Redesigning and modelling of a food assembly process

A case study at KLM Catering Services

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by

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Glossary

Table 1: List of terms

Term	Explanation
C class	Business class
Flow coordinators	Employee of Intercontinental who is always on the floor, a flow coordinator is responsible for the flow and they cope with small problems. There are five flow coordinators at the Intercontinental department.
I shape	Assembly line in Opdek for trolleys with C class equipment.
J shape	Assembly line in Opdek for trolleys with M class equipment.
M class	Economy class
KCS	KLM Catering Services
Marfo	External food supplier.
NT drive	If errors are found just before departure or when equipment is not produced in time a car on the platform can deliver last minute the missing parts. This car is always on the platform close to the planes with spare equipment and meals. When the situation arises that the car is necessary it is a so called NT drive.
OIS	Oven
Opdek	Opdek is the second, all equipment is delivered from the ROA and delivered to the final cooling. In Opdek all equipment is assembled.
Outstation	Location outside of Europe were catering is done for aircraft arriving at Amsterdam Schiphol Airport.
PSU	PSU (Pre set-up) is equipment which is empty. An example is a tray without food. PSU prevents outstations running out of equipment. PSU is given for each empty passenger seat.
ROA	ROA is the first department and the names stands for Return and dishes department. Distribution delivers equipment to the ROA, ROA sends equipment to Opdek. In ROA all equipment is sorted, emptied and washed.
Schiphol Centre	Production location of KCS, twelve times a day products are delivers from Schiphol North to Schiphol Centre.
Schiphol North	Storage location of KCS, almost all products go via Schiphol North. Twelve times a day a truck goes from Schiphol North to Schiphol Centre.
Shiftleader	Coordinator of the Intercontinental department, there are three shiftleaders in each team.
Skid	Used in ovens, it is a drawer with holes in it. Food is placed on the skids of an oven.
SQC	Type of container.
STC	Type of container.
T11	Type of trolley, twice as large as T12 trolley.
T12	Type of trolley, twice as small as T11 trolley.
Trolley	Piece of equipment which goes into planes. In trolleys trays and equipment is stored.
VLAS	Assembly station in Opdek were all types of equipment are assembled, trolleys with M class and C class trays excluded.
VSM	Value stream map

Summary

Define KLM Catering Services (KCS) cater flights of KLM, some foreign airlines departing from Amsterdam Schiphol Airport and some KLM flights departing in a foreign country and arriving at Amsterdam Schiphol Airport. This research focuses only on the Dutch assembly. KCS has three assembly departments at Amsterdam Schiphol Airport, namely for KLM flights with a destination in- and outside Europe and for non KLM companies. Only the food flow for KLM flights from Schiphol Airport to a destination outside of Europe is discussed in this paper. KCS strives for on time deliveries with zero errors. Errors are divided into errors noticed before departure and errors noticed after departure. Errors noticed before departure are solved by delivering the missing parts. There is a target with a maximum 15 errors noticed before departure per week. Half of the times information is missing from complains noticed after departure, with this missing information the cause can not be determined. Therefore it is chosen to look only at the complaints noticed before departure. The department also has a high number of employees who are incapacitated to work. From 2015 to 2017 this percentage varied between 10% and 15%. With this in mind, it is stated that there is a gap between the desired performance and the current performance. It is not clear what drivers influence this gap and how the performance can be improved. The aim of this research is to design a framework to optimize the processes of food assembly and subsequently apply the framework to increase the throughput time at the intercontinental department of KLM Catering Services. The main research question is stated as following; How can the assembly process of KLM Catering Services be optimized in order to improve the throughput time?

Lean, TIMWOODS, 5s, theory of constraints, critical path and swimlane are described in literature to analyze performance. Also Delft Systems Approach and conceptual modelling are described in literature as tools how models can be created.

Measure The food department has 63 employees and three stages, being ROA, Opdek and final cooling. All trolleys, containers and oven carriers from the planes are unloaded in the ROA. In ROA all equipment is divided into two flows, one for business class and one for economy class. The flow is further divided into type of trolley, container and oven and trolleys and even divided for specific content. All equipment is emptied on five washing machines and all equipment is washed in two trolley washing machines. In Opdek all trolleys, containers and ovens are filled with food and small equipment via four assembly stations. These station include robot and J shape for trolleys with economy class trays, I shape for trolleys with business class trays and VLAS for all other equipment types. In the final cooling all trolleys, containers and ovens are sorted by flight and the equipment is cooled. Distribution will collect trolleys, containers and ovens in the final cooling for a specific flight. All stations in ROA are measure together with J shape from Opdek. Processing times for VLAS are already known and processing time of I shape are discussed with employees.

Current key performance indicators give a global overview of the state of the department, actual performance of individual workplaces however can not be measured. For this report new key performance indicators are used. Resource key performance indicators are work in progress inventory and number of working hours. Output key performance indicators are too late delivery and throughput time.

Analyze To analyze current performance for each workstation it is chosen to measure in number of trolleys, containers and ovens. The total number of trolleys, containers and trolleys for each day in September is given in Table 2. Differences in the amount of equipment can be seen for arriving and departing flights. A flowchart, vsm, swimlane and TIMWOODS is used to further analyze current performance.

Table 2: Equipment of arriving flights and departing flights in September

	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday	Total
Arriving	4335	4152	4166	4308	4193	4375	4283	29812
Departing	4268	4194	4137	4332	4295	4078	4508	29812

A discrete event simulation is made in Simulink to analyze the department. Five entities are used, being two types of trolleys, two types of containers and ovens. Attributes are processing times for emptying and

assembling, equipment type, sub department, creation time and departure time. The source is trucks arriving at ROA and the sink is trucks leaving the final cooling. The key performance indicators are answered in the model. Scope of the model is the ROA, Opdek and final cooling and the time scale is four weeks. Different data sets are available for KCS for calculating the number of equipment. The data set used has approximately 28% more equipment compared with historical data. Constraints are searched via the current situation in the simulation model, current problems of the department, a flowchart and use of TIMWOODS.

Design Constraint VLAS is exploited and high number of illness and sorting is analyzed, this leads to four concepts. Concept 1; wash everything on each washing machine, concept 2; create one piece flow workstation in Opdek, concept 3; automatic input of equipment, food and items in Opdek and concept 4; automation of trolleys with M class trays. All concepts can be combined, which gives sixteen solution alternatives.

Control The model is used to analyze the department with normal equipment levels and with a data set with 1,3 times the amount of equipment. Also different robot configurations are tested. Concept 3 is the most important concept for improving performance. There is a clear distinction in performance for design alternatives with and without automatic input of equipment, food and items.

1,3*dataset; 57500 trays per 16 hour									
	1111	1121	2121	1221	2221	1122	2122	1222	2222
Throughput time	130684	95087	108405	76908	104134	91083	91504	20849	8685
Utilization ROA	0,93	0,93	1,00	0,93	1,00	0,89	0,93	0,89	0,93
Utilization Opdek	0,96	0,87	0,86	0,86	0,83	0,84	0,84	0,64	0,65
Inventory	13133,46	9449,38	11893,27	7908,00	11606,83	8726,41	8713,38	1730,80	913,74
Entities to cooling	133427	138549	137959	144602	139076	138577	138577	155173	155173

Figure 1: Results for 1,3x current data set with 57500 trays per 16 hours

Results of 1,3 times normal equipment levels are given in 1, it can be seen that the current situation can not handle all equipment. Only 133427 out of 155173 trolleys, containers and ovens are produced. The throughput time is 130684 seconds and the average total inventory is 13133,46 trolleys, containers and ovens. The best solution uses all concepts, all trolleys, containers and ovens are assembled. Also the throughput time is 8685 seconds and the average total inventory 913,74 trolleys, containers and ovens. When it is not possible to introduce a robot, design alternative 1221 performance the best. The throughput time, utilization of the Opdek, inventory and entities assembled are less compared with design alternative 1222 and 2222.

For KLM Catering Services it is recommended to implement the design alternative described above. Concept 3 is the most important. In the near future a new robot will be bought. To prevent long throughput time and high inventory at least 47500 trays per 16 hours is recommended for the robot. Additionally, it is recommended to keep the inventory in the final cooling at a lower level, benefits of lower inventory numbers are more accurate passenger numbers with assembly, less rework and lower throughput time. It is recommended to measure performance in number of trolleys, containers and ovens assembled, instead of number of flights and number of passengers catered. With this level of detail individual workplaces can be measured instead of the whole department. Processing times are now kept constant. It is recommended to test design alternatives with varying processing times. Additionally, shifting the focus to improving single workstations instead of improving a whole department can improve performance. Breaks of employees can be used for smoother production. Finally it is interesting to model Europe and foreign airline departments. Another possibility is to combine Intercontinental, Europe and foreign airlines department in one model. Resources from whole KCS can be distributed in such a way that the whole performance improves. Next to combining Intercontinental, Europe and foreign airlines in a model, the three department can be combined in the real world. All trolleys, containers and ovens can be emptied, cleaned and assembled at the same department. Then a sandwich for a Europe flight can be assembled next to a business class meal for an intercontinental flight.

The outcome of this case study is limited on the quantity and quality of the data. There are different data sets with other information. Also measurements are done in a short period in the year and employees could notice that processing times were being measured and there is too few data available to calculate variation. Concepts are not validated in the real world. Measuring performance in the number of trolleys, containers and ovens assembled is new and there was no information available yet about this topic. Finally, the model is limited by all assumption and simplifications made while modelling.

Contents

I

Define

1 Introduction

While flying it is often possible to order something to drink. With a longer flight a simple sandwich or even complete meals are available. There are a few different meals which a person can choose. When the destination is still further away, also a second meal is served.

Drinks are served from trolleys full with soft drinks and alcohol. A trolley is the car moved by stewardesses in the aisle. When it is time to eat passengers can choose one of the meals and receives a tray out of a trolley. A meal is given on a tray, mostly with water, cutlery and side dishes. When the passenger is finished with its meal, someone collects all trays and put them into the same trolley again. Also other items are served in a plane, for instance earphones and sometimes even sandals or toys for children. In this research the world behind all services in airplanes is investigated.

1.1. Research context

This research concerns KLM Catering Services (KCS). KLM Catering Services has its headquarter located at Amsterdam Schiphol Airport. KCS cater some flights departing form Amsterdam Schiphol Airport and some flights departing in a foreign country and arriving at Amsterdam Schiphol Airport. Nevertheless, his research focuses only on the Dutch assembly. The other locations where assembly takes place are named outstations. KLM Catering Services has three different assembly departments at Schiphol Airport, namely for KLM flights with a destination in Europe, for KLM flights with a destination outside of Europe and for non KLM companies. The departments are called respectively Europe, Intercontinental and Foreign airlines.

The flow of Europe department is a closed system. Flights are catered at only Amsterdam Schiphol Airport. At Amsterdam Schiphol Airport it is catered for the outbound and the homebound flight. Traveling times are relative short. The Intercontinental department is an open system. Flights are catered not only at Amsterdam Schiphol Airport. In Amsterdam Schiphol Airport outbound is catered, at an outstation the homebound is catered. Traveling times are relative long. The trolleys, containers and ovens are standing all over the world. This makes the Intercontinental department harder then the Europe department. Also the content of trolleys, containers and ovens is more diverse. For European flights for instance only a simple sandwich is catered for economy class passenger, where Intercontinental flights have different trays with meals and different snacks. The last department is foreign airlines, where non KLM flights are catered. Each foreign airline has their own equipment and recipes. The number of aircraft is however less compared with Europe and Intercontintal department.

This research is only concerned with the intercontinental department. Intercontinental is responsible for supplying food, non-food and beverages for intercontinental flights. Intercontinental is divided into two departments, namely food versus non-food and beverages. This research focuses on the intercontinental food flow. So only the food flow for KLM flights from Schiphol Airport to a destination outside of Europe is discussed. In Figure 1.1 all flights are given with blue lines from Amsterdam Schiphol Airport by KLM flights to Europe and outside of Europe. The black dots are cities according to [22].

Figure 1.1: Destinations from Amsterdam Schiphol Airport from [22]

Since food can only be consumed for a short period of time, food for the way back to Schiphol Airport is most of the times prepared at the destination. So food prepared at Schiphol Airport is only meant for an one way flight. This principle is illustrated in Figure 1.2 with a simplified flowchart. In the left side of the figure one can see what happens in Amsterdam Schiphol Airport and on the right the flow of equipment in the outstation is illustrated. KLM Catering Services collects their used and unused equipment from the planes in Schiphol Airport, all equipment is then sorted, cleaned and filled again. Afterwards the equipment is distributed to planes. In the outstation exactly the same process occurs. For each flights approximately three sets of equipment are available. One set in the home base Amsterdam Schiphol Airport, one set is currently flying and the last set in the outstation.

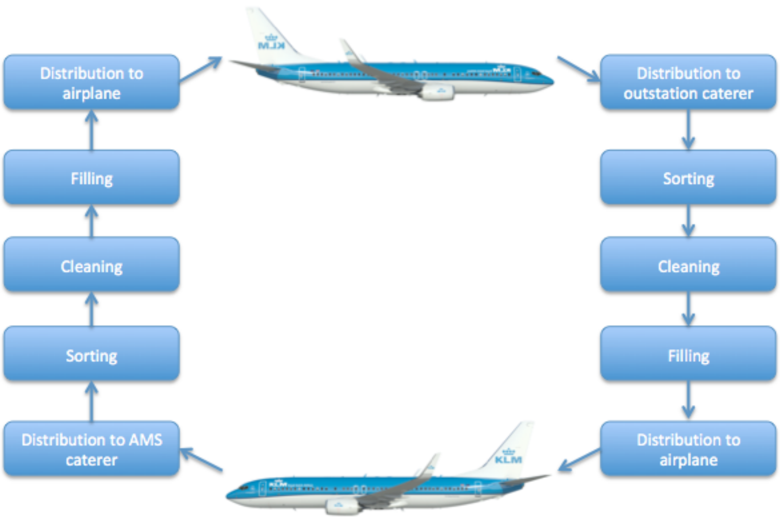


Figure 1.2: Flow of equipment

The food is not prepared on the intercontinental department, this happens at Marfo and in the kitchen. Marfo is an external food supplier and the kitchen is a department next to the intercontinental department. Next to Schiphol Centre, there is another building in the Netherlands located at Schiphol North. Schiphol North is a station between external suppliers and Schiphol Centre. At Schiphol North a big inventory is present. The total input of the intercontinental department is Marfo, the kitchen, Schiphol North and incoming flights. The output is all equipment with food going to the planes and when the production is changing Schiphol North acts as an inventory.

1.1.1. Intercontinental food department

Generally the food department has three stages, namely ROA, Opdek and final cooling, which is illustrated in Figure 1.3. These stages can also be seen in the layout of the building with different areas. Distribution puts all trolleys, containers and oven carriers from the planes in the ROA. In ROA all trolleys, containers and ovens are sorted and washed in washing machines. A wall with washing machines divides the ROA and Opdek. In the Opdek all trolleys, containers and ovens are again filled with smaller items and food. In the final cooling all trolleys, containers and ovens are sorted by flight and are cooled. Distribution will lastly collect trolleys, containers and ovens in the final cooling for a specific flight. A rough layout is also sketched in Figure 1.3.

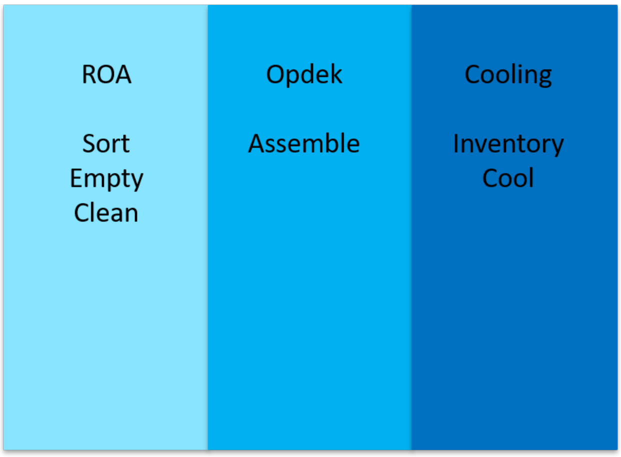


Figure 1.3: Flow in food department for intercontinental flights

1.1.2. Demand

KLM Catering Services measures production in the number of flights and the number of passengers catered. The number of flights are not the same for each day in the week as is illustrated in Table 1.1. The number of flights are not the same during the year, each month has another flight schedule. For instance in June there are more flights with a maximum of 57 flights on Sunday.

Table 1.1: Number of departed flights per day in 2018

	January	February	March	April	May	June
Monday	50	50	50	53	53	54
Tuesday	51	50	50	52	52	53
Wednesday	50	49	49	52	52	53
Thursday	51	51	51	54	54	55
Friday	51	51	51	53	53	54
Saturday	51	51	51	51	51	52
Sunday	53	53	53	56	56	57

In Figure 1.4 the number of flights for Intercontinental department are illustrated for 2008-2018. In 2009 and 2010 a large decrease in flights is visible. This numbers are received from internal files. [21] argues that a crisis is reason for this decrease. A slight increase in number of flights is noticeable. The growing demand is mostly produced with the same resources as the year before. So every year intercontinental must be a little more efficient. This efficiency can be achieved by improving the department or employees must work harder.

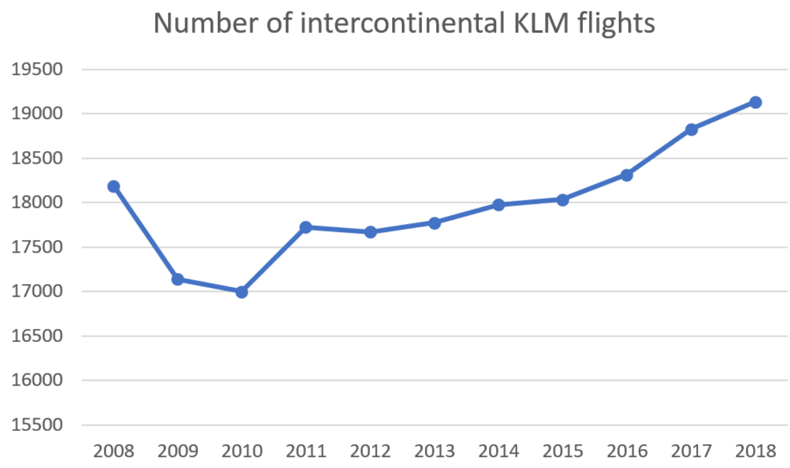


Figure 1.4: Number of flights for Intercontinental department 2008-2018

In Figure 1.5 the number of passengers are shown for KLM Intercontinental. The passenger are divided into business class and economy class passengers, respectively C class and M class passengers. For M class passenger a slight increase is noticeable, the number of C class passengers however is almost constant.

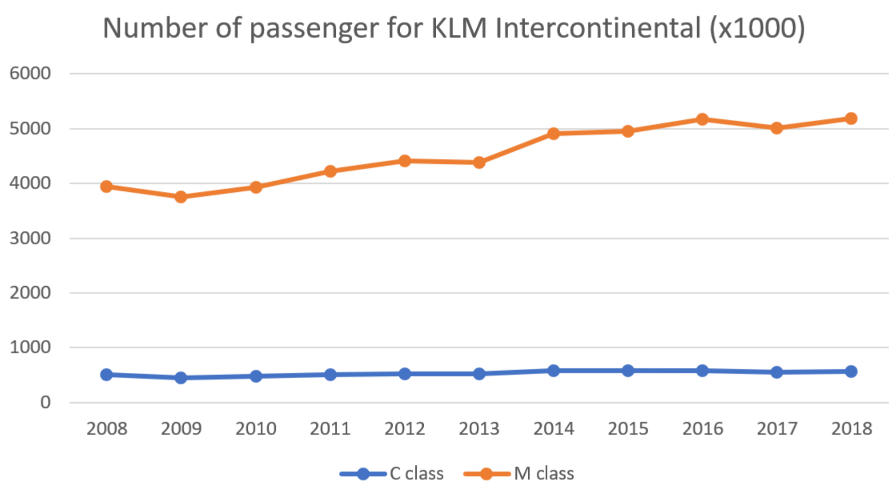


Figure 1.5: Number of passengers for Intercontinental department 2008-2018 (x1000)

1.2. Research scope

This research concerns KLM Catering Services (KCS). KLM Catering Services has its headquarter at Amsterdam Schiphol Airport, also in other countries food is catered. This research focuses only on the Dutch assembly for food of intercontinental KLM flights. All aircraft types which fly for KLM to an intercontinental destination are included. The whole intercontinental department will be covered, namely the ROA, Opdek and cooling. For the input of the ROA also the time it takes to bring everything from the planes to the ROA is investigated.

In this research no disturbances and changes of the flight schedule are taken into account. In the Intercontinental flow, equipment is washed for other departments, this is also excluded for this project.

In a few years time KLM Catering Services is forced to move to another location. The exact date is not known yet, nevertheless it is estimated to be in four years time. For this a completely new building will be designed. For the new building the layout of this department will change drastically. This research examines the current situation and analyzes possible improvements for the current situation. However, while keeping the new building in account also more rigorous design alternatives are possible to analyze.

1.3. Research problem

KLM Catering Services strives for on time deliveries with zero errors. Unfortunately this is sometimes not achievable. If errors are found just before departure or when equipment is not produced in time a car on the platform can deliver last minute the missing parts. This car is always on the platform close to the planes with spare equipment and meals. When the situation arises that the car is necessary it is a so called 'NT drive'. Every day the NT drives are registered and investigated. In Figure 1.6 the number of NT drives are shown for 2018. On the horizontal axis week numbers are visible and on the vertical axis the number of NT drives. There are two horizontal lines, the orange line indicates the maximum allowed NT drives from the management. The grey line is the ambition of this department, unfortunately this ambition is not met. In Figure 1.7 causes of NT drives are given. When defects are not registered before departure it ends as complains from KLM. Half of the times information is missing from these complains, with this missing information the cause can not be determined. Also complaints are sometimes given unjustified. To determine the sections were errors are made, data from errors noticed before departure are used.

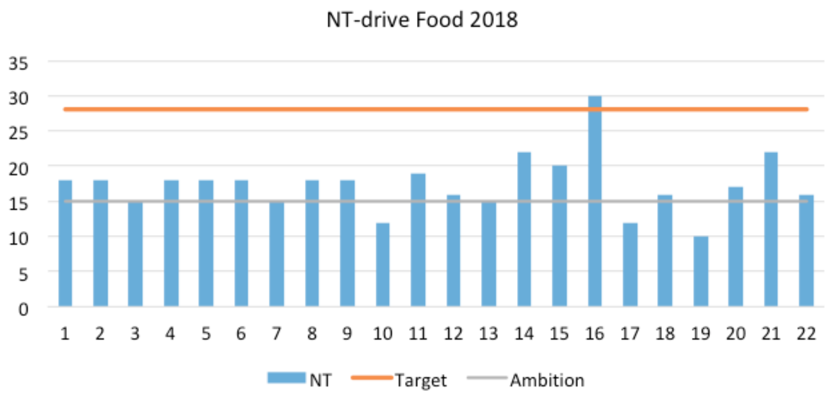


Figure 1.6: NT drives in 2018 for food department

Figure 1.7 is looking in more detail to the source of the NT drives in the last part of 2017. As one can see there a lot of different reasons for NT drives.

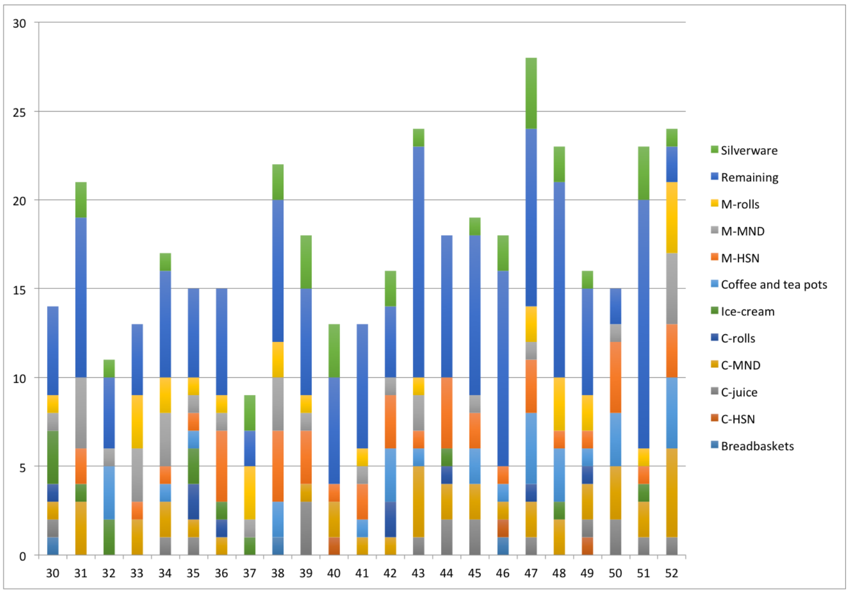


Figure 1.7: NT drives in 2017 for food department in categories

Food department has also a high number of employees who are not fit to work. From 2015 to 2017 this percentage is between 10% and 15%. This is partly due to bad ergonomics now and in the past. Also a lot of employees are partly incapacitated. An example is an employee who can only put one item on the tray instead of two. Nowadays there is a lot of attention for ergonomics. Bad ergonomics and a high percentage of employees who are not able to work are not direct visible in the production. Nevertheless, they are certainly a issue for the intercontinental department.

This all leads to the following problem statement.

There is a gap between the desired performance and the current performance. It is not clear what drivers influence this gap and how the performance can be improved.

1.4. Research objective

The goal of this research is not only to create a valuable outcome for KLM Catering Services, also outcome with enough academic value must be created. From the previous derived scope and problem statement the following objective is derived.

The aim of this research is to design a framework to optimize the processes of food assembly and subsequently apply the framework to increase the throughput time at the intercontinental department of KLM Catering Services.

1.5. Research questions

With the objective is mind, the main research question is formulated as followed.

How can the assembly process of KLM Catering Services be optimized in order to improve the throughput time?

From the main research question, several sub-questions are derived. Answers from the sub-questions will lead to the answer of the main research question.

1. Which process improvements methods are suggested in literature to analyze and redesign the food assembly process?
2. How is the food assembly process structured currently?
3. What criteria can be used to assess performance of the different solution alternatives?
4. What is the current performance of the food assembly process for methods found in literature?
5. How can the current situation and design alternatives be modelled and evaluated?
6. What constraint is limiting the performance?
7. What solution alternatives can possibly improve the design of the food assembly process?
8. How do these solution alternatives improve the performance?
9. What is the best solution alternative?

1.6. Approach

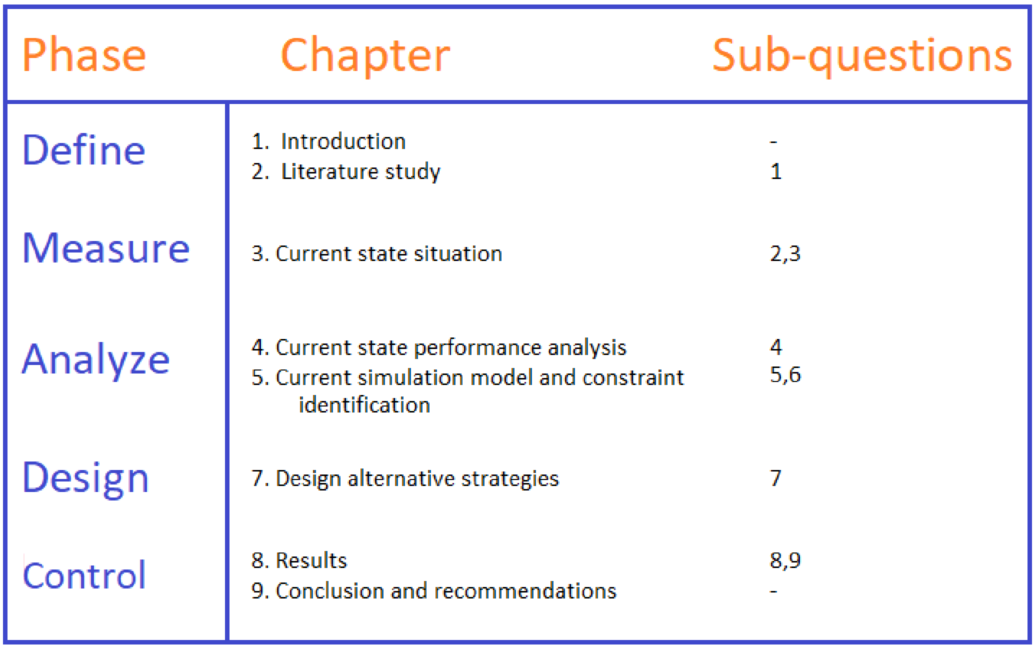
For this report six sigma approach is used. [28] Six sigma approach has five main steps, namely define, measure, analyze, improve and control. The focus of the first three steps is to study processes, with improve and control phase, the processes are changed.

DMAIC is a structured method for improving processes that leads from the definition of the problem to implementing solutions. Define phase is to clarify the goal of the research, in the measure phase the data is collected for this problem, with analyzing data is used to find the cause and effect relationships, in the improving phase changes are made in the process to cancel the causes and finally in the control phase it is ensured that all improvements are preserved. [15]

Plan-do-study-act is another cycle, it is also called Shewhart cycle or Deming wheel. In the plan phase the current process is determined, including the current problems. Plans are made for the current problems. In the do phase these plans are implemented, with study the data from the do phase are studied. At least in the act phase, is acting based on the found date in the previous phase. Also plan-do-study-act is a continuous cycle. [28]

In this research excludes the real improve phase, dr. W.W.A. Beelaerts van Blokland suggested to use a design phase instead of the improve phase. So in this research define, measure, analyze, design and control.

1.7. Research structure



Phase	Chapter	Sub-questions
Define	1. Introduction 2. Literature study	- 1
Measure	3. Current state situation	2,3
Analyze	4. Current state performance analysis 5. Current simulation model and constraint identification	4 5,6
Design	7. Design alternative strategies	7
Control	8. Results 9. Conclusion and recommendations	8,9 -

Figure 1.8: Structure of this report

2

Literature study

In this Chapter theoretical background is discussed, first a brief explanation of transport logistics strategies can be found in Section 2.1. Different process improvement strategies are explained in Section 2.2 with lean manufacturing, six sigma, lean six sigma, theory of constraints, total quality management, critical path method, value stream map and swim lane analysis. Possible performance indicators are discussed in Section 2.3. Finally in Section 2.4 methods are stated to create a simulation model, this is done by Delft Systems Approach, conceptual modelling Gantt chart and a flowchart. This Chapter is concluded in Section 2.5 where the first research question is answered.

Which process improvements methods are suggested in literature to analyze and redesign the food assembly process?

2.1. Transport logistics strategies

2.1.1. Forward and reverse logistics

A supply chain is the process wherein raw materials are manufactured into final products and final products are distributed to customers. The supply chain brings together machines, people and organizations. [41] A this supply chain is divided into four echelons, namely supply, manufacturing, distribution and consumers. [6] There are three flows in the supply chain, namely the flow of material, flow of information and flow of people or processes. [33] The Forrester model however describes a system with six flows, namely the flow of information, materials, orders, money, manpower and capital equipment. The materials flow downstream from the supplier to the consumer, orders flow upstream from the consumer to the supplier. [4]Figure 2.1 shows the four echelons.

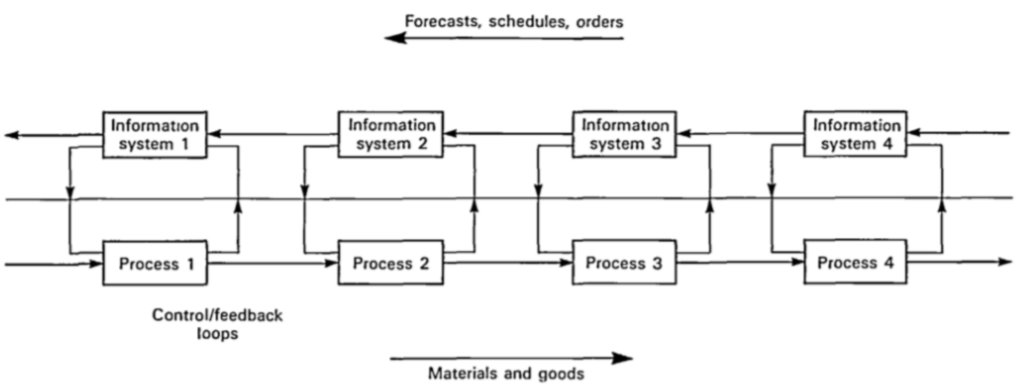


Figure 2.1: Supply chain with information flow from [6]

This describes is forward logistics, reverse logistics however are products and materials that flow the other way around, from the consumer to the supplier. The reversed flow is more reactive, less visible and products tend to arrive random. [40]When the good is collected and inspected, the sorting takes place. [2]

2.1.2. Reusable items

Reusable articles can be divided into three categories[9], namely

- Returnable transport items, this includes secondary and tertiary packaging materials and can be used multiple times. These packaging materials are not in direct contact with the products, such as kegs, pallets, crates, roll cages, barrels, trolleys and liquid or gas containers. [38]
- Reusable packaging materials are primary packaging materials, these are in direct contact with the product such as glass bottles and barrels for chemicals.
- Reusable products are products used by customers which can be reused.

There are four different forms of reuse, namely direct reuse, repair, recycling and ramanufacturing. Direct reuse is without prior repair operations, small maintenance and cleaning takes place, repair is reuse including repair operations, recycling is material recovery and remanufacturing includes disassembly, overhaul and replacement operations. [8]

Fleet size is determined by demand and cycle time. The amount of returnable items can be calculated by the number of expected uses in a given time horizon divided by the average number of times a returnable item is used during the same time. [9]

2.1.3. Assembly lines

In the end of the nineteenth century mass production started. With mass production the job is divided into tiny segments. [29] Also assembly lines were introduced. An assembly line is a system where a number of stations are combined with a conveyor belt. After a certain time interval the conveyor moves and the products are transported to the next station. A product can be divided into components and sub-assemblies. Work is divided into tasks.

There are three kind of production lines, namely for single products, family of products and for multiple products. A manual line can be self-balancing and workers need to stand from slowest at the beginning of the line to fastest at the end. [30] [29] All tasks are sorted on task time and are assigned to a station, starting with the longest task. When a task exceeds the remaining time of a station, the task is assigned to the next station. When there are no tasks left which can fit in a station, the station is closed. [30]

Assembly times occur in different forms. In a serial line all stations are arranged in a straight line along a conveyor belt. In a U-line stations are arranged in line with a U form. An advantage is improved quality, increased flexibility and workers gain more skills. It is easier to monitor the progress of other workers and assist if needed. When two or more workers perform the same tasks it is called a parallel stations. Parallel stations can be necessary when the longest task exceeds the cycle time. Parallel lines are when two or more lines perform the same tasks. Benefits are less sensibility, more flexibility and the possibility to increase the cycle time. A disadvantage is that more equipment is needed. Assembly system divided into subsystems are workcenters. This is use full for complex products. An assembly line can also be (partly) automatic. [30] [29]

2.2. Process improvements theories

2.2.1. Lean manufacturing

Lean manufacturing focuses on the removal of waste.Advantages of lean are the ability to cope better with product variety, increased quality and decreased lead times. Also inventory levels in the process are reduced, which reduces costs. [42] Food industry is far behind in implementing lean. Possible reasons for this are political, reliability, batch processing, food fashion and limited shelf life. [25] [46] When the basic steps of lean manufacturing are introduced in a company, lean manufacturing can be introduced by its supplier. [1] There are five basic steps in removing waste, the five steps are listed below. [26]

- Identify which processes creates value for the customer. All processes can be divided into three categories, namely value adding, non-value adding and non-value adding but necessary. Everything the customer wants is value adding. Sometimes a process does not create value for the customer and are still necessary for the process, these activities are called non-value adding but necessary or type one muda. At last there are processes which do not create value for the customer and are not necessary, this is type two muda.

- Create a value stream map (VSM) of the process. A VSM is the sum of every process and action from the beginning to the final product and is explained in Section 2.2.7.

- Make the activities flow. Batch processing, queuing and transportation are activities which decreases flow. With batch processing for example products will wait before and after a process step, this makes continuous flow impossible. Large batches are mostly handled with big and advanced machines, these machines have long changeover times. Due to this large changeover time the machine will produce the same product as long as possible, after that a long period of another product will be produced. This creates even longer waiting times fore and after the large machine, this process is called batch and queue. The first goal can be to produce each product every shift, this already reduces inventory and throughput time. [33] The machine can mostly be divided into smaller easier machine which can handle continuous flow. When focusing on one product at the time, the processes will become more efficient and with higher accuracy.

- Create pull; the customer can now pull the product through the production process. This is possible since flow decreases throughput time drastically. With flow the exact product the customer wants can be produced in acceptable time.

- Perfect the process; the effort, time, space, errors and costs can be reduced continuously, almost into perfection.

Methods to create flow and pull Mostly continuous small steps are introduced to improve the chain. The method of small improvement is called kaizen. For creating flow and pull several tools can be used, these tools are explained below. [1] [35]

- Combining discrete processes; this reduces internal lead time since intermediate handling is eliminated. A special way of combining processes is cellular manufacturing, here processes for a particular product or product group are organized in cells. Each cell includes machines, equipment and operators with flow between. [27] The average cell size is 10.7 men and 14.0 machines. 80% of the cells have less then 20 employees and 63% of the cells have between 5 and 20 employees. [27] When a production cell is too small, they usually have a short term viability and do not produce a significant part of the capacity. However there are also warnings for big production cells, when there are too much employees there are multiple social groups and the cell can not manage itself.

- Just-in-time (JIT); more frequent, smaller quantity deliveries. This reduces both lead time and inventory.

- Kanban is a signaling system, with this system the progress of the whole process can easily be seen. This can be done by traffic lights for each workplace. When the employees are on schedule there is a green light, when the traffic light is orange the employees are a bit behind schedule however they can probably solve it by themselves. A red traffic light indicates even less progress, help is desirable.

- Total preventive maintenance (TPM); instead of fixing broken machine, employees carry out regular equipment maintenance. This reduces random machine breakdowns.

- Changeover time reduction; changeover time is the time between two different products coming from one machine. A rapid changeover time decreases internal lead time, increases flow, increases flexibility and encourage smaller batch sizes. Changeover time can be divided into three periods, namely rund-down or clean-up, setup and run-up or start-up. Run-down or clean-up is the removal from old products and cleaning of the machine, setup is converting the machine to produce another product and run-up or start-up is when the machine is producing steady state the new product. Single-minute exchange of die (SMED) is a methodology to systematically reduce changeover times. SMED consists out of three steps. In Figure 2.2 the steps are illustrated with its effect on changeover times. External activities are orange and internal activities are green. The steps are listed below. [25]

1. Separate, here all activities are separated into internal or external activities. Internal activities can not be preformed while the machine is working and external activities can be preformed while the machine is working.
2. Convert, first all internal activities are evaluated if they are really internal and not external. Later internal activities are tried to be converted into external activities.
3. Streamline, all activities in the changeover operation must be streamlined and simplified by reduction and elimination.

- Layout of the workplace can be changed from process-oriented to product-oriented, this reduces internal lead time by reducing materials handling time.
- Products can be designed for manufacture, this reduces component stock and increase manufacturing speed.
- Quicker and more accurate data capture, this can be done via bar coding. With quicker data capture, reaction time is reduced and inventory numbers are more reliable. With more reliable inventory knowledge the total inventory can be reduced.
- Electronic data interchange of orders and other data. This reduces lead times since order processing time is reduced. Electronic data interchange also improves accuracy and control.
- Decrease size of equipment and introduce conveyors. This reduces internal lead time and the batch size will decrease.
- Total quality management (TQM) explained in Section 2.2.5.
- 5S is explained in Section 2.2.1.

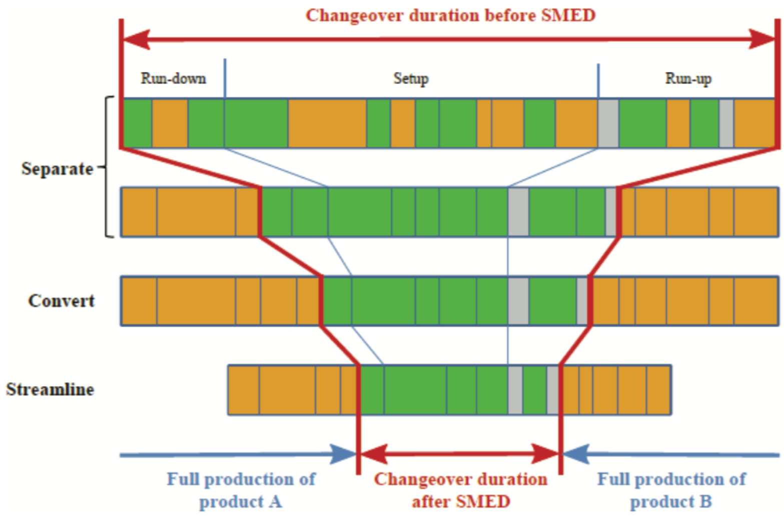


Figure 2.2: Steps of SMED methodology and its impact on changeover times from [25]. External activities are orange and internal activities are green

5S 5S is used to create clean, organized and good looking workplaces. The checklist from Figure 2.3 can be useful with 5S implementation. [25] The five rules of 5S are also explained below. [25]

- Seiri - sort; for the workstation a detailed analysis is made which equipment, tools and documents are needed. All other objects and documents will be removed from the workplace.
- Seiton - set in order; the items that are required are organized and stored in a suitable place.
- Seiso - shine; keeping machines and workplaces clean and checking if they are in an optimal operating condition.

- Seiketsu - standardize; with the first three steps workplaces are clean, organized and good looking. With standardize rules are defined to prevents the return of old habits.
- Shitsuke - sustain; make a habit of maintaining the procedures.

	Nr	Evaluation criteria	Observations	Corrective measures
1S	1.1	Obsolete materials in the workstation (WS)?		
	1.2	Unused or obsolete equipment in WS?		
	1.3.	Unnecessary transportation or storage materials in WS?		
	1.4	Unnecessary elements in WS?		
	1.5	Unnecessary information in WS?		
2S	2.1	WS identified and according to defined standards?		
	2.2	Distinctive markings in WS and according to standards?		
3S	3.1	WS, equipment, transportation and storage material clean?		
	3.2	Cleaning schedules or checklist defined?		
	3.3	Necessary cleaning materials available in WS?		
4S	4.1	Objects stored in the correct place?		
	4.2	Standards defined and being followed?		
	4.3	Checklists for correct handling of equipment being followed?		
5S	5.1	Standards in 4S implemented and continuously improving?		
	5.2	Norms defined in previous topics being followed?		

Figure 2.3: Checklist for workstation for performing 5S from [25]

TIMWOODS waste TIMWOODS is a method to identify waste. The different forms of waste are stated below. [45]

- Transport; any movement in the factory could be viewed as waste and transport must be minimized. Transport could not always be eliminated.
- Inventory; increases lead time, preventing fast identification of problems and increasing space.
- Motion; when operators have to stretch, bend and pick up while these actions could be avoided.
- Waiting; when time is not being used efficiently.
- Overproduction; is when products of produced more, sooner or faster than required. It leads to longer lead times, more storage space and less flexibility.
- Over processing; when complex machines are used for easy problems, when there is produced better then tolerances or processes that are not required from the customer.
- Defects
- Skills

2.2.2. Six sigma

Six sigma is used to describe the level of quality in a process. Other aspects of six sigma are reducing variation, use of technical tools to help with identifying and eliminating problems and people involvement. This involves in training people to use these technical tools. Six sigma approach has five main steps, namely define, measure, analyze, improve and control. The focus of the first three steps is to study processes, with improve and control phase, the processes are changed. [28] [26][13]

2.2.3. Lean six sigma

Lean six sigma is a combination of lean and six sigma. This leads to better performance than applying both methodologies alone. [47] The power of lean six sigma is in the total process of both lean and six sigma. Lean six sigma helps to increase speed, quality and decrease costs in processes. [15]

2.2.4. Theory of constraints

Theory of constraints focuses on system constraints. The performance of a process is limited by the performance of the constraint. If there is no constraint, the company will make unlimited profit. Theory of constraints focuses on the link which slows down the flow. The process consists out of five steps explained below. The five steps are also illustrated in Figure 2.4. [26] [43]

- Identify the limiting constraint, this can be done by looking at the queue length of processes or where batching still occurs. The constraint can be physical or managerial. In general there are more managerial constraints then physical constraints.
- Exploit the constraint. A physical constraint can be exploited, a managerial constraint however needs to be eliminated and replaced with a policy which will support increased throughput.
- Subordinate other processes to the constraint, these are mostly found ahead of the constraint. The other processes must be adjusted to the new effectiveness of the constraint.
- Elevate the constraint, if the output of the constraint is not sufficient enough, further improvement is required.
- Repeat the cycle, another point in the cycle is now the weakest link.

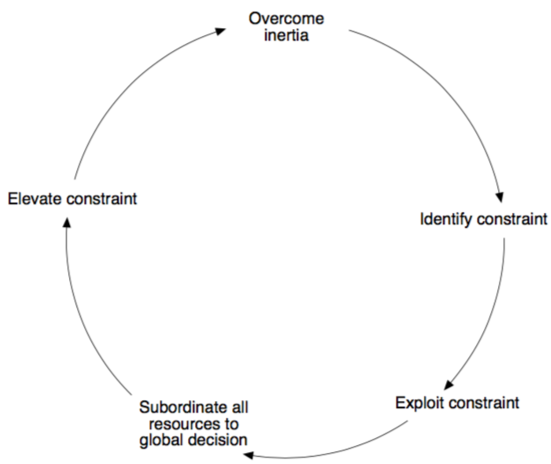


Figure 2.4: Process of on-going improvement from [43]

Theory of constraints has nine rules for optimizing production technology. [43] The flow needs to be balanced instead of balancing capacity. Occupancy rate of a non-bottleneck process is determined by the constraint and not by its own capacity. There is no use for running a non-bottleneck process it this leads to a larger queue in front of the bottleneck process. Time lost at the bottleneck process is also the same time lost for the total process. Time saved at a non-bottleneck process is way less important then time saved in a bottleneck situation. Since the time saved at a non-bottleneck process does not increase the total throughput time of the process. Bottleneck determines throughput and inventories in the system. There is no need to produce at maximum numbers for each resource. The process batch should be variable. To schedule production, all constraint need to be included, lead time is a result of this schedule.

2.2.5. Total quality management

In 1960 the view of quality changed that the entire organization is responsible for the quality. Quality was inspected and corrected. Since 1970 companies are improving quality and the perspective changed from reactive to proactive. [28]

It all starts with identifying the needs of the customer and meeting their expectations. The level of quality is continuously improved. Employees are expected to seek out quality problems and correct them if necessary. This can be done with use of quality tools. Quality is taken into account by product design and into the process. [28] Quality improvement is divided into five steps, namely defining what quality customers want, translate the wished of the customer into measurable items, continuous measure the current quality, set certain targets and deadlines and at least develop a method to keep increasing the quality. [28]

2.2.6. Critical path method

The length of a path is the total duration of all activities on that particular path. Mostly there are different paths in a system. The route with the longest total duration is called critical path. If there are more path with the same duration, there are multiple critical paths. [16] [47]

2.2.7. Value stream map

A value stream map (VSM) is the flow of all processing steps of a product. A VSM helps with visualizing the flow and mapping the sources of waste. It is also a linkage between information flow and material flow. [33] A VSM consists out of three phases, namely choosing a product or product family, drawing a current state map and drawing a future state map.

Choose product or product family A customer cares about a specific product or product family, not all the products. So a specific product or product family must be chosen. A family is a group of products that undergoes similar processing steps and has common equipment. [33] [1]

Current state map The second step is to draw a current state map. Small boxes represent processes and the number in the boxes are the number or workers. Each process has a data box which contains for instance cycle time, machine reliability (MR), number of shifts or changeover time. All processes which are connected and where the material keeps flowing can be written as one process box. After the material flow, information flow is added. Information flow tells each process what to do. The best way to collect information is by walking along the flow and follow materials and information from the customer to the begin. It is better to measure all data, since most data in files is outdated or wrongly measured. [33] [1]

Information flow is drawn from right to left on the top half of the map. Notice that there are mostly different kinds of information flow, such as forecast and daily orders. Push is indicated by for instance processes which know what to make and when. Some important definitions in processes are explained below. [33]

Future state map The last step is to draw a future state map. Important characteristics of processes which must be improved are large inventories, a difference between total production lead time and value added time and if process are producing according to an own schedule. [1] Unless a new product facility needs to be build, the first iteration of the future state map should take product design, process technologies and plant location as given. Next questions are given which help to create a future state map. [33] [1] Thing to keep in mind are the takt time, what happens after production and where continuous flow or pull can be introduced. Continuous flow is producing one product at the time and the item is immediately passed from one process step to the other without stagnation. Only one point can be scheduled to reduce overproduction. This point is called the pacemaker process. The schedule of the pacemaker process determines the pace for all upstream processes. Mostly the most downstream continuous flow process is the pacemaker process. Also the increment of work at pacemakers process needs to be determined.

2.2.8. Swimlane analysis

A process map or swimlane analysis is a tool to display how processes are going and which steps department go through. Creating the swimlane starts with identifying functions, departments and disciplines involved in the process. All actors are listed on the left axis and have a horizontal band. All processes are divided into those actors and processes of a certain actor are placed in the band of the actor. The map shows connections between different actors during the process. This map helps to see critical interfaces, time needed for several sub processes and identify disconnects. Disconnects are illogical, missing or extraneous steps. [34]

2.2.9. Combining lean six sigma and critical path analysis

Combining critical path with bottle neck analysis and lean six sigma creates a framework to improve a system. [47] The first step is to find the critical path of a system, in the critical path the machine or process is sought which is the bottleneck in the critical path. This machine or process is then improved with lean six sigma. A summary of this combined process is given in Figure 2.5.

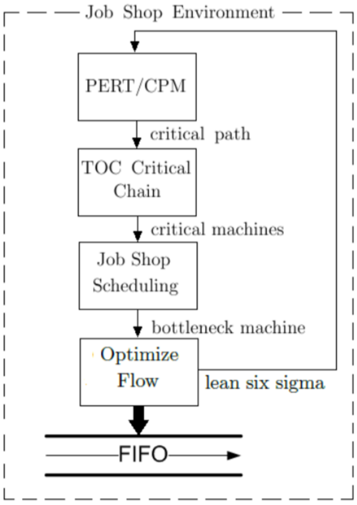


Figure 2.5: Combining lean six sigma with critical path analysis from [47]

2.2.10. Lean, six sigma and theory of constraints

Lean manufacturing, six sigma and theory of constraint all give greater understanding how processes can be improved. Every theory has a different focus and different primary results, however the secondary effects have big similarities with the other theories. The comparison of lean thinking, six sigma and theory of constraints are summarized in Figure 2.6. Lean thinking matches a company which values visual change and immediate acting. Six sigma matches an organization which values analytic studies and data. Theory of constraints matches an organization with a separation between worker and management. [26] [13]

Program	Six Sigma	Lean thinking	Theory of constraints
Theory	Reduce variation	Remove waste	Manage constraints
Application guidelines	1. Define. 2. Measure. 3. Analyze. 4. Improve. 5. Control.	1. Identify value. 2. Identify value stream. 3. Flow. 4. Pull. 5. Perfection.	1. Identify constraint. 2. Exploit constraint. 3. Subordinate processes. 4. Elevate constraint. 5. Repeat cycle.
Focus	Problem focused	Flow focused	System constraints
Assumptions	A problem exists. Figures and numbers are valued. System output improves if variation in all processes is reduced.	Waste removal will improve business performance. Many small improvements are better than systems analysis.	Emphasis on speed and volume. Uses existing systems. Process interdependence.
Primary effect	Uniform process output	Reduced flow time	Fast throughput
Secondary effects	Less waste. Fast throughput. Less inventory. Fluctuation – performance measures for managers. Improved quality.	Less variation. Uniform output. Less inventory. New accounting system. Flow – performance measure for managers. Improved quality.	Less inventory/waste. Throughput cost accounting. Throughput – performance measurement system. Improved quality.
Criticisms	System interaction not considered. Processes improved independently.	Statistical or system analysis not valued.	Minimal worker input. Data analysis not valued.

Figure 2.6: Comparison of improvement programs from [26]

2.2.11. Basic terms

Cycle time is the time between two parts coming off the process. Changeover time is the time needed to switch a machine or process from one process to another. [33] Lead time or throughput time is the time is needed for one product to travel from start to finish, this can be calculated by dividing quantity of inventory by the daily customer demand. Inventory and lead time are related since the more the inventory, the longer any item must wait and the longer the lead time. [1] [29] The order in which tasks need to be performed is called precendence constraints. Capacity supply is the total time to assemble each product, capacity supply is equal or bigger then the sum of each individual task. Makespan is the maximum time available to complete all tasks for a product. Maximum peak time is the maximum time to complete the tasks of a workstation. Imbalance is the difference between cycle time on one hand and the total time for all tasks on the other. Work content is the sum of all process times, station time is the work content of a station. Line efficiency is the work content divided by capacity supply. [29]

2.3. Performance indicators

The goal of measuring is the ability to monitor, control and improve system performance. With measurements communication is easier, performance can be identified and knowledge what is happening in the organization is provided. It is important that the right things are being monitored and that the measures are a good representative of the total process. [34]

The required performance measures for a organization is dependent on the strategy from the company. A supply chain performance which relies on only one performance measure is generally inadequate since it does not include the whole system. A supply chain measurement system must contain three types of performance measures, namely resource, output and flexibility. Since these three types of performance measure are crucial to the overall performance. [6] Important performance measure are also called key performance indicators (KPI). [8] When looking at performance measures the supply chain is divided in four phases. The first state is before any improvement and the fourth state is the ideal state. [48]Below the types of performance measures are explained.

[6]

- Resources; goal is a high level of efficiency, this includes total costs, distribution costs, manufacturing costs, inventory and return on investment. Inventory is divided into investment, obsolescence, work-in-progress and finished goods. Resources generally need to be minimized.
- Output; goal is a high level of customer services, this includes sales, profit, fill rate, on-time deliveries, stockout, customer response time, manufacturing throughput time, shipping errors and customer complaints.
- Flexibility; goal is to respond easily to changing environment. Range flexibility is to what extent a operation can be changed and response flexibility is the ease with which the operation can be changed. Different kinds of flexibility's are explained below.
  - Volume flexibility; change the number of products
  - Delivery flexibility; change planned delivery dates
  - Mix flexibility; change variety of products
  - New product flexibility; ability to introduce new products

2.4. Process modelling

Supply chain performance can be measured in three ways, namely analytic, with simulation or with physical experiments. Analytic models are impractical since mathematical models are mostly too complex to be solved and physical experiments often has technical- and cost related limitations. Simulation seems the best possibility to analyze performances. [39] [10]

Advantages of simulation are that systems can be described a highly realistic manner, also experiments can be done that cannot be performed on real manufacturing systems. [18] [10] Simulation models can explain behaviour of an existing system, can be used for verification and validation, predict system behaviour, can rank different improvement strategies and determine buffer capacity. It can as well investigate the impact of timetables and capacity of material handling equipment and buffers. [41] [23] [12] Disadvantages of simulation is that special training is required. Simulation is also time consuming and expensive. [36] Simulation helps the user with making decisions, such as feasibility of production. With simulation parameters can quickly be changed and gives fast results. [24] Performance of the model depends on operating conditions. For a similar situation different models can be made with different purposes. [5]Different models of the same process are required to study different parts of the same system. [36] Users should be able to change the simulation. [23]

To be highly realistic, a complex model is needed, which includes more factors and variations. Complex models are hard to develop, run and analyze. [7] Simple models however can be developed faster, are more flexible, require less data, run faster and results are easier analyzed. [31] [32]. A downside of a simple model is that results are sometimes inadequate. Multiple simple model can sometimes be combined in less time and with the same characteristics then one complex model. [7]

Combining a value stream map and simulation is a powerful tool to identify the overall system performance and tune design concepts. The information collected by a value stream map, can easily be added in simulation. Each process or element of the value stream map is given in discrete elements. [17] This combination calculates the benefits of each improvement in an early stage. The simulation results can help the management to compare the expected performance with the existing system. First the current system is modelled, which is modified to the proposed state. Before evaluating the future system, the current system needs to be verified and validated. [1]

There are four different models, an abstract model is in the mind of an analyst. A conceptual model is a representation of an abstract model expressed in objectives, input, output and model content. Coding is not taken into account yet. Programmed model in a programming language or simulator. Operational model for developing experimental results. [11]

2.4.1. Delft Systems Approach

Delft Systems Approach is a method for creating models. [44] A system is a collection of elements, with interaction between the elements. Elements also have a relation with elements outside of the system. A different research question will result in a different group of elements. An element is the smallest part in a system and can be material or non-material, this is also called concrete or abstract elements. Properties of elements are called attributes. Elements can influence other elements if there is a relation between them. In a concrete system this is called dynamic exchange and in a abstract system a conceptual interchange. A relation can also refer to the positioning of elements. The structure of a system is the summation of all relationships.

There are two methods to divide systems, namely in subsystems and in aspectsystems. A subsystem is a collection of elements with the original relationship between the elements. A subsystem is by definition a system and the original system is an important part of the environment. An aspectsystem however is a collection of elements where not all relationships remained. In an aspectsystem only certain aspects and certain relationships of a system are described. [44]

When a system is in a certain state, the properties of the elements have a certain value at that time. An events will result in a change of these values. An activity is when one event leads to another event. An event can also change the structure of a system, then relationships between elements are changing. This is called a changing structure. Time-dependent systems often need supplies from the environment, some systems deliver supplies to the environment. Time-dependent systems can be divided into input, throughput and output. [44]

A time-dependent system will change over time. The behaviour of elements in a certain time period can be studied, this is called a phase of the system. Behaviour can be seen as a property of an element which describes how an element react. [44]

A function of a element is the contribution of that element to the greater whole. A task on the other hand is the actual work what needs to be done to complete its function. The goal of a system is can be to fulfill certain functions. In Figure 2.7 a basic concept of a function is given. Requirements is what the functions fulfill, this is expressed by performance. [44]

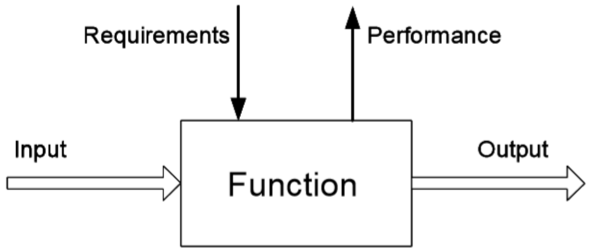


Figure 2.7: Basic concept of a function from [44]

When elements interact with the environment of the system, the system is open. Closed systems are systems with no interaction with the environment. To separate a system from the environment a system boundary needs to be drawn. Only the input and output will go through this boundary in the case of a closed system.

An object has attributes and operations. An attribute is a data structure and operations its behaviour. [3] A state is a possible condition of all objects with their attributes and behaviour is responsible for state changes.

PROPER model PROPER stands for PROcess PERformance and consider three aspects, namely material flow, order flow and resources flow. [44] In Figure 2.8 a PROPER model of a system is shown. Input are orders, products and resources, the output are delivered products, handled orders and used resources. Mostly the flow of resources is slower then the other flows. For a PROPER model it is not important how processes are done, only what exactly is done and why the processes are done. Not describing how processes are achieved has advantages, namely it encourage to create more creative solutions.

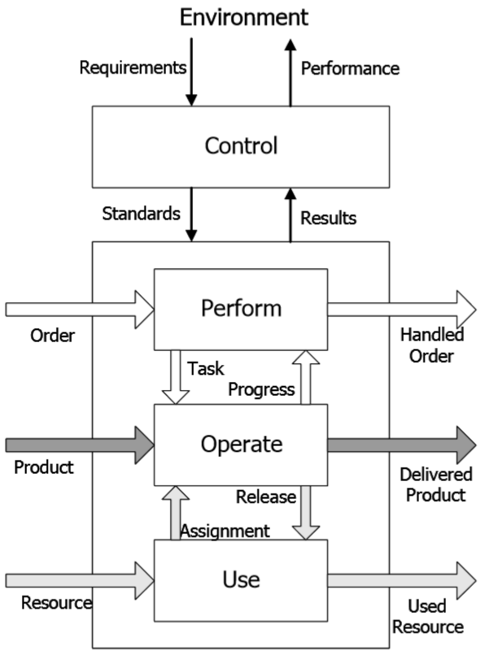


Figure 2.8: PROPER model of a industrial system from [44]

2.4.2. Conceptual modelling

Conceptual modelling is the process of making a model of a real situation and is a representation of an abstract model expressed in objectives, input, output and model content. Coding is not taken into account yet. Conceptual modelling can also be seen as an art. Three different roles are assumed for a simulation study, namely a client, modeller and the domain expert. A client is the problem owner, a modeller develops the model and a domain expert provides data and information for the project. It is important to keep the problem definition in mind while creating the conceptual model. From the same system different simulation models can be created answering different problem definitions. [31]

Creating a simulation problem can be divided into four steps, namely conceptual modelling, model coding, experimentation and implementation. This is explained in Figure 2.9. [31] [32]

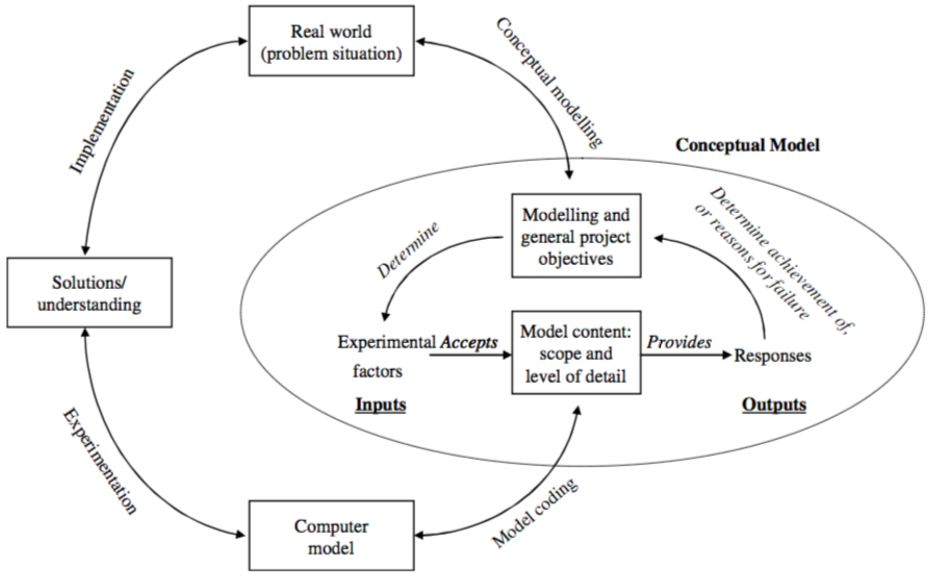


Figure 2.9: Conceptual model in the simulation project life-cycle from [31]

Conceptual model consists out of the following steps. [31] [32]

- Objectives describe the purpose of the model and modelling project, it is the overall aim of the project. Different modelling objectives lead to different models, even with the same problem definition. The purpose of a simulation study should never be to develop a model, otherwise the study is finished when the model is created. Objectives can be expressed in achievement, performance and constraints. Also general objectives are given, this includes flexibility, run-speed, visual display, ease-of-use and model or component reuse.

- Outputs or responses are the results of a run. The output can have two purposes, namely whether the objectives are achieved or why the objectives are not achieved. Once the outputs are identified information is reported.

- Inputs or experimental factors are elements what need to be improved or where better understanding is needed. The input can be quantitative or qualitative. It is advised to experiment with factors that are outside the control area to gain understanding in the process. [32]

- Model content consists out of the model scope and the level of detail for each component. The scope is determined in the following three steps.

  1. Identify the model boundary
  2. Identify all the components in the real world within the model boundary. Components that can be included into the scope can be divided into four different categories, namely entities, activities, queues and resources.
  3. Determine whether to include or exclude all components mentioned in step 2. Identify for each component whether it is important to validity, credibility, utility and feasibility of the model.

- Identify assumptions and simplifications. Assumptions are made when there are uncertainties about the real world and simplifications are used to create faster models and reduce complexity. Simplification can be done by making variables into constants, eliminating variables, using linear relations, strengthening assumptions and restrictions and reducing randomness.

2.4.3. Gantt chart

A Gantt chart is a matrix with all resources on the vertical axis and time on the horizontal axis. Every job is illustrated with its duration on the correct row of that task or activity. If one compare resources it is clear which machine has the highest utilization. [3]

2.4.4. Flowchart

A flowchart is a tool to describe a model in a high level of detail. [3] A flowchart is illustrated in Figure 2.10. It is a graphical representation of different actions with symbols. Each symbol describes a certain aspect in the process, such as operation, data, flow direction and equipment. A flowchart has high flexibility, is easy to use and easy for communication. Downside is that the flowchart is maybe too flexible, boundary is not always clear, tend to be very big and there is no difference between main activities and sub activities. A flowchart is useful in overseeing the total process and there is no precise format. [28]

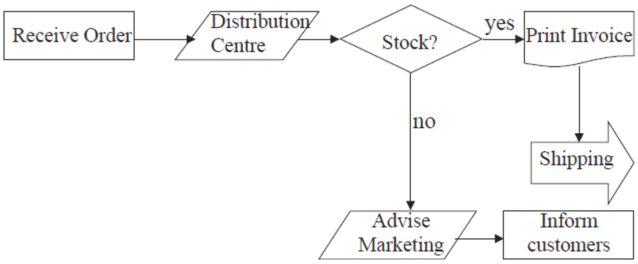


Figure 2.10: Flow chart from [3]

2.4.5. Validation and verification of simulation models

Validation is if we develop the right model. [36] Validation can be done by structured walkthrough, expert evaluation, comparison against performance of the existing system, comparison against existing theory and sensitivity analysis. [10]

Model verification is determining of the model is right. Model verification can be done by exposition of the model to all players who have contributed information and opinions. If this group finds the outcome realistic, than the model can be used without much additional numerical evidence. [41] [36]

2.4.6. Other simulation terms

A static model represents a supply chain at a particular point in time whereas dynamic model represents a supply chain as they changes over time. In deterministic models all variables are known, this results in unique set of outputs, in stochastic models however at least one variable is unknown, this variable is random. Stochastic models do not have a unique set of outputs. A system is in steady state when the behaviour repeats itself over time. When behaviour is not repeated, the system is transient.

In a discrete model states of the variables change only at a different points in time, in a continuous variables change continuously. [24] At least process-oriented, object-oriented and agent-based models are explained. [39] [10]

- Process-oriented model; simulation model consist out of processes which are initiated by events. Simulation is used for decision making in strategic and operational decisions. [10]
- Object-oriented model; are used for more complex models, since object-oriented models are great in decomposing problems. The model consists out of a set of standardized object. [10]
- Agent-based models; try to capture the details of supply chain management in the model, such as implicit aspects and collaboration. [10]

Deterministic times has constant tasks times, this only occurs with highly qualified workers at a manual assembly line or modern robots and machines. Deterministic times can be used if the variability is sufficiently small. Stochastic times have variable task times, this can be a result of machine breakdown. Mean time before failure and mean time to repair can be added. Other reasons for variance in task times are non-qualified workers, motivation or lack of training. Hidden times occur when the sum of each operating time is not equal to the actual duration. Dynamic times is the variance between workers and the change of task time of a worker of time. [30] [29]

A value stream map can be combined with discrete event simulation. Now structural and random variability can easily be included into a simulation model. It helps with identifying important processes, it can quantify these processes and can validate possible future processes. Even multiple experiments can take place to compare the behaviour of future systems without implementation. [14]

Employees in simulation Since industrial revolution machinery takes over tasks from employees. Robots are used nowadays for repetitive, high precision tasks, monotonous tasks and demanding physical work. An operator is mostly required for loading and unloading of the machines or transferring the products from a machine to the following production step. [18]

Computer simulation describes machines in an extensive detail. These models frequently overestimate the production capacity. This difference increases when there is more labour extensive systems. While building a simulation model employees are not accurately modelled. Employees are mostly treated as quasi-technical elements which operate the same as machines. Employees can be modelled with its schedule, including setup, testing, cleaning and breaks. [18]

The behaviour of employees are far from this, they are unstable, unpredictable and capable of independent actions. Employees can better be simulated either via a model with high level factors with complex interactions of psychological mechanisms or with low level factors with basal physiological mechanisms. [5] Young people are mostly physically fit, the age effect, and older people have mostly greater professional experience,experience effect. Psychological factors are tiredness, illness and mood swings. [18]

2.5. Conclusion

Which process improvements methods are suggested in literature to analyze and redesign the food assembly process?

Several methods are described in literature. Lean manufacturing focuses on the removal of waste. Lean consists out of identifying which process creates value, making a value stream map, make activities flow, create pull and perfect the process. Creating flow and pull can for instance be done by combining discrete processes, just in time, kanban signaling system, total preventive maintenance, change over time reduction and changing layout of workplaces. 5S is part of lean and is used to create clean, organized and good looking workplaces and consists of sort, set, shine, standardize and sustain. Total quality management is divided into five steps, namely defining what quality customers want, translate the wishes of the customer into measurable units, measure the current quality continuously, set certain targets and deadlines and at least develop a method to keep increasing the quality. TIMWOODS is a method of lean to identify waste, waste is categorized in transport, inventory, motion, waiting, over processing, overproduction, defects and skills.

Six sigma focuses on reducing variation, six sigma is problem focused and includes define, measure, analyze, improve and control. Theory of constraints focuses on the constraint which slows down the flow and consists out of identify the constraint, exploit the constraint, subordinate other processes, elevate constraint and repeat. Critical path is defining the longest route in a process, route with the longest total duration is called critical path. Swimlane shows the steps that the departments go through to go from input to output for a specific process.

Lean six sigma combines lean and six sigma, this leads to better combined performance then applying both methodologies alone. Combining lean six sigma and critical path gives even better understanding how processes can be improved. The first step of this process is to find the critical path of a system, in the critical path the machine or process is sought which is the bottleneck. This machine or process is then improved with lean six sigma.

One method to analyze processes is simulation. Delft Systems Approach, conceptual modelling, Gantt charts and flow charts can be used to create a simulation model.

II

Measure

3
Current state situation

The current situation is explained in this Chapter. This start with a short company background in Section 3.1 where the relation between KLM and KLM Catering Services is discussed. In Section 3.2 basic information is given about the department, this includes employees, equipment, layout of the department and the information structure. In Section 3.3 the different parts of the Intercontinental flow are discussed. This means, the input and output of the department and the different processing steps. The processing steps are sorting, washing, assembly and finally cooling in the final cooling. In Section 3.4 the measured output performance of different stations is given. Finally in section 3.5 the key performance indicators are determined. This chapter is concluded in Section 3.6 where the second and third research questions are answered.

How is the food assembly process structured currently?

What criteria can be used to assess performance of the different solution alternatives?

3.1. Company background

KLM (Royal Aviation Company) Royal Dutch Airlines was founded in 1919, KLM is the oldest airline in the world which still flies under the same name according to [20]. In 1920 the first scheduled flights from KLM took place between Amsterdam and London. Then only 345 passengers and 25.000 kilos of cargo was transported in a year. Nowadays a single Boeing 747 can carry almost the same amount with more then 400 passengers and 20.000 kilos of cargo.

In 1924 the first plane flew from Amsterdam to Batavia and in 1934 KLM crossed the Atlantic Ocean for the first time. KLM moved to Schiphol in 1967, since 1989 KLM worked together with mayor US carrier Northwest Airlines and in 2004 KLM merged with Air France.

Since the flying distance and the time spend in planes increased, KLM founded KLM Catering Services (KCS) as inflight caterer eighty years ago. KCS is the largest inflight caterer of the Netherlands and number five in Europe. Daily 350 intercontinental, European and cargo flights with approximately 55.000 meals are served. Next to meals KCS provides also liquor, newspapers and tax free shopping. KCS is a wholly owned subsidiary of KLM with over 1300 employees. [19]

KLM aircrafts are equipped with food at the home base Amsterdam Schiphol Airport by KCS. With intercontinental flights the way back is catered at the destination by other companies. In the home base a new factory will be build in a few years time.

3.2. Structure and equipment

3.2.1. Employees

The Intercontinental department works seven days a week with two shifts a day. The first shift is from 6 am to 2.30 pm and the second shift starts at 2.30 pm and ends at 11 pm. Each shift contains 8.5 hours with

7 effective working hours. One hour is for breaks and half an hour for set up. A shift starts with a small announcement, usually this includes the number of trays to be produced and special circumstances. There are three teams, namely team A, team B and team C. These team works three or four shifts in a row. After a block of morning shifts a team switches to the afternoon shift and vice verse. After the production of the morning shift, all employees do a basic cleaning for the afternoon shift. At night there is a more thorough cleaning by an external cleaning company.

67 people are working directly on the food department, the employees are divided into several categories. Four employees are working in the office, namely the director, customer process developer, operational manager and process improvement developer. Their focus is strategic and tactical. There are three shiftleaders, they are coordinating production from the work floor, their focus is on operational and partly tactical process. The five flow coordinators are responsible for the flow and focus on the operational process. Left are 55 other employees, they are running the performance.

The mean age of the permanent staff at this department is 50 years and most employees already have minimum 10 year working experience at KCS. However, approximately 50% of all employees are temporary workers. Flexibility is the main reason for this amount of temporary workers. When temporary workers fit in the system, the temporary worker can receive a contract for one year. Most positions in the food department can be done without significant training, ideal for temporary workers. Other positions need a small training or some experience, this can be done by employees with a contract for one year. More significant training is given to permanent employees.

3.2.2. Equipment

Intercontinental department handles equipment from KLM. There are three kinds of equipment carriers, namely trolleys, containers and ovens. Trolleys are small carts used in the aisles of the plane. There are two different sizes of trolleys, namely T11 and T12 trolleys. T11 stands for 1/1 and T12 stands for 1/2, so full and half size trolleys. There are two different T11 trolleys, namely one for C class and one for M class and there are four types of T12 trolleys, namely one for C class, two for M class and waste trolleys. C class stands for business class and M class is economy class. Waste trolleys are used to collect all waste in the plane. Types of trolleys are illustrated in Figure 3.1.

(a) T11 trolleys

(b) T12 trolleys

Figure 3.1: T11 and T12 trolleys

For small equipment standard (STC) and squared (SQC) containers are used. Containers are boxes which stay in position in planes. Containers are moved at KLM Catering Services in special carts, there is place for four standard containers or six squared containers on one cart. Oven carriers are used by heating meals in the plane. There are two different ovens carriers, namely Atlas ovens and KSSU ovens. An oven carrier is placed in an oven in the aircraft, an oven carrier can not heat meals by itself. Atlas ovens are specially designed for dreamliners aircrafts and KSSU ovens are used for all other aircraft types. An oven has several drawers with holes in it, these are called skids. KSSU ovens have seven skids and Atlas ovens have eight skids. The skids for the two different ovens have different dimensions. Standard equipment, squared containers and ovens are illustrated in Figure 3.2.

(a) Standard and squared containers

(b) Oven inserts

Figure 3.2: Standard containers, squared containers and oven inserts

Both in C class as M class passengers receive trays with food on it. M class has currently two different trays, namely 1/2 tray and 2/3 tray. In a T11 trolley fit 42 2/3 trays or 56 1/2 trays. In 2018 there is a shift from 2/3 trays to 1/2 trays. In July the first nine destinations were served with a 1/2 tray instead of a 2/3 trays. In the winter the rest of the destinations will fly with 1/2 trays. The shift in trays is caused by less stewardesses on intercontinental flights.

All items on the tray will be thrown away with M class, with C class however almost all products on the tray are reusable. The reusable items are mostly Chinese porcelain. A few examples of Chinese porcelain are shown in figure 3.3.

(a) Casserole

(b) Delft blue large

(c) China plate small

Figure 3.3: Different reusable items for the C class

3.2.3. Layout

In Figure 3.4 a layout is given of the intercontinental department with all flow coordinators and other employees given. Also washing machines, a robot, assembly lines and other workplaces are shown. In Figure 3.5a the department is subdivided into M class, other workstations and C class. M class illustrated in red, ohter workstations in blue and C class in green. In Figure 3.5b the department is divided into ROA, Opdek and final cooling. These are the different sub departments explained in Section 3.3. The final cooling is illustrated in red, Opdek in blue and the ROA indicated in green.

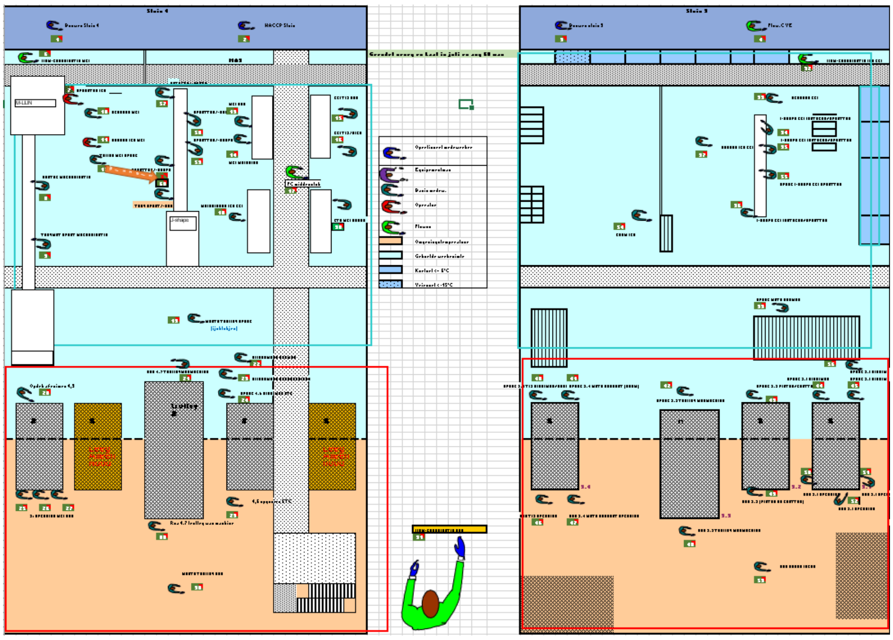
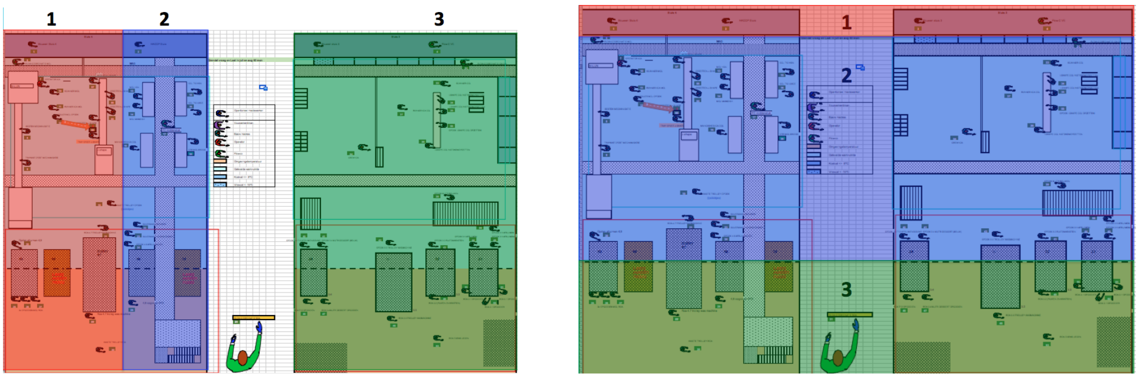


Figure 3.4: Layout

The final cooling and Opdek are cooled. In the final cooling the temperature is $-15°C$ and the Opdek is $12°C$. Between the final cooling and Opdek is a wall with different doors and between the Opdek and ROA is a wall with nine washing machines and a few openings.



(a) Layout with M class, rest and C class

(b) Layout with final cooling, Opdek and ROA

Figure 3.5: Department divided in two different ways

3.2.4. Information structure

Each day is divided in blocks, there are 12 blocks of 1 hour and 25 minutes each. Every block consists out of four or five flights. In a block there is freedom for each workplace when exactly each flight must be finished. Food is delivered in these blocks, so just before the block starts all food for the coming 1 hour and 25 minutes is delivered.

Shiftleaders can see the required production for the day with a computer program and employees know what needs to be made via information cards. These cards are printed on the department itself and are attached on each trolley, container or oven. On this card information is given which items needs to be in this trolley, container or oven and which position the trolley, container or oven need to stand in which flight. An information card is given in Figure 3.6. In the top information is given for all items which needs to be in this trolley, container or oven. In the bottom all information is given about the flight, such as number of C class and M class passengers, type of plane, flight number, departure day and departure time. Also two barcodes are given on this card for scans.

Figure 3.6: Information card

To check if everything is made on schedule, information cards are scanned two times, namely the A and B scan. The A scan is given when the production is finished. After the A scan trolleys, containers and ovens are moved to the final cooling and sorted by flight. The second scan is given when an employee in the final cooling add the last items. When a trolley, container or oven has a B scan, it is ready for pick up. Also the control station of KCS can check with these scans if all trolleys, containers and ovens are prepared on time and are ready for distribution.

A plane is always equipped for full passenger configuration. So equipment levels are the same for different passenger configuration, only the food is missing for empty seats. Reason for this is to prevent that outstations run out of equipment. Equipment what is meant for empty seats is called pre-setup (PSU). PSU trays for instance are trays with equipment and without food.

3.3. Process analysis

3.3.1. Input and output of trolleys, containers and ovens

Another department called distribution collects all trolleys, containers and ovens from arriving flights and brings them to the ROA, this in the input of the system. Distribution also collects trolleys, containers and ovens from the final cooling and brings this to the planes, the output of the system. There is no strict time plan when equipment arrives at the ROA or is collected from the final cooling. This is dependent on the situation outside on the platform. Distribution can handle flights in two different ways, namely first collecting all used equipment from the plane and bringing this to the ROA, later distribution can drive all clean equipment from the final cooling to the plane. Another way of handling, is driving once from to the plane and switch the used equipment with a new set. Intercontinental flights stand for a few hours at Amsterdam Schiphol airport and the second method is used. So mostly the used equipment is already standing in the plane for a few hours. In Intercontinental department trolleys, containers and ovens go through ROA, Opdek and final cooling.

3.3.2. Sorting

Distribution brings all trolleys, containers and ovens to the first sub department from intercontinental, namely the ROA. All equipment is divided into two separate flows, one for C class and one for M class. Now trolleys, containers and ovens are divided into T11 trolleys, T12 trolleys, standard containers, squared containers and ovens. Some kinds are even further divided based on the actual content of the equipment. All these different types stays in the inventory next to washing machines.

All ovens are collected in special oven carts. Most ovens still have food laying on the skids and skids are often in the wrong position. One employee is emptying ovens and rearranging the skids. When a full cart is prepared for washing, the cart is transported to the trolley wash machine and are washed.

3.3.3. Washing

There are nine washing machines standing between the ROA and the Opdek. Three washing machines for the C class, three washing machines for the M class, one washing machine for the C class and the M class combined, one washing machine for other washing activities and one washing machine which is only used for emergencies. Washing machines have a number, the numbers are counted from right to left. From right to left there is 3,1-3,5 and 4,6-4,9. Washing machines 3,3 and 4,7 are trolley washing machines, they are higher then the other washing machines and used for washing trolleys, containers and ovens. The other washing machines are used to wash everything what is inside trolleys, containers and ovens. On the other side of the washing machine is the second sub department, named the Opdek. Now all washing machines are briefly summarized.

- 3,1; trolleys with trays of the C class go to washing machine number 3,1. A lot of different equipment is going through this washing machine. The trays in C class are full with fragile porcelain, most items must be handled with care and are reused. All food in the bowls and on the plates need to be thrown away and the bowls and plates are washed. In most trolleys a drawer with glasses are present, the drawer with glasses must be filled in a specific way. There are three different positions for employees by washing machine 3,1 and every position has an elevator for three different trolleys. So in total nine trolleys can be emptied at the same time by three employees. For emptying three trolleys, an employee has 15 minutes. When equipment is on the other side of the washing machine, it is first placed in crates and some are later reorganized in flatter crates, the so called blue plates. Blue plates go to the internal or external food supplier. Other equipment goes to the storage and later to assembly line for C class.

- 3,2; washes material from the kitchen, other departments, crates and drawers. Those materials are usually offered in big carts. On the other side of the washing machine the materials are usually again put in big carts.

- 3,3; all trolleys from 3,1 and 3,4 and some containers from 4,6 are pushed to the trolley washing machine 3,3 for C class. Also ovens from oven carts for C class are washed here. In the Opdek information cards are matched with just washed trolleys. The trolleys, containers and ovens with information cards go to the assembly line for C class and the assembly station VLAS.

- 3,4; T11 dessert trolleys and T12 trolleys with equipment are washed by washing machine 3,4. One employee is responsible for dessert trolleys and another employee is emptying T12 trolleys with equipment. Both have an elevator for three T11 trolleys or six T12 trolleys. For emptying the elevator with items, an employee has 15 minutes. In the Opdek equipment is going to assembly line for C class and the assembly station VLAS.

- 3,5; is only used for emergency.

- 4,6; all standard and squared containers are emptied at washing machine 4,6. The containers have all kind of equipment, the items in the containers are reused. There is no specific time given for washing machine 4,6. On the other side of the washing machine equipment goes into crates.

- 4,7; some containers from 4,6 and all trolleys from 4,8 and 4,9 are pushed to trolley washing machine 4,7 for M class. Also ovens from oven carts for M class are washed here. In Opdek M class trolleys go to a place near the assembly line for M class, also trolleys, containers and ovens go to the assembly station VLAS.

- 4,8; is only used for several hours per shift. Trolleys with trays for M class go to washing machine number 4,9. All material on the trays is thrown away, this is plastic and food. Only the tray must be washed. For emptying three trolleys with trays, an employee has 10 minutes. In documentation washing machine 4,8 is only used for emergency. In Opdek all trays go onto big carts and will stay in the inventory until needed by the robot or the assembly line for trolleys with M class trays.

- 4,9; trolleys with trays for M class go to washing machine number 4,9. All material on the trays is thrown away, this is plastic and food. Only the tray must be washed. For emptying three trolleys with trays, an employee has 10 minutes. In Opdek all trays go onto big carts and will stay in the inventory until needed by the robot or the assembly line for trolleys with M class trays.

3.3.4. Assembly

Now all trolleys, container and ovens have arrived at the second department, the Opdek. There are four different processes for assembly, namely assembly process of trolleys with M class trays, assembly process of trolleys with C class trays and two processes for assembling of all other trolleys, containers and ovens. The last two processes are done by VLAS and silverware. This can also be seen in Figure 3.7, here the layout of the Opdek is illustrated. Next all different processes are discussed.

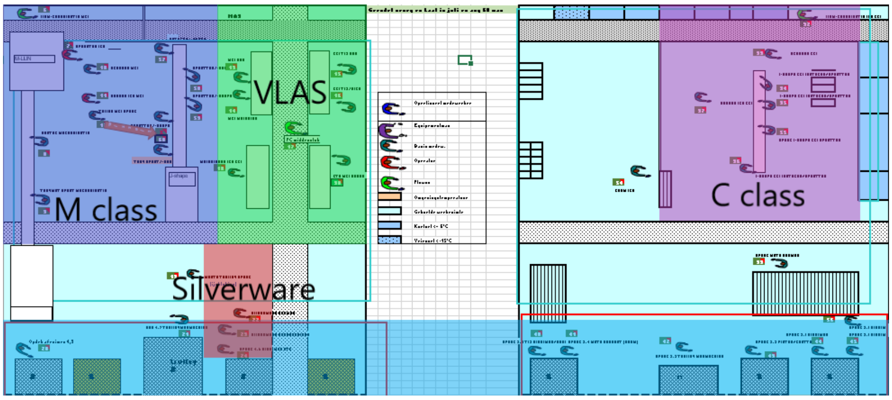


Figure 3.7: Layout Opdek with different parts

M class, robot and J shape M class trays are prepared in two different ways, namely with the robot and with the assembly line for M class, namely the J shape. The basic principle of the robot and J shape is identical. A tray travels on the assembly line and every station adds elements on that tray. At the end of the assembly line the tray with traymat, food, water bottle and cutlery is placed in a trolley. J shape has only manual stations, with the robot some stations are automatic.

The flow coordinator of the M class receives information cards for the trolleys. On the cards the number of trays and type of meals for each trolley are given. There are only a few types of meals for M class. One employee is responsible for enough equipment for both lines. Four employees are needed for the robot, namely one for the traymat, one for cutlery and two operators. Five employees are needed for the J shape, one for the traymat, three for adding water bottles, cutlery and food on trays and finally one for placing the trays into the trolley. One scanner is responsible for completing the trolleys with empty trays, scanning and moving the trolleys to the final cooling by the right flight. Extra trays are added for PSU.

C class, I shape C class trays are prepared on the assembly line for C class, the I shape. There is one employee responsible for enough food and equipment, one scanner and four employees for the I shape. There are a lot of different variations in trays with food and equipment. When the business class is not full, PSU trays with equipment must be made.

The setup time is relatively high. In the beginning of the shift all employees for the I shape are adding traymats on trays. There are two different traymats for C class. When there are a few hundred trays with traymats, the production of the first tray will start. After a set of trays the production line will stop and all equipment will be moved to the storage for trays with other items. For the next set of trays the food and equipment is searched in the storage. One scanner is responsible for scanning the trolleys and moving the trolleys to the final cooling by the right flight.

VLAS VLAS department counts four elevators with in total seven employees. Elevators are used for better ergonomics. C class is prepared on two elevators and M class is prepared on the other two elevators. For C class, hot snacks, main meals and juices are added in trolleys, containers and ovens. For M class only hot snacks and main meals are added in trolleys, containers and ovens. An employee responsible for one set of trolleys, containers and ovens, the employee will first collect all equipment and food. Food can be found in coolings and trolleys, containers and ovens can be collected by trolley washing machines. Information cards are already attached on every trolley, container and oven. .

Food is delivered in the cooling per flight, all items for a flight are counted. An employee of VLAS collects all items for one flight from the cooling and adds the correct number items in the trolleys for the flights. When there are items left or if there is a shortage at the end of a flight the employee need to count all items again. An employee brings the trolleys, containers and ovens go to the final cooling afterwards.

Silverware Silverware workplace is close to the washing machine with silverware equipment. This workplace builds standard containers and squared containers. Standard containers and squared containers come from the trolley was machine. All other equipment coming from a normal was machine is placed via certain loading diagrams in drawers. The drawers are again placed in the containers. When there are new containers needed, information cards are attached to the container.

3.3.5. final cooling

All trolleys, containers and ovens are sorted by flights in the final cooling, the temperature in the final cooling is $-15°C$. Four employees are working here with one flow coordinator. Employees check temperature of the meals and add special meals to the trolleys, containers and ovens. Also a last check is made with the number of passengers with the control of KCS. If the number of passengers is increased, meals are added. Since the information in the Opdek is mostly outdated meals needs to be added in the final cooling.

3.4. Measured output performance

3.4.1. Washing, J shape, VLAS and I shape

All workplaces in the ROA with a washing machine are equipped with an elevator, this elevator is used for ergonomics. When the elevator is up the trolleys or containers are on a good height to be emptied. When the elevator is down the trolleys and containers are switched for other ones. With measurements it is assumed that an employee is emptying trolleys and containers when the elevator is up and is switching equipment when the elevator is down. To measure the time it takes to empty equipment the time is noted when the elevators start moving up and down.

In Table 3.1 measurements for different washing machines in the ROA and assembly at J shape can be seen. Washing machines can have different amount of equipment, this is showed in the second column. For each washing machine average, standard deviation is given. The standard deviation is high. For washing machine 3,1 this is 06:55 for emptying three T11 trolleys, this is 27,5% of the total time. For washing machine 4,9 this is 01:44 for emptying three T11 trolleys, this is 19,3% of the total time.

There was no fixed number of measurements. There are a lot of small breaks which make it difficult to make a lot of measurement after each other. With a break no information could be used from the ongoing processes. At washing machine 3,1 and 4,9 three employees or more empty equipment and at washing machine 3,4 and 4,7 only one employee empties equipment. When only one employee is emptying an equipment type, only one measurement can be done at the same time. A few washing machines could be observed together, this clarifies also the difference in number of measurements.

Table 3.1: Measurements for different washing machines and J shape

Machine	Equipment	Up / down	Average	Standard deviation	Number of measurements
3,1	3 T11	Up	23:55	06:55	27
		Down	01:50	01:01	22
3,4	3 T11	Up	16:16	04:52	13
		Down	02:49	01:30	12
	6 T12	Up	07:20	03:27	20
		Down	03:15	01:35	18
4,7	1 STC	Up	00:24	00:11	16
	1 SQC	Up	00:20	00:07	14
		Down	01:02	00:25	15
4,9	3 T11	Up	09:00	02:21	111
		Down	01:44	00:53	105
J shape			01:39	00:17	16

The standard deviation is high for each measurement, since this process is really dependent on the speed of the employee. The process is simple and the pace can easily be adjusted. Mostly the same employee works at washing machine 4,7 for each team, so only three persons could be measured (one for each team). One of the three employees has a different way of emptying and does not use the elevator. The employee empties individual carts with containers from the ground. To compare this employee 4,7 washing machine is measured only per container.

Processing times of 2017 are used for VLAS assembly station. This is the only assembly station with known processing times. These measurements are done by a student [37]. Processing times are divided into valuable adding and non value adding steps. Processing times are also given different kind of equipment, this is explained in Section 3.4.3. The processing times are given in Table 3.2.

Table 3.2: Processing times for VLAS

	T11	T12	STC	SQC	OIS
mo3					
co3	03:43	02:17	01:47	01:47	02:13
ma3	02:44	01:30	00:41	01:47	00:41
se3			01:55	01:55	

I shape is not measured, processing times are discussed with management of the intercontinental flow and several shiftleaders. Processing times of I shape are not constant. Approximately one third of the time, no assembly takes place at I shape. Processing times are based on knowledge and the total production numbers per day.

Washing machine 4,9 has by far the easiest process, almost no skill is needed. This gives a good view on the mentality and speed of employees, since the pace can easily be adjust by the willingness of the employee. The process of washing machine 4,9 is measured for each team individually. A big difference is noted between the teams as can be seen in Table 3.3. Team B is with an average of 9:21 the fastest team with 7:58 for emptying trolleys and 1:23 for switching trolleys. Team A is the slowest with an average of 12:48 with 10:48 for emptying trolleys and 2:00 for switching trolleys. This can also be seen while observing the department.

Table 3.3: Measurements for washing machine 4,9 for different teams

Team	Equipment	Up / down	Average	Standard deviation	Number of measurements
A	3 T11	Up	10:48	02:21	38
	3 T11	Down	02:00	00:58	37
B	3 T11	Up	07:58	01:45	37
	3 T11	Down	01:23	00:43	35
C	3 T11	Up	08:09	01:45	36
	3 T11	Down	01:49	00:51	33

Histograms 3,1 and 4,9 washing machines In Figure 3.8 and Figure 3.9 histograms are shown of washing machine 3,1 and 4,9. In the histograms it can be seen that there is a high variance in the processing times.

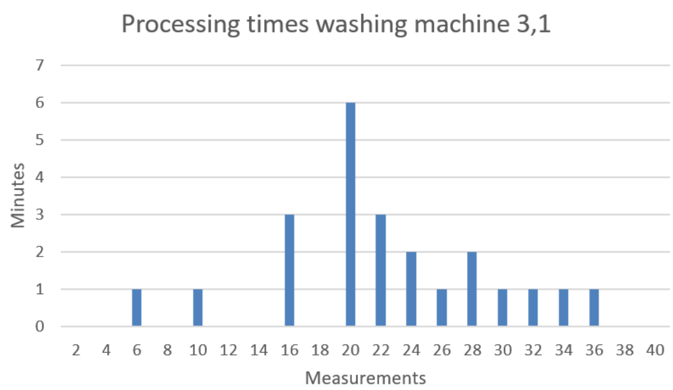


Figure 3.8: Processing times was machine 3,1

This is also illustrated in Table 3.1. For washing machine 3,1 this is 06:55 for emptying three T11 trolleys, this is 27,5% of the total time. For washing machine 4,9 this is 01:44 for emptying three T11 trolleys, this is 19,3% of the total time.

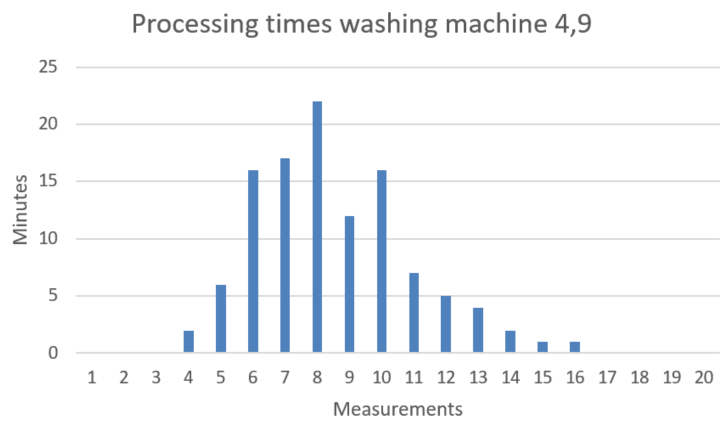


Figure 3.9: Processing times was machine 4,9

3.4.2. Robot

The robot for M class trays calculates its own production data. The robot is designed for assembling 24000 trays each day, however the amount of trays assembled is much lower. In Figure 3.10 the number of trays are shown for each day in July 2018. Notable are the big fluctuations each day. Due to the big fluctuations it is difficult to predict the production for a shift. The production is much lower then expected, there are different reasons for this. One of the reasons is that the last part of the robot where trays are put in trolleys had a lot of errors. It is chosen to prevent the errors by decreasing the velocity of the assembly line. Another reason is that the robot is a few years old and less effective compared with a few years ago. The last reason is that the operators are not skilled enough. Operators are production employees with a bit more training.

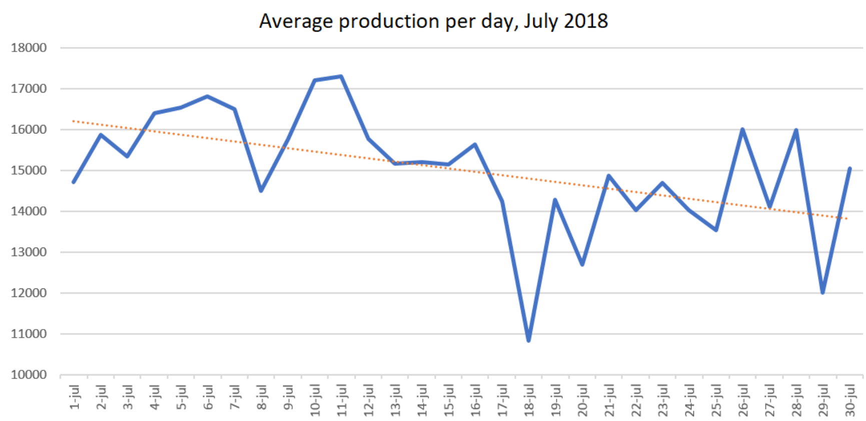


Figure 3.10: Production robot per day in July 2018

Production numbers in July fluctuate a lot compared with other months. March was one of the most steady months in 2018 so far as can be seen in Figure 3.11. The trendline is almost horizontal and difference between the trendline and the actual production per day is less compared with July.

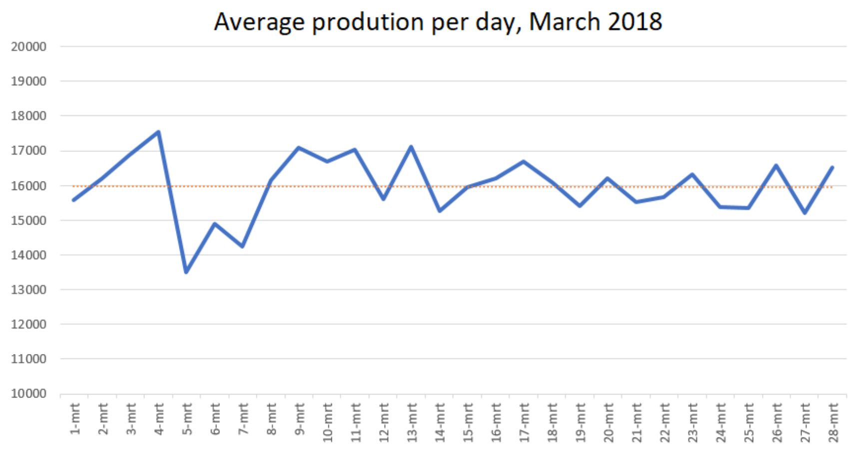


Figure 3.11: Production robot per day in March 2018

In Figure 3.12 the average production in July for the robot can be seen for every hour of the day. There are two blocks, one for each shift. The production starts not exactly at 6 am and the oil in the robot needs to be heated, so the number of trays slowly increases to approximately 1000 trays an hour. Reason for the decrease between 9 and 10 pm can be an early stop of production.

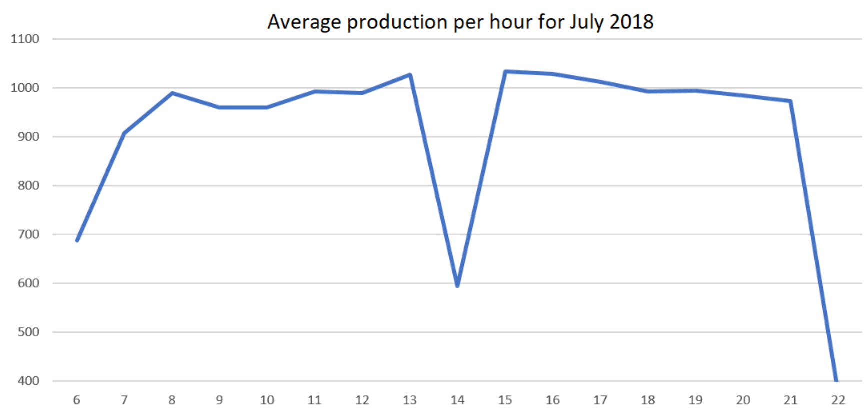


Figure 3.12: Production robot per hour in July 2018

In July almost all errors of the robot are human related. The five top reasons are; not enough crates in the cooling, no trolleys, no product meal on place one, stop due to cutlery workplace and trolley handling. Only the last one happened due to the robot itself.

3.4.3. Processing times

All processing times are combined for ROA and Opdek and given in Table 3.4 for ROA and 3.5 for Opdek. Here all equipment types are further divided in sub departments. Each departments handles specific types of trolleys. For instance MO3 handles trolleys with M class trays. The calculation to achieve these processing times is given in Section B.1

Table 3.4: Current state ROA

	T11	T12	STC	SQC	OIS
MO3	00:03:35	00:01:47			
CO3	00:07:41	00:01:50	00:00:29	00:00:23	00:00:56
MA3	00:00:00	00:01:52	00:00:29	00:00:23	00:00:56
SE3			00:00:29	00:00:23	

Table 3.5: Current state Opdek

	T11	T12	STC	SQC	OIS
MO3	00:01:39	00:00:49			
CO3	00:04:34	00:02:17	00:01:47	00:01:47	00:02:13
MA3	00:02:44	00:01:30	00:00:41	00:01:47	00:00:41
SE3			00:01:55	00:01:55	

3.5. Key performance indicators

3.5.1. Current way of measuring key performance indicators

KCS measures its performance with key performance indicators (KPI). KPI are currently defined in two different ways, namely the KPI on the year planning and the KPI measured each month. Also NT drives are measured each day. NT drives occur when an error is discovered before departure. A cart will deliver missing elements to the plane. First the KPI's on the year board are discussed followed by the KPI's measured every week.

Yearly key performance indicators Here all indicators are divided into customer, people, process and quality topics.

- Customer, indicators about KLM.
  - NPS 7, the desire that KLM will give KCS a seven out of ten at the end of the year for performance.
  - ICA parameter of minimum 82%, this is on time deliveries at the aircraft.
  - Deliver according to instructions.
  - Short time to market.
- People, indicators about employees of KCS.
  - Zero red workplaces, this means non workplaces with really bad ergonomics.
  - 90% of all judgments of employees delivered on time.
  - Employability of 91%, so 9% of employees can be ill at the same time.
  - Right development and training for every employee.
- Process
  - Maximum 15 NT drives each week for the food department.
  - Continue improvement.
  - Increasing efficiency.
- Quality
  - Hazard Analysis and Critical Control Points score of minimum 93%.
  - Monthly KPI round has a minimum score of 80%.
  - Zero accidents.
  - Corporate social responsibility (CSR)

Monthly key performance indicators Monthly all KPI's of the food department are measured. This check is done for the whole company and all scores are compared for each month and between different departments. For each indicator one can score three or four different amounts of points. For instance one can score 0, 5, 7 or 10 points for the temperature on the departments. All points are summed and compared with the maximum amount of point available. The indicators measured are explained below.

- Temperature

- Products, two products for C class, two products for M class and four products in the final cooling are measured. Critical products needs to be bellow $7°C$ and not critical products bellow $10°C$.
- Environment, ROA needs to be warmer then $17°C$ and the Opdek must be colder then $13°C$.
- Refrigerators must have a temperature between $0°C$ and $4°C$.
- Freezers must have a certain temperature, the required temperature of the freezer is not given on the KPI form.
- Washing machine must have a temperature higher then $71°C$, except the trolley washing machine. The trolley was machine must have a temperature bellow $71°C$.

- Best before date
  - Products are not over their best before date.
  - All products are handled first in first out.
  - Products are handled according the required procedure.
  - Use of required date cards.
- Hazard Analysis and Critical Control Points
  - Thermometers are available.
  - All forms are filled in.
  - Bactowipes are available.
  - Use of stickers.
- Code of behaviour
  - All employees are wearing the right clothing for the department.
  - There is no food on the department what does not belong there. There is no liquid available at the Opdek.
  - Employees do not wear jewellery.
  - Right use of gloves.
  - Right use of hairnet and beard net.
- Cleaning of hands
  - All employees wash their hands while entering the department.
  - All sinks are available and clean.
- Cleaning
  - All cleaning equipment is available.
  - All equipment is clean and placed in the right place.
  - All storage equipment is clean.
  - Refrigerators and freezers are in excellent state.
  - Internal and external equipment in the right place and clean.
  - Department is clean.
- Doors/flaps
  - All flaps and rubbers are intact.
  - Doors of the trolleys are open.
- Strange items
  - There is no wood, rubber, staples and paperclips available on the department.

  - No glass at the department.

- Remaining
  - Regeneration is done right.
  - No products or equipment are placed on the ground.
  - All products are stored in the right way.
  - The technical state of the department is good.
  - All tasks are done according to visualizations.

3.5.2. Key performance indicators for model

Though the big amount of current KPI's, there is no clear overview. All parameters for the yearly check are neglected since they are not important for a computer model, not measurable or not specific. For instance continue improvement is not specific and difficult to measure. Also monthly KPI's are mostly neglected, this happens since almost all parameters make sure that the department is in an acceptable state and employees do some basic tasks. Some parameters will be measured indirect. For instance, temperature of meals are corresponding with the time spend of food on the department. This last one, total time on the floor, is an interesting parameter for the model. Of course the indicators are not meant to decrease. Most current KPI's are measured in the total of the food department, however KPI's mostly need to be measured per workplace.

It is chosen to work with other KPI's for the model, these are found in the literature. Literature states that at least one kpi must be measured for resources, output and flexibility, since these three types are crucial to the overall performance. Resource key performance indicators are work in progress inventory and number of working hours. Output key performance indicators are too late delivery, stock out and throughput time. A flexibility key performance indicator is not used, since this key performance indicator is hard to measure with a model and difficult to assign scores to design alternatives.

3.6. Conclusion

How is the food assembly process structured currently?

Working hours of the Intercontinental department are from 6 am to 11 pm seven days per week, with 14 effective working hours per day. There are five equipment types, namely T11 trolleys, T12 trolleys, STC containers, SQC containers and oven carriers. Equipment arriving from planes is the input of the intercontinental department, the output is equipment going to planes. Information is provided with information cards attached to trolleys, containers and ovens.

The department consists out of three parts, namely ROA, Opdek and the final cooling. In ROA trolleys, containers and ovens are sorted, emptied and cleaned. There are seven washing machines for emptying equipment and two trolley washing machines for cleaning the equipment. In Opdek trolleys, containers and ovens are assembled with four assembly station. Robot and J shape for trolleys with M class trays, I shape for trolleys with C class trays and VLAS for all other equipment types. After assembling trolleys, containers and ovens are stored in the final cooling. This is an inventory where trolleys, containers and ovens wait until they are transported to planes.

All stations in ROA are measure together with J shape from Opdek. Processing times for VLAS are already known and processing time of I shape is discussed with employees. In Table 3.6 processing times are given for ROA and Opdek.

Table 3.6: Current state ROA (left) and Opdek (right)

	T11	T12	STC	SQC	OIS	T11	T12	STC	SQC	OIS
MO3	03:35	01:47				01:39	00:49			
CO3	07:41	01:50	00:29	00:23	00:56	04:34	02:17	01:47	01:47	02:13
MA3	00:00	01:52	00:29	00:23	00:56	02:44	01:30	00:41	01:47	00:41
SE3			00:29	00:23				01:55	01:55	

What criteria can be used to assess performance of the different solution alternatives?

Current key performance indicators give a global overview of the state of the Intercontintal department. Actual performance of individual workplaces can not be measured with the current key performance indicators.

For this report new key performance indicators are used. Resource key performance indicators are work in progress inventory and number of working hours. Output key performance indicators are too late delivery, stock out and throughput time.

III

Analyze

4

Current state performance analysis

In this Chapter the current performance of the Intercontinental department is analyzed. This is done with various techniques described in the literature. First is starts with introducing new variables in Section 4.1. These variables are calculated at the end of the chapter in Section 4.6. In between various techniques are used to analyze the current performance. In Section 4.2 a flowchart is given, in Section 4.3 a value stream map is given, in Section 4.4 TIMWOODS is used to identify waste and finally in Section 4.5 a swimlane is given. The chapter is concluded in Section 4.7 with answering the fourth research question.

What is the current performance of the food assembly process for methods found in literature?

4.1. New variables introduced

Currently performance is measured in the number of flights and the number of passengers catered. Not all aircraft types have the same passenger configuration. An aircraft with the a small number of passengers is different to cater compared with an aircraft with a large number of passengers. Also not all aircraft types have place for the same number of trolleys, containers and ovens. The load of an aircraft is dependent on destination, passenger configuration and aircraft type.

To measure performance in a level with more detail, the choice is made to measure performance in number of trolleys, containers and ovens. Now the performance of each location of the department can be measured instead of the department as a whole. The number of trolleys, containers and ovens that needs to be assembled every day is not known in the Intercontinental department. Section 4.6 explains how this can be calculated.

4.2. Flowchart

In Figure 4.1 a simplified flowchart is given. This Figure illustrates the flow of trolleys, containers and ovens throughout the department. A triangle illustrates an inventory. At the start all trolleys, containers and ovens are sorted and put in an inventory close to washing machines. After the first inventory trolleys, containers and ovens are emptied and cleaned. All trolleys, containers and ovens have arrived in the Opdek, here is the second inventory. When trolleys, containers or ovens are needed, they are assembled at assembly station. The last triangle is a regulated inventory, this inventory is the final cooling. Here trolleys, containers and ovens wait until distribution will bring it to planes. This is the output of the department.

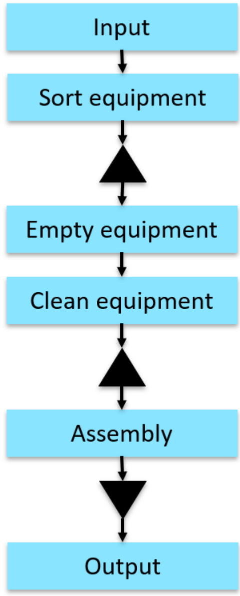


Figure 4.1: Compact flowchart of equipment

Equipment streams are showed in Figure 4.2. On the left side trucks arrive with trolleys, containers and ovens. This equipment stream is divided into M class and C class, this is the second line. M and C class are divided into different equipment types and even on content of equipment meant for different washing machines, on line three. There are four different washing machines for emptying trolleys, containers and ovens. These are described from the top down, namely one washing machine emptying trolleys with M class trays, one for all containers, one with all other trolleys and the last washing machine for trolleys with C class trays. All trolleys, containers and ovens are washed at two different trolley washing machines illustrated at line four, namely one for M class and one for C class. In these was machines the trolleys, containers and ovens are washed. In the Opdek there are four different assembly stations, namely the robot and J shape for assembling trolleys with M class trays, VLAS for assembling all other equipment and I shape assembly line for assembling trolleys with C class trays. The assembly station are given on line 5. After assembling all trolleys, containers and ovens are collected in the final cooling, the most right dot.

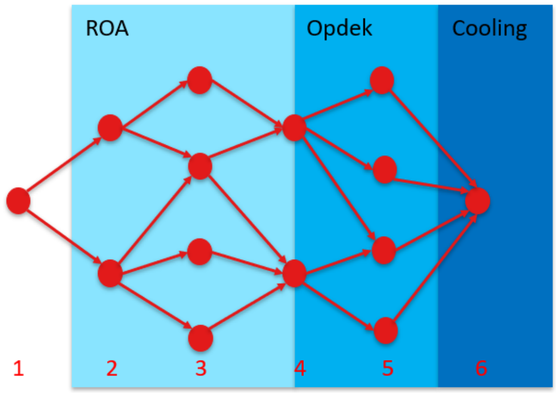
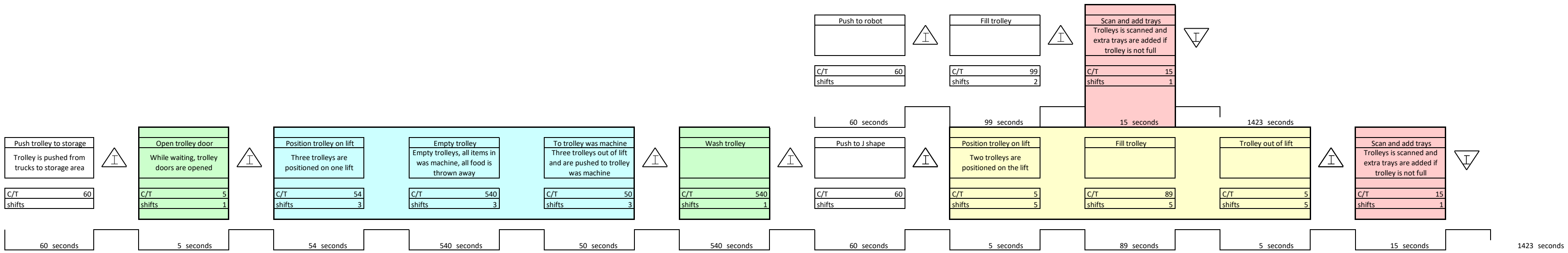


Figure 4.2: Department with equipment stream

4.3. Value stream map

Since most flows throughout the department are quite similar, only one Value stream map is made the flow. It is chosen to look at T11 trolleys filled with M class trays. The value stream is given on the next page. Some processes are boxed with a colour. Processes with the same colour are done by the same employee or group of employees. So for instance the trolley doors are opened by the same employee who also puts trolleys in the trolley was machine. Inventories are given with a triangle, the last inventory is a regulated inventory.



Push to robot
C/T 60
shifts
Fill trolley
C/T 99
shifts 2
Scan and add trays
Trolleys is scanned and extra trays are added if trolley is not full
C/T 15
shifts 1
60 seconds
99 seconds
15 seconds
1423 seconds
Push trolley to storage
Trolley is pushed from trucks to storage area
C/T 60
shifts
Open trolley door
While waiting, trolley doors are opened
C/T 5
shifts 1
Position trolley on lift
Three trolleys are positioned on one lift
C/T 54
shifts 3
Empty trolley
Empty trolleys, all items in was machine, all food is thrown away
C/T 540
shifts 3
To trolley was machine
Three trolleys out of lift and are pushed to trolley was machine
C/T 50
shifts 3
Wash trolley
C/T 540
shifts 1
Push to J shape
C/T 60
shifts
Position trolley on lift
Two trolleys are positioned on the lift
C/T 5
shifts 5
Fill trolley
C/T 89
shifts 5
Trolley out of lift
C/T 5
shifts 5
Scan and add trays
Trolleys is scanned and extra trays are added if trolley is not full
C/T 15
shifts 1
60 seconds
5 seconds
54 seconds
540 seconds
50 seconds
540 seconds
60 seconds
5 seconds
89 seconds
5 seconds
15 seconds
1423 seconds

4.4. TIMWOODS waste

TIMWOODS is explained in Section 2.2.1 and is a method to define waste. Different kinds of waste are explained below.

Transport There is a lot of transport in ROA and Opdek. One of the reasons is that inventory can be found in every empty part of the department. Since there is inventory between processing steps, employees start with walking and collecting equipment. In ROA this means that the floor area between the entrance and the washing machines is a queue for the washing machines. An employee of the washing machine will collect trolleys and containers out of a certain queue. This queue is placed immediately in front of the washing machine. In the Opdek the inventory is more spread and employees need to walk for collecting equipment and food all over the Opdek and in several coolings. The walking distance in Opdek is larger.

Inventory As said in the transport section, there is a lot of inventory and inventory can be found between almost every processing step. Inventory levels change during the year, week and even day. A different season means a different flight schedule and different amounts of trolleys, containers and ovens on the floor. During the month the flight schedule will not change, there are also different amounts of flights in the week. During the day there are several peaks for arriving and departing flights, this can also be seen on the ROA and Opdek. Another consequence of the peaks during the day is that there is a big inventory in the cooling, since the output has big fluctuations and the production is semi continuous. Trolleys, containers and ovens wait for 6 to 12 hours in the final cooling. The final cooling is also used for decreasing the temperature of food items and as buffer for disturbances. Every 1 hour and 25 minutes food will arrive which will be assembled. So a maximum inventory of food is 1 hour and 25 minutes. Batching occurs at every wash and assembly station, however only one piece is handled at the same time, the other trolleys, containers and ovens in the washing or assembly station can be seen as inventory.

Motion Motion can be divided in searching for information and searching for equipment, food and items. All information is given on information cards, these cards have codes for each type of product. Since 50% of the employees work here for several years, searching for information is mostly not needed. However when there is a change in the menu or other employees learn new stations where products codes are used, searching for information is needed. There is a change in menu twice a year. Searching for equipment, food and items is much more common. This increases processing times of VLAS and I shape significantly. For every batch equipment, food and items need to be searched. Food can mostly be found in several coolings on the sides of the department and equipment and trolleys on the ends of washing machines.

Waiting Waiting occurs at all assembly stations and sometimes in the ROA. There are two main causes of waiting at I shape and J shape, namely a shortage of food, items or equipment at the assembly line and waiting at the last person of the assembly line. For J shape there is one person responsible for the presence of food, items and equipment. For I shape all employees are responsible for the presence of food and items, a separate employee is responsible for equipment. The main cause of waiting at the robot are errors of the robot. At VLAS section there are four elevators in total and six employees. So two elevators need to be shared by two different employees, when one employee is ready the other has to wait while the first employee changes equipment. Also all assembly stations sometimes have to wait when food, items or equipment are out of stock or too late. When an employee in the Opdek is not quick enough in emptying the washing machine, the washing machine will stop and the person in the ROA has to wait.

Overproduction A lot of food is not eaten by the passenger and is thrown away in the ROA. This food is produced while it was not wanted by the end customer. Also PSU is given for all empty seats, PSU is empty equipment. C class PSU are trays with porcelain and without food. When on the way back this seat is also empty, the PSU was not needed. To flatten productions, it often occurs that output is produced before it is needed, the output will stay longer in the final cooling.

Over processing Food is allowed to be maximum $7°C$ while leaving this department. To be sure that all food is maximum $7°C$, the output will stay in the final cooling for a while. When food temperature is lower then $7°C$ the output stays longer then necessary in the final cooling. Since the output is produced hours before departure, the number of passengers is no longer accurate and trays must be added manually in the final cooling. Adding of trays in the final cooling is much slower then producing these trays on current assembly lines.

Defects A failure of this department is really challenging for the stewardesses, since no errors can be compensated when the aircraft is in the air. Adding trays in the final cooling can be seen as a defect. Namely the production of trays was lower then needed. Another defect happens at VLAS section. The employee receives a certain amount of meals, this amount is supposed to be the number of meals the employee needs to add to trolleys, containers or ovens. This is often not the case. The number of meals added for each part of the trolley, container and oven needs to be calculated by the employee while stowing. When the employee has more meals then places every meal needs to be counted as well. This precaution is made for calculation mistakes, however since the number of meals given is mostly not correct the second time counting is done for nothing.

Skills Not all employees can work in every workplace, reason for this is unskilled workers or workers with a small handicap. The most experienced employees generally stand at the most difficult positions and temporary workers at the easiest positions. 50% Of all employees are temporary, some are working for only a few days and the maximum for temporary worker is two years. A lot of employees have minimum skills and can not operate at every place. Operators for the robot are regular employees with a small training. Operators are mostly skilled enough to solve malfunctions of the robot, however are not skilled enough to find the root cause and prevent the problem from happening again.

4.5. Swimlane analysis

Swimlane is given in Appendix D. The lanes of the swimlane are front office, Marfo, kitchen, Schiphol North, GOC, Trolley was machine, 3,4, 4,6, M class, VLAS, C class, ROA, final cooling and distribution.

Front office controls all activities and is responsible for the information flow for production. Front office also regulates all trucks between planes and the building of KCS. Marfo is an external food supplier and the kitchen the internal food supplier. Schiphol North is the distribution centre. GOC is transports goods between Schiphol North and Schiphol Centre, distribution transport goods between planes and Schiphol Centre. The other rows of the swimlanes are part of the intercontinental food flow, namely trolley was machines, 3,4, 4,6, M class, VLAS, C class, ROA and final cooling. Information cards are distributed to trolley was machines, 4,6 and M class. The swimlane gives an overview of the relations with other departments and the time planning for handling equipment.

4.6. Production calculated in number of trolleys, containers and ovens

To work with the new variables introduced, the number of trolleys, containers and ovens need to be calculated. First the input is better defined. An aircraft usually has three galley positions. In Figure 4.3 galley positions of a 787-900 are illustrated. This aircraft has an after, mid and front galley. Usually all trolleys, containers and ovens of one galley position go into one truck from and to the aircraft. Sometimes two galley positions go into one truck. All trolleys, containers and ovens for one flight are delivered in three parts at the aircraft and also in three parts at the ROA. So the input and the output of the intercontinental department are batches of trolleys, containers and ovens intended for one galley position. To determine the exact input and output of the intercontinental department all trolleys, containers and ovens of each galley position need to be investigated. This is done via three excel files.

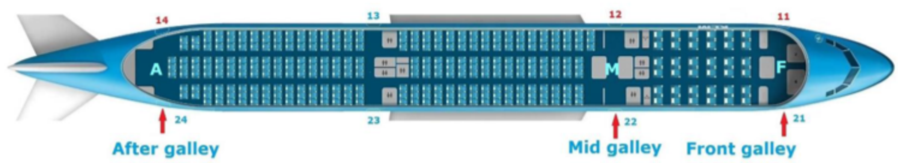


Figure 4.3: Galley positions of a 787-900 from internal KCS source

Important to note is that the data splits the intercontinental department in four different sub departments, namely MO3, CO3, MA3 and SE3. These four departments handle different kinds of trolleys, containers and ovens. For instance MO3 department consists only out of T11 and T12 trolleys with M class trays.

To calculate the number of trolleys, containers and ovens several Excel files and Matlab are used. The first Excel file is a flight schedule for the summer of 2018, in this schedule all planned flights are given with destination, flightnumber, departure time, arrival time, aircraft type and passenger configuration. First all flights for a specific day are determined. These specific flights have products codes, product codes are determined with the second excel file. A product code stands for everything what needs to be loaded for this specific flight by KCS. All information for a specific product code can be found in the third Excel file. This information is on equipment level and each trolley, container and oven has information about galley position, departure or arrival time and the sub department.

With Matlab one starts with the desired date and Matlab searches all flights for that specific date with corresponding information. With the second Excel file the product code is added for those flights and lastly all data from the product codes for that day is searched. This data is a big table for each flight and gives no overview yet of the amount of equipment. First all lines is this table from other departments are deleted, so only MO3, CO3, MA3 and SE3 will remain. Later all types of equipment are counted for each galley position and department. In Appendix B the output of this process is given. Only the first ten arriving flights are given of 23 August.

The number of arriving and departing trolleys, containers and ovens are calculated for each day in September, this is illustrated for arriving flights in Table 4.1 and for departing flights in Table 4.2. The total number of trolleys, containers and ovens fluctuates during the week. On Sunday most trolleys, containers and equipment is assembled with in total 4508 and on Saturday the least amount with 4078 trolleys, containers and ovens. In Section B the total amount of trolleys, containers and ovens are illustrated for September divided in sub departments.

Table 4.1: Equipment of arriving flights in September

Arrival	T11	T12	STC	SQC	OIS	Total
Monday	1119	990	662	602	962	4335
Tuesday	1064	952	654	543	939	4152
Wednesday	1064	954	615	610	923	4166
Thursday	1112	980	701	546	969	4308
Friday	1070	972	595	635	921	4193
Saturday	1126	999	693	578	979	4375
Sunday	1099	980	615	650	939	4283
Total	7654	6827	4535	4164	6632	29812

Table 4.2: Equipment of departing flights in September

Departure	T11	T12	STC	SQC	OIS	Total
Monday	1092	985	627	619	945	4268
Tuesday	1082	952	647	575	938	4194
Wednesday	1057	948	645	562	925	4137
Thursday	1110	996	656	607	963	4332
Friday	1099	990	651	602	953	4295
Saturday	1049	931	609	584	905	4078
Sunday	1165	1025	700	615	1003	4508
Total	7654	6827	4535	4164	6632	29812

4.7. Conclusion

What is the current performance of the food assembly process for methods found in literature?

To measure current performance for each workstation a level with more detail is chosen. Now performance is measured in number of trolleys, containers and ovens instead of number of passenger and number of flights. In Table 4.3 the total number of trolleys, containers and ovens are given for each day in September for arriving and departing flights. T11 and T12 are two types of trolleys and STC and SQC are two types of containers.

Table 4.3: Equipment of arriving flights (left) and departing flights (right) for each day in September

	T11	T12	STC	SQC	OIS	Arr	T11	T12	STC	SQC	OIS	Dep
Monday	1119	990	662	602	962	4335	1092	985	627	619	945	4268
Tuesday	1064	952	654	543	939	4152	1082	952	647	575	938	4194
Wednesday	1064	954	615	610	923	4166	1057	948	645	562	925	4137
Thursday	1112	980	701	546	969	4308	1110	996	656	607	963	4332
Friday	1070	972	595	635	921	4193	1099	990	651	602	953	4295
Saturday	1126	999	693	578	979	4375	1049	931	609	584	905	4078
Sunday	1099	980	615	650	939	4283	1165	1025	700	615	1003	4508
Total	7654	6827	4535	4164	6632	29812	7654	6827	4535	4164	6632	29812

A simple flowchart shows that equipment is sorted, emptied, cleaned, assembled and cooled in the inventory. After sorting and after cleaning are inventories. The swimlane shows how the intercontinental department is connected with other departments of KCS.

TIMWOODS showed different waste. Transport is a big problem, the transport in ROA is relatively small compared with the transport in Opdek, since the walking distance is smaller in ROA. Inventory is a result of other waste. So inventory will decrease if the other waste is eliminated, only eliminating batching can be interesting. Searching for information happens not that often since information and knowledge is only needed at certain workplaces. Experienced workers mostly stand on these workplaces. Searching for equipment, food and items however, is a much bigger problem. Decreasing or eliminating this is certainly a must. Also waiting needs to be decreased as much as possible. Waiting occurs on missing equipment, food and items and also on other employees when task time is not matched. Overproduction and over processing is mostly explained with too much inventory in the final cooling. Better skills of workers can improve performance of the robot.

Trolleys, containers and ovens wait for 6 to 12 hours in the final cooling. The cooling is an inventory and a buffer for peaks of arriving and departing planes and possible distortions in the process. Maximum temperature of food can be maximum $7°C$, while assembling the food stays on the department which is $12°C$ and food will warm up. Food that stays too long on the department must stay longer in the final cooling, which increases inventory numbers and throughput time. Since food is produced hours before departure, passenger number are not accurate and reproduction is necessary.

5

Current simulation model and constraint identification

In this Chapter the current simulation model is given and the constraint is identified. The first part describes the simulation model. This starts with explaining which methods are used for the simulation model in Section 5.1, here it is decided that discrete event simulation is used, together with the programming language. Also delft systems approach and conceptual model from literature are used to create a model. In Section 5.2 assumptions and simplifications of the model are given. The model is validated and verified in Section 5.3 and results of the current simulation in the simulation model is given in Section 5.4. Finally in Section 5.5 the constraints are identified of the department. This is done by the simulation model, current problems, VSM, flowchart and TIMWOODS. This chapter is concluded in Section 5.6 with answering the fifth and sixth research question.

How can the current situation and design alternatives be modelled and evaluated?

What constraint is limiting the performance?

5.1. Methods used for simulation

5.1.1. Discrete event simulation

A simulation can be continuous or discrete. With discrete event simulation variables only change at different points in time, while in continuous simulation the state changes continuously. While modelling the intercontinental department there is no need for continuously changing states and discrete event simulation is easier. So discrete event simulation is used.

5.1.2. Programming language

Not all variables in this model have an exact value, some values have variables with a certain distribution. However all variables have the same value for each iteration, since comparing design alternatives is necessary. So there is an unique set of outputs and the model is deterministic. The model must be dynamic, since multiple days are simulated and not only the behaviour of a certain time.

It is chosen to work with the Simulink environment from Matlab. Simulink can handle deterministic, dynamic, discrete simulation and has a great combination with the Matlab environment. Also mechanical engineering at Delft University of Technology has a few courses with Matlab and Simulink.

5.1.3. Delft Systems Approach

The Delft Systems Approach uses elements which run through the system. Those elements are called entities in Matlab. Trolleys, containers and ovens are used as entities, these are material entities. Or more specifically

T11 trolleys, T12 trolleys, standard containers, squared containers and ovens are the entities of this system. Each entity has different attributes, the attributes are stated below.

- Service time for emptying trolleys, containers and ovens.
- Service time for assembly of trolleys, containers and ovens.
- Equipment; with this attribute it is decided if the entity is an T11 trolley, T12 trolley, standard containers, squared container or an oven.
- Department; this attribute gives the sub department where the activities or servers are situated for this trolley, container or oven.
- Time when an entity is created.
- Departure time of the plane.

The source of this system are the trucks transporting trolleys, containers and ovens from the planes to the ROA and the sink is when trolleys, containers and ovens are again transported to the planes. There are certain activities or servers in this model, namely for all processing steps. So for instance emptying trolleys, containers and ovens is done at a activity or server. Design alternatives can be modelled as subsystems, a system which is part of the original bigger system. When subsystem alternatives are used, the model can easily switch between different design alternatives.

5.1.4. Conceptual model

- Objective; is to evaluate different design alternatives of the future state for food assembly at the intercontinental flow of KCS. The time scale of the simulation is four weeks. Since only a week is not representative and steady state is not guaranteed. A week can be repeated four times since the flight schedule does not change. A bigger time interval is chosen not to be necessary. A high level of flexibility is needed from the model, since different design alternatives are tested with the same model. Changing from the current model to a design alternative must be easy. The run speed is not important, the difference between seconds or minutes is not of great importance. Only once in a while a simulation needs to be done. The final visual display of this model is valuable, since the outcomes need to explained to the company. However the final visual display can be made by hand from the results of the model to make the model simpler. Ease of use is at first not really important, since only the programmer will work with this model. Maybe later a simplified version of this model is needed for the company.
- Output of the model need to be at least the key performance indicators. So the number of working hours, work in progress inventory, stock out of equipment, too late deliveries and throughput time are the output variables. Number of working hours can be given by utilization of the employees and production numbers. When utilization is low, the number of actual working hours is low and vice versa. The most important work in progress inventory will probably be between the ROA and Opdek. Finished goods inventory is the number of items available in the final cooling. Stockout can be illustrated by the number of entities in queue between ROA and Opdek. When there are no entities in queue, there is a stockout. Too late deliveries are when the entities are not available in the final cooling when trolleys, containers and ovens for that flight are distributed to the plane. Throughput time is the time between creating the entity and destroying the entity. To get a better feeling of the throughput time in the simulation the time between creating the entity and going to the final cooling can be chosen.
- Input: first all incoming and outgoing flights per day are determined for the time interval. For each flight the amount of trolleys, containers and ovens needs to be defined. This is done with the aircraft type, passenger configuration and destination of the flight. With the arrival and departure time the exact moment can be determined when trolleys, containers and ovens arrive at the ROA or are needed in the final cooling. Also processing times are needed for emptying and assembling trolleys, containers and ovens and at last current inventory. Each entity created has an equipment type and department where it is made. The equipment type and department will determine the time it takes for each process. Processing times are given in Section 3.4.3.
- Model scope; ROA, Opdek and final cooling
- Assumptions and simplifications are given in Section 5.2.

5.2. Assumptions and simplifications

- A crucial assumption is that everything is loaded according to the loading diagram. This includes KCS and all outstations. It is also assumed that the loading diagram of arriving and departing flights are equal with the same aircraft type, passenger configuration and destination. The loading diagram from the same flight departing from Amsterdam Schiphol Airport is equal to the flight arrival at Amsterdam Schiphol Airport.
- The flow of trolleys, containers and ovens is a good representation of the complete flow of the intercontinental department.
- The month chosen is representative for the department.
- VLAS and silverware is organized in one station, all processing times are determined for the right station.
- Measurements of processing times are representative of the actual processing times.
- The number of employees is always the same, when someone is ill, the employee is replaced.
- All washing machines have the same speed.
- Processing times of J shape and robot are assumed identical.
- Planes with a destination to Tel Aviv are neglected. Tel Aviv is an exception for KCS since it is not part of either Europe and intercontinental flow. All information is given to Europe and it is assembled in Intercontinental department.
- There are several types of T11, T12 trolleys and ovens, with the simulation only one type of T11 trolleys, one type of T12 trolleys and one type of ovens is assumed.
- For assembling trolleys with C class trays, some preparation is done at the start of the Opdek. This preparation is neglected.
- No breaks are included, it is assumed that the production will go on. Arrival times and departure times are scaled to a workday without breaks.
- Input of the ROA stands immediately at the inventory at the ROA.
- There is enough space in each inventory position.
- There is enough space for washing trolleys, containers and ovens in the trolley was machine.
- All washing machines have sufficient capacity with current configuration.
- The way employees are simulated is acceptable.
- Crew trolleys are full with food for the crew, for simplification crew trolleys are treated as C class trolleys.

5.2.1. Side activities

The core business of KCS is cleaning and assembling trolleys, containers and ovens with food and equipment. However next to these activities other tasks are done as well in this department. Underneath is a list given of other activities, per activity it is mentioned if this is included or excluded in the model.

- Waste trolleys are trolleys especially for trash. Every aircraft has a few waste trolleys. The process of waste trolleys are independent of the flow of other trolleys, contains and ovens. It is chosen not to include waste trolleys.
- Washing process of crates. Every piece of food is stored and transported in crates to this department. Since there was food in crates, all crates must be washed after using. Crates are mostly washed at the end of the shift or by an employee at washing machine 3,2 together with equipment from other departments. Washing machine 3,2 is independent of the flow of trolleys, containers and ovens. It is chosen not to include washing of crates. However different concepts can have influence on the amount of crates.

- Cleaning cutlery in the first try is difficult. Often remaining food sticks to the cutlery. When some cutlery is not clean after the first try the whole batch is rejected and must be cleaned by hand. Cleaning cutlery is chosen to be out of scope.
- Two cars with glasses and one car with mugs are washed for the non food department for the intercontinental flow. This is an agreement with the non food department since they have not enough capacity to clean all of their own equipment. It is assumed that washing machine 3,2 is only intended for cleaning equipment for other departments and a part of the crates. Is is excluded for this model.
- Equipment for the kitchen is washed by washing machine 3,2. This contains several cars full with used equipment. This is an agreement with the kitchen since they have not enough capacity to clean all of their own equipment. It is assumed that washing machine 3,2 is only intended for cleaning equipment for other departments and a part of the crates. This is also excluded for this model.

5.3. Verification and validation

Verification and validation will be done in several phases. Verification occurs continuously throughout creating the model. First only one entity flows to the system via a push mechanism. Later other entities are added and pull is introduced. All servers are checked continuously on their queue and utilization. At last also entities are destroyed when distributed to planes. First the current situation is made, tested and checked by the management of the Intercontinental flow on logic and structure. Later other design alternatives are added. To verify the model, entities were traced between the source and the sink. Also processing times are verified by different shiftleaders. Shiftleaders are responsible for the work floor on operational level and have lots of knowledge about the Intercontinental department.

For the current situation queues and utilization were quite high compared with the real situation. When introducing the design alternative with specifications of the new robot, the model could not assemble the desired amount of trolleys, containers and ovens.

Before modelling it was not known by the management of the Intercontinental flow how many trolleys, containers and ovens were assembled. This number is calculated in this report by use of Excel files and Matlab. During the implementation of design alternatives it became clear that the engineering department of KCS was building a model to also count the number of trolleys, containers and ovens. The engineering department has access to other, more reliable, data sources. While implementing design alternatives, data is verified with the other model. The other model could only display the number of carriers for a specific day. While running that specific day a difference was noted. The other model assembles only 3151 trolleys, containers and ovens, while this model assembles 4357 trolleys, containers and ovens. This is a difference of 28%. The way of calculating the number of carriers is the same for both models, only different data is used.

For validation a structured walkthrough of the model is done with the management of the Intercontinental department and a short walkthrough is also done with the engineering department. The results were declared reasonable.

5.4. Current situation in simulation model

The current situation is modeled in the simulation model. All trolleys, containers and ovens are assembled. The total throughput time is four weeks, with 14 effective working hours each day. Between ROA and Opdek there is an inventory. The average value of this inventory for each equipment type is given in Table 5.1. Wednesday evening all equipment is counted, the average value required on Wednesday evening is the starting value of the simulation. This is also given in Table 5.1.

Table 5.1: Queue start Opdek for current situation

Equipment	Starting value	Queue
T11	212	18,23
T12	154	76,90
STC	78	59,50
SQC	112	8,75
OIS	342	293,38

Utilization and queues for each server is given in Table 5.2. The first part gives average queue length and utilization for different washing machines in ROA and the second part average queue length and utilization for different assembly station in Opdek. In Opdek an fixed amount of entities can occur, the other entities stay in the inventory between ROA and Opdek. VLAS section had the largest queue for the flow, the utilization for I shape is the largest.

Table 5.2: Queue and utilization of servers current situation

Workstation	Queue	Utilization	Utilization	Utilization	Utilization
3,1	26,22	0,8581	0,8545	0,8401	
3,4	8,493	0,5688	0,5571		
4,6	39,68	0,6656			
4,9	79,84	0,8748	0,8748	0,8736	0,8733
J shape+robot	7,966	0,8154	0,796		
I shape	8,926	0,9392			
VLAS	102	0,92			

5.5. Methods used to find constraints

Several methods are used for creating possible solutions. First it is important to find constraint or problems in the current system which needs to be addressed. This is done by looking at constraints in the current situation in the simulation model, the current problems which caused this research, a value stream map or flow chart and at last TIMWOODS.

5.5.1. Current situation in simulation model

The current situation is made in a simulation model explained in Section 5.4. For every washing and assembly section the number of carriers in queue and utilization of the server can be seen. The queue length is crucial for identifying the constraint. When comparing ROA en Opdek it is found that the constraint lies in the Opdek, since the waiting line for Opdek is longer then the waiting line for the ROA. Inventories are build up between the ROA and Opdek. VLAS has the biggest queue and is the constraint. However for assembling M class trays the J shape is used for approximately half of the time in the real world. So also assembling M class trays can cause a problem with the current amount of employees when J shape indeed used for only 50% of the time. I shape has a smaller queue compared with VLAS, however the utilization of I shape is still 0,94. For ROA washing M class trays and washing C class trays both have an utilization of approximately 0,86. The constraint of the simulation model is VLAS.

5.5.2. Current problems

Section 1.3 gives two main reasons for the gap between the current performance and the actual performance, namely errors and a high percentage of illness under the employees. The errors made are divided into to the exact location where the error is made. Figure 5.1 shows all NT drives for the last weeks of 2017. On the right side of the Figure the causes of the NT drives are given. Almost all reasons lay withing VLAS section. Only in the remaining section of the Figure, other section can cause the NT drive.

A high percentage of ill employees has several reasons. The average age of the regular staff is 49 years and most of them are working for more than 10 years for KCS. It is tough physical work and the ergonomics are not always sufficient. Almost all employees encounter highly repetitive and monotonous tasks. The last years there was a lot of improvement in ergonomics, however still not all workplaces have acceptable ergonomics. It is certainly necessary to design workplaces with better ergonomics. However adjusting ergonomics of a single workplaces is considered out of scope for this research. Alternatives which increase the overall working conditions are in the scope. Employees have to walk a lot, at the VLAS section each employee has to collect their own equipment and food. Another reason for a high percentage of ill employees is that the speed of working is sometimes predetermined. Not all tasks at the assembly line take the same time. The first person in line, with one of the lowest task time, sets the task time for the entire line. The last person on the assembly line has the highest task time, so the speed of work is forced to increase by the overall task time of the assembly line. It is better to set an own pace or a pace which is determined for each task individually.

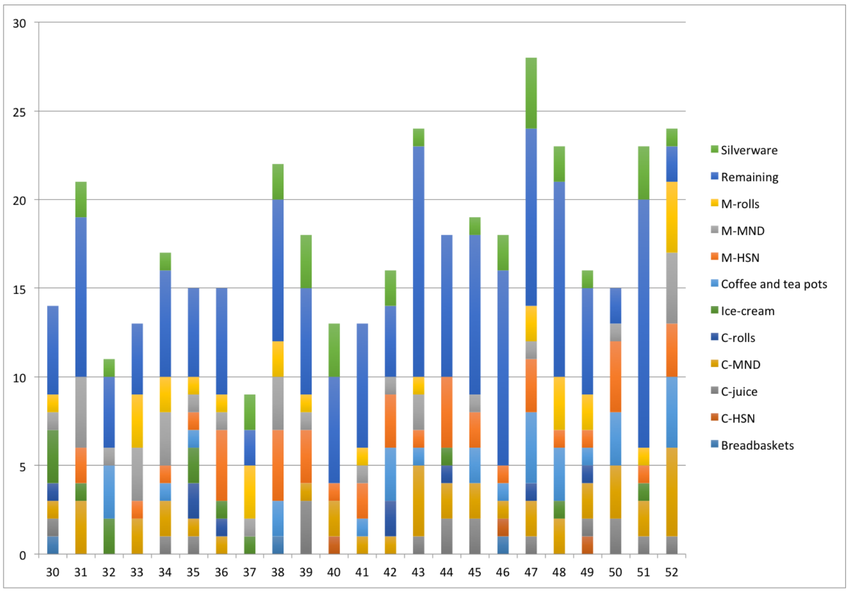


Figure 5.1: NT drives in 2017 for food department in categories

5.5.3. VSM and flowchart

The VSM contains only the flow of trolleys with M class trays is given. To have a fast overview the flowchart with equipment streams is used. In Figure 5.2 the equipment streams are showed, this Figure is explained in Section 4.2. In ROA the stream of equipment is divided into M class and C class, type of equipment and even specific content of the trolley, container and oven. Also the Opdek divides streams a bit, however most types are assembled in VLAS section.

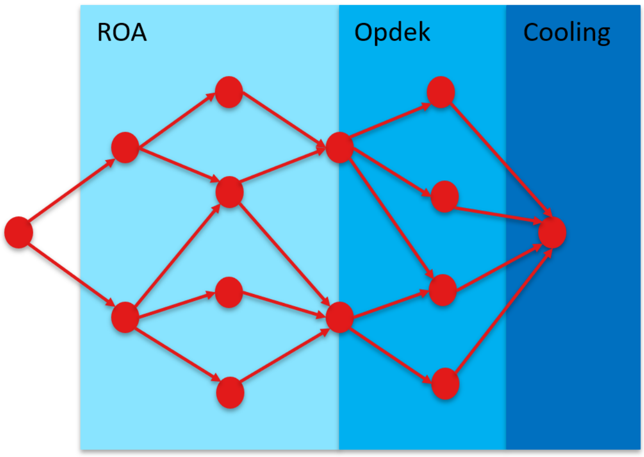


Figure 5.2: Department with equipment stream

5.5.4. TIMWOODS

Performance of TIMWOODS is decribed in Section 4.4. TIMWOODS showed different waste. Transport is certainly a big problem, the transport in ROA is relatively small compared with the transport in Opdek, since the walking distance is smaller in ROA. So transport in Opdek has a higher priority. Inventory is a result of other waste. So inventory will decrease if the other waste is eliminated, only eliminating batching can be interesting. Searching for information happens not that often since information and knowledge is only needed at certain workplaces. Experienced workers mostly stand on these workplaces. Searching for equipment, food and items however, is a much bigger problem. Decreasing or eliminating this is certainly a must. Also waiting needs to be decreased as much as possible. Waiting occurs on missing equipment, food and items and also on other employees when task time is not matched. Overproduction and over processing is mostly explained with too much inventory in the final cooling. Better skills of workers can improve performance of the robot.

Trolleys, containers and ovens wait for 6 to 12 hours in the final cooling. The cooling is an inventory and a buffer for peaks of arriving and departing planes and possible distortions in the process. Maximum temperature of food can be maximum $7°C$, while assembling the food stays on the department which is $12°C$ and food will warm up. Food that stays too long on the department must stay longer in the final cooling, which increases inventory numbers and throughput time. Since food is produced hours before departure, passenger number are not accurate and reproduction is necessary.

5.6. Conclusion

How can the current situation and design alternatives be modelled and evaluated?

A discrete event simulation is made in Matlab and Simulink. Matlab is used to define the input for Simulink. Five material entities are used, namely T11 trolleys, T12 trolleys, STC containers, SQC containers and OIS ovens. The attributes are processing times for emptying equipment, processing times for assembly equipment, equipment type, sub department, time creation entity and departure time of the plane. The source are trucks with equipment arriving at ROA, the sink are trucks with equipment leaving the final cooling. The key performance indicators must be answered in the model. Scope of the model is the ROA, Opdek and final cooling and the time scale is four weeks. Different data sets are available for KCS for calculating the number of trolleys, containers and ovens, the input of the simulation model.

Calculating the current situation in the simulation model gives the results given in Table 5.3. Queue length and utilization is given for each station in ROA and Opdek. The largest queue is in front of VLAS and the highest utilization is at I shape. Extra inventory is between ROA and Opdek. This is an average of 18,23 T11 trolleys, 76,90 T12 trolleys, 59,50 STC containers, 8,75 SQC containers and 293,38 ovens.

Table 5.3: Queue and utilization of servers current situation

Workstation	3,1	3,4	4,6	4,9	J + robot	I	VLAS
Queue	26,22	8,493	39,68	79,84	7,966	8,926	102,0
Utilization	0,8509	0,5630	0,6656	0,8741	0,8057	0,9392	0,92

What constraint is limiting the performance?

The current simulation model concluded that the first focus must be improving the constraint VLAS, since VLAS has the highest queue length. Current problems stated that most errors occurred at VLAS and there is percentage of ill employees between 10% and 15% in 2015 to 2017. The flowchart shows a lot of sorting of equipment streams is done, also processes are done parallel in ROA and Opdek.

IV

Design

6
Design alternative strategies

In this Chapter different design alternatives are created. First methods are described which are used to create solutions, this is done in Section 6.1. Here VLAS section is exploited and also solutions are searched for high number of illness and sorting. In Section 6.2 four different concepts are given. All concepts can be combined with each other, this leads to sixteen design alternatives described in Section 6.3. In Section 6.4 is described how these design alternatives are implemented in the simulation model. This chapter is concluded in Section 6.5 with answering the seventh research question.

What solution alternatives can possibly improve the design of the food assembly process?

6.1. Methods used to create solutions

In Section 5.5 constraints and problems are stated, also the key performance indicators are repeated. In this Section 5.5 and literature from Section 2 are used to create possible directions for solutions for constraints and problems. The current simulation model concluded that the first focus must be improving VLAS station, later washing and assembling of trolleys with M class trays can be improved. Current problems stated that most errors occurred at VLAS and there is a high percentage of ill employees. The flowchart shows a lot of sorting of equipment streams is done, also processes are done parallel in ROA and Opdek.

TIMWOODS showed different waste. Transport is certainly a big problem, the transport in ROA is relatively small compared with the transport in Opdek, since the walking distance in ROA is smaller. So transport in Opdek has a higher priority. Inventory is a result of other waste. So inventory will decrease if the other waste is eliminated. Only eliminating batching can be interesting. Searching for information happens not that often since information and knowledge is only needed at certain workplaces. Experienced workers mostly stand on these workplaces. Searching for equipment, food and items however, is a much bigger problem. Decreasing or eliminating this is certainly a must, this decreases processing times of VLAS and I shape. Also waiting needs to be decreased as much as possible. Waiting occurs on missing equipment, food and items or on other employees when task time is not matched. Overproduction and over processing is mostly explained with too much inventory in the final cooling. Better skills of workers can improve performance of the robot.

First VLAS workplace is exploited, later solution directions for high percentage of illness and for the results of the flowchart and TIMWOODS are explained.

6.1.1. Exploit VLAS

In the simulation model, VLAS is encountered as a constraint. The next step according to theory of constraints is exploiting the constraint. TIMWOODS identified certain types of waste at VLAS, namely a lot of walking for collecting equipment, food and items. Often equipment, food and items must be searched at different places in the Opdek. VLAS uses also the biggest batches. Also recounting of meals can be seen as waste. The current processing times for VLAS are divided into how long the employee is stowing meals and how long it takes for collecting meals and equipment. This last part of collecting is a considerable amount of time.

With a lean perspective, one piece flow is considered better then batching. To decrease batch size other smaller elevators must be used or other smaller assemble places. Now the whole elevator is full with equipment and the throughput time and inventory are high. In a workstation where only one piece of equipment can be produced at the time, frequency will increase and the quantities of deliveries will decrease. Since the walking distance is long for collecting equipment, food and items and often these must be searched one piece flow is now not profitable. Collecting equipment, food and items will be a substantial part of the time, since walking distance is too far. To create one piece flow another way must be found for getting equipment, food and items at VLAS.

6.1.2. High number of illness

It is tough physical work and the ergonomics are not always up to standards. Almost all employees encounter high repetitive and monotonous tasks. Better ergonomics will prevent employees for becoming ill. Every workplace should have acceptable ergonomics, this is not yet the case. Another way of decreasing illness is hiring more employees to do the same tasks, the pace can be decreased. Also automation decreases the number of ill employees. There are lots of possibilities for automation. Robots can be used to lighten tasks, for example lift heavy equipment for an employee. Automation can also take over a whole task. Currently there is a robot for assembling a part of the trolleys with M class trays, also J shape assembles trolleys with M class trays. Reason for choosing M class for automation is that all materials are robust, the process is simple and there are almost no changes in items or equipment. With emptying trolleys with M class trays everything on the tray can be thrown away. C class however has a lot of fragile porcelain and porcelain changes regularly. A downside of automating VLAS is the huge amount of different equipment. Automation will also decrease variance of the process.

6.1.3. Sorting

An aspect of lean is defining which parts of the production creates value. When all trolleys, containers and ovens enter the ROA every piece of equipment is sorted in different streams. This does not add value to the product. At the end of the washing machine all equipment types are again sorted. Another way of washing equipment is not sorting at all in the ROA. All kinds of trolleys and containers can be emptied at the same washing machine since the process is similar. Also all trolleys, containers and ovens can be washed at the same trolley washing machine instead of dividing trolley, container and ovens in C class and M class.

Sorting in the Opdek can be eliminated as well. The process of the robot, I shape and J shape are identical, namely items are placed in trolleys, containers and ovens. Sometimes this happens first on a tray or in a drawer. Since the process is very similar, a workstation can be designed where trolleys, containers and ovens can be filled. Another important aspect of lean manufacturing is creating flow, one tool for doing this is cellular manufacturing. With cellular manufacturing processes for a particular product or product group are organized in cells. Another tool of creating flow is just-in-time. With just-in-time smaller and more frequent quantities are delivered. Combining these two theories can lead to a manufacturing cell for producing one piece of equipment at the time. [27] pointed out that cellular production cells must not be too small and not be too large. A few workstations can be joined together to make groups of workstations. One workstation is not a significant proportion of the total flow.

6.2. Concepts

Four concepts are stated in this Section. These changes are based on Section 6.1. All concepts can be combined, so in total there are sixteen design alternatives. These possibilities will be explained in Section 6.3.

6.2.1. Concept 1; Wash everything on each washing machine

Section 6.1.3 states that sorting is non value adding. In the ROA now every piece of equipment is separated, sorting can be eliminated in ROA. With this concept all trolleys and containers from M class and C class are emptied on each washing machine, no sorting takes places. Also all kinds of trolleys, containers and ovens are cleaned on each washing machine.

6.2.2. Concept 2; Create one piece flow workstations in Opdek

Section 6.1.3 states that sorting is non value adding. This concept does not sort trolleys, containers and ovens by type in Opdek, all trolleys, containers and ovens are assembled on the same place. This concept has workstations designed for only one person. So one person is assembling a whole trolley, container or oven by itself. When the trolley, container or oven is finished, the employee starts on a new one.

6.2.3. Concept 3; Automatic input of equipment, food and items in Opdek

Section 6.1.1 states that VLAS is currently a constraint. Not the full potential of this workstation is now used. Significant time is now used for collecting and searching equipment, food and items. Automatic input of food and items can be a solution. Employees do not need to search and walk anymore, they can stand still at a workstation and all items come to them. At the workplace an employee only needs to put the items presented in the trolley, container or oven.

6.2.4. Concept 4; Automation of trolleys with M class trays

In Section 6.1.2 is stated that there is high percentage of ill employees. Also a few possible solutions are given. With this concept two robots will be introduced, namely one for emptying of trolleys with M class trays and one for assembling trolleys with M class trays. In ROA all trolleys with M class trays consist out of trays with trash on it. Everything standing on the tray can be thrown away. Now there are mostly four employees emptying these trolleys. Every tray is packed and all items on top of it are discarded. The tray is then put in the washing machine.

In 2016 a design was made to empty the trolleys automatic. All fourteen rows with trays are pushed out of the trolley at the same time and later all rows are put after each other to be cleaned. This concept is never introduced since it is considered to use too much square meters.

Assembly of trays consists out of putting items on a tray. This is currently done in two ways, namely manually or by a robot. With this concept a new robot will be introduced which can assemble all trolleys with M class trays.

6.3. Combination of concepts

Current situation In Figure 6.1 the current situation is given, the current situation is explained in Section 4.2.

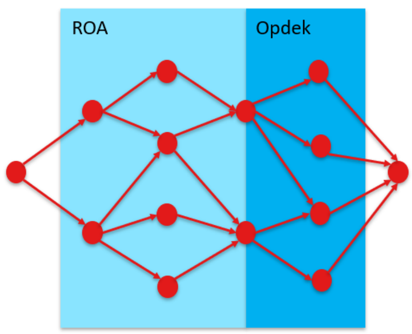


Figure 6.1: Current state

Concept 1 Wash everything on each washing machine. Now ROA oncly consist out of one stream of trolleys, containers and ovens. The Opdek is still divided into J shape, robot, VLAS and I shape. In the beginning of the Opdek all equipment is divided in the desired streams.

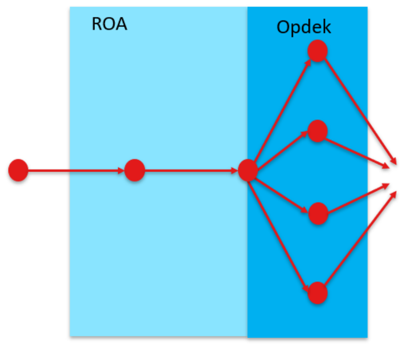


Figure 6.2: Concept 1

Concept 2 Create one piece flow workstation in Opdek. ROA still divide all equipment for the different washing machines. In Opdek an one piece flow workstation is introduced, at the workstation one employee assembles one trolley, container and oven at the time. J shape, robot and I shape will be replaced for workstations. However since VLAS currently has long walking distances it is decided that VLAS will still assemble in the old way. So workstations will only assemble trolleys with M class and C class trays.

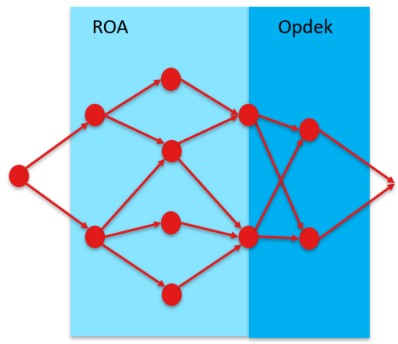


Figure 6.3: Concept 2

Concept 3 Automatic input of equipment, food and items in Opdek. The flow of trolleys, containers and ovens will stay the same. The only difference is faster assembly times for VLAS and I shape.

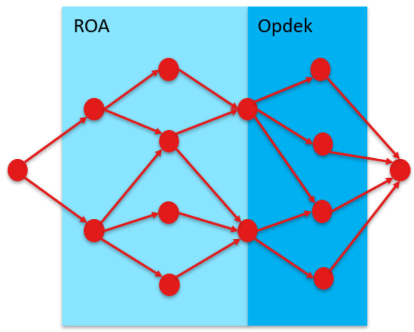


Figure 6.4: Concept 3

Concept 4 Automation of trolleys with M class trays. In ROA all trolleys with M class trays are emptied by a robot instead of employees. Also all trolleys with M class trays are assembled by a robot in Opdek. So J shape and robot are now replaced for one robot for the entire production. This can be seen in the Opdek, with three different stations instead of four.

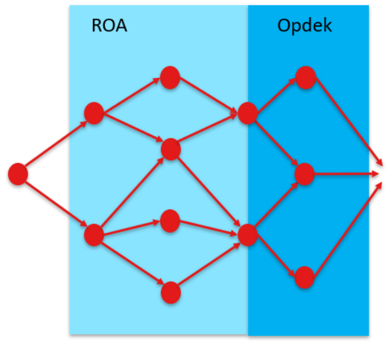


Figure 6.5: Concept 4

Concept 1 and 2 Wash everything on each washing machine and create one piece flow workstation in Opdek. In ROA all trolleys and containers are emptied on every washing machine. In Opdek an one piece flow workstation is introduced, at the workstation one employee assembles one trolley, container and oven at the time. J shape, robot and I shape will be replaced for workstations. However since VLAS currently has long walking distances it is decided that VLAS will still assemble in the old way. So workstations will only assemble trolleys with M class and C class trays.

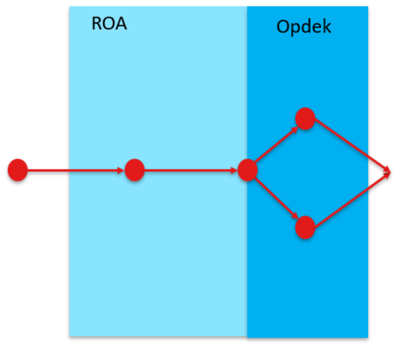


Figure 6.6: Concept 1 and 2

Concept 1 and 3 Wash everything on each washing machine and automatic input of equipment, food and items in Opdek. In ROA all trolleys and containers are emptied on every washing machine. In Opdek the flow of trolleys, containers and ovens will stay the same. The only difference is faster assembly times for VLAS and I shape.

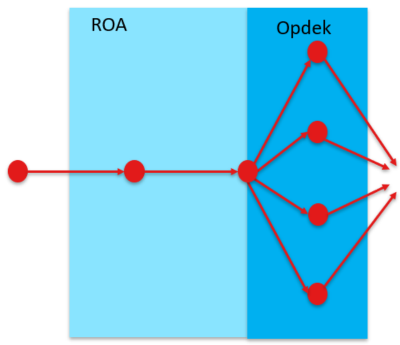


Figure 6.7: Concept 1 and 3

Concept 1 and 4 Wash everything on each washing machine and automation of trolleys with M class trays. In ROA all trolleys with M class trays are emptied by a robot, all other trolleys and containers are emptied together on washing machines. In Opdek all trolleys with M class trays are assembled by a robot. So J shape and robot are now replaced for one robot for the entire production. This can be seen in the Opdek, with three different stations instead of four.

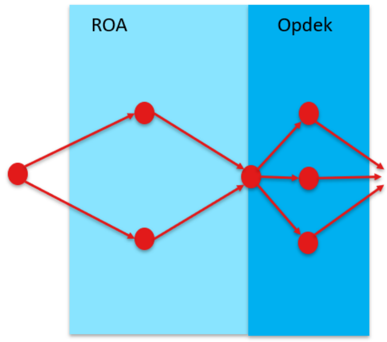


Figure 6.8: Concept 1 and 4

Concept 2 and 3 Create one piece flow workstation in Opdek and automatic input of equipment, food and items in Opdek. There is no difference for the ROA. In Opdek however all trolleys, containers and ovens are assembled in the same kind of workstations. Since there is automatic input of equipment, food and items, the walking distance is eliminated for VLAS. So also VLAS section is replaced for workstations. Now J shape, robot, I shape and also VLAS section are now workstations.

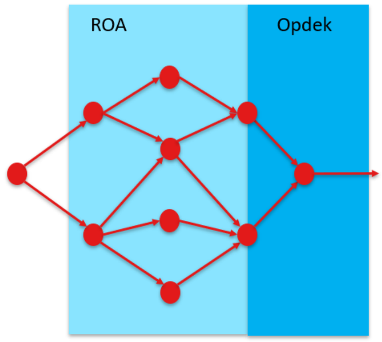


Figure 6.9: Concept 2 and 3

Concept 2 and 4 Create one piece flow workstation in Opdek and automation of trolleys with M class trays. In ROA all trolleys with M class trays are emptied by a robot instead of employees. In Opdek workstations are introduced. Since there is no automatic input of equipment, food and items VLAS does not change. Also all trolleys with M class trays are assembled by a robot. So in Opdek only trolleys with C class trays are assembled in workstations.

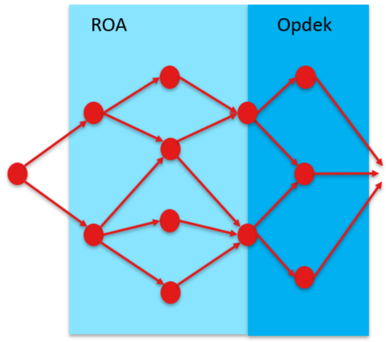


Figure 6.10: Concept 2 and 4

Concept 3 and 4 Automatic input of equipment, food and items in Opdek and automation of trolleys with M class trays. In ROA all trolleys with M class trays are emptied by a robot instead of employees. Also all trolleys with M class trays are assembled by a robot in Opdek. So J shape and robot are now replaced for one robot for the entire production. Assembly is done by robot, VLAS and I shape.

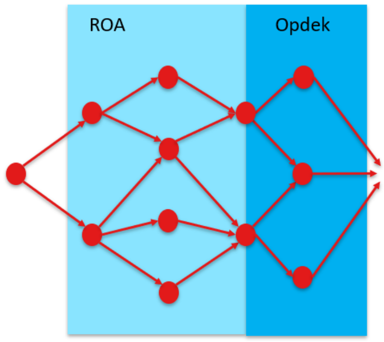


Figure 6.11: Concept 3 and 4

Concept 1, 2 and 3 Wash everything on each washing machine, create one piece flow workstation in Opdek and automatic input of equipment, food and items in Opdek. The flow of trolleys, containers and ovens is a straight line. In ROA all trolleys and containers are emptied on every washing machine and in Opdek all trolleys, containers and ovens are assembled on the same kind of workstations.

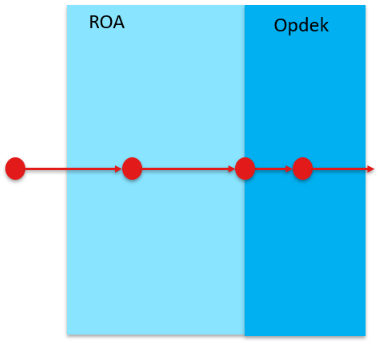


Figure 6.12: Concept 1, 2 and 3

Concept 1, 2 and 4 Wash everything on each washing machine, create one piece flow workstation in Opdek and automation of trolleys with M class trays. In ROA all trolleys with M class trays are emptied by a robot instead of employees. All other equipment is washed in all washing machines. In Opdek assembly is done by a robot, VLAS and workstations. So only trolleys with C class trays are assembled in workstations.

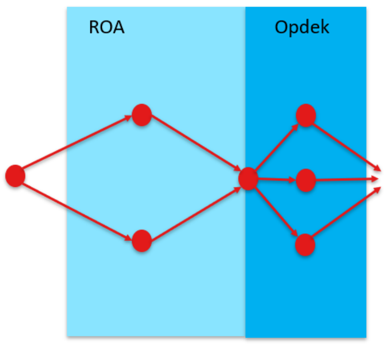


Figure 6.13: Concept 1, 2 and 4

Concept 1, 3 and 4 Wash everything on each washing machine, automatic input of equipment, food and items in Opdek and automation of trolleys with M class trays. In ROA all trolleys with M class trays are emptied by a robot instead of employees. All other equipment is washed in all washing machines. In Opdek assembly is done by a robot, VLAS and I shape.

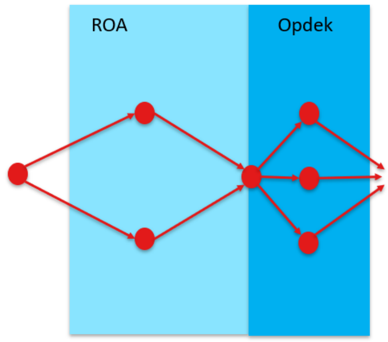


Figure 6.14: Concept 1, 3 and 4

Concept 2, 3 and 4 Create one piece flow workstation in Opdek, automatic input of equipment, food and items in Opdek and automation of trolleys with M class trays. In ROA all trolleys with M class trays are emptied by a robot instead of employees. The flow of the ROA remains the same. In Opdek all trolleys with M class trays are assembled by a robot, all other equipment is assembled in workstations.

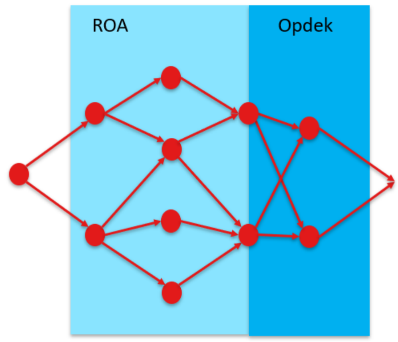


Figure 6.15: Concept 2, 3 and 4

Concept 1, 2, 3 and 4 Wash everything on each washing machine, create one piece flow workstation in Opdek, automatic input of equipment, food and items in Opdek and automation of trolleys with M class trays. In ROA all trolleys with M class trays are emptied by a robot instead of employees. All other equipment is washed in all washing machines. In Opdek all trolleys with M class trays are assembled by a robot. All other equipment is assembled in workstations.

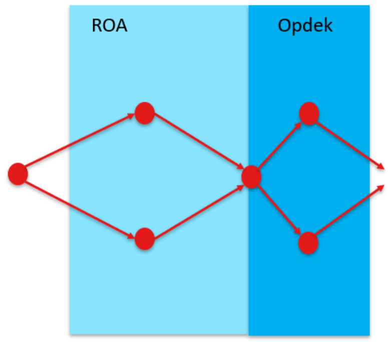


Figure 6.16: Concept 1, 2, 3 and 4

6.4. Concepts in simulation model

Design alternatives have different flow of trolleys, containers and ovens and design alternatives sometimes have different processing times. To create different flow of equipment variant subsystems are used in the Simulink environment for ROA and Opdek. Different subsystem can be modelled parallel to each other. With every simulation the programmer can choose which variant subsystem is needed. Variant subsystems are used for ROA and Opdek.

Different processing times are calculated with Matlab as input of the Simulink model. There are four different processing times, namely for the current system, system with concept 2; Create one piece flow workstation in Opdek, current system with concept 3; Automatic input of equipment, food and items in Opdek and systems with concept 2 and 3. In total there are sixteen design alternatives with four design alternatives for each processing times.

To push the department to its boundaries different amount of equipment is tested. The first set is the current data set and the second set is the current data set times 1,3. All equipment is divided into twenty categories, for four departments and five types of equipment. Each individual group is multiplied by 1,3 for the second set of data and rounded to an integer.

To calculate the desired specification of the robot, different scenario's are tested with the model. The lowest specification of the robot for the current data set is determined for an utilization of just below one. In total three different robot specifications are tested for each dataset.

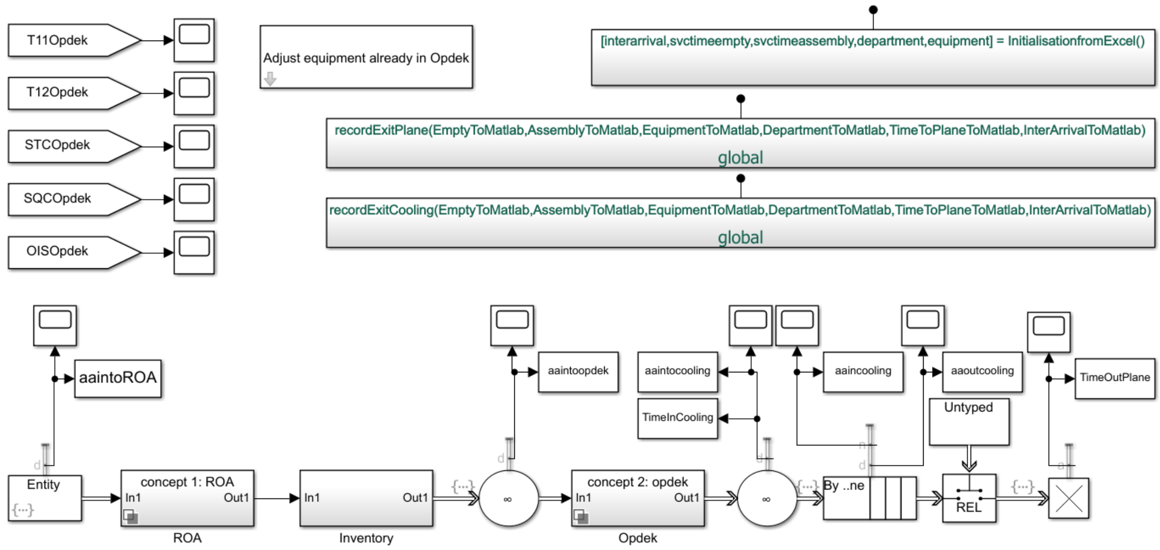


Figure 6.17: Simulink model

In Figure 6.17 the Simulink model is given. The flow of entities is given in the lower part of the Figure. In the bottom left corner entities are created and in the bottom right corner entities are destroyed. The entities flow through ROA, inventory at the start of the Opdek, Opdek and final cooling. All trolleys, containers and ovens are pushed from the ROA to the inventory. In the inventory queues are present with release ports. When a trolley, container or oven is needed, one entity will flow via a server to the Opdek. In the server sub department, processing time for assembly and departure time are given to the trolley, container or oven. After assembly the entity flows via the release port and a server to the final cooling, the final cooling is a queue. In this queue all entities are sorted on departure time. The server is used to get easily specific information of the entity. Finally a release gate is used to move entities from the final cooling to planes. Entities are destroyed when leaving the final cooling.

In the upper right corner current entity levels can be seen of the inventory at the start of the Opdek. These entity levels have a certain value of the start of the simulation, this value can be adjusted in the 'Adjust equipment already in Opdek' block. In the upper right corner different blocks are given. The upper one is used to load data in the entities and attributes created at the entity generator. The other two blocks are used to load specific data from Simulink to Matlab at the end of the simulation. This data is used to evaluate the model.

6.5. Conclusion

What solution alternatives can possibly improve the design of the food assembly process?

Constraint VLAS is exploited and high number of illness and sorting is analyzed, this leads to four different concepts. Concept 1 is wash everything on each washing machine. Concept 2 is Create one piece flow workstation in Opdek. Concept 3 is automatic input of equipment, food and items in Opdek and concepts 4 is automation of trolleys with M class trays. All concepts can be combined, which gives sixteen different solution alternatives.

V

Control

7

Results

In this Chapter results are given from the simulation model. First the effect of variance in arriving times of equipment is stated in Section 7.1. The selection is divided into two parts, a first selection is based on large difference between all design alternatives in Section 7.2. Later smaller differences are noticed in Section 7.3 where the best design alternative is chosen. This chapter is concluded in Section 7.4 with answering the eighth and ninth research question.

How do these solution alternatives improve the performance?

What is the best solution alternative?

In this Section results are given of the solution alternatives proposed in Section 6. All solution alternatives have a code of four numbers, one for each concept. The first number corresponds with the first concept, the second number for the second concept, etcetera. When the number is one, the design alternative does not have that concept. When the number is two that concepts is used for the design alternative. So for instance 1111 indicates the current situation and 2222 indicates that all concepts are used.

There are sixteen design alternatives, in Section 7.2 a first selection is made. Later values are compared for the key performance indicators. Working hours are showed with utilization of workplaces were employees are involved and if the desired production is achieved. With utilization only workplaces with employees are taken into account. This number is an average for all employees in ROA or Opdek. Work in progress inventory is shown as inventory. Too late deliveries are only shown when design alternatives with that experiment were not sufficient. Also throughput time is given in the results. Stock out as key performance indicator is reconsidered. All design alternatives with low inventory show stock outs. Stock outs also occur when Opdek is assembling faster then ROA is able to wash. Only design alternatives with huge inventories does not show stock outs, it is therefore chosen not to use stock out as a key performance indicator. Given throughput time is time between creation of the entity until arriving in the final cooling.

7.1. Variance

In the flow of Intercontinental department variance can occur in different parts. One possibility is variance in the arriving time of trolleys, containers and ovens in ROA. Another possibility is variance in processing times. Variance in processing times is dependent on the workstation.

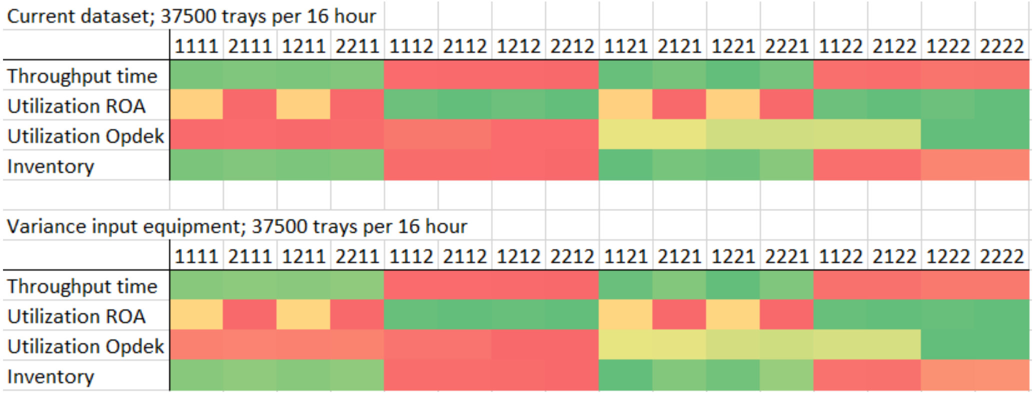


Figure 7.1: Results variance input equipment

In Figure 7.1 results are given for the influence of variance in arriving times of equipment. Time between original arrival time of the plane and equipment arriving in the ROA is determined with actual data. When comparing results of the current data set with a data set with variance in input of equipment almost no difference can be found. While comparing solution alternatives equal results can be found for the two tables.

Arrival times of planes are not equally distributed over the day. The actual data set already has huge variations in arriving times during the day. Adding different processing times for distributing equipment to ROA does not add extra difficulties for the flow. In the coming results the processing time between original arrival time and equipment arriving in the ROA are taken constant.

7.2. First selection

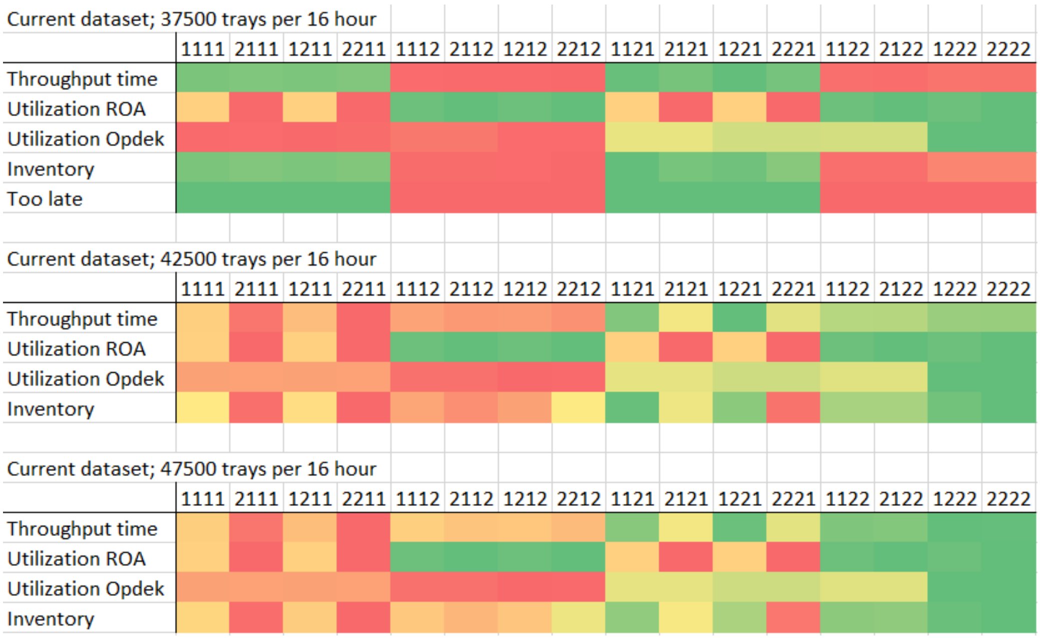


Figure 7.2: Results for current data set, only colours

In Figure 7.2 results are given for the current data set with different specifications of the robot. Concepts are compared relatively for the first analysis. In the upper table results are given for a robot which assembles 37500 trays per 16 hours, the middle table has a robot which assembles 42500 trays per 16 hours and the last robot assembles 47500 trays per 16 hours. One of the first things that stands out is strictly other behaviour per four rows. In the first four rows from left side only concept 1; Wash everything on each washing machine and concept 2; Create one piece flow workstations in Opdek are used, without concept 3: Automatic input of equipment, food and items in Opdek and concepts 4; Automation of trolleys with M class trays. In row 5-8 concept 3 is introduced, in row 9-12 concept 4 is used and finally in row 13-16 both concept 3 and concept 4 are both used.

In the upper graph row 5-8 and row 13-16 are coloured mainly red. Reason for this is a robot with too low specifications. The processing times of the robot are too high and large queues are build up. This results in delayed delivery of trolleys, containers and ovens. Too late deliveries are shown in the last line of the table. Only the first table has too late deliveries. The long processing time for the robot leads also to higher throughput times and higher on floor inventories. An advantage of the robot is lower utilization in ROA and Opdek. The difference in utilization for ROA is larger compared with alternatives without a robot since emptying M class trays in ROA by hand has a very high utilization. The utilization of assembling M class trays in Opdek by hand is lower.

Also standing out is that the right side of the lower two tables are mainly green, while the left side are mainly red. Results in the left side has concept 3 in common, namely automatic input of equipment, food and items in Opdek. This concepts lead to shorter processing times for VLAS and I shape. Concept 3 leads to lower throughput time, lower utilization in Opdek and lower on floor inventory.

Concept 1; Wash everything on each washing machine has slightly higher throughput time, mostly higher utilization and slightly higher inventories compared with design alternatives without concept 1.

Concept 2; Create one piece flow workstations in Opdek is not interesting without the use of concept 3; Automatic input of equipment, food and items in Opdek. Only the use of concept 2 leads to high throughput time, high utilization and high inventories. Adding concept 3 to concept 2 however, leads to low throughput time, low utilization and low inventories.

Concept 3 and 4 has higher influence compared with concepts 1 and 2. For concepts 1 and 2 only a small difference can be noted. Concepts 3 has a better effect on the results then concepts 4. This can be seen while comparing 1112 versus 1121, 1212 versus 1221 and 2212 versus 2221.

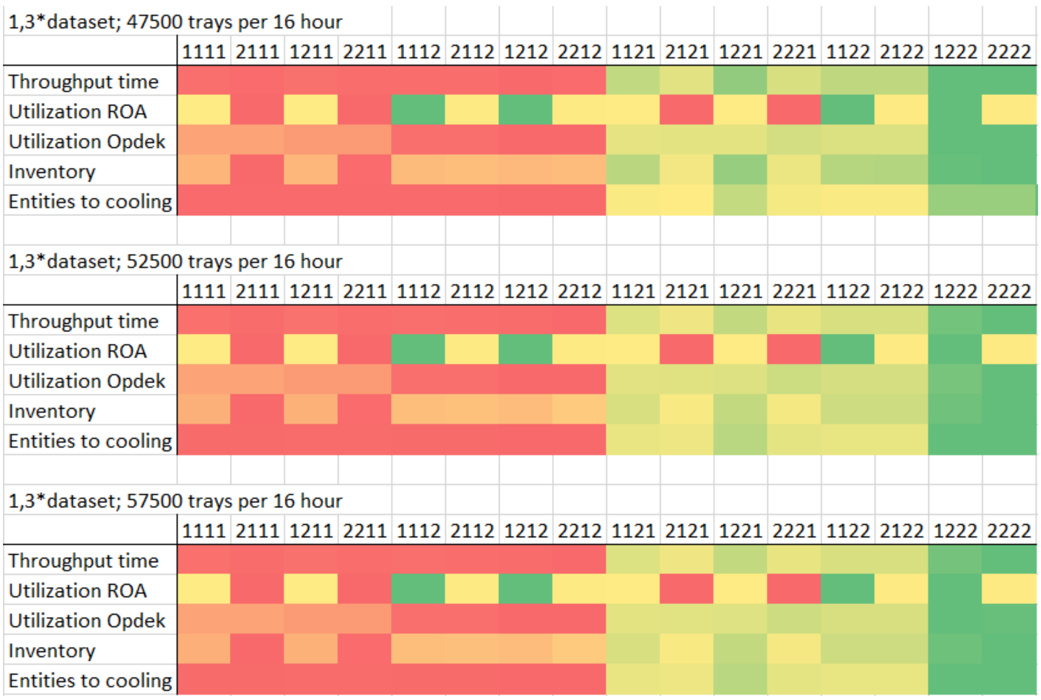


Figure 7.3: Results for 1,3x current data set, only colours

In Figure 7.3 results are given for 1,3x current data set. With this data set the model is pushed to its boundaries. Specifications of the robot are also increased. The processing time of the robot is 47500, 52500 and 57500 trays per 16 hours. In the last line of each table the number of trolleys, containers and ovens that arrive at the final cooling is given. Only the last two concepts 1222 and 2222 in the middle and bottom table achieve the desired production.

With higher production numbers an even bigger gap occurs between the right side and the left side of the tables. Automatic input of equipment, food and items is a must. It is also visible that a robot ensures lower utilization in the ROA.

To analyze different solution alternatives it is chosen to further investigate all solution alternatives with automatic input of equipment, food and items. This is done in Figure 7.4 and Figure 7.5.

7.3. Selection design alternatives

Current dataset; 37500 trays per 16 hour									
	1111	1121	2121	1221	2221	1122	2122	1222	2222
Throughput time	9177	6598	8723	6032	8423	43215	43333	42590	42659
Utilization ROA	0,78	0,78	0,89	0,78	0,89	0,73	0,72	0,73	0,72
Utilization Opdek	0,89	0,78	0,78	0,73	0,73	0,74	0,74	0,48	0,48
Inventory	729,88	521,37	705,00	629,15	854,49	3163,73	3171,13	2940,12	2928,21
Too late									

Current dataset; 42500 trays per 16 hour									
	1111	1121	2121	1221	2221	1122	2122	1222	2222
Throughput time	9177	6598	8723	6032	8423	7590	7580	7077	7042
Utilization ROA	0,78	0,78	0,89	0,78	0,89	0,73	0,72	0,73	0,72
Utilization Opdek	0,89	0,78	0,78	0,73	0,73	0,77	0,77	0,50	0,50
Inventory	729,88	521,37	705,00	570,84	788,66	610,10	610,50	535,66	514,74

Current dataset; 47500 trays per 16 hour									
	1111	1121	2121	1221	2221	1122	2122	1222	2222
Throughput time	9177	6598	8723	6032	8423	6427	6500	5862	5914
Utilization ROA	0,78	0,78	0,89	0,78	0,89	0,73	0,72	0,73	0,72
Utilization Opdek	0,89	0,78	0,78	0,73	0,73	0,77	0,77	0,50	0,50
Inventory	729,88	521,37	705,00	568,66	785,61	512,51	517,12	451,46	438,10

Figure 7.4: Results for current data set

In Figure 7.4 it is also noticeable that the first table has too low specifications for the robot, a consequence is too late deliveries for 1122, 2122, 1222 and 2222. The second and third table have sufficient specifications for the robot. In the left the current situation with design alternative 1111.

The right side of the tables perform generally better then the left side of the table. The right side has concept 3; Automatic input of equipment, food and items and concept 4; Automation of trolleys with M class trays. The left side only has concept 3. The combination of concepts 2, 3 and 4 gives the best results, so design alternative 1222 and 2222. This results in a lowest throughput time, lowest utilization in Opdek and lowest inventory. Difference between 1222 and 2222 is dependent on the processing times of the robot. In the middle table concepts 2222 performs slightly better in throughput time and inventory levels. In the lowest table 1222 has a slightly better throughput time, however 2222 has better inventory levels.

Concept 1; Wash everything on each washing machine results in higher utilization of the ROA. When everything is washed on separate washing machines, it sometimes occurs that the queue in front of one of the washing machines is empty. All employees of that washing machine can not empty trolleys, containers and ovens. However, employees on other washing machines are emptying trolleys, containers and ovens and still have a queue. When everything is washed on each washing machine, there will be a queue in front of all washing machines.

Utilization of ROA will be changed by concept 1; Wash everything on each washing machine and concept 4; Automation of trolleys with M class trolleys. Concept 2; Create one piece flow workstations in Opdek and concept 3; Automatic input of equipment, food and items have no influence of the utilization of the ROA. This is also true for the results found in the Figures.

1,3*dataset; 47500 trays per 16 hour									
	1111	1121	2121	1221	2221	1122	2122	1222	2222
Throughput time	130684	95087	108405	76908	104134	94482	94381	58664	58011
Utilization ROA	0,93	0,93	1,00	0,93	1,00	0,89	0,93	0,89	0,93
Utilization Opdek	0,96	0,87	0,86	0,86	0,83	0,84	0,84	0,61	0,61
Inventory	13133,46	9449,38	11893,27	7907,84	11606,68	9247,59	9211,18	5781,53	5620,06
Entities to cooling	133427	138549	137959	144602	139076	138547	138547	149184	149215

1,3*dataset; 52500 trays per 16 hour									
	1111	1121	2121	1221	2221	1122	2122	1222	2222
Throughput time	130684	95087	108405	76908	104134	91543	91920	22107	9542
Utilization ROA	0,93	0,93	1,00	0,93	1,00	0,89	0,93	0,89	0,93
Utilization Opdek	0,96	0,87	0,86	0,86	0,83	0,84	0,84	0,69	0,65
Inventory	13133,46	9449,38	11893,27	7907,91	11606,74	8770,49	8755,47	1864,93	984,08
Entities to cooling	133427	138549	137959	144602	139076	138573	138573	155173	155173

1,3*dataset; 57500 trays per 16 hour									
	1111	1121	2121	1221	2221	1122	2122	1222	2222
Throughput time	130684	95087	108405	76908	104134	91083	91504	20849	8685
Utilization ROA	0,93	0,93	1,00	0,93	1,00	0,89	0,93	0,89	0,93
Utilization Opdek	0,96	0,87	0,86	0,86	0,83	0,84	0,84	0,64	0,65
Inventory	13133,46	9449,38	11893,27	7908,00	11606,83	8726,41	8713,38	1730,80	913,74
Entities to cooling	133427	138549	137959	144602	139076	138577	138577	155173	155173

Figure 7.5: Results for 1,3x current data set

In Figure 7.5 results are given for the current data set with 1,3 times the number of trolleys, containers and ovens. Also here is the current situation with design alternative 1111 given on the left side. There are small differences compared with Figure 7.4. Only design alternative 1222 and 2222 in the middle and lowest table assembles the desired production, all other design alternatives can not assemble all trolleys, containers and ovens. Design alternative 1221 has the third best performance in throughput time and the number of entities to cooling.

In the four most left columns there is a bigger difference in the performance with and without concept 2; create one piece flow workstations in Opdek. The combination of concept 2, 3 and 4 performs better then only concept 3 and 4.

In Figure 7.4 design alternative 1222 and 2222 were close together. In Figure 7.5 however there is a more clear distinction. Design alternative 2222 has the best throughput time and inventory levels, the utilization of the ROA however is higher then 1222.

When it is not possible to introduce a robot, design alternative 1221 performance the best. The throughput time, utilization Opdek, inventory and entities assembled are compared with design alternative 1222 and 2222.

7.4. Conclusion

How do these solution alternatives improve the performance?

Concept 1; Wash everything on each washing machine has slightly higher throughput time, mostly higher utilization and slightly higher inventories compared with design alternatives without concept 1. Influence of concept 1 is the lowest.

Concept 2; Create one piece flow workstations in Opdek is not interesting without the use of concept 3; Automatic input of equipment, food and items in Opdek. Only use of concept 2 leads to high throughput time, high utilization and high inventories. Adding concept 3 however, leads to low throughput time, low utilization and low inventories.

Concept 3; Automatic input of equipment, food and items in Opdek leads to shorter processing times for VLAS and I shape. This ensures lower throughput time, lower utilization in Opdek, lower on floor inventory and lower throughput time. Concept 3 has the highest influence ans is certainly a must for better performance.

Concepts 4; Automation of trolleys with M class trays has two possible results. A robot with high processing times provides large queues, high throughput time, high inventories and too late delivery of trolleys, containers and ovens. A robot with shorter processing times ensures lower throughput time, lower utilization in ROA and Opdek, lower on floor inventory, less too late deliveries and lower throughput time. An advantage of the robot is lower utilization in ROA and Opdek for workplaces with employees. Especially utilization of ROA is improved.

What is the best solution alternative?

1,3*dataset; 57500 trays per 16 hour									
	1111	1121	2121	1221	2221	1122	2122	1222	2222
Throughput time	130684	95087	108405	76908	104134	91083	91504	20849	8685
Utilization ROA	0,93	0,93	1,00	0,93	1,00	0,89	0,93	0,89	0,93
Utilization Opdek	0,96	0,87	0,86	0,86	0,83	0,84	0,84	0,64	0,65
Inventory	13133,46	9449,38	11893,27	7908,00	11606,83	8726,41	8713,38	1730,80	913,74
Entities to cooling	133427	138549	137959	144602	139076	138577	138577	155173	155173

Figure 7.6: Results for 1,3x current data set with 57500 trays per 16 hours

In Table 7.6 results are given for a data set with 1,3 times the amount of equipment with 57500 trays per 16 hours. Design alternative with a combination of concept 2 and 3 (*22*) and a combination of concept 3 and 4 (**22) are powerful. Combination 2, 3 and 4 (*222) gives an even better performance. Design alternatives with *222 result in a low throughput time, low utilization in Opdek, no too late deliveries and a low inventory. For the current data set 1222 and 2222 are close together, however there is a more clear distinction with higher production numbers. Design alternative 2222 performs the best, it has the best throughput time with 8685 seconds and inventory level of an average of 913,74 trolleys, containers and ovens. The utilization of the ROA with 0,93 is not on first place. The current situation assembles only 133427 out of 155173 trolleys. The throughput time is 130684 seconds and the average total inventory is 13133,46 trolleys, containers and ovens.

When it is not possible to introduce a robot, design alternative 1221 performance the best. The throughput time, utilization Opdek, inventory and entities assembled are less compared with design alternative 1222 and 2222.

8 Conclusion and recommendations

8.1. Research questions

This research focuses only on the Dutch assembly of food of intercontinental KLM flights at KLM Catering Services. Due to errors in the production and a high percentage of illness there is a gap between the desired performance and the current performance. It is not clear what drivers influence this gap and how the performance can be improved. The aim of this research is to design a framework to optimize the processes of food assembly and subsequently apply the framework to increase the throughput time at the intercontinental department of KLM Catering Services. To fill this gap the following main research question is formulated. First all sub research questions need to be answered to find a fitting and well supported answer to the main research question.

How can the assembly process of KLM Catering Services be optimized in order to improve the throughput time?

8.1.1. Which process improvements methods are suggested in literature to analyze and redesign the food assembly process?

Several methods are described in literature. Lean manufacturing focuses on the removal of waste and consists out of identifying which process creates value, making a value stream map, make activities flow, create pull and perfect the process. 5S and TIMWOODS are discussed as part of lean manufacturing. Also Six sigma, theory of constraints, total quality management, critical path and swimlane are described as methods to improve performance. Lean and six sigma can be combined to lean six sigma and lean six sigma can again be combined with critical path.

One method to analyze processes is simulation. Delft Systems Approach, conceptual modelling, Gantt charts and flow charts can be used to create a simulation model.

8.1.2. How is the food assembly process structured currently?

The department consists out of three parts, namely ROA, Opdek and the final cooling. In ROA trolleys, containers and ovens are sorted, emptied and cleaned. There are seven washing machines for emptying equipment and two trolley washing machines for cleaning the equipment. In Opdek trolleys, containers and ovens are assembled with four assembly station. Robot and J shape for trolleys with M class trays, I shape for trolleys with C class trays and VLAS for all other equipment types. After assembling trolleys, containers and ovens are stored in the final cooling. This is an inventory where trolleys, containers and ovens wait until they are transported to planes.

8.1.3. What criteria can be used to assess performance of the different solution alternatives?

Current key performance indicators give a global overview of the state of the Intercontintal department. Actual performance of individual workplaces can not be measured with the current key performance indicators. For this report new key performance indicators are used. Resource key performance indicators are work in progress inventory and number of working hours. Output key performance indicators are too late delivery, stock out and throughput time.

8.1.4. What is the current performance of the food assembly process for methods found in literature?

To measure current performance for each workstation a level with more detail is chosen. Now performance is measured in number of trolleys, containers. The department assembles 29812 trolleys, containers and ovens in September per week. This amount changes during the year.

A flowchart, swimlane and TIMWOODS are used to analyze performance. TIMWOODS showed different waste for especially, transport for walking to collect items, batching, searching for items, waiting and over-production and over processing caused by large inventories in the final cooling.

8.1.5. How can the current situation and design alternatives be modelled and evaluated?

A discrete event simulation is made for four weeks in Matlab and Simulink. Trolleys, containers and ovens are material entities. The attributes are processing times for emptying equipment, processing times for assembly equipment, equipment type, sub department, time creation entity and departure time of the plane. Different data sets are available for KCS for calculating the number of trolleys, containers and ovens, the input of the simulation model. The current situation has the largest queue in front of VLAS and the highest utilization is at I shape. Extra inventory is between ROA and Opdek. This is an average of 18,23 T11 trolleys, 76,90 T12 trolleys, 59,50 STC containers, 8,75 SQC containers and 293,38 ovens.

8.1.6. What constraint is limiting the performance?

The current simulation model concluded that the first focus must be improving the constraint VLAS, since VLAS has the highest queue length. Current problems stated that most errors occurred at VLAS and there is percentage of ill employees between 10% and 15% in 2015 to 2017. The flowchart shows a lot of sorting of equipment streams is done, also processes are done parallel in ROA and Opdek.

8.1.7. What solution alternatives can possibly improve the design of the food assembly process?

Constraint VLAS is exploited and high number of illness and sorting is analyzed, this leads to four different concepts. Concept 1 is wash everything on each washing machine. Concept 2 is Create one piece flow workstation in Opdek. Concept 3 is automatic input of equipment, food and items in Opdek and concepts 4 is automation of trolleys with M class trays. All concepts can be combined, which gives sixteen different solution alternatives.

8.1.8. How do these solution alternatives improve the performance?

Concept 1 has slightly higher throughput time, mostly higher utilization and slightly higher inventories compared with design alternatives without concept 1. Influence of concept 1 is the lowest. Concept 2 is not interesting without the use of concept 3. Only use of concept 2 leads to higher throughput time, higher utilization and higher inventories. Adding concept 3 however, leads to lower throughput time, lower utilization and lower inventories. Concept 3 leads to shorter processing times for VLAS and I shape. This ensures lower throughput time, lower utilization in Opdek, lower on floor inventory and lower throughput time. Concept 3 has the highest influence ans is certainly a must for better performance. Concepts 4 has two possible results. A robot with high processing times provides larger queues, higher throughput time, higher inventories and too late deliveries. A robot with shorter processing times ensures lower throughput time, lower utilization in ROA and Opdek, lower on floor inventory, less too late deliveries and lower throughput time.

8.1.9. What is the best solution alternative?

There are sixteen design alternatives with combinations of the four concepts. Concept 3 is essential for good performance. Design alternative with a combination of concept 2 and 3 and a combination of concept 3 and 4 are powerful. Combination 2, 3 and 4 gives an even better performance, this results in a low throughput time, low utilization in Opdek, no too late deliveries and a low inventory. For the current data set there is a small difference between adding concept 1, however there is a more clear distinction with higher production numbers. Design alternative with all four concepts performs the best, it assembles all 155173 trolleys, containers and ovens, has the best throughput time with 8685 seconds and inventory level of an average of 913,74 trolleys, containers and ovens. The utilization of the ROA with 0,93 is not on the first place. The current situation assembles only 133427 out of 155173 trolleys. The throughput time is 130684 seconds and the average total inventory is 13133,46 trolleys, containers and ovens.

When it is not possible to introduce a robot, design alternative with only concept 2 and 3 performance the best. The throughput time, utilization Opdek, inventory and entities assembled are less compared with design alternative with concept 2, 3 and 4.

The main research question can now be answered - *How can the assembly process of KLM Catering Services be optimized in order to improve the throughput time?*

A flowchart, swimlane and TIMWOODS are used to analyze performance. TIMWOODS showed different waste for especially transport for walking to collect items, batching, searching for items, waiting and over-production and over processing caused by large inventories in the final cooling. Delft Systems Approach, conceptual modelling and flow charts are used to create a simulation model. Resource key performance indicators are work in progress inventory and number of working hours. Output key performance indicators are too late delivery, stock out and throughput time. The current simulation model concluded that VLAS is the constraint. Current problems stated that most errors occurred at VLAS and there is high percentage of ill employees. The flowchart shows a lot of sorting of equipment streams, also processes are done parallel in ROA and Opdek. Constraint VLAS is exploited and high number of illness and sorting is analyzed, this leads to four different concepts. Concept 1 is wash everything on each washing machine. Concept 2 is Create one piece flow workstation in Opdek. Concept 3 is automatic input of equipment, food and items in Opdek and concepts 4 is automation of trolleys with M class trays. All concepts can be combined, which gives sixteen different solution alternatives. Concept 3 is essential for better performance. Design alternative with all four concepts performs the best, it assembles all 155173 trolleys, containers and ovens, has the best throughput time of 8685 seconds and average inventory level of 913,74 trolleys, containers and ovens. The utilization of the ROA with 0,93 is not on the first place. The current situation assembles only 133427 trolleys, containers and ovens. The throughput time is 130684 seconds and the average total inventory is 13133,46 trolleys, containers and ovens. When it is not possible to introduce a robot, design alternative with only concept 2 and 3 performance the best, with slightly less performance.

8.2. Recommendations

For KLM Catering Services it is recommended to implement the design alternative with washing everything on each was machine, creating one piece flow workstations in Opdek, automatic input of equipment, food and items in Opdek and automation of trolleys with economy class trays. The implementation of all concepts can be challenging. The most important concept is automatic input of equipment, food and items in Opdek. It is recommended to look at least for this option now or in the future.

In the near future a new robot will be bought, processing times of the robot are just enough for the summer period. To prevent long waiting times better specifications are recommended for this robot. Current specifications will lead to high inventories and high throughput time. When same throughput time and inventories are needed and only a robot is introduced a minimum of 47500 trays per 16 hours is advised. There are different data sets in KCS. For each data set correct specifications need to be calculated.

It is also recommended to keep the inventory in the final cooling at a lower level. This can be done by keeping the temperature of food as low as possible and making the process more stable. Shorten the time that food spends on the Opdek is one way of keeping the temperature as low as possible. Another option is that temperature of food increases slower in Opdek. Benefits of lower inventory numbers is more accurate passenger numbers with assembly, less rework is needed. Also total throughput time and inventories decrease.

Performance is now measured in number of flights and number of passengers catered. It is recommended to measure performance also in number of trolleys, containers and ovens assembled. With this level of detail individual workplaces can be measured instead of the whole department.

Processing times are now taken constant. This is not the case in the real world. In ROA and Opdek processing times vary a lot. It is recommended to test design alternatives with varying processing times. It is assumed that automation of trolleys with M class trays and automatic input of equipment, food and items perform even better compared with the real situation.

This research only focus on improving the whole department and is not focusing on single workstations. It can easily be tested with this model to find the right amount of employees for each workstation.

ROA, Opdek and cooling do not have breaks on the same time. It is also interesting to use breaks of employees for smoother flow. One possibility is to test what happens when all employees have a break on the same time. Another option is to use breaks for smoother production.

Also interesting is modelling Europe and foreign airlines. The different department can easily be compared and ideas from one department can be integrated in other departments. It is also possible to make one model for Intercontinental, Europe and foreign airlines department. Resources from whole KCS can be distributed in such a way that the whole performance improves. Next to combining Intercontinental, Europe and foreign airlines in a model, the three department can be combined in the real world. All trolleys, containers and ovens can be emptied, cleaned and assembled at the same department. Then a sandwich for a Europe flight can be assembled next to a business class meal for an intercontinental flight.

8.3. Research limitations

The outcome of this case study is limited on the quantity and quality of the data. Since there are different data sets available with different information about the same object, the data becomes visible unreliable. The data set is used which is provided during the research. When the model was finished a data set with real data of the past was provided.

Measurements were only done during the summer period and not during the whole year. In summer period more passengers are served and the production is higher. This can also have influence on the processing times. Another influence factor is that employees can see when measurements are done and tend to work faster. To illustrate processing times in a correct way also variation needs to be added. This is not done during this research.

Calculate the best alternative is a good method. However to concepts are not validated with the real world.

Measuring performance in the number of trolleys, containers and ovens assembled is new. There was no information available about this subject and all information had been calculated.

The model is limited by all assumption and simplifications made while modelling.

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A

Scientific paper

Redesigning and modelling of a food assembly process - A case study at KLM Catering Services

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Abstract

This paper deals with the food flow for intercontinental KLM flights. The aim of this research is to design a framework to optimize the processes of food assembly and subsequently apply the framework to increase the throughput time at the intercontinental department of KLM Catering Services. A discrete event simulation model is created to compare key performance indicators for different design alternatives. In this simulation model different amount of equipment is handled together with different settings for a robot. With the use of this simulation model a combination of design alternatives is proposed.

1 Introduction

While flying it is often possible to order something to drink. On a longer flight a simple sandwich or even complete meals are available. Drinks are served from trolleys full of soft drinks and alcohol beverages. A trolley is the car moved by stewardesses in the aisle. When it is time to eat passengers can choose one of the meals and receive a tray out of a trolley. A meal is given on a tray, mostly with water, cutlery and side dishes. When the passenger is finished with its meal, stewardesses collect all trays and put them into the same trolley again. Also other items are served in a plane, for instance earphones and sometimes even sandals or toys for children. In this research the world behind all services in airplanes is investigated.

This research concerns KLM Catering Services (KCS). KCS has its headquarter located at Amsterdam Schiphol Airport. KCS cater flights of KLM, some foreign airlines departing form Amsterdam Schiphol Airport and some KLM flights departing in a foreign country and arriving at Amsterdam Schiphol Airport. This research focuses only on the Dutch assembly. The other locations where assembly takes place are called outstations. KCS has three assembly departments at Amsterdam Schiphol Airport, namely for KLM flights with a destination in- and outside of Europe and for other airlines. Intercontinental and Europe are both further divided into two departments, namely food versus non-food and beverages.

This research focuses on the food flow for Intercontinental KLM flights. The food is not prepared on the intercontinental department, this is done at other companies and departments. Only the assembly takes place at the Intercontinental food department.

The food department has three stages, being ROA, Opdek and final cooling. Distribution transports all trolleys, containers and oven carriers from the planes to the ROA. In ROA all trolleys, containers and ovens are sorted and washed in washing machines. A wall with washing machines divides the ROA and Opdek. In the Opdek all trolleys, containers and ovens are refilled with smaller items and food. In the final cooling all trolleys, containers and ovens are sorted by flight and are cooled. Distribution will lastly collect trolleys, containers and ovens in the final cooling for a specific flight.

The number of flights are not the same for each day of the week, as illustrated in Table 1. The number of flights changes each month, since each month another flight schedule is introduced. For instance, in June, there are more flights compared to January. Currently, performance is measured in number of flights and number of passengers catered.

Table 1: Number of departed flights per day in 2018

	Jan	Feb	Mar	Apr	May	June
Mon	50	50	50	53	53	54
Tue	51	50	50	52	52	53
Wed	50	49	49	52	52	53
Thu	51	51	51	54	54	55
Fri	51	51	51	53	53	54
Sat	51	51	51	51	51	52
Sun	53	53	53	56	56	57

KCS strives for on time deliveries with zero errors. Unfortunately this is sometimes not achievable. Errors are divided into errors noticed before departure and errors noticed after departure. Errors noticed before departure are solved by delivering the missing parts to the aircraft. There is a target with a maximum of 15 errors noticed before departure per week. The department also has a high number of employees who are incapacitated for work. From 2015 to 2017 this percentage varied between 10% and 15%.

With this in mind, it is stated that there is a gap between the desired performance and the current performance. It is not clear what drivers influence this gap and how the performance can be improved. The aim of this research is to design a framework to optimize the processes of food assembly and subsequently apply the framework to increase the throughput time at the intercontinental department of KLM Catering Services. The main research question is stated as following; How can the assembly process of KLM Catering Services be optimized in order to improve the throughput time?

2 Methods

Several methods are described in literature to analyze the performance. Lean manufacturing focuses on the removal of waste and consists of identify which process creates value, making a value stream map, make activities flow, create pull and perfect the process. [1] [2] Creating flow and pull can be done by combining discrete processes, just in time, kanban signaling system, total preventive maintenance, change over time reduction, changing layout of workplaces, designing products for manufacturing, quicker and more accurate data capture, electronic data interchange of orders and other data, decrease size of equipment and introduce conveyors, total quality management and 5s. [3] [4] Total quality management is divided into five steps, namely define what quality customers want, translate the wishes of the customer into measurable units, measure the current quality continuously, set certain targets and deadlines and at last develop a method to keep increasing the quality. [5] 5S is used to create clean, organized and good looking workplaces and consists of sort, set, shine, standardize and sustain. [6] TIMWOODS is a method of lean manufacturing to identify waste. Waste is categorized in transport, inventory, motion, waiting, over processing, overproduction, defects and skills. [7]

Next to lean manufacturing, other methods from literature applied in this research include six sigma, theory of constraints, critical path and swimlane. Six sigma focuses on reducing variation. It is problem focused and includes define, measure, analyze, improve and control. [5] Theory of constraints focuses on the constraint that slows down the flow and consists out of the following steps; identify the constraint, exploit the constraint, subordinate other processes, elevate constraint and repeat. [1] [8] Critical path concerns defining the longest route in a process. The route with the longest total duration is called critical path. [9] Swimlane shows the steps that the departments go through to go from input to output for a specific process. [10]

The required performance measures for an organization are dependent on the strategy of the company. A supply chain measurement system must contain three types of performance measures, namely resource, output and flexibility. Since these three types of performance measure are crucial to the overall performance. [11]

Supply chain performance can be measured in three ways, namely analytic, with simulation or with physical experiments. Analytic models are impractical since mathematical models are mostly too complex to be solved and physical experiments often have technical- and cost related limitations. Simulation turns out to the best possibility to analyze performances. [12] [13] Advantages of simulation are that systems can be described a highly realistic manner and experiments can be done that cannot be performed on real manufacturing systems. [14] Delft Systems Approach (DSA) is a method for creating models. DSA uses elements that flow through the system. An element is the smallest part in a system, properties of elements are called attributes. [15] Conceptual modelling is the process of making a model of a real situation and is a representation of an abstract model expressed in objectives, input, output and model content. [16]

With that in mind, the current performance is analyzed. Working hours of the Intercontinental department are from 6 am to 11 pm, seven days per week, with fourteen effective working hours per day. There are five equipment types, namely T11 trolleys, T12 trolleys, STC containers, SQC containers and oven carriers. Equipment arriving from planes is the input of the intercontinental department, the output is equipment going to planes. Information is provided with information cards attached to trolleys, containers and ovens. The department consists of three parts, namely ROA, Opdek and the final cooling. In ROA trolleys, containers and ovens are sorted, emptied and cleaned. There are seven washing machines for emptying equipment and two trolley washing machines for cleaning the equipment. In Opdek trolleys, containers and ovens are assembled with four assembly stations. These stations include robot and J shape for trolleys with economy class trays, I shape for trolleys with business class trays and VLAS for all other equipment types. Robot, I shape and J shape use an assembly line for production. VLAS uses four elevators for lifting equipment a bit in the air for better ergonomics. Economy class uses trays with food stored in plastic boxes. Business class uses all kinds of porcelain on the trays. After assembling trolleys, containers and ovens are stored in the final cooling. This is an inventory where trolleys, containers and ovens wait until they are transported to planes.

Table 2: Current state ROA

	T11	T12	STC	SQC	OIS
MO3	03:35	01:47			
CO3	07:41	01:50	00:29	00:23	00:56
MA3	00:00	01:52	00:29	00:23	00:56
SE3			00:29	00:23	

All stations in ROA are measure together with J shape from Opdek. Processing times for VLAS are already known and processing time of I shape is discussed with employees. All equipment is divided into four different sub departments, namely MO3, CO3, MA3 and SE3. Each departments handles its own types of equipment. For instance MO3 only handles trolleys with economy class trays. Processing times are given in Table 2 for ROA and in Table 3 for Opdek.

Table 3: Current state Opdek

	T11	T12	STC	SQC	OIS
MO3	01:39	00:49			
CO3	04:34	02:17	01:47	01:47	02:13
MA3	02:44	01:30	00:41	01:47	00:41
SE3			01:55	01:55	

Key performance indicators used currently, give a global overview of the state of the Intercontintal department. Actual performance of individual workplaces can not be measured with these key performance indicators. For this report new key performance indicators are used. Resource key performance indicators are work in progress inventory and number of working hours. Output key performance indicators are too late delivery, stock out and throughput time. A flexibility key performance indicator is not used, since this key performance indicator is hard to measure with a model and difficult to assign scores to design alternatives.

To analyze current performance for each workstation it is chosen to measure in number of trolleys, containers and ovens instead of the number of flights and the number of passengers. Most aircrafts have an after, mid and front galley. Usually all trolleys, containers and ovens of one galley position go into one truck from and to the aircraft. All trolleys, containers and ovens for one flight are delivered in three parts at the aircraft and also in three parts at the ROA. So the input and the output of the Intercontinental department are batches of trolleys, containers and ovens intended for one galley position. To determine the exact input and output of the intercontinental department for each galley position, all trolleys, containers and ovens need to be investigated. This is done via three excel files. The total number of trolleys, containers and ovens for each day in September is given in Table 4. Differences in the amount of equipment can be seen for arriving and departing flights for every day.

Table 4: Equipment of arriving flights and departing flights in September

	Arrival	Departure
Monday	4335	4268
Tuesday	4152	4194
Wednesday	4166	4137
Thursday	4308	4332
Friday	4193	4295
Saturday	4375	4078
Sunday	4283	4508
Total	29812	29812

In Figure 1 a simplified flowchart is given. This Figure illustrates the flow of trolleys, containers and ovens throughout the Intercontinental department. A triangle illustrates an inventory. The last triangle is a regulated inventory, this inventory is the final cooling. Here trolleys, containers and ovens wait until distribution will bring it to planes. This is the output of the department.

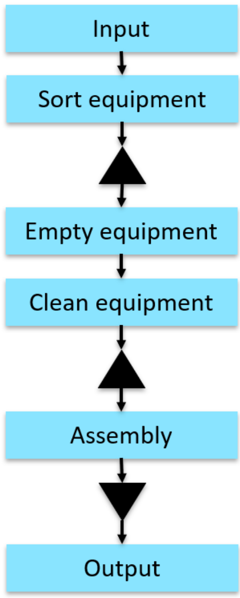

Figure 1: Compact flowchart of equipment

Equipment streams are showed in Figure 2. On the left side trucks arrive with trolleys, containers and ovens. This flow is first divided into economy and business class equipment. At line three equipment is emptied, at line four equipment is washed and at line five equipment is assembled. The point on line six is the final cooling.

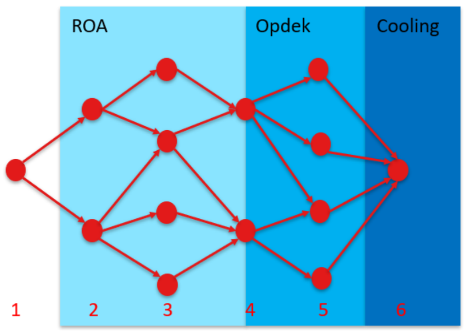

Figure 2: Department with equipment stream

TIMWOODS showed different waste. Transport is a big problem, the transport in ROA is relatively small compared with the transport in Opdek, since the walking distance is smaller in ROA. Inventory is a result of other waste. So inventory will decrease if the other waste is eliminated, only eliminating batching can be interesting. Searching for information happens not that often. Searching for equipment, food and items however, is a much bigger problem. Decreasing or eliminating this is certainly a must. Also waiting needs to be decreased as much as possible. Waiting occurs on missing equipment, food and items and also on other employees when task time is not matched. Overproduction and over processing is mostly explained with too much inventory in the final cooling. Better skills of workers can improve performance of the robot.

A discrete event simulation is made in Matlab and Simulink to analyze the department. Five material entities are used, namely two types of trolleys, two types of containers and one type of ovens. The attributes are processing times for emptying equipment, processing times for assembling equipment, equipment type, sub department, time creation entity and departure time of the plane. The source are trucks with equipment arriving at ROA, the sink are trucks with equipment leaving the final cooling. The key performance indicators must be answered in the model. Scope of the model is the ROA, Opdek and final cooling and the time scale is four weeks. Different data sets are available for KCS for calculating the number of trolleys, containers and ovens. The data set used has approximately 28% more equipment compared with the historical data.

Calculating the current situation in the simulation model gives the results given in Table 5. Queue length and utilization is given for each station in ROA and Opdek. The largest queue is in front of VLAS and the highest utilization is at I shape. Extra inventory is between ROA and Opdek. This is an average of 18,23 T11 trolleys, 76,90 T12 trolleys, 59,50 STC containers, 8,75 SQC containers and 293,38 ovens.

Table 5: Queue and utilization of servers current situation

Workstation	Queue	Utilization
3,1	26,22	0,8509
3,4	8,493	0,530
4,6	39,68	0,6656
4,9	79,84	0,8741
J shape+robot	7,966	0,8057
I shape	8,926	0,9392
VLAS	102	0,9200

The current simulation model concluded that the first focus must be improving the constraint VLAS, since VLAS has the highest queue length. Current problems state that most errors occurred at VLAS and there is percentage of ill employees between 10% and 15% in 2015 to 2017. The flowchart shows a lot of sorting of equipment streams, also processes are done parallel in ROA and Opdek.

TIMWOODS is used to exploit constraint VLAS. TIMWOODS identified certain types of waste at VLAS, namely a lot of walking for collecting equipment, food and items. Often equipment, food and items must be searched at different places in the Opdek. VLAS uses also the biggest batche. Recounting of meals can be seen as waste, this happens when the number of meals provided for a certain flight is incorrect. With a lean perspective, one piece flow is considered to be better than batching. In a workstation where only one piece of equipment can be produced at the time, frequency will increase and the quantities of deliveries will decrease. To create one piece flow another way must be found for getting equipment, food and items at VLAS.

It is tough physical work and the ergonomics are not always up to standards. Almost all employees encounter high repetitive and monotonous tasks. Better ergonomics will prevent employees for becoming incapacitated for work. Another way of decreasing illness is hiring more employees to do the same tasks, the pace can be decreased. Also automation decreases the number of ill employees.

An aspect of lean manufacturing is defining which parts of the production creates value. When all trolleys, containers and ovens enter the ROA every piece of equipment is sorted in different streams. This does not add value to the product. Another important aspect of lean manufacturing is creating flow, one tool for doing this is cellular manufacturing. With cellular manufacturing processes for a particular product or product group are organized in cells. Another tool of creating flow is just-in-time. With just-in-time smaller and more frequent quantities are delivered. Combining these two theories can lead to a manufacturing cell for producing one piece of equipment at the time.

Combining the last three sections, exploiting constraint VLAS, high number of illness and sorting, leads to four different concepts. The four concepts are created for improving the performance. Concept 1 is wash everything on each washing machine. Concept 2 is create one piece flow workstation in Opdek. Concept 3 is automatic input of equipment, food and items in Opdek and concept 4 is automation of trolleys with economy class trays. All concepts can be combined, which gives sixteen different solution alternatives.

Design alternatives have different flows of trolleys, containers and ovens and design alternatives sometimes have different processing times. To create different flows of equipment various variant subsystems are used in the Simulink environment for ROA and Opdek. Different subsystems can be modelled parallel to each other. With every simulation the programmer can choose which variant subsystem is needed. To push the department to its boundaries, different amount of equipment is tested. The first set is the current data set and the second set is the current data set times 1.3. All equipment is divided into twenty categories, resulting from four sub departments and five types of equipment. These are presented for FOA in Table 2 and for Opdek in Table 3. To determine the desired specification of the robot, different scenarios are tested with the model. The lowest specification of the robot for the current data set is determined for an utilization of just below one. In total three different robot specifications are tested for each data set.

3 Results

In this Section results are given from the simulation model.

1,3*dataset; 57500 trays per 16 hour					
	Throughput	Utilization ROA	Utilization Opdek	Inventory	Entities to cooling
1111	130684	0,93	0,96	13133,46	133427
1121	95087	0,93	0,87	9449,38	138549
2121	108405	1,00	0,86	11893,27	137959
1221	76908	0,93	0,86	7908,00	144602
2221	104134	1,00	0,83	11606,83	139076
1122	91083	0,89	0,84	8726,41	138577
2122	91504	0,93	0,84	8713,38	138577
1222	20849	0,89	0,64	1730,80	155173
2222	8685	0,93	0,65	913,74	155173

Figure 3: Results for 1,3 times the data set with 57500 trays per 16 hours

Concept 1 has slightly higher throughput time, mostly higher utilization and slightly higher inventories compared with design alternatives without concept 1. Influence of concept 1 is the lowest. Concept 2 appears not to be interesting without concept 3. Only use of concept 2 leads to higher throughput time, higher utilization and higher inventories. Adding concept 3 however, leads to lower throughput time, lower utilization and lower inventories. Concept 3 leads to shorter processing times for VLAS and I shape. This ensures lower throughput time, lower utilization in Opdek, lower on floor inventory and lower throughput time. Concept 3 has the highest influence and is certainly required for improved performance. Concepts 4 has two possible results. A robot with high processing times provides larger queues, higher throughput time, higher inventories and too late deliveries. A robot with shorter processing times ensures lower throughput time, lower utilization in ROA and Opdek, lower on floor inventory, less late deliveries and lower throughput time.

In Table 3 results are given for a data set with 1,3 times the amount of equipment with robot specification of 57500 trays per 16 hours. The design alternative with a combination of concept 2 and 3 (*22*) and a combination of concept 3 and 4 (**22) are powerful. Combination 2, 3 and 4 (*222) gives an even better performance. Design alternatives with *222 result in a low throughput time, low utilization in Opdek, no too late deliveries and a low inventory. For the current data set 1222 and 2222 are close together, however there is a more clear distinction with higher production numbers. Design alternative 2222 performs the best, it has the best throughput time with 8685 seconds and inventory level of an average of 913,74 trolleys, containers and ovens. The utilization of the ROA with 0,93 is not on first place. The current situation assembles only 133427 out of 155173 trolleys. The throughput time is 130684 seconds and the average total inventory is 13133,46 trolleys, containers and ovens.

When it is not possible to introduce a robot, design alternative 1221 performs the best. The throughput time, utilization Opdek, inventory and entities assembled are less compared with design alternative 1222 and 2222.

4 Discussion

For KLM Catering Services it is recommended to implement the design alternative 2222, with all four concepts. Concept 3 is the most important, so the first focus must be to create automatic input of equipment, food and items in Opdek. In the near future a new robot will be bought. To prevent long throughput time and high inventory at least 47500 trays per 16 hours is recommended for this robot. Additionally, it is recommended to keep the inventory in the final cooling at a lower level, benefits of lower inventory numbers are more accurate passenger numbers with assembly, less rework and lower throughput time. It is recommended to measure performance in number of trolleys, containers and ovens assembled, instead of number of flights and number of passengers catered. With this level of detail individual workplaces can be measured instead of the whole department. Processing times are now kept constant. It is recommended to test design alternatives with varying processing times. Additionally, shifting the focus to improving single workstations, instead of improving a whole department, can improve performance. Breaks of employees can be used for smoother production. Finally it is interesting to model Europe and foreign airline departments. Another possibility is to combine Intercontinental, Europe and foreign airlines department in one model. Resources from the entire KCS can be distributed in such a way that the whole performance improves. Next to combining Intercontinental, Europe and foreign airlines in a model, the three department can be combined in the real world. All trolleys, containers and ovens can be emptied, cleaned and assembled at the same department. Then a sandwich for a Europe flight can be assembled next to a business class meal for an intercontinental flight.

The outcome of this case study is limited on the quantity and quality of the data. There are different data sets available with other information. Also measurements are done in a short period in the year and employees could notice that processing times were being measured and there is too few data available to calculate variation. Concepts are not validated in the real world. Measuring performance in the number of trolleys, containers and ovens assembled is new and there was no information available yet about this topic. Finally, the model is limited by all assumption and simplifications made while modelling.

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B

Input Simulink model

B.1. Input processing times

In this Section processing times are determined for the simulation model. First the current processing times, later processing times for concepts are stated.

For ROA and J shape measurements are used for determining processing times. In Table 3.1 measurements for different washing machines in the ROA and assembly at J shape can be seen.

I shape is not measured, processing times are discussed with management of the intercontinental flow and several shiftleaders. Processing times of I shape are not constant. Approximately one third of the time, no assembly takes place at I shape. Processing times are based on knowledge and the total production numbers per day.

Processing times of 2017 are used for VLAS assembly station. This is the only assembly station with known processing times. These measurements are done by a student [37]. Processing times are divided into valuable adding and non value adding steps.

For ROA only one table is needed. Opdek uses three tables, one table with processing times of VLAS, one table with processing times of I shape and J shape and the last table combines VLAS with I shape and J shape. Some equipment types in sub departments has trolleys, containers or ovens assembled in VLAS and I shape. For combining the number of CO3 trolleys is counted for I shape and VLAS.

B.1.1. Current processing times

In Table B.1 processing times in ROA are given for each type of equipment. In Table B.2 processing times of VLAS are given in Opdek, in Table B.3 processing times of I shape and J shape in Opdek are given and finally in Table B.4 processing times in Opdek are given. The last table is a combination of B.2 and B.3.

Table B.1: Current state ROA

	T11	T12	STC	SQC	OIS
MO3	00:03:35	00:01:47			
CO3	00:07:41	00:01:50	00:00:29	00:00:23	00:00:56
MA3	00:00:00	00:01:52	00:00:29	00:00:23	00:00:56
SE3			00:00:29	00:00:23	

Table B.2: Current state VLAS

	T11	T12	STC	SQC	OIS
MO3					
CO3	00:03:43	00:02:17	00:01:47	00:01:47	00:02:13
MA3	00:02:44	00:01:30	00:00:41	00:01:47	00:00:41
SE3			00:01:55	00:01:55	

Table B.3: Current state I shape and J shape

	T11	T12	STC	SQC	OIS
MO3	00:01:39	00:00:49			
CO3	00:05:09	00:02:34			
MA3					
SE3					

Table B.4: Current state Opdek

	T11	T12	STC	SQC	OIS
MO3	00:01:39	00:00:49			
CO3	00:04:34	00:02:17	00:01:47	00:01:47	00:02:13
MA3	00:02:44	00:01:30	00:00:41	00:01:47	00:00:41
SE3			00:01:55	00:01:55	

B.1.2. Concept 1; Wash everything on each washing machine

For concept 1 all processing times are equal to processing times in the current situation, so processing times of ROA can be seen in Table B.1 and processing times of Opdek can be seen in Table B.4. Only the routing of entities changes with concept 1.

B.1.3. Concept 2; Create one piece flow workstation in Opdek

Processing times of ROA stay the same for concept 2. In Table B.5 processing times of VLAS are given in Opdek, in Table B.6 processing times of I shape and J shape in Opdek are given and finally in Table B.7 processing times in Opdek are given. The last table is a combination of B.5 and B.6.

Table B.5: Concept 2 VLAS

	T11	T12	STC	SQC	OIS
MO3					
CO3	00:03:43	00:02:17	00:01:47	00:01:47	00:02:13
MA3	00:02:44	00:01:30	00:00:41	00:01:47	00:00:41
SE3			00:01:55	00:01:55	

Table B.6: Concept 2 I shape and J shape

	T11	T12	STC	SQC	OIS
MO3	00:06:36	00:03:18			
CO3	00:11:35	00:05:47			
MA3					
SE3					

Table B.7: Concept 2 Opdek

	T11	T12	STC	SQC	OIS
MO3	00:06:36	00:03:18			
CO3	00:08:25	00:02:17	00:01:47	00:01:47	00:02:13
MA3	00:02:44	00:01:30	00:00:41	00:01:47	00:00:41
SE3			00:01:55	00:01:55	

B.1.4. Concept 3; Automatic input of equipment, food and items in Opdek

Processing times of ROA stay the same for concept 3. So processing times of ROA can be seen in Table B.1. In Table B.8 processing times of VLAS are given in Opdek, in Table B.9 processing times of I shape and J shape in Opdek are given and finally in Table B.10 processing times in Opdek are given. The last table is a combination of B.8 and B.9.

Table B.8: Concept 3 VLAS

	T11	T12	STC	SQC	OIS
MO3					
CO3	00:02:48	00:01:29	00:01:09	00:01:09	00:01:35
MA3	00:01:55	00:01:02	00:00:29	00:01:09	00:00:29
SE3			00:01:10	00:01:10	

Table B.9: Concepts 3 I shape and J shape

	T11	T12	STC	SQC	OIS
MO3	00:01:39	00:00:49			
CO3	00:02:09	00:01:04			
MA3					
SE3					

Table B.10: Concept 3 Opdek

	T11	T12	STC	SQC	OIS
MO3	00:01:39	00:00:49			
CO3	00:02:24	00:01:29	00:01:09	00:01:09	00:01:35
MA3	00:01:55	00:01:02	00:00:29	00:01:09	00:00:29
SE3			00:01:10	00:01:10	

B.1.5. Concept 4; Automation of trolleys with M class trays

For concept 4 almost all processing times are equal to processing times in the current situation, so processing times of ROA can be seen in Table B.1 and processing times of Opdek can be seen in Table B.4. The only difference is the sub department MO3. Processing times for this sub department are given in Table B.11.

KCS is planning to buy a robot which is capable of assembling 30000 trays per 16 hours. However with the current data set this is insufficient. To determine the specification of the robot, the current situation in Simulink is tested with a robot. The lowest specification of the robot are determined when the robot in ROA has an utilization of 0,99 instead of 1.

Table B.11: Processing times concept 4

Number of trays per 16 hours	T11 [s]	T12 [s]
37500	65	32
42500	57	28
47500	51	25
52500	46	23
57500	42	21

B.1.6. Combination concepts 2 and 3

Processing times of ROA stay the same with combining concept 2 and 3. So processing times of ROA can be seen in Table B.1. In Table B.12 processing times of VLAS are given in Opdek, in Table B.13 processing times of I shape and J shape in Opdek are given and finally in Table B.14 processing times in Opdek are given. The last table is a combination of B.12 and B.13.

Table B.12: Concept 2 and 3 VLAS

	T11	T12	STC	SQC	OIS
MO3					
CO3	00:02:48	00:01:29	00:01:09	00:01:09	00:01:35
MA3	00:01:55	00:01:02	00:00:29	00:01:09	00:00:29
SE3			00:01:10	00:01:10	

Table B.13: Concept 2 and 3 I shape and J shape

	T11	T12	STC	SQC	OIS
MO3	00:06:36	00:03:18			
CO3	00:08:35	00:04:17			
MA3					
SE3					

Table B.14: Concept 2 and 3 Opdek

	T11	T12	STC	SQC	OIS
MO3	00:06:36	00:03:18			
CO3	00:06:15	00:01:29	00:01:09	00:01:09	00:01:35
MA3	00:01:55	00:01:02	00:00:29	00:01:09	00:00:29
SE3			00:01:10	00:01:10	

B.2. Input inventory start Opdek

Between ROA and Opdek there is an inventory. Wednesday evening all equipment is counted, the average value required on Wednesday evening is the starting value of the simulation. This is also given in Table B.15. This value is determined based on internal forms.

Table B.15: Queue start Opdek for current situation

Equipment	T11	T12	STC	SQC	OIS
Starting value	212	154	78	112	342

B.3. Input creating and destroying entities in Simulink model

To calculate the number of trolleys, containers and ovens several Excel files and Matlab are used. All Excel files are received from KCS. The first Excel file is a flight schedule for the summer of 2018, in this schedule all planned flights are given with destination, flightnumber, departure time, arrival time, aircraft type and passenger configuration. First all flights for a specific day are determined. These specific flights have products codes, product codes are determined with the second excel file. A product code stands for everything what needs to be loaded for this specific flight by KCS. All information for a specific product code can be found in the third Excel file. This information is on equipment level and each trolley, container and oven has information about galley position, departure or arrival time and the sub department.

With Matlab one starts with the desired date and Matlab searches all flights for that specific date with corresponding information. With the second Excel file the product code is added for those flights and lastly all data from the product codes for that day is searched. This data is a big table for each flight and gives no overview yet of the amount of equipment. First all lines is this table from other departments are deleted, so only MO3, CO3, MA3 and SE3 will remain. Later all types of equipment are counted for each galley position and department.

Important to note is that the data splits the intercontinental department is four different sub department, namely MO3, CO3, MA3 and SE3. These four departments handle different kinds of trolleys, containers and ovens. For instance MO3 department consists only out of T11 and T12 trolleys with M class trays.

In Figure B.1 the total amount of trolleys, containers and ovens are illustrated for September divided in sub departments.

	MO3					CO3					MA3					SE3					
Arrival	T11	T12	STC	SQC	OIS	T11	T12	STC	SQC	OIS	T11	T12	STC	SQC	OIS	T11	T12	STC	SQC	OIS	Total
Monday	776	80	0	0	0	275	507	223	112	243	68	353	257	145	719	0	50	182	345	0	4335
Tuesday	733	74	0	0	0	268	490	227	101	238	63	340	247	126	701	0	48	180	316	0	4152
Wednesday	733	76	0	0	0	266	495	210	115	232	65	340	238	148	691	0	43	167	347	0	4166
Thursday	775	79	0	0	0	272	500	232	95	243	65	359	272	125	726	0	42	197	326	0	4308
Friday	737	79	0	0	0	267	495	206	125	233	66	339	228	153	688	0	59	161	357	0	4193
Saturday	784	80	0	0	0	276	507	230	108	245	66	363	270	134	734	0	49	193	336	0	4375
Sunday	759	81	0	0	0	270	502	206	126	235	70	339	237	154	704	0	58	172	370	0	4283
Total	5297	549	0	0	0	1894	3496	1534	782	1669	463	2433	1749	985	4963	0	349	1252	2397	0	29812
	MO3					CO3					MA3					SE3					
Departure	T11	T12	STC	SQC	OIS	T11	T12	STC	SQC	OIS	T11	T12	STC	SQC	OIS	T11	T12	STC	SQC	OIS	Total
Monday	753	79	0	0	0	272	505	214	120	238	67	343	239	148	707	0	58	174	351	0	4268
Tuesday	748	75	0	0	0	268	497	220	106	236	66	338	248	136	702	0	42	179	333	0	4194
Wednesday	733	76	0	0	0	262	482	216	102	232	62	350	251	132	693	0	40	178	328	0	4137
Thursday	767	78	0	0	0	276	512	223	115	243	67	354	252	143	720	0	52	181	349	0	4332
Friday	763	83	0	0	0	271	495	219	114	240	65	355	252	142	713	0	57	180	346	0	4295
Saturday	724	73	0	0	0	260	482	207	113	227	65	327	234	139	678	0	49	168	332	0	4078
Sunday	809	85	0	0	0	285	523	235	112	253	71	366	273	145	750	0	51	192	358	0	4508
Total	5297	549	0	0	0	1894	3496	1534	782	1669	463	2433	1749	985	4963	0	349	1252	2397	0	29812

Figure B.1: Amount of trolley, containers and ovens in September

In Table B.16 the first ten flight of 23 August are given. This data comes from the Excel files. Each line in this table indicates a galley position of the plane and each galley position is a batch for the input and the output of the department. The last six columns are important for the Simulink model. Here the number of trolleys, containers and ovens are given with the arrival time of the plane. This is used for creating entities. A similar table is made for departure, this table is used for destroying entities.

Table B.16: Data from Excel files

Airport	Type	Pax	Flightnr	Product code	Galley	T11	T12	STC	SQC	OIS	Time
NRT	77W	34C/374M	0861	PA861V5_1	A	8	3	9	0	6	05:05
NRT	77W	34C/374M	0861	PA861V5_1	F	6	5	6	2	4	05:05
NRT	77W	34C/374M	0861	PA861V5_1	M	7	7	2	3	5	05:05
ACC	77W	34C/374M	0589	PA587V5_1	A	4	6	6	0	6	05:45
ACC	77W	34C/374M	0589	PA587V5_1	F	4	5	4	1	4	05:45
ACC	77W	34C/374M	0589	PA587V5_1	M	3	6	4	2	5	05:45
DXB	772	34C/286M	0427	PA427V5_1	A	5	2	5	0	6	05:50
DXB	772	34C/286M	0427	PA427V5_1	F	2	5	4	1	4	05:50
DXB	772	34C/286M	0427	PA427V5_1	M	4	6	3	2	5	05:50
LIM	77W	34C/374M	0743	PA743V6_1	A	8	5	9	0	6	05:50
LIM	77W	34C/374M	0743	PA743V6_1	F	4	5	4	1	4	05:50
LIM	77W	34C/374M	0743	PA743V6_1	M	7	9	2	3	5	05:50
IAH	789	30C/264M	0661	PA661V5_1	A	8	6	0	9	5	06:00
IAH	789	30C/264M	0661	PA661V5_1	F	4	5	0	7	3	06:00
IAH	789	30C/264M	0661	PA661V5_1	M	6	3	0	8	4	06:00
SIN	77W	34C/374M	0835	PA835L1V5_1	A	8	3	7	0	6	06:00
SIN	77W	34C/374M	0835	PA835L1V5_1	F	4	5	5	2	4	06:00
SIN	77W	34C/374M	0835	PA835L1V5_1	M	7	6	2	3	5	06:00
EZE	77W	34C/374M	0701	PA701L1V5_1	A	8	4	7	0	6	06:30
EZE	77W	34C/374M	0701	PA701L1V5_1	F	4	5	5	2	4	06:30
EZE	77W	34C/374M	0701	PA701L1V5_1	M	7	8	2	3	5	06:30
ATL	77W	34C/374M	0621	PA621V5_1	A	4	7	5	0	6	06:45
ATL	77W	34C/374M	0621	PA621V5_1	F	4	5	4	1	4	06:45
ATL	77W	34C/374M	0621	PA621V5_1	M	3	7	3	2	5	06:45
JFK	74E	35C/233M	0643	PA643V4_1	A	2	3	3	0	4	06:50
JFK	74E	35C/233M	0643	PA643V4_1	F	10	15	11	0	14	06:50
NBO	744	35C/373M	0565	PA565V4_1	A	11	2	10	0	9	06:55
NBO	744	35C/373M	0565	PA565V4_1	F	15	11	11	0	14	06:55

C
Data results

Current dataset; 37500 trays per 16 hour

	1111	2111	1211	2211	1112	2112	1212	2212	1121	2121	1221	2221	1122	2122	1222	2222
Throughput time	9177	9871	9316	9971	43773	43873	43903	44003	6598	8723	6032	8423	43215	43333	42590	42659
Utilization ROA	0,78	0,89	0,78	0,89	0,73	0,72	0,73	0,72	0,78	0,89	0,78	0,89	0,73	0,72	0,73	0,72
Utilization Opdek	0,89	0,89	0,89	0,89	0,89	0,89	0,89	0,89	0,78	0,78	0,73	0,73	0,74	0,74	0,48	0,48
Inventory	729,88	791,06	735,87	793,65	3195,52	3202,38	3206,13	3225,14	521,37	705,00	629,15	854,49	3163,73	3171,13	2940,12	2928,21

Variance input equipment; 37500 trays per 16 hour

	1111	2111	1211	2211	1112	2112	1212	2212	1121	2121	1221	2221	1122	2122	1222	2222
Throughput time	10181	10725	10304	10830	33845	33857	34010	34021	7124	9619	6505	9349	33319	33347	32518	32518
Utilization ROA	0,76	0,88	0,76	0,88	0,71	0,71	0,71	0,71	0,76	0,88	0,76	0,88	0,71	0,71	0,71	0,71
Utilization Opdek	0,88	0,88	0,88	0,88	0,89	0,89	0,89	0,89	0,77	0,77	0,73	0,72	0,74	0,74	0,48	0,48
Inventory	808,87	860,65	813,50	865,08	2536,09	2541,07	2546,98	2565,17	564,70	775,48	669,46	925,29	2502,37	2507,93	2271,23	2264,52

Figure C.1: Results variance input equipment

In this Chapter values from all results are given. In Figure C.1 all results are given for the current data set with and without variation in the input of equipment. In Figure C.2 results are given for the current data set and in Figure C.3 results are given for the data set with 1,3 times more equipment.

Current dataset; 37500 trays per 16 hour	1111	2111	1211	2211	1112	2112	1212	2212	1121	2121	1221	2221	1122	2122	1222	2222
Throughput time	9177	9871	9316	9971	43773	43873	43903	44003	6598	8723	6032	8423	43215	43333	42590	42659
Utilization ROA	0,78	0,89	0,78	0,89	0,73	0,72	0,73	0,72	0,78	0,89	0,78	0,89	0,73	0,72	0,73	0,72
Utilization Opdek	0,89	0,89	0,89	0,89	0,89	0,89	0,89	0,89	0,78	0,78	0,73	0,73	0,74	0,74	0,48	0,48
Inventory	729,88	791,06	735,87	793,65	3195,52	3202,38	3206,13	3225,14	521,37	705,00	629,15	854,49	3163,73	3171,13	2940,12	2928,21
Too late																

Current dataset; 42500 trays per 16 hour	1111	2111	1211	2211	1112	2112	1212	2212	1121	2121	1221	2221	1122	2122	1222	2222
Throughput time	9177	9871	9316	9971	9512	9598	9580	9664	6598	8723	6032	8423	7590	7580	7077	7042
Utilization ROA	0,78	0,89	0,78	0,89	0,73	0,72	0,73	0,72	0,78	0,89	0,78	0,89	0,73	0,72	0,73	0,72
Utilization Opdek	0,89	0,89	0,89	0,89	0,93	0,93	0,93	0,93	0,78	0,78	0,73	0,73	0,77	0,77	0,50	0,50
Inventory	729,88	791,06	735,87	793,65	763,74	774,82	766,07	727,32	521,37	705,00	570,84	788,66	610,10	610,50	535,66	514,74

Current dataset; 47500 trays per 16 hour	1111	2111	1211	2211	1112	2112	1212	2212	1121	2121	1221	2221	1122	2122	1222	2222
Throughput time	9177	9871	9316	9971	9168	9261	9237	9331	6598	8723	6032	8423	6427	6500	5862	5914
Utilization ROA	0,78	0,89	0,78	0,89	0,73	0,72	0,73	0,72	0,78	0,89	0,78	0,89	0,73	0,72	0,73	0,72
Utilization Opdek	0,89	0,89	0,89	0,89	0,93	0,93	0,93	0,93	0,78	0,78	0,73	0,73	0,77	0,77	0,50	0,50
Inventory	729,88	791,06	735,87	793,65	737,60	748,96	739,91	685,01	521,37	705,00	568,66	785,61	512,51	517,12	451,46	438,10

Figure C.2: Results for current data set

1,3*dataset; 47500 trays per 16 hour																
	1111	2111	1211	2211	1112	2112	1212	2212	1121	2121	1221	2221	1122	2122	1222	2222
Throughput time	130684	131045	130567	130926	130916	130810	131224	131116	95087	108405	76908	104134	94482	94381	58664	58011
Utilization ROA	0,93	1,00	0,93	1,00	0,89	0,93	0,89	0,93	0,93	1,00	0,93	1,00	0,89	0,93	0,89	0,93
Utilization Opdek	0,96	0,96	0,97	0,97	1,00	1,00	1,00	1,00	0,87	0,86	0,86	0,83	0,84	0,84	0,61	0,61
Inventory	13133,46	14058,91	13111,20	14036,45	13058,22	13024,51	13088,24	13042,06	9449,38	11893,27	7907,84	11606,68	9247,59	9211,18	5781,53	5620,06
Entities to cooling	133427	133427	133442	133442	133428	133428	133386	133386	138549	137959	144602	139076	138547	138547	149184	149215

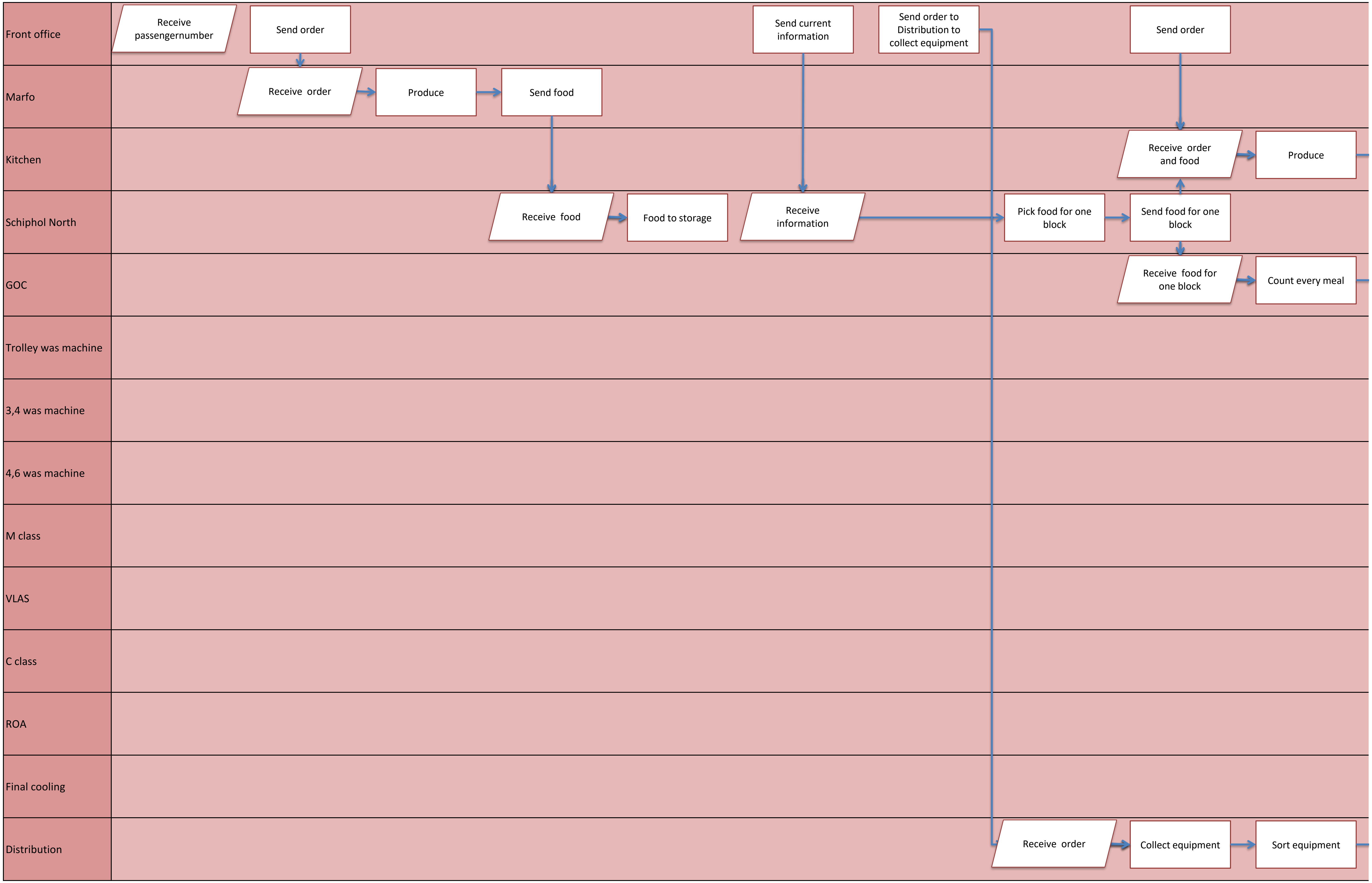
1,3*dataset; 52500 trays per 16 hour																
	1111	2111	1211	2211	1112	2112	1212	2212	1121	2121	1221	2221	1122	2122	1222	2222
Throughput time	130684	131045	130567	130926	130799	130999	131105	131305	95087	108405	76908	104134	91543	91920	22107	9542
Utilization ROA	0,93	1,00	0,93	1,00	0,89	0,93	0,89	0,93	0,93	1,00	0,93	1,00	0,89	0,93	0,89	0,93
Utilization Opdek	0,96	0,96	0,97	0,97	1,00	1,00	1,00	1,00	0,87	0,86	0,86	0,83	0,84	0,84	0,69	0,65
Inventory	13133,46	14058,91	13111,20	14036,45	12938,29	12906,98	12967,93	12788,23	9449,38	11893,27	7907,91	11606,74	8770,49	8755,47	1864,93	984,08
Entities to cooling	133427	133427	133442	133442	133429	133429	133387	133387	138549	137959	144602	139076	138573	138573	155173	155173

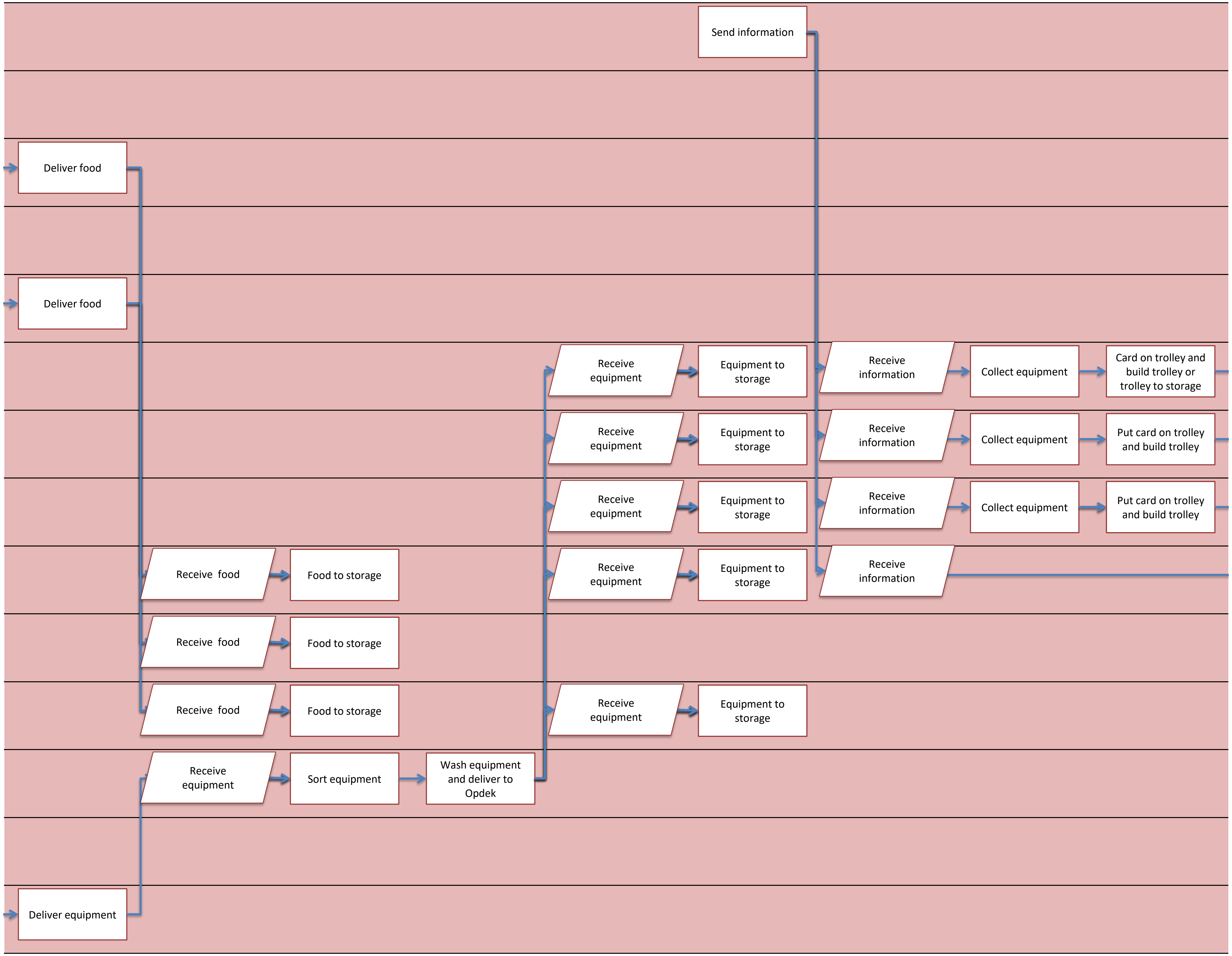
1,3*dataset; 57500 trays per 16 hour																
	1111	2111	1211	2211	1112	2112	1212	2212	1121	2121	1221	2221	1122	2122	1222	2222
Throughput time	130684	131045	130567	130926	130782	130986	131078	131285	95087	108405	76908	104134	91083	91504	20849	8685
Utilization ROA	0,93	1,00	0,93	1,00	0,89	0,93	0,89	0,93	0,93	1,00	0,93	1,00	0,89	0,93	0,89	0,93
Utilization Opdek	0,96	0,96	0,97	0,97	1,00	1,00	1,00	1,00	0,87	0,86	0,86	0,83	0,84	0,84	0,64	0,65
Inventory	13133,46	14058,91	13111,20	14036,45	12938,30	12907,32	12967,38	12781,06	9449,38	11893,27	7908,00	11606,83	8726,41	8713,38	1730,80	913,74
Entities to cooling	133427	133427	133442	133442	133432	133432	133387	133387	138549	137959	144602	139076	138577	138577	155173	155173

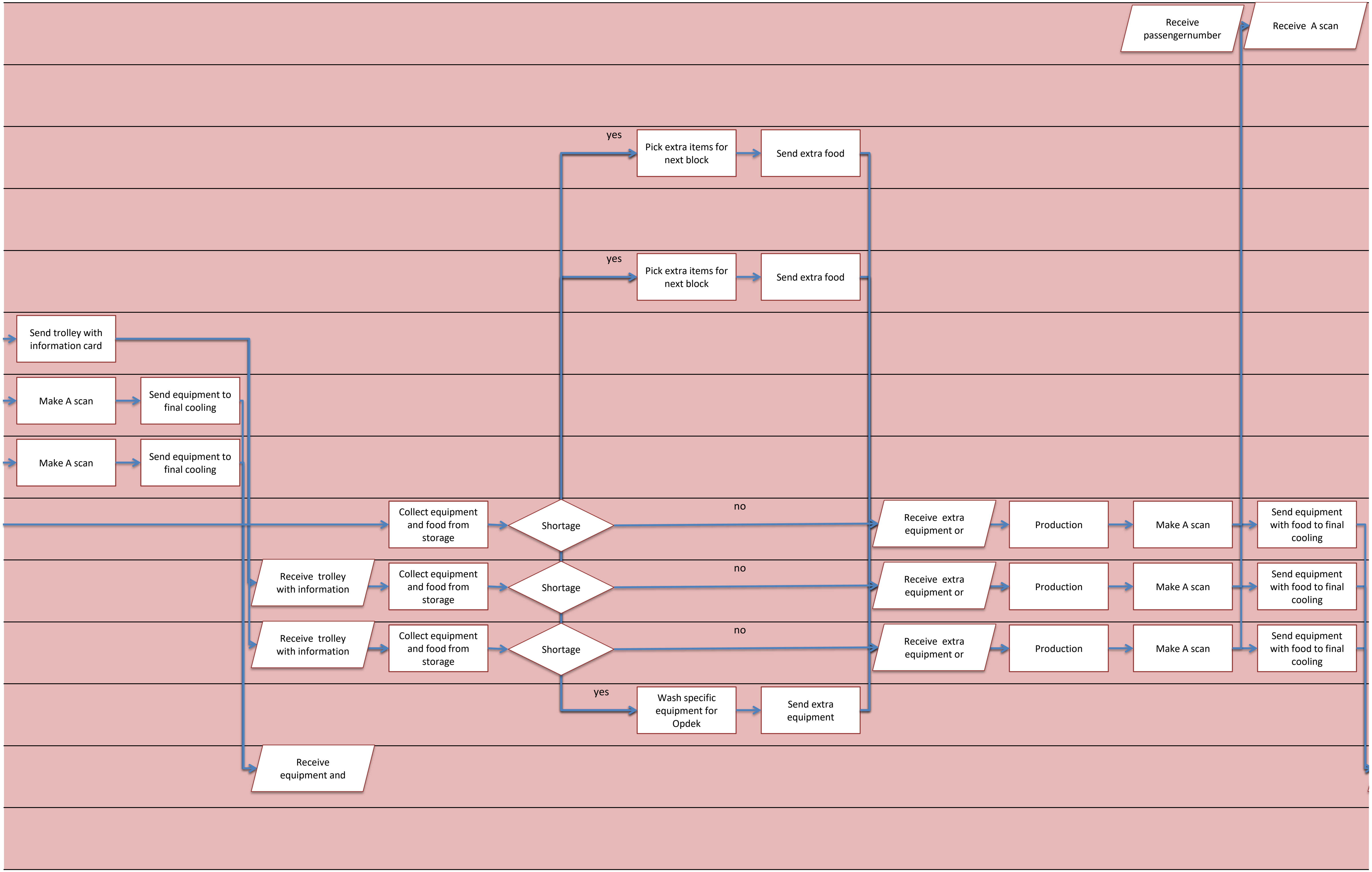
Figure C.3: Results for 1,3x current data set

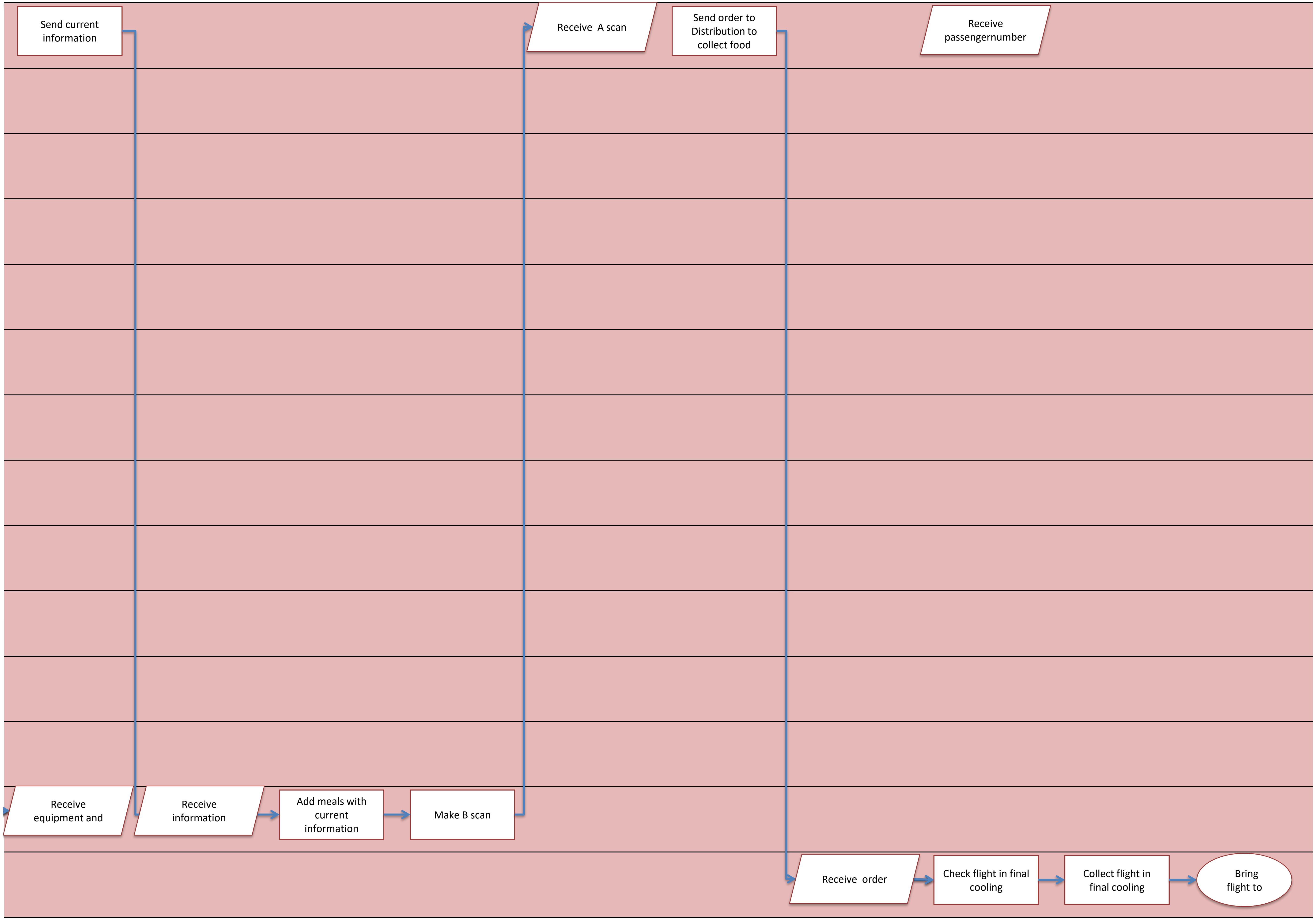
D

Swimlane


Front office
Marfo
Kitchen
Schiphol North
GOC
Trolley was machine
3,4 was machine
4,6 was machine
M class
VLAS
C class
ROA
Final cooling
Distribution
Receive passengernumber
Send order
Send current information
Send order to Distribution to collect equipment
Send order
Receive order
Produce
Send food
Receive order and food
Produce
Receive food
Food to storage
Receive information
Pick food for one block
Send food for one block
Receive food for one block
Count every meal
Receive order
Collect equipment
Sort equipment


Send information
Deliver food
Deliver food
Receive equipment
Equipment to storage
Receive information
Collect equipment
Card on trolley and build trolley or trolley to storage
Receive equipment
Equipment to storage
Receive information
Collect equipment
Put card on trolley and build trolley
Receive equipment
Equipment to storage
Receive information
Collect equipment
Put card on trolley and build trolley
Receive food
Food to storage
Receive equipment
Equipment to storage
Receive information
Receive food
Food to storage
Receive food
Food to storage
Receive equipment
Equipment to storage
Receive equipment
Sort equipment
Wash equipment and deliver to Opdek
Deliver equipment


Receive passengernumber
Receive A scan
yes
Pick extra items for next block
Send extra food
yes
Pick extra items for next block
Send extra food
Send trolley with information card
Make A scan
Send equipment to final cooling
Make A scan
Send equipment to final cooling
Collect equipment and food from storage
Shortage
no
Receive extra equipment or
Production
Make A scan
Send equipment with food to final cooling
Receive trolley with information
Collect equipment and food from storage
Shortage
no
Receive extra equipment or
Production
Make A scan
Send equipment with food to final cooling
Receive trolley with information
Collect equipment and food from storage
Shortage
no
Receive extra equipment or
Production
Make A scan
Send equipment with food to final cooling
yes
Wash specific equipment for Opdek
Send extra equipment
Receive equipment and


Send current information
Receive A scan
Send order to Distribution to collect food
Receive passengernumber
Receive equipment and
Receive information
Add meals with current information
Make B scan
Receive order
Check flight in final cooling
Collect flight in final cooling
Bring flight to