusions/ profiles	Container	10
	Oven kits	25
	Beverage maker C	5
	Beverage maker D	5
	Ice drawer	20
	Trolley installation	90
	Waste bin	21
	Air intrusion system	2
	No steam oven provision	3
	Work deck	27
	Customization kit	32
Install shelfs	Oven kits	48
	Ice drawer	36
Install retainers	Container	20
	Ice drawer	15
	Misc stowage	5
	Trolley installation	48
	Waste bin	5
	Work deck	5
	Pull out table	10
Install pull out table	Pull out table	84
Install rub strips/ fillers	Container	60
	Oven kits	28
	Trolley installation	75
	Waste bin	25
	Customization kit	10
Install work deck	Work deck	144
Install dividers	Misc stowage	25
	Trolley installation	107
Install doors	Ice drawer	105
	Misc stowage	15
	Waste bin	30
Making subparts	Oven kits	124
	Air intrusion system	60
	Electrical panel	110
Install water systems	Beverage maker C	115
	Beverage maker D	119

Install electrical systems	Oven kits	45
	Beverage maker C	15
	Beverage maker D	24
	Electrical panel	300
Install drain	Ice drawer	28
	No steam oven provision	80
Install air conditioning	Air intrusion system	144
Install isolation	-	156

I. Tool change times FA

Table R gives the tool change times between the processes of FA. We assume that the tool change times are symmetric. The tool change times are estimated by the team leaders and the production supervisor.

Table R: Tool change times FA

Tool change time (min)	Install extrusions	Install shelfs	Install retainers	Install pull out table	Install rub strips	Install work deck	Install dividers	Install doors	Making subparts	Install water systems	Install electrical installations	Install drain	Install air conditioning	Install isolation
Install extrusions	-	5	5	5	5	10	0	0	5	5	5	5	5	5
Install shelfs	5	-	3	0	5	3	0	0	3	5	5	5	5	5
Install retainers	5	3	-	5	5	5	5	5	5	5	5	5	5	5
Install pull out table	5	0	5	-	5	3	5	0	5	3	3	3	3	5
Install rub strips	5	5	5	5	-	5	5	5	5	5	5	5	5	5
Install work deck	10	3	5	3	5	-	5	3	5	5	5	5	5	5
Install dividers	0	0	5	5	5	5	-	3	3	3	3	3	3	5
Install doors	0	0	5	0	5	3	3	-	5	3	3	3	3	5
Making subparts	5	3	5	5	5	5	3	5	-	5	5	5	5	5
Install water system	5	5	5	3	5	5	3	3	5	-	3	3	3	5
Install electrical installation	5	5	5	3	5	5	3	3	5	3	-	3	3	5
Install drain	5	5	5	3	5	5	3	3	5	3	3	-	3	5
Install air conditioning	5	5	5	3	5	5	3	3	5	3	3	3	-	5
Install isolation	5	5	5	5	5	5	5	5	5	5	5	5	5	-

J. Number of decision variables and constraints

Solving the given mathematical model in Section 5.2 will result in a large run time, because of the large number of decision variables and constraints. Below we give the calculations for the number of decision variables and constraints.

Number of decision variables

When there are 45 activities and 2 employees. We have:

- 3960 (=2*45*(45-1)) times X_{eij};
- 45 times C_i;
- 1980 (=45*(45-1)) times V_{ij};
- 1 times C_{max};

This gives in total 3960+45+1980+1 = 5986 decision variables.

Number of constraints

Again we take 45 activities and 2 employees. This gives the following number of constraints per given constraint in the mathematical model of Section 5.2.

1. $\sum_{e=1}^{E}\sum_{i=0,i\neq j}^{N} X_{eij} = 1 \qquad j = 1 \dots N$
   Constraint 1 = 2*46*45 = 4140, we have 46 activities because i=0 must also be taken into account to determine the number of constraints.
2. $\sum_{e=1}^{E}\sum_{j=1,i\neq j}^{N} X_{eij} \leq 1 \qquad i = 1 \dots N$
   Constraint 2 = 2*45*(45-1) = 3960
3. $\sum_{j=1}^{N} X_{e0j} \leq 1 \qquad e = 1 \dots E$
   Constraint 3 = 2*45 = 90
4. $\sum_{h=0,h\neq i,h\neq j}^{N} X_{ehi} \geq X_{eij} \qquad i = 1 \dots N, j = 1 \dots N, e = 1 \dots E$

   Constraint 4 = 2*45*(45-1) = 3960
5. $C_j + M\left(1 - \sum_{e=1}^{E} X_{eij}\right) \geq C_i + p_j + t_{ij} \qquad i = 0 \dots N, j = 1 \dots N, i \neq j$
   Constraint 5 = 2*45*(45-1) = 3960
6. $(C_j - C_i) * Y_{ij} \geq p_j * Y_{ij} \qquad i = 1 \dots N, j = 1 \dots N, i \neq j$
   Constraint 6 = 45*(45-1) =1980
7. (1) $Z_{ij}\left(-C_i + C_j\right) \leq M(1 - V_{ij}) \qquad i = 1 \dots N, j = 1 \dots N, i \neq j$
   (2) $Z_{ij}(-C_j + C_i) \leq MV_{ij} \qquad i = 1 \dots N, j = 1 \dots N, i \neq j$
   (3) $Z_{ij}\left(1 - V_{ij}\right)(-M) \leq \left(C_i - C_j - p_i\right) \qquad i = 1 \dots N, j = 1 \dots N, i \neq j$
   Constraint 7 = 3*45*(45-1) = 5940
8. $C_i \geq 0 \qquad i = 1 \dots N$
   Constraint 8 = 45
9. $C_{max} \geq C_i \qquad i = 1 \dots N$
   Constraint 9 = 45

This gives in total 4140+3960+90+3960+3960+1980+5940+45+45 = 24120 constraints.

K. Influence parameters

In the model we can set two parameters, 'number of iterations' and 'number of employees'. Below we analyse the sensitivity of the outcome of the model by these parameters.

For the galley G1 601850-001801 we run the VNS heuristic several times, each time with different settings of number of employees and number of iterations. "A rule of thumb is that a modeller should always perform at least three to five replication for each experiment" (Mehta, 2000, p.103). We have done the experiments in Table S, each 5 times. For 1 employee we only do 10 iterations, because 50 iterations gives a run time of more than 10 hours. We do not go further than four employees. This is because the manager of the planning department states that working with more than four employees on one galley, has a negative effect on the lead time. Then, the employees cannot move properly around the galley anymore to grab a tool or assemble parts on the galley. For the G1 type, more than three employees is already too much, according to manager of the planning department. This is also supported by the 'Ringelmann effect', which states that by increasing the size of the group the productivity per individual decreases (Ingham, 1974).

Table S: Experimental designs

Experiment	Number of employees	Number of iterations
1	1	10
2	2	10
3	2	50
4	2	100
5	2	200
6	2	500
7	2	1000
8	3	10
9	3	50
10	3	100
11	3	200
12	3	500
13	3	1000
14	4	10
15	4	50
16	4	100
17	4	200
18	4	500
19	4	1000

Influence 'number of iterations'

Figure E gives the average completion time (lead time) of the five runs per experiment. Experiment 1 is excluded from Figures E and F, the average completion time of experiment 1 is 2552 minutes. Figure F gives the average run time of the five runs per experiment, the calculation time of the model to come up with an answer.

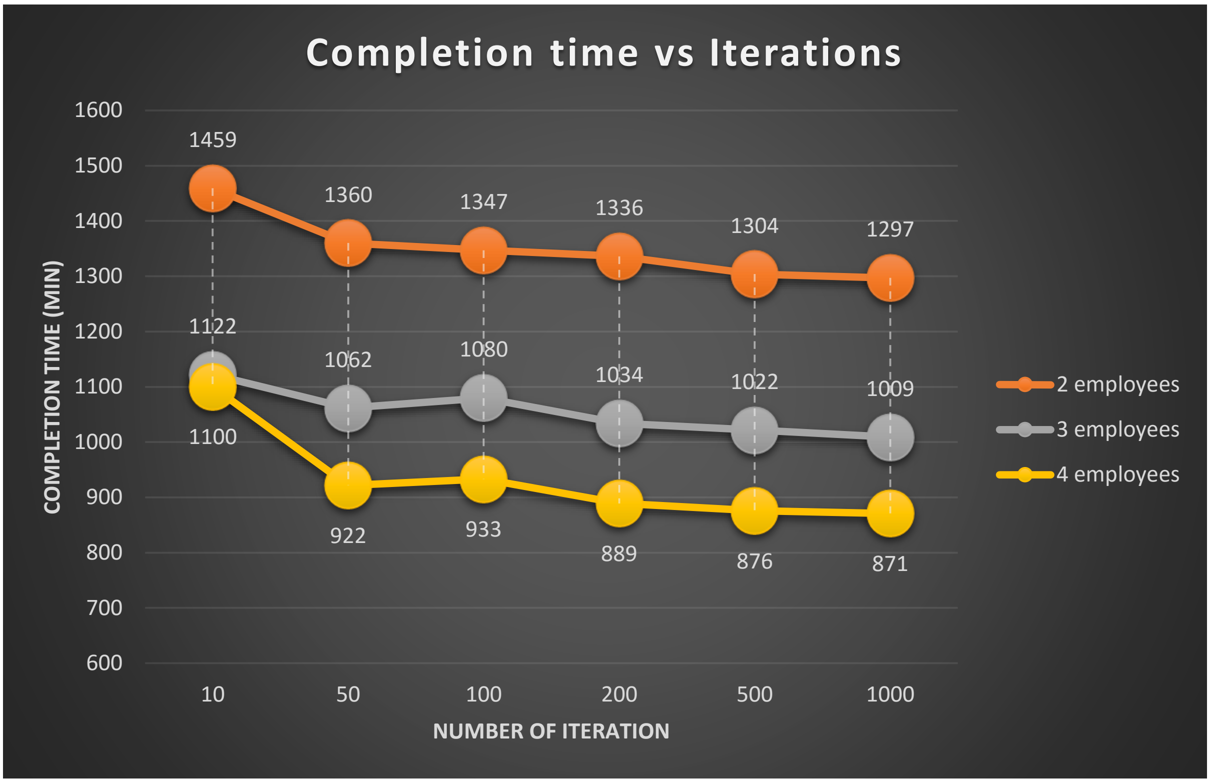


Figure E: Completion time vs Iterations

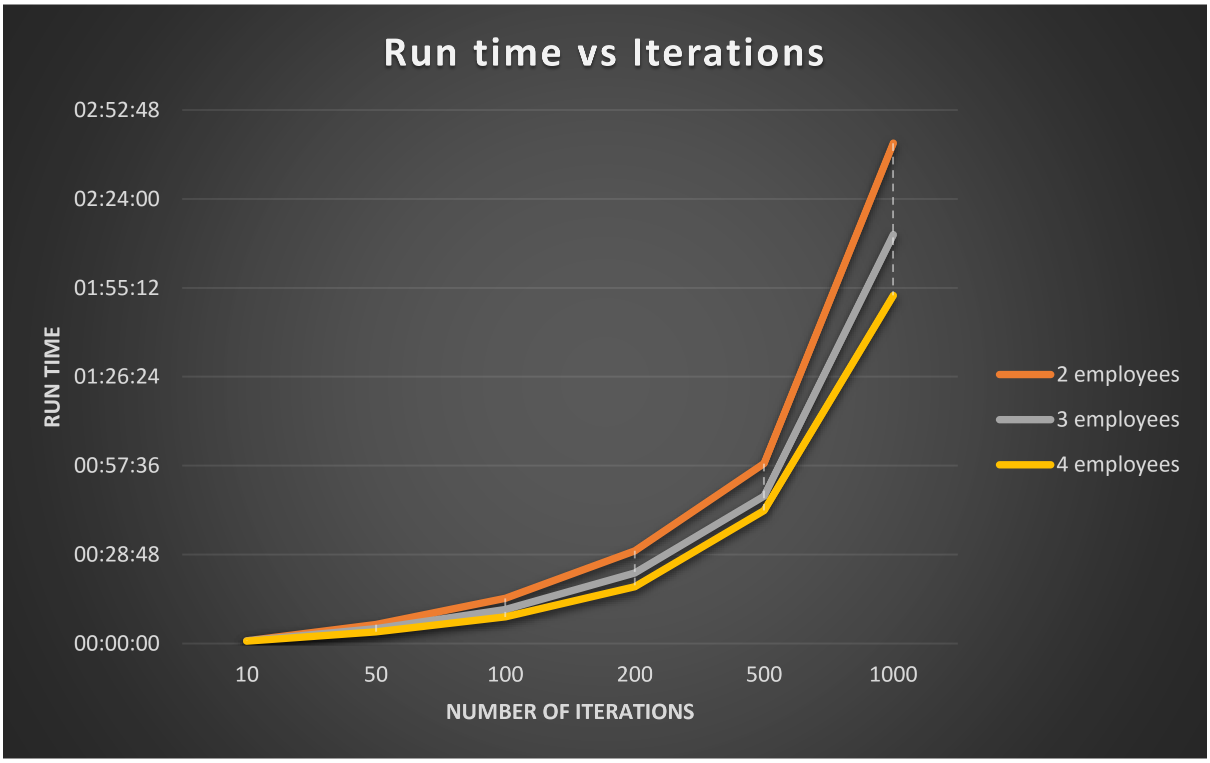


Figure F: Run time vs Iterations

The lines of 2, 3 and 4 employees follow approximately the same curve. Therefore, we can state that the parameter ‘number of employees’ does not influence the setting of the parameter ‘number of iterations’. But the parameter ‘number of iterations’ influence the outcome of the model, more iterations gives a lower average completion time. Thus, the model is sensitive for the setting of this parameter. Therefore, it is important to determine the best setting.

The gained improvement on the completion time between 200 iterations and 500 iterations is on average 20 minutes, over all settings of the parameter ‘number of employees’. The run time increases with approximately 25 minutes. The gained improvement on the completion time between 500 iterations and 1000 iterations is on average 8 minutes, over all settings of the parameter ‘number of employees’. But the run time increases with approximately 1.5 hours. Because of the small improvement of the completion time between 500 and 1000 iterations and the increase of the run time, we conclude that the optimal number of iterations is 500 for all settings of the parameter ‘number of employees’. Of course 1 employee is an exception on this. The best setting for 1 employee is 10 iterations, because of the long run time 50 iterations already results to. The VNS heuristic optimises scheduling problems with parallel machines, which can explain why it has troubles with one employee.

Influence ‘number of employees’

Below we analyse the influence of the parameter ‘number of employees’ on the outcome of the model. With more employees the completion time reduces, but the waste time increases. Figure G underpins this, we have gained the data from the model outcomes of the experiments. Thus, the outcome of the model is also sensitive for the setting of this parameter. Therefore, it is also important to determine the best setting for this parameter.

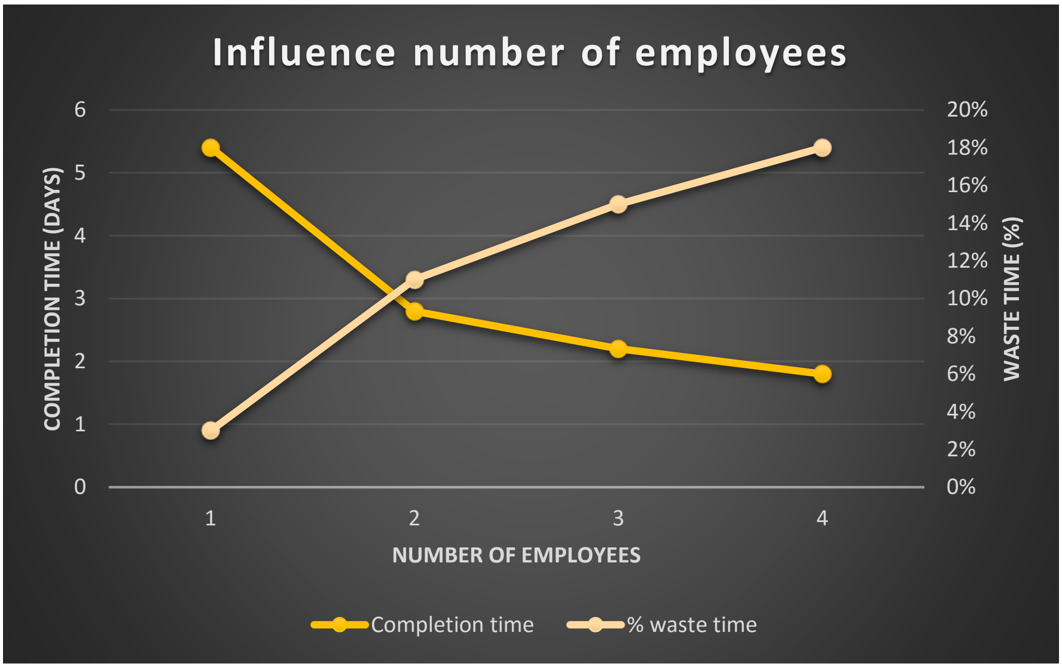


Figure G: Influence number of employees

When ZGEU adds an extra employee the waste time increases with 1 hour. According to the manager of the planning department, for the G1 galley type three employees is the maximum. Because of the small possible gain in lead time with a third employee related to the increase in the percentage of waste time and considering the space around the galley, we have chosen with ZGEU to keep working with two employees on one galley.

L. Detailed time schedule

Table T gives the detailed time schedule of the best solution sequence, which is shown in Figure 17 in Section 5.4. The red marked lines are non-added value activities, like tool change (TC) and waiting (W).

Table T: Detailed time schedule best solution sequence

Activity	Employee A	Employee B	Day	Start time (min)	Finish time (min)
	Processing time (min)				
G1	90		1	0	90
K1	27		1	90	117
H1	21		1	117	138
A1	10		1	138	148
TC	5		1		
E2	36		1	153	189
TC	3		1		
E3	15		1	192	207
TC	5		1		
E1	20		1	212	232
TC	5		1		
C10	115		1	237	352
D10	119		1	352	471
TC	5		1		
H3	5		2	476	481
L3	10		2	481	491
F3	5		2	491	496
TC	5		2		
J12	80		2	501	581
TC	3		2		
M11	300		2	584	884
B11	45		2	884	929
TC	3		2		
I13	144		3	932	1076
TC	3		3		
H8	30		3	1079	1109
I1	2		3	1109	1111
TC	5		3		
U5	10		3	1116	1126
TC	5		3		
I4	156		3	1131	1287
I9		60	1	0	60
B9		124	1	60	184
TC		5	1		
G5		75	1	189	264

TC		5	1		
G7		107	1	269	376
B2		48	1	376	424
TC		3	1		
M9		110	2	427	537
TC		5	2		
L4		84	2	542	626
TC		3	2		
E12		28	2	629	657
TC		3	2		
D11		24	2	660	684
C11		15	2	684	699
TC		5	2		
D1		5	2	704	709
C1		5	2	709	714
B1		25	2	714	739
TC		5	2		
A5		60	2	744	804
H5		25	2	804	829
TC		5	2		
F8		15	2	834	849
TC		3	2		
K6		144	3	852	996
TC		5	3		
G3		48	3	1001	1049
A3		20	3	1049	1069
TC		5	3		
J1		3	3	1074	1077
TC		5	3		
K3		5	3	1082	1087
TC		5	3		
E8		105	3	1092	1197
U1		32	3	1197	1229
F7		25	3	1229	1254
TC		5	3		
B5		28	3	1259	1287