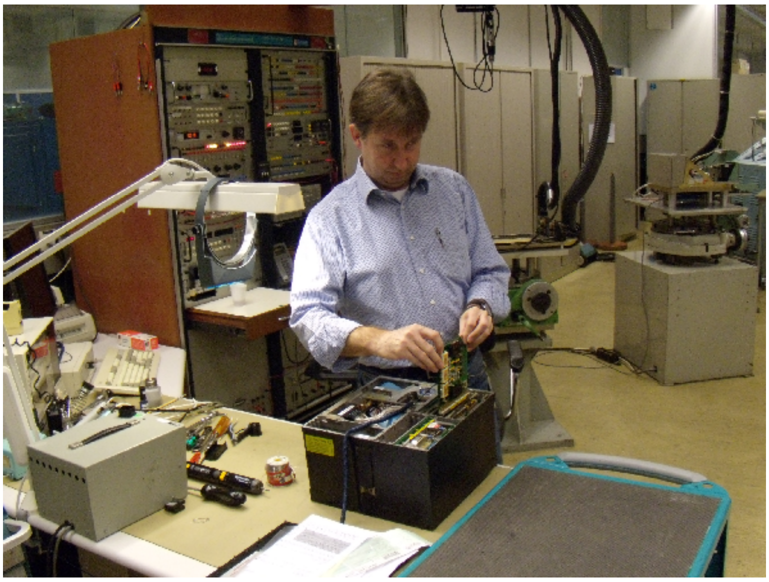

Shop Floor Control in Repair shops

Floor Cornelissen

UNIVERSITY OF TWENTE.

KLM Engineering & Maintenance

Shop Floor Control in Repair Shops

Which shop floor control method can be used for which repair shop?

Master program Production and Logistic Management

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Date: 20 January 2010

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Summary

The Component Services (CS) department of the KLM, repairs and maintains various components of the airline fleet of KLM and other airlines. The repair shops of CS have to cope with a high variability in the arrival times of the components and a high variability in how to repair them. This makes it hard to predict the processing steps that a component needs to go through and how much time these steps will take. The capacity of the repair shops is more or less fixed. Therefore it is not possible to capture this variability with temporarily increasing or decreasing the capacity. Another problem is that some of the components can only be repaired by specific skilled workers. This makes the capacity even more restricted. These factors make it very complicated to give a customer a reliable Turn Around Time (TAT), although this is demanded by customers. This project investigates the use of shop floor control methods to cope with these uncertainties in the repair shops of Component Services.

The objective of this research is to get a better understanding of and advise the KLM on the use of shop floor control methods in the component repair shops of KLM. Not much research is done on the use of shop floor control methods in repair shops. The little research that exists focuses on the use of release methods. A release method determines when and which component will be released with the use of triggering mechanisms (when to release the next order) and sequencing rules (which order to release next). Based on the literature we selected the following three triggering mechanisms and three sequencing rules.

- *"Immediate release" triggering mechanism.* After the components enter the shop, they are immediately released to the shop floor.
- *"Work In Process (WIP) level for the whole system" triggering mechanism.* The components are released when the total number of components on the shop floor falls below a certain level.
- *"WIP level per component group" triggering mechanism.* The components are divided into groups that need similar resources for the repair. When the number of components on the shop floor of a specific group is below a certain level, the next component of this group is released.

- *First In First Out (FIFO) sequencing rule.* The component that enters the buffer first, is released first
- *Earliest Due Date (EDD) sequencing rule.* The component that has the earliest due date, is released first
- *Minimum slack (MS) sequencing rule.* The component that has the least slack (= due date - processing time), is released first

The literature concludes that the use and effectiveness of the release methods depends on the characteristics of a shop. Based on the literature and the experiences in the shop, the following four shop characteristics that might influence the choice of release method are defined.

- *Workload of the shop.* The workload of the shop is determined by the amount of components that enter the shop and the capacity the shop has to repair all these components. If the capacity suffices the input, the shop is in balance.

- *The skill level of the mechanics.* The skill level of the mechanics is determined by the type of components they are certified to repair. This can be limited or the mechanics can do all processing steps.
- *Differences in Turn Around Time (TAT) agreements with the clients*. The clients of the shop have agreements on when the components need to be finished. These agreements can differ per component
- *The number of process disruptions*. The repair process of the component can be disrupted by not having the right material, resources, or skills for the repair.

Table 1 displays the three shop categories that exist in Component Services, based on the shop characteristics.

	Workload	Skill level	TAT agreements	Process disruptions
Category 1	Balanced	Limited	No differences	Several
Category 2	Balanced	Limited	Differences	Several
Category 3	Balanced	Every mechanic can do most repair steps	No differences	Several

Table 1. The three shop categories identified at Component Services

Results

With the use of a simulation model of one of the shops, the different release methods are tested and the shop characteristics were manipulated in order to test whether these characteristics influence the selection of release method. The simulation model indicates that the immediate release triggering mechanism in combination with the EDD sequencing rule is the most suitable release method for the simulated shop in the current situation. Below, we describe the influence of the shop characteristics.

- *The decrease of workload* does not influence the selection of release method.
- *The increase of workload* does change the selection of release method. The WIP level for the whole system triggering mechanism in combination with the EDD sequencing rule is recommended when the workload is increased.
- *The skill levels of the mechanics we tested* do not influence the selection of release method.
- *The differences in TAT agreements* do influence the selection of release method. The immediate release triggering mechanism in combination with the FIFO sequencing rule is recommended, when there are no differences in TAT agreements.
- *The number of process disruptions* does not influence the selection of release method.

Conclusion

Based on these results, Table 2 displays, per shop category identified in Table 1, the release method this research recommends.

	Triggering mechanism	Sequencing rule
Category 1	Immediate release	EDD
Category 2	Immediate release	FIFO
Category 3	Immediate release	FIFO

Table 2. The recommended release methods for the three identified shop categories

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Table of contents

Preface

This thesis concludes my study Industrial Engineering and Management at the University of Twente. I followed the mastertrack Production and Logistic Managment. When there was an opportunity to finish my study at KLM Engineering and Maintenance, I accepted this opportunity.

I thank my supervisors of the University, Marco Schutten and Waling Bandsma for their guidance during my research, for their shared knowledge, and for the constructive and very helpful comments on my writing. Further, I thank Arjan van Duinen as my supervisor for the KLM. He was very helpful for the brainstorming and getting me in touch with the right persons. I always enjoyed the interesting discussions and our conversations during our meetings. Next, I thank Dick Dam for the initiating of the assignment and for his knowledge, especially for the statistic parts.

I also thank all the staff of Component Services for their support and assistance. Everyone was always very helpful and always ready to help me. Especially thanks to the two team supervisors of the simulated shops, Jan Wortel and Ton van Schie. They shared a lot of knowledge of their shops with me.

Special thanks to my brother, who helped me with sorting all the data.

Schiphol, January 2010

Floor Cornelissen

Introduction

This master thesis is performed at the Component Services department of the Engineering and Maintenance department of the Koninklijke Luchtvaart Maatschappij (KLM E&M) at Schiphol. This department is responsible for the maintenance of components of the KLM fleet. The repair shops that repair these components are coping with high variabilities such as random arrival of components, diversity in the required service for the component, and diversity in the type of components arriving. This makes it complicated to plan and control the shops is order to guarantee on time delivery.

The objective of this research is to get a better understanding of and advise the KLM on the use of release methods in the component repair shops by comparing different shop floor control methods.

This thesis starts with the project framework in Chapter 1. This chapter starts with a short description of the Component Services (CS) department. Next, we discuss the motivation of the research, the research objective and questions, and the research methodology.

Chapter 2 presents a literature review of shop floor control methods. This chapter also discusses the use of simulation models for the review of different control methods and the steps that need to be taken in order to construct a simulation model.

Chapter 3 describes which type of repair shops Component Services (CS) has and the differences and similarities between the characteristics of the shops. Based on these characteristics, we select a shop for further investigation.

Chapter 4 discusses the steps that we take in order to create a valid simulation model. The chapter discusses the collection of the data and the validation of the simulation model.

Chapter 5 discusses the experiments with the simulation model. Chapter 6 contains the conclusions and recommendations of this thesis.

1. Project Framework

This chapter presents relevant issues related to this thesis. Section 1.1 gives a short impression of Koninklijke Luchtvaart Maatschappij (KLM). Section 1.2 describes the Engineering and Maintenance (E&M) department in more detail. Section 1.3 displays the motive of this thesis. Section 1.5 introduces the objective and the research question. The last section presents the methodology we will use to complete this thesis.

1.1 Koninklijke Luchtvaart Maatschappij (KLM)

KLM is a worldwide operating Dutch airline founded in 1919, with its basis at Schiphol Airport. KLM is the heart of the KLM group, which also consists of KLM cityhopper and Transavia.com. Since the merge with Air France in 2004 the two airlines work closely together under the name Air France KLM. In turnover, the holding is the largest airline holding in the world and is the second largest in the number of passengers and cargo they transport.

KLM has three major activities: Passenger Business, Cargo, and Engineering and Maintenance. Appendix B contains all the organization charts of the organization.

1.2 KLM Engineering and Maintenance (E&M)

KLM Engineering & Maintenance (E&M) is the business unit that provides engineering and maintenance services to aircraft and aircraft components for the KLM fleet and third parties. Together with Air France Industries, they are one of the largest engineer and maintenance services for aircrafts in the world. With over 5.000 employees at Schiphol, KLM E&M is the largest technical company in the Netherlands. KLM E&M consists of six main units which are supported by a number of central support units. The main location of KLM E&M is Schiphol East where several hangars are situated.

The Component Services (CS) department takes care of the repair and maintenance of the components of the fleet of KLM and also the components of other airlines. CS has extensive maintenance and testing facilities for a wide range of components, such as wheels, chairs, ovens, lavatories, and altimeters. The maintenance of these components is situated at two units: Base Maintenance Support Shops (BMSS) and Avionics and Accessories (A&A). The two units are divided into *27* repair shops, which all have their own specific group of components. In Chapter 3 we will describe the shops and their processes in more detail.

Currently, one of the projects at CS is *CS towards lean* with the goal to make all the repair shops of CS lean shops. Lean is a philosophy and practice of minimizing non value adding processing steps in the production process from design to customer (lean training material, General Electrics). Lean principles originate from the Japanese manufacturing industry especially Toyota. The lean six sigma office of E&M (Appendix figure B2) supports CS to reach this goal.

1.3 Motive

The repair shops of CS have to cope with high variability in the arrival times of the components and the variability in how to repair the components. This makes it hard to predict the processing steps that a component needs to go through and what time these steps will take. The capacity of the repair shops is more or less fixed. This means that it is not possible to capture this variability with temporarily increasing or decreasing the capacity. Another problem is that some of the components can only be repaired by specific skilled workers, which makes the control more complicated. These factors make it very complicated to give a customer a reliable Turn Around Time, although this is demanded by customers.

The research that exists on how to cope with these uncertainties mainly focuses on the use of inventory levels. Not much research is done on shop floor control methods to control the mentioned uncertainties (Keizers *et al.* 2003). Considerably more research is done on *job* shop floor control and in particular on release methods. In a job shop, small lots are produced with a high variety of routings through the shop floor (Hopp and Spearman, 2000). Release methods are used to determine *which* order should be released to the shop floor and *when* it should be released. Although there are differences between a job shop and repair shop, Guide *et al.* (1997) tested the use of the job shop control methods in an aircraft engine repair shop. This study provides significant improvement over a random approach for a variety of performance measures. This study also concludes that still more research needs to be done on the shop floor control methods in repair shops.

1.4 Objective and research questions

The objective of this research is to get a better understanding of and advise the KLM on the use of shop floor control methods in the component repair shops of KLM. This will be done by comparing different shop floor control methods.

In order to reach the research objective, we formulate four main research questions. We address these research questions in separate chapters of this thesis.

1. *What is known in the literature about the shop floor control methods in production and repair shops?*

This question forms the theoretical framework of the research. To answer this question, Chapter 2 addresses the following sub questions:

- Which shop floor control methods for repair shops exist in the literature?
- Which shop floor control methods for production shops exist in the literature?
- What is the influence of shop characteristics on the use of shop floor control methods?
- How can the different shop floor control methods be analysed and compared to each other?

In this chapter we conclude that simulation modelling is the most appropriate method to compare different shop floor control methods. This conclusion leads to the following question

- How should a valuable simulation model be constructed according to the literature?

2. *What is the current situation in the repair shops and which shop floor control methods seem suitable to test?*

Chapter three describes the current situation of the repair shops of Component Services (CS). We address the following sub questions in this chapter:

- What kind of repair shops does CS have?
- Which different and common characteristics do the shops have?
- Considering the characteristics of the repair shops, which shop floor control methods are suitable to implement in these shops?

3. *What is necessary to construct a valid simulation model?*
In Chapter 2 we conclude that simulation modelling is the most suitable method to test different method. In order to construct a simulation model several steps need to be considered. This question discusses how these steps are performed. We address the following sub questions in this part:

- What data needs to be collected in order to create the simulation model?
- Is the model valid?

4. *Which shop floor control methods are the most suitable for which repair shop and why?*
In this we chapter analyse and discuss the tested methods based on the identified performance indicators.

- What is the influence of the shop characteristics on the selection of the most suitable method?
- What is the most suitable method for each of the repair shops?

1.5 Research methodology

Figure 1.1 presents the overview of the research, in order to get a better idea what needs to be done.

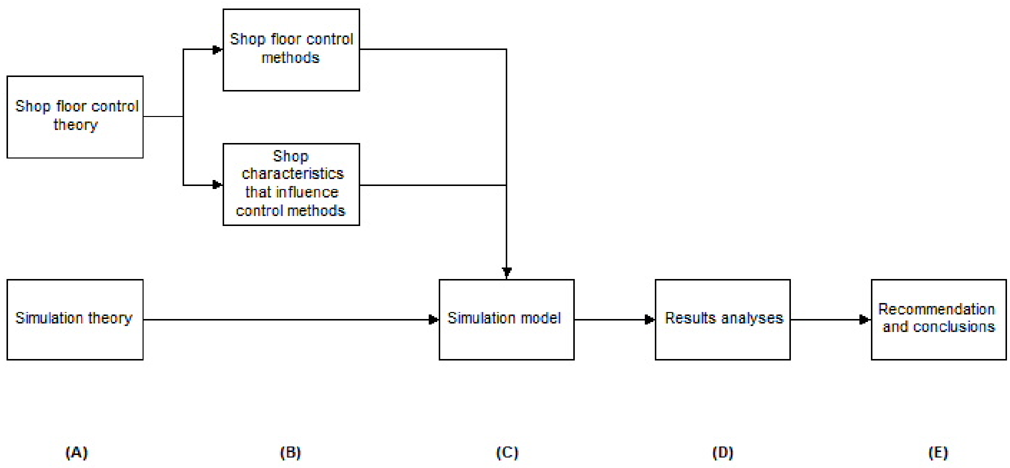

Figure 1.1 Research methodology

The research starts in (A) with the studying of literature on simulation theory and shop floor control theory. Appendix C explains the method for collecting and selecting relevant literature. As simulation theory, we use the method described by Law and Kelton (1991). Chapter 2 presents the review on release and simulation theories.

In (B), the shop floor control theory leads to a selection of shop floor control methods that will be experimented with and shop characteristics that might have an influence on the performance of the shop floor control methods.

In (C), we test the selected methods and the influence of shop characteristics with the use of a simulation model. This model is constructed with the use of the simulation theory. The data for the model is gathered in two ways; by observing the system for some time and by collecting historical data from the two data information systems that Component Services uses. During this stage the staff members of the shop are constantly involved. They will validate the data, the flow charts and the simulation model in order to create a high credibility of the models. We will also us statistical methods to validate the models and data. We test the selected shop floor control methods with the use of this simulation model. We manipulate the shop characteristics and simulate in order to test the influence of these characteristics on the use of shop floor control methods.

In stage (D), we compare the results of the simulation model based on the formulated performance indicators. For this analysis, we use the statistical methods described in Law and Kelton (1991), Chapter 10.

In the last stage (E), all the preceding stages lead to the recommendations and conclusions.

2. Literature review

This chapter contains a literature review on what research is done on the shop floor control problem discussed in Chapter 1. Appendix c presents an overview of how the literature review is performed. We start in Section 2.1 and 2.2 with an overview of the existing shop floor control methods in repair and job shops. Section 2.3 discusses one of the shop floor control method, the release method, in more detail. Section 2.4 displays several methods that can be used to analyse a system. Section 2.5 gives an overview of the performance indicators used in the literature to compare different methods.

2.1 Shop floor control in repair shops

Repair is a form of life extension that reduces the number of products being land filled and the demand on natural resources (Keizers *et al.* 2003). The timing of when the products arrive at a repair shop and the unknown condition at arrival, highly complicate the planning and control process in a repair shop. As Section 1.3 describes, little research has been done on the production planning and control in repair shops. This is remarkable, due to the fact that the use of repair as an alternative to replacement of products is a growing trend in manufacturing industries, especially those working with expensive assets (Guide *et al.* 2000). This trend is due to the possible economic advantages and a growing interest in environmentally friendly behaviour of the customers. Most research on repair shops focuses on the control of the inventory levels and not so much on the planning and control of the shop floor (Keizers *et al.* 2003). The next paragraph displays the little research that exists on this topic.

Guide and Srivastava (1997) suggest the use of release methods to control the repair shop floor. A release method determines when and which job will be selected to be processed next. They propose release methods for a repair environment, which are also used in the job shop environment. They test these suggested release methods in an aircraft engine component repair shop. When compared to a situation where the jobs are immediately released to the shop floor, the tested methods show improved performances for the mean Cycle Time (CT), and the mean Work In Process (WIP) (Guide and Srivastava*.*, 1997). The CT is the time an order spends in the system from release until completion. The WIP is the number of orders on the shop floor. Later research conducted by Guide *et al.* (2000) demonstrates that the usability of order release methods is related to the characteristics of the shop for example, the characteristics utilization rate and product structure.

2.2 Shop floor control in job shops

As mentioned in Section 2.1, shop floor control methods for job shops are also used in repair shops. This section discusses the differences between a job shop and a repair shop and presents the job shop control methods used in the job shop environment.

A job shop produces small lots of products with a high variety of routings through the shop floor (Hopp and Spearman, 2000). Job shops are complex and dynamic systems, for which future conditions cannot be anticipated by analysing only current performances. As a result, the planning and control of such systems is one of the most important and challenging problems in operations management (Cigolini *et al.* 1998).

The repair shop is similar to the job shop in a way that in both shops it is hard to predict when a new order will arrive and what the routing of this order will be on the shop floor. The difference between the two is that the routing for the order in the job shop is determined when the order is accepted and will not change during the process. The processing time can be fairly reliably calculated just after the order is accepted. In a repair shop it first needs to be determined exactly what proccesinsg steps need to be taken in order to repair the component. Even when those steps are determined, they can change during the repair steps.

Cigolini *et al.* (1998) indicate that the effectiveness of the shop floor control methods is highly related to the ability of the method to control the variance in the Work In Process (WIP). This is because the WIP affects almost all the relevant performances of job shops such as the mean Cycle Time (CT) and utilization rate. Little's formula indicates that the WIP relates to the Throughput (TH) and the CT in the following manner: WIP = TH * CT (Little, 1961). An accepted method to control the WIP is by controlling the CT (Cigolini *et al., 1998*). According to lean thinking, the CT is, among other things, dependent on the input level (the amount of work put in the system per period) and the capacity (how much can the system handle). The relationship between those three variables is demonstrated with the lean triangle in Figure 2.1 (lean training material, General Electrics*)*.

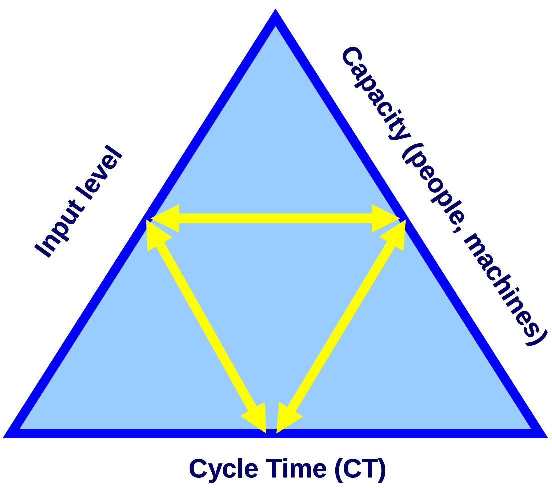

Figure 2.1 Lean triangle

When the input level increases and the capacity remains the same, at some point the shop does not have enough capacity to repair the input and the CT will increase. If the capacity and the input level increase with the same proportion the CT will stay the same. If the capacity decreases and the input level stays the same then the CT will increase. So if the input level is in proportion to the capacity, the CT will be stable.

Figure 2.2 displays a general model of a job shop with the points in the system where it is possible to control the input level (Bechte, 1988). There are three points in the process were a manager can make a decision in order to control the input level. The first decision that needs to be made is whether to accept or reject an order when it arrives. The second stage consists of two decisions, which job will be released and when. Release methods are developed and used to support this decision (Bergamaschi et al. 1997). In Section 2.3 we discuss these techniques in more detail.

Once an order is released it stays on the shop floor until it is completely finished. During this process it could be possible that the order has to wait in a queue before a machine or an operator in order to be further processed. When the machine or the operator becomes available, the third decision needs to be made; which order from the queue will be processed next. The release method already determines the order in which the jobs are released to the shop floor, but the use of sequencing rules on the floor may improve the performance. However, sequencing rules will lose effectiveness as the release method reduces the length of the queues in front of the machines and operators. Therefore Bechte (1994) suggests that the use of simple sequencing rule First In First Out (FIFO) suffices when using an effective release method. For that reason, we will not test different sequencing rules for the decision on the shop floor and we will only use same rule as for the central buffer.

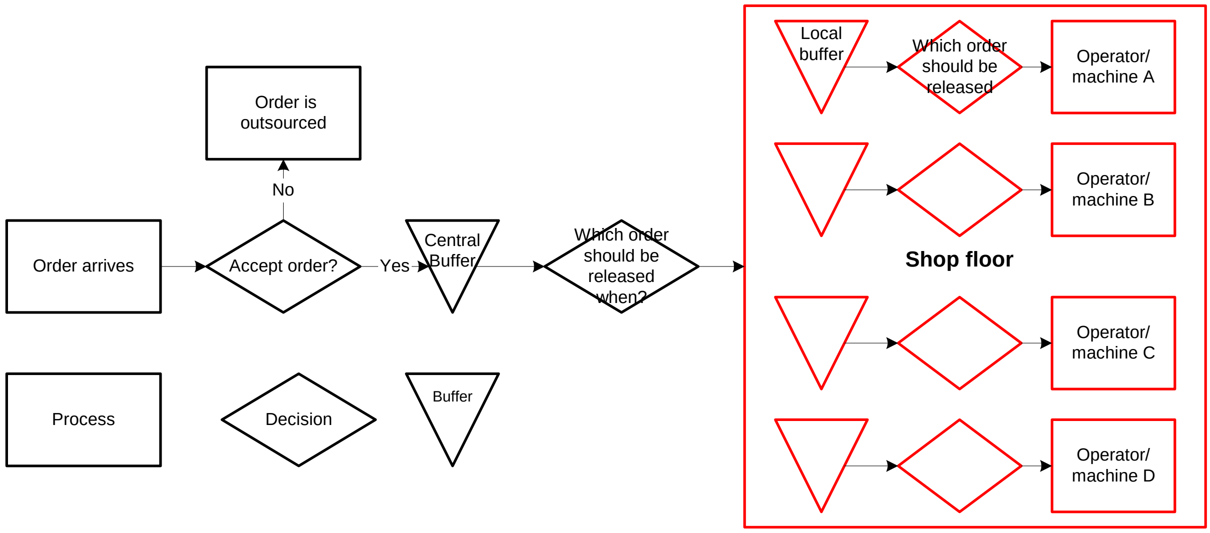

Figure 2.2 General flow model of a job shop

2.3 Release methods

This section focuses on the second decision stage in a job shop. At this stage the order is still in the central buffer and not on the shop floor. In this stage the sequence of the orders and the moment of order release should be determined. The sequence of the orders can be determined with the use of sequencing rules. The moment of order release can be determined with the use of triggering mechanisms. The next two sections describe the existing sequencing rules and triggering mechanisms.

2.3.1. The sequence of the orders

Traditionally researchers have focussed on the sequence of how the orders flow through the shop as the tool to plan and control a job shop. The reason for this focus is that researchers assumed that the factors causing the variability are outside the control of the managers, except the order in which the jobs are processed (Melnyk *et al.* 1994). This resulted in an enormous amount of sequencing rules with different rates of complexity. Sequencing rules determine the order by calculating the priority indices of the order in the buffer. Several ways to determine this priority index exist. Panwalker and Iskander 1977 classified these ways into five categories.

- *Simple priority rules* are based on information related to a specific job. Rules with information such as buffer size at the machine where the order will go next are also included in this category. This also accounts for random rules that are not dependent on information of a specific job.

- *Combination of simple priority rules* divide the queue into two or more priority groups with different rules applied.
- *Weighted priority indexes* are combining rules with different weights.
- *Heuristic scheduling rules* involve a more complex consideration such as anticipated machine loading and the effect of variable routings.
- *Other rules* are those rules not categorized.

Lawrence and Sewell (1997) and Stockton *et al.* (2008) show that simple sequencing rules outperform complex optimization scheduling systems in shops with moderate to high levels of uncertainty. The other advantage of the simple sequencing rules is that they are reasonably simple to implement, understand, and use. It is not possible to discuss all the existing sequencing rules separately, so we made a selection of the simple and combination of simple rules that performed well in studies according to the selected performance indicators (Guide *et al.* 2000, Bergamaschi *et al.* 1997, Panwalker *et al.* 1976, Lawrence and Sewell 1997).

- *First In First Out (FIFO)*, the order that arrives first, will be released first. The FIFO rule is an effective rule for minimizing the Cycle Time (CT) and the variance in the CT (Rajendran, 1999).

- *Earliest Due Date (EDD)*, the order that has the earliest due date, will be released first. In general this rule performs well with respect to minimizing the number of late jobs and minimizing the variance of the time a job is late (Rajendran, 1999).

- *Minimum Slack (MS)*, the order with the least slack (= Due Date – Processing Time) will be released first. MS performs well in minimize cycle time objectives (Pinedo, 2005). In order to make this rule work it should be possible to calculate reliable processing times at the beginning of the process.

Bahaji and Kuhl (2008) observe that no single sequencing rule will perform optimally for all important performance indicators, such as mean CT and mean time an order is past its due date. They also observe that still a significant amount of research remains to be done in measuring the effectiveness of sequencing rules in different systems. Section 2.4 presents a more detailed explanation of performance indicators.

2.3.2 The moment of order release

As mentioned in Section 2.2.1, traditionally researches have focused on the sequence of the flow of orders through the shop as the tool for shop floor control. More recently experience has demonstrated that using sequencing rules is a relatively weak mechanism (Kingsman, 2000). He indicates that if only sequencing rules are used, it will have little effect in reducing long and variable lengths of queues in front of machines and mechanics. A stronger tool is the use of a triggering mechanism, which controls *when* the next order from the buffer will be released. Many different triggering mechanisms have been proposed and evaluated in the literature. The general conclusion of the evaluation performed by Bergamaschi *et al.* (1997) is that the use of a triggering mechanism has several beneficial effects on shops, such as reduced WIP levels and mean CTs. However, not all studies support this statement. For instance, Melnyk and Ragatz (1994) claim that triggering mechanisms can lead to a longer mean CT. Still, the methods are used a lot in practice due to the fact that it makes the orders in the system more controllable. Philipoom *et al.* 1993 developed a system to classify the existing triggering mechanisms. They discuss that the decision on when to release the next order can be based on shop floor conditions, on conditions of the orders, on a combination of both, or on neither of the two. Next, we describe these categories in more detail and the use of them.

Shop floor based mechanisms

In this category the orders are released based on the conditions on the shop floor, such as the size of the queues in front of the machines or operators. Two of the most researched mechanisms in this category are: a WIP level for the whole system and work centre information based loading (Hales and Laforge, 2006). In the first method, an order is released when the total workload on the shop floor is below a predetermined WIP level. According to Hales and Laforge (2006), this shop floor based triggering mechanism has, in comparison with order based mechanisms, the lowest mean tardiness (the average lateness per order), the highest percentage of orders on time, and the lowest WIP levels. The work centre information based loading method uses more detailed information of the shop floor. It only considers the load levels of the resources the order needs for processing, to make a release decision. An associated mechanism is when only the load of the bottleneck machine is used to determine the moment of release. These two mechanisms provide similar results as the aggregated loading mechanism; however in complex and dynamic shops the actual load in front of a resource might be very difficult to determine (Hales and Laforge, 2006).

Order based mechanisms

In this category orders are released based on the conditions of the order to be processed, such as the due date. One of these methods is to calculate a release date for every order and release the orders according to this date. The release date is calculated as follows: due date – expected processing time. The expected processing time is calculated based on historical data. This mechanism is not proposed often in the literature, because in general shop floor based mechanisms perform better than the order based mechanisms. The triggering mechanisms of this category do not make use of sequencing rules to determine which order should be released from the buffer onto the shop floor.

Shop floor and order based mechanisms

The mechanisms in this category use both shop floor and order based criteria to determine the moment of release. In this category shop floor conditions are used to estimate the processing time for each order, next the release date is calculated with the use of the due date. The release date can be defined as due date – estimated processing time. A lot of mechanisms are developed to estimate the processing times for the orders, but there is not an overview of the results of these mechanisms. Just like the order based mechanism, this triggering mechanism makes the use of sequencing rules for releasing orders to the shop floor redundant.

Neither order nor shop floor based mechanisms

These mechanisms use neither order based nor shop based conditions in determining the release time. Two main triggering mechanisms that belong to this category are the immediate release of orders and the interval release of orders. In the immediate release mechanism there is no buffer in front of the shop floor, all the orders are immediately released to the shop floor. It is shown that immediately release provides the least Turn Around Time (TAT) in a number of shop environments, and is typically used as a benchmark for other mechanisms (Hales and Laforge, 2006). Interval release is somewhat similar to the immediate release except it only releases orders on a periodic basis, such as daily or weekly. Hales and Laforge (2006) discuss that immediate release mechanisms perform better than interval release mechanisms (Hales and Laforge, 2006). Both release methods have the expectations to lead to longer queues on the shop floor, which could require some controlling as well. Therefore it is necessary to use sequencing rules in order to determine the sequence of the queues on the shop floor when using immediate release.

2.3.3 Influence of shop characteristics

As said before there are some disagreements on the usability of release methods. These differences can be due to the fact that each shop has specific characteristics. Henrich *et al.* (2004) developed a framework on how shop characteristics influence the use of a release method. They conclude that the usability of a release method increases when the variability increases. The variability is indicated by arrival rate variability, differences in TAT agreements, and processing time variability. Henrich *et al.* (2004) do not explain what happens when one of the proposed characteristics is not according to the 'best fit'. Also they do not indicate which release method can be used in a shop with which shop characteristics. More research on this subject is needed.

Guide *et al.* (2000) conclude that the selection of a sequencing rule in the remanufacturing environment depends on the workload of the shop and on the product structure. The structure of the product is defined by the number of levels a component consists of. In the study by Guide *et al.* (2000) the product needs to be disassembled and parts of the component are repaired by different resources. The parts need to be assembled again, which can complicate the scheduling of orders and parts. This influences the use of release methods.

2.4 Method of analysis

This section gives on overview of several methods that are used in the literature to evaluate the different release methods for the repair shop.

2.4.1 Methods to evaluate a process

There are several ways to study a process to try to gain some insight into relationships among different components or to predict performances for some new strategies. Figure 2.3 shows a systematic view of these methods (Law and Kelton, 2007, page 4).

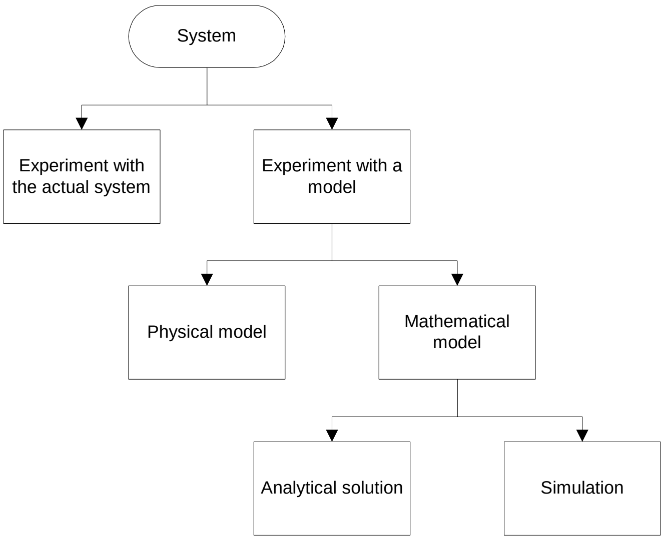

Figure 2.3 Methods used to analyse a system

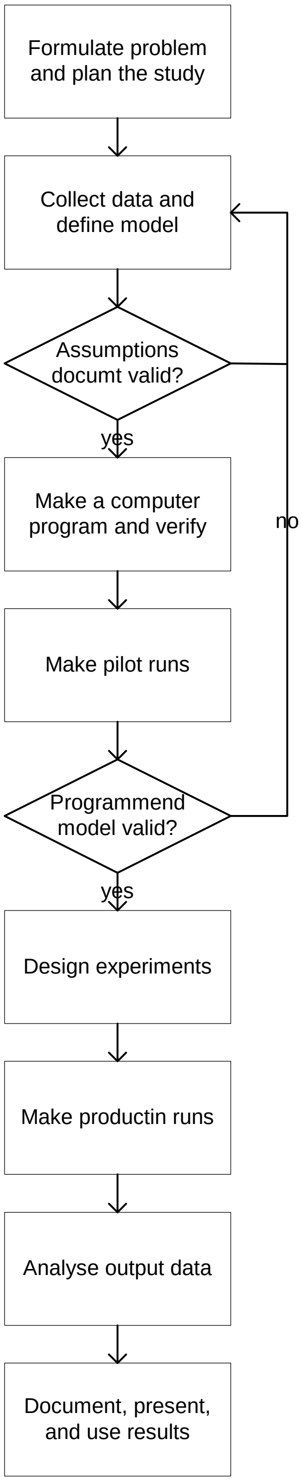

Figure 2.4 Steps for a simulation model

If it is possible to experiment with the actual process it is desirable to do so, because then there is no discussion on whether the study is valid. However this is often too costly or too disruptive for the process to be studied. For this reason it is usually necessary to build a model and experiment with this model. Two sorts of models exist; a physical model and a mathematical model. The first model is a real representation of the actual process, such as model cockpits for pilots to practice in. For the repair shops it is not possible to create a physical model due to among other things the expensive machines. A mathematical model, which represents the process in terms of logical and quantitative relationships, is more suitable. Once a mathematical model is constructed it must be determined how it can be used to answer the questions of interest. If the model is simple enough it may be possible to get an exact, analytical solution. If an analytical solution to a mathematical model is available and does not take too much time to calculate, it is usually desirable to study the model in this way. However, many processes are highly complex, so that valid mathematical models become very complex, which makes it impossible to generate an exact solution in a short time frame. This is the reason why in all the papers concerning shop floor control methods, the methods are tested using simulation modelling and the reason why we will also use this method.

2.4.2 Simulation modelling

Simulation modelling is the process of designing a model of a system and conducting experiments with this model for the purpose of either understanding the behaviour of the system or of evaluating various strategies (within the limits imposed by a criterion or set of criteria) for the operation of the system (Shannon, 1975). Law and Kelton (2007) provide a method with a number of steps which can be followed in order to create a valid and credible simulation model. Figure 2.4 displays these steps. Appendix D describes these steps in more detail. These steps will be used to construct the simulation models.

2.5 Performance indicators

To critically analyze the results of the simulation models, performance indicators need to be formulated. Bahaji and Kuhl (2008) indicate the two major classes of performance measures that are used the most in the literature of shop floor control; job-oriented and shop-oriented measures.

Examples of job-oriented measures

- Mean tardiness: the average time a component is past its due date, when a component is late
- Percentage of tardy jobs: the ratio of components on time and components late

Examples of shop-oriented measures

- Turn Around Time (TAT): average time a component spends in the shop from accepting the order to completion
- Cycle Time (CT): the average time a component spends in the system from the release of the order to the shop floor until completion
- Throughput (TH) rate: the number of orders that are delivered during a certain period

The above mentioned performance indicators only indicate the mean value and not the dispersions of the means. The wider the dispersion of values the means, the less precise and reliable the mean value becomes. Therefore, when the performance indicators will be displayed, the dispersion of this value is also displayed.

2.6 Summary

Little can be found in the literature on the planning and control of repair shops. What is known relates to how job shops are planned and controlled. The control of the job shop is highly related to the ability to control variance in Work In Process (WIP). To create a stable WIP it is important to control the input level of the shops. This research focuses on the control of the input level, with the use of release methods. Release methods determine the sequence of the orders to be released and the moment when a release takes place. It is shown that simple priority rules outperform complex priority rules for shops from moderate to high levels of uncertainty, so three simple priority rules are presented. The triggering mechanisms which determine the moment of release can be divided into four categories: shop floor based, order based, shop floor and order based, and neither order nor shop floor based.

What the best method is varies per research, but order based mechanisms do not seem to be used that much. Further research needs to be done on the influence of shop characteristics on the usability of a certain method.

Several methods exist to analyse a system and predict performances for some new strategies. Due to the high variability of the repair shops, the simulation model is the most suitable. To analyse the results of the simulation model the following performance indicators are used: mean tardiness, mean Turn Around Time (TAT), mean Cycle Time (CT), percentage of jobs delivered on time, and the throughput rate.

3. The repair shops of Component Services

This chapter describes the current situation of the repair shops at the Component Services (CS) department of KLM Engineering and Maintenance (E&M). In Section 3.1 we give a general view of the repair shops of CS and a general flow model of a repair shop. In Section 3.2, we determine the shop characteristics that can influence the selection of release method. Due to time constraints it is not possible to evaluate all the shops individually. For that reason we select one shop to experiment with. Section 3.3 presents a selection of the release methods from Chapter 2 that we will evaluate in the selected shop.

3.1 Overview of shops

CS consists of two units; Base Maintenance Support Shops (BMSS) and Avionics and Accessories (A&A). These two units consist of a total of 27 different repair shops. Section 3.1.1 and 3.1.2 explain in more detail which sorts of repair shops are located at these units.

3.1.1 Base Maintenance Support Shops (BMSS)

The Base Maintenance Support Shops (BMSS) support the D checks of the airplanes. The D-check is the most extensive check where every part of the airplane is checked. When this check needs to be performed depends on the flying hours of the airplane but is approximately performed every five years and takes around five weeks. Another part of the orders comes from components with defects that occurred during operation hours of the planes.

3.1.2 Avionics and Accessories (A&A)

Avionics and Accessories (A&A) repairs all the avionic components and accessories of the airplane. Most of the components the department repairs have an inventory so they do not need to be repaired during a specific check of an airplane. A&A gets components as a result of D-checks and from defects that occur during operating hours. A&A consists of two departments with repair shops, which are described below.

3.1.3 General flow model of a repair shop

Figure 3.1 displays a flow model which contains all the common steps in the processes of the repair shops of Component Services (CS). The process starts when a component enters the shop and the input check has to be performed. The input check checks whether the component carries all the right documents. The component is also labelled and entered into the computer system at this step. After the input check, two other checks are performed. The first checks whether the shop has the capabilities to repair the component. If not, the component needs to be outsourced. The second checks if the right resources are available. Resources in this case mean repair manuals or (test) equipment. If the resources are not available, the component needs to wait for these in order to proceed. After the two checks, the component is placed in the buffer, waiting to be released on the shop floor. The first step after the release is the first test. When a component arrives with a specifically defined task, the test phase can be skipped, but this only happens rarely. The test could indicate that the component cannot be repaired and needs to be rejected. The test could also indicate that some of the materials need to be replaced. When no new materials are on stock, these need to be ordered and the component needs to wait for these materials. The next steps are the repair steps that are defined in the test phase. These steps differ per shop and component. During the repair steps other steps can be added and removed, due to new perceptions. This makes the repair process unpredictable and complicated to plan. At the end of the repair process, the component has to follow the final test, where is checked whether the component is ready to be used again. When the component does not pass the test it has to be repaired and checked again, otherwise the component leaves the shop.

The repair of the components is performed by the mechanics of the shops. For each type of component the mechanic needs to have a specific skill to be able to repair it. Not all the mechanics are able to perform the first and final test, only the CADD mechanics are certified to test the components.

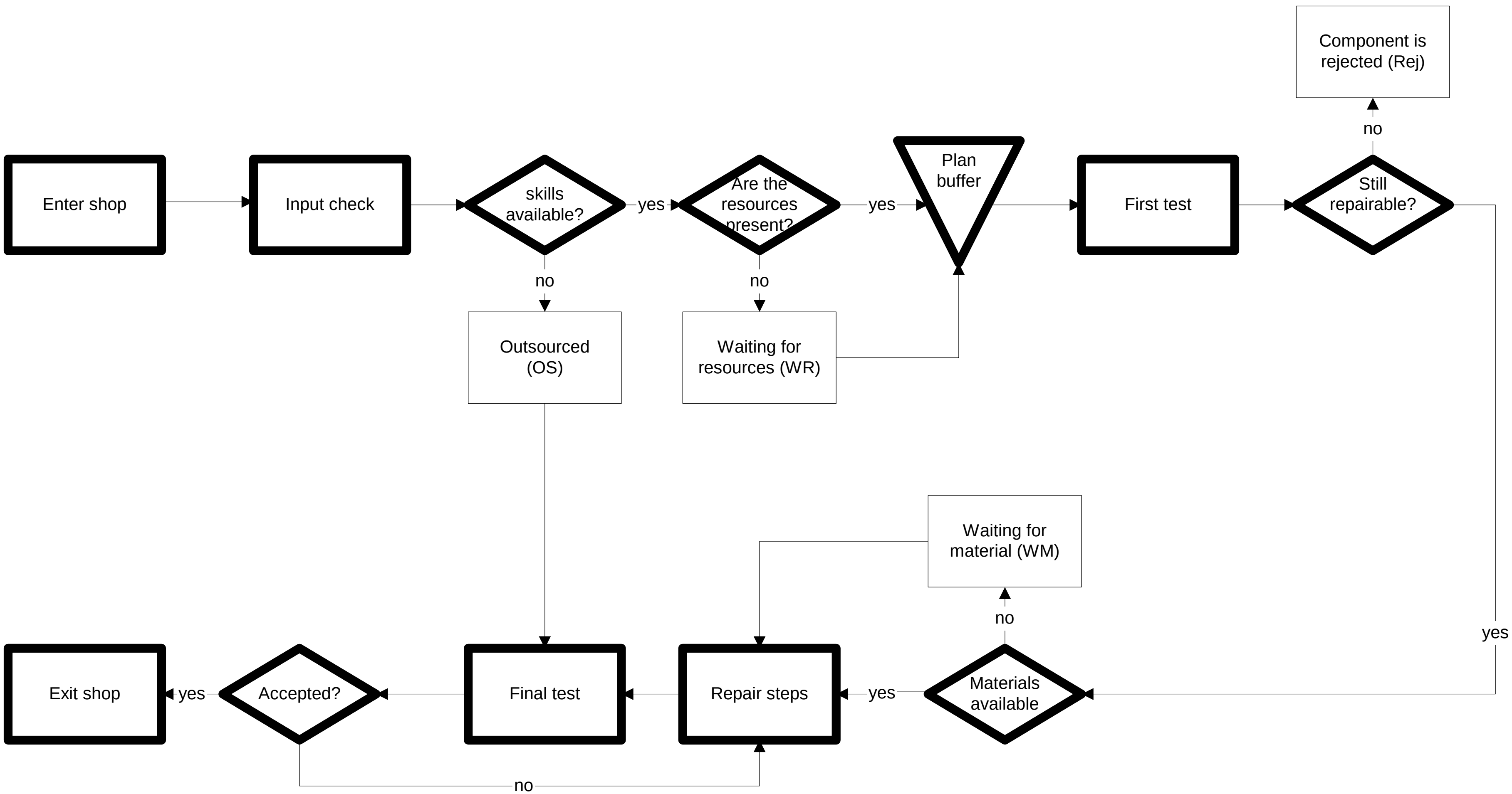

Figure 3.1 General flow model of the repair shops of Component Service

3.2 Shop characteristics

Section 2.2.3 explains that the usability of the release method can depend on the characteristics of the shop that uses the methods. In this section we start with an identification of the shop characteristics that influence the selection of release method. Next, we select a shop for further experimentation.

3.2.1 Shop characteristics

This section explains the shop characteristics that we will experiment with in the simulation model in order to test the influence on the selection of release method. Appendix E explains how we got to this four characteristics.

Workload of the shop

Section 2.2.3 indicates that the workload has proven to influence the selection of release method. When the workload increases the queues will increase as well, so the control of these queues becomes more important. The queues will grow especially when the workload is not in balance with the capacity.

Different skill levels in the shop

In some of the shops, all mechanics have the skills to perform all processing steps of all components that flow through the shop. In other shops, only a limited amount of mechanics can do all processing steps of all components. This can put a lot of restrictions on which order can be released.

Difference in Turn Around Time agreements with clients

The clients of each shop have agreements on how long the shop can take to repair the component, the Turn Around Time (TAT). In several shops, these agreements are all the same but in other shops these agreements differ. This means that some components have longer TATs than other components. In particular the shops that repair components for the defence department of the Dutch government (IAMCO components) have to handle differences in TATs. The TAT for the *IAMCO* components could be up to a year. The differences between the components will become less, when no differences exist between the TAT agreements. This can influence the selection of release method. For example, the Earliest Due Date (EDD) sequencing rule will be similar to the First In First Out (FIFO) sequencing rule since all components that arrive on the same day, will have the same due dates.

Process disruptions

Figure 3.1 displays that the component can have several disruptions in the process. The component can be in a state where it has to wait for resources or material or the component can be outsourced. This disrupts the process and can lead to missing due dates. The chance on a process disruption differs per component type. This can influence the selection of release method.

Table 3.1 gives an overview of all the characteristics and the generally observed possibilities of these characteristics.

Workload	In balance Not in balance
Skill level	Limited Every mechanic do most repair steps
TAT agreements	No differences TAT agreements Differences in TAT agreements per component type
Process disruptions	No process disruptions Several process disruptions

Table 3.1 Overview of shop characteristics and observed values.

One shop needs to be selected for the simulation model. In this model the four shop characteristics can be manipulated in order to test the influence of these characteristics on the selection of the release method. This means that with the use of a simulation model of one shop the release methods for the others shops can be evaluated as well. In consultation with the managers and team supervisors of the departments, the hydro mechanic shop EWB is selected for simulation. Although the workload and process disruptions characteristics are equal for all the shops, we will still discuss the influence of these factors. The results can be used when the current situation in the shops change.

3.3 Selection of release methods to be tested

Section 2.3 describes several order release methods for releasing components from the first buffer that are developed and analysed in the literature. These methods consist of two parts: the sequence in which the orders should be released (based on sequencing rules) and when should the next order be released (based on triggering mechanism). In Section 2.3.1 we describe three sequencing rules in more detail. These rules are rather easy and demonstrated to perform well in several studies. Table 3.3 gives an overview of these three rules.

Sequencing Rule	Based on	Which order is released first	Minimizing
First In First Out (FIFO)	Arrival date	Earliest	TAT & CT Variance in TAT & CT
Earliest Due Date (EDD)	Due date	Earliest	% of jobs late Variance in time a job is late
Minimum Slack (MS)	Due date — Processing time	Smallest	% of jobs late Variance in time a job is late

Table 3.3 Overview of sequencing rules and their characteristics

Due to time constraints, it is not possible to test all the triggering mechanisms, especially not in combination with the sequencing rules. When making a selection of the triggering mechanism to be tested, two factors are important: the mechanism needs to be effective and easy to use. Especially the last factor is important. Due to the high variability in the repair shops, it easily becomes too complicated to understand the method. If a method is hard to understand it can lead to a low acceptation level. In that view, we will only test the shop based mechanisms and the immediate release mechanism. The next paragraphs describe these triggering mechanisms in more detail.

WIP level for the whole system

This method is the most prominent shop based mechanism according to the research of Hales and Laforge (2006). In this mechanism, a standard WIP level is determined for the whole system. When the WIP falls below this level, the next order will be released. The WIP level needs to be determined based on the main performance indicators, which will be explained in Section 4.1.3. This method was tested by Guide and Srivastava (1997) in an aircraft engine repair shop and this resulted in a decrease in mean TAT, mean number of components late, and a decrease mean WIP, in comparison with the immediate release mechanism. It is not stated how the WIP is calculated; in number of jobs or in the workload of the job. Due to the fact that in the repair shops of E&M it is hard to determine what the workload of a component is before it is tested, we will calculate the WIP in number of jobs.

WIP level per component group

This method is derived from the work centre information based loading method described in Section 2.3.2. This method only considers the WIP level of the resources the order needs to be repaired, when making the release decision. Due to high variability it might be hard to determine which resources a component needs when the component enters the shop. For that reason we will determine specific component groups that contain components that need the same resources. Per component group, an optimal WIP level will be determined. When the WIP falls below this level, the next order from that component group will be released.

Immediate release

This triggering mechanism is the simplest mechanism. It will be used as a comparison method for the other three methods. When an order arrives at the shop it will be immediately released to the shop floor. This may lead to long queues on the shop floor, so this makes the use of sequencing rules on the shop floor necessary.

4. Simulation model

This chapter describes the steps taken to construct the simulation model as described in Section 2.4.2 and Appendix D. Chapter 5 discusses the last two steps.

4.1 Formulation of the problem and planning of the study

In this section we discuss the overall objective of the simulation study, the performance indicators, the scope of the simulation model, and the system configurations to be modelled in this study. We start with the overall objective:

The overall objective of the study is to analyse different release methods for the release of components to the repair shops

4.1.1 Performance indicators

To analyse the results of the simulation model, we use the performance indicators described in Section 2.5. Table 4.1 gives an overview of the performance indicators and their descriptions. Below, the table the mathematical representation of the performance indicators is given.

Performance indicator	Description
Mean Turn Around Time (TAT)	The average time a component spends in the shop from input check to final check
Mean Cycle Time (CT)	The average time a component spends in the shop from being released to the shop floor to final check
Mean Tardiness (MT)	The average time a component is late, *for the components that are delivered past its due date*
Percentage delivered on time	The average percentage of jobs delivered before or on the due date
Mean throughput rate (TH)	The average number of components delivered per week

Table 4.1 Overview of performance indicators and their descriptions

Mean TAT = $\frac{\sum_{i=1}^{n} TAT_i}{n}$;

TAT_i = Time component *i* leaves the shop – time component *i* enters the shop

n = Total number of components

Mean CT = $\frac{\sum_{i-1}^{n} CT_i}{n}$;

CT_i = Time component *i* leaves the shop – time component *i* is release to the shop floor

Mean Tardiness = $\frac{\sum_{i=1}^{n} \max(0, LA_i)}{nt}$;

LA_i = Lateness of job i= completion time_i – due date_i

$nt = \sum A_i$; $A_i = 1$ if $LA_i > 0$, $A_i = 0$ if $LA_i \le 0$

Percentage delivered on time = $100 - \frac{nt}{n}$

Mean throughput rate $= \dfrac{\sum_{j=1}^{m} TH_j}{m}$; TH_j= Number of components delivered in week j

m = Total number of weeks

4.1.4 Scope of the model

The current processes in the shop are complex and it would be difficult and time-consuming to take all the data and aspects of the system into account when making the simulation model. Robinson (1996) concluded that: “Initially, increasing the scope and level leads to significant gains in accuracy. However, the advantage of further increase is not as great; there are diminishing marginal returns. Basically, 80 percent of the accuracy is obtained from 20 percent of the model detail”. For that reason it is not necessary to take all the facets of the shop into account when making the simulation model.

The shop has a large range of different components to repair (more than 400 different component types). These components cannot all be modelled separately. We determine which component types were repaired the most frequently during the last year. In consideration with the team supervisor of the concerning shop, a selection of components is made which give a good representation of the actual flow through the shops.

During the process components can get missing during the repair process. However, this event occurs only a few times a year and will not have a considerable influence on the results. For that reason we will not take this event in consideration.

4.1.5. System configurations to be modelled

This section gives an overview of the configurations to be modelled. As described in Section 2.3, a release method consists of two stages: the moment of release (determined with the triggering mechanism) and the order of release (determined with the sequencing rule). Table 4.2 states an overview of the different options of the moment of release and the order of release. Section 3.3 provides more detailed information on these methods. In order to analyse the influence of the shop characteristics on the choice of release method, different shop characteristics will be simulated as well. Section 3.2.1 explains these shop characteristics.. Table 4.2 gives an overview of these characteristics.

Triggering mechanism	**Sequencing rule**	**Shop characteristics**
Immediate release	First In First Out (FIFO)	Workload - current situation - higher workload - lower workload
Norm WIP whole system	Earliest Due Date (EDD)	Process disruptions -current situation -no disruptions
Norm WIP per component type	Minimum Slack (MS)	Restriction on skills -current situation -no restrictions
		TAT agreements -current situation -no differences

Table 4.2 Configurations to be modelled

For the queues on the shop floor we will use the same sequencing rule as for the queue in front of the shop, because as explained in Section 2.2, Bechte (1994) suggest that a simple sequencing rule suffices when using an effective release mechanism.

5. Results of the simulation model

This chapter analyses and discusses the output of the simulation model for the shop EWB (step 9 in the Figure 2.4). We test the suggested release methods showed in Table 4.2. We start by exploring the differences between the different release methods for the current shop characteristics. Next, we manipulate the shop characteristics in order to test the influence of the shop characteristics on the selection of a release method. Table 4.2 also shows the shop characteristics that we test in this chapter. In Section 5.6 we discuss the release methods for the other shops of Component Services (CS).

5.1 Current situation

This section contains the testing and analysing of the suggested release methods in the current situation of the shop. As Section 2.2 describes, the release method consists of two parts: the moment of release (which can be determined with the use of a triggering mechanism) and which component to release (which can be determined with the use of sequencing rules). This sections starts with the discussion of the triggering mechanisms. Next, we discuss the sequencing rules.

5.1.1 Conclusion

No significant differences exist between the three triggering mechanisms. Currently, EWB uses the immediate release mechanism in the shop. For that reason we recommend this triggering mechanism. There are differences between the sequencing rules. The EDD and MS rule are more favourable for the *normal* components and the FIFO rule is more favourable for the *IAMCO* components. Since all of the *IAMCO* components are delivered on time, we do not recommend using the FIFO rule. The EDD rule is more effortless to implement than the MS rule, since the processing times do not have to be taken in to account. For that reason we recommend using the EDD rule. This results in the release method with an immediate release triggering mechanism in combination with the EDD sequencing rule.

5.2 Influence of the skill level of the mechanics

Section 5.1.1 concludes that the minor differences between the triggering mechanisms could be due to the fact that with a low WIP level a mechanic can become idle because he or she does not have the right skills to repair a component from the buffer. To test the influence of the restricted skill level of the mechanics, all mechanics will get all possible skills in the simulation model. This means that every mechanic is now able to repair all components in the shop.

5.2.1 Conclusion

The differences between the three triggering mechanisms are minor. Since the immediate release mechanism is already used in the shop, we recommend using this method for the setting with extra skills. As in the current setting, the EDD and MS sequencing rule are more favourable for the *normal* components and the FIFO sequencing rule is more favourable for the *IAMCO* components. Since the mean TAT for the EDD and MS rule for the *IAMCO* components is under the minimal TAT agreement, either the EDD or MS rule should be used. Since the EDD rule is the most effortless, we recommend using the EDD rule. This results in a release method with an immediate release triggering mechanism in combination with the EDD sequencing rule. This is the same conclusion as for the system without extra skills. This means that the tested skill level of the mechanics did not influence the selection of release method. However, not all the possible skill levels are tested so there could be skill levels that do influence the selection of release method. We recommend further research on this topic.

5.3 Influence of the workload

Section 5.2 discusses the influence of the skill level on the selection of release method. This section discusses the influence of the next shop characteristic; the workload of the shop. First, we experiment with an increase of the shop workload. Next, we investigate the influence of the decrease of the shop workload.

5.3.1 Increase of the workload

When the workload of the shop increases, the queues in the shop increase as well. This means that the control of these queues becomes more important. In that view, we expect that the differences between the release methods increase.

5.3.2 Decrease of the workload

When the workload of the shop decreases, smaller and fewer queues will exist on the shop floor. In that view, we expect that the differences between the release methods will have similar results.

5.3.3 Conclusion

When increasing the workload, the differences between the release methods increase. However, the variances of the results increase as well, which makes the differences not significant. Although the differences are not significant, they are still major. The WIP level for the whole system leads to a better CT than the immediate release mechanism. For that reason we recommend this triggering mechanism. The choice for the sequencing rule did not change. Since the triggering mechanism is different than in the current setting, we conclude that the increase workload does have an influence on the selection of release method.

When decreasing the workload, the differences between the release methods become only minor. For that reason we recommend the system which has the least effort to be implemented and to be maintained; the immediate release mechanism in combination with the EDD sequencing rule. This is the same method as we recommend for the current system. Therefore, we conclude that the decrease of the workload does not influence the selection of release method.

5.4 Influence of the process disruptions

In the previous sections we discuss the influence of the workload and the skill level of the shop on the selection of release methods. In this paragraph, we discuss the influence of the next shop characteristic: the process disruptions. To determine the influence that the process disruptions (waiting for material, waiting for resources, and outsourcing) have on the selection of the release method, a simulation run is made with no process disruptions.

5.4.1 Conclusion

As in the current setting, the differences between the three triggering mechanisms are only minor. Therefore, we recommend the same triggering mechanism as in the current settings, the immediate release mechanism. The differences between the three sequencing rules are also similar to the current settings. For that reason we recommend the same release method as in the current system, the immediate release mechanism in combination with the EDD sequencing rule. The process disruptions do not influence the selection of release method.

5.5 Influence of the differences in TAT agreements

In the previous sections we discuss the influence of the workload, the skill level, and the process disruptions of the shop on the selection of release method. In this paragraph we discuss the influence of the next shop characteristic: the process disruptions. To indicate the influence of the TAT agreements differences among the component types, all components will get the same TAT agreements. In this setting, all the components should be finished 21 days after arrival.

5.5.1 Conclusion

As in the current settings, the differences between the three triggering mechanisms are only minor. So we recommend the same triggering mechanism as in the current setting, the immediate release mechanism. The selection of sequencing rule is different than in the current situation. We recommend using either the FIFO or the EDD rule. Since the FIFO rule is already in use, recommend using the FIFO rule.

5.6 Release methods for the other shops of Component Services

This section argues, based on the shop characteristics, what the most suitable release method for what shop category is (Table 3.1). Table 5.1 gives an overview of the results of the different shop characteristics that we tested for the EWB shop. Below, we discuss the release methods for the other two shop categories.

	Triggering mechanism	**Sequencing rule**
Current setting	Immediate release	EDD
Extra skills	Immediate release	EDD
Extra workload (+9%)	WIP level for the whole system	EDD
Less workload (-14%)	Immediate release	EDD
Without process disruptions	Immediate release	EDD
All components have the same TAT agreements	Immediate release	FIFO

Table 5.1 Overview of the suggested release methods for the different shop characteristics

6. Conclusions and recommendations

This chapter presents the conclusions and recommendations. We start with the conclusions and next we present the recommendations.

6.1 Conclusions

The objective of this research is to get a better understanding of and advise the KLM on the use of shop floor control methods in the component repair shops of KLM. To reach this objective, we started with a literature review on this topic. This review concludes that not much research is done on the use of shop floor control methods in repair shops. The little research that exists focuses on the use of release methods. Release methods determine when and which components will be released, with the use of triggering mechanisms and sequencing rules. The literature concludes that the use of the release method also depends on the characteristics of the shop. Three triggering mechanisms and three sequencing rules are selected to be tested for the repair shops of KLM. Also four shop characteristics that might influence the choice of release method are defined. With the use of a simulation model of one of the shops, these methods are tested for the four shop characteristics. Table 6.1 displays the selected methods and the four shop characteristics. The next section contains the selected release mechanism for the current system and the influence of the shop characteristic on this selection.

Triggering mechanism	**Sequencing rule**	**Shop characteristics**
Immediate release	First In First Out (FIFO)	Workload - current situation - lower workload - higher workload
Norm WIP whole system	Earliest Due Date (EDD)	Process disruptions -current situation -no disruptions
Norm WIP per component type	Minimum Slack (MS)	Restriction on skills -current situation -no restrictions
		TAT agreements -current situation -no different TAT agreements

Table 6.1 The selected release methods and the shop characteristics

Current setting

We recommend the immediate release mechanism in combination with the EDD sequencing rule for the simulated shop. We expected that the MS rule would perform better than de EDD rule because it takes, next to the due date, the processing time into account when determining the sequence of the orders. However, reliable processing times are difficult to determine due to the possibilities of process disruptions. This leads to a decrease in performance of the MS rule.

Skill level

For the simulated shop, the tested skill levels of the mechanics do not influence the selection of a release method. Process disruptions that take longer than the agreed Turn Around Time are the only reason that components are delivered late for both the EDD and MS rule. For that reason, the use of a different release method cannot improve the performance of the shop. Not all possible skill levels could be tested, so more research should be done on this topic.

Workload

The 9% decrease in workload does not lead to the recommendation of a different release method. The 14% increase in workload did influence the selection of release method. For this setting, the WIP level for the whole system triggering mechanism performs better than the immediate release mechanism. The queues on the shop floor become that long that it should be better controlled with the use of a WIP level. This reduces the mean Cycle Time (CT) and the standard deviation of the CT. As in the current situation, we advise using the EDD sequencing rule.

Process disruptions

For the simulated shop, the process disruptions do not influence the selection of a release method. Since the process disruptions influence the reliability of the processing times, we expect that the MS rule would perform better than the EDD and FIFO rule. However, no significant differences between the EDD and MS rule exist. This is due to the fact that all the components that are late with the EDD and MS rule are late because they have to wait for release until a mechanic with the right skills is available; the performance of the shop cannot be improved without adding extra skills. Another factor that might influence the usability of the MS rule is the fact that the waiting times in the buffer are not considered when determining the processing times. This waiting time differs between the component types, because the components need different sources.

Differences in TAT agreements

For the simulated shop, the differences in TAT agreements did influence the selection of sequencing rule but not the selection of triggering mechanism. The EDD rule is the same as the FIFO rule in this setting and is considerate as one option. No significant differences between all the methods exist for this setting. Since the FIFO rule and the immediate release mechanisms are easier in operation we recommend the FIFO rule in combination with the immediate release mechanism.

6.2 Recommendations for further research

In this section, we discuss the topics that came up during the research and need further investigation by the KLM.

In Section 5.2, we test four different skill levels of the mechanics in the shop on what their influence is on the selection of release method. For all four methods, we suggest the same release method. So these four levels did not influence the selection of release method. However, not all the possible skill levels could be tested. In order conclude that the skill level of the mechanics does not influence the selection of release method, more skill levels should be tested.

In Section 5.3, we test the increase and decrease of the workload. We conclude that the increase has an influence and the decrease does not have an influence. However, we did not test all possible increase and decrease percentages. In order conclude that the skill level of the mechanics does not influence the selection of release method, more increase and decrease percentages should be tested.

We did not include the shops that have to cope with emergency repairs in this research. We recommend further investigation of the influence of the emergency repairs on the selection of release method for the shops.

This research does not test the influence of all the possible combinations of shop characteristics. For example, the combination of not limiting skill level with no differences in TAT agreements is not tested. In order to get a better understanding of the influence of the shop characteristics, all possible combinations should be tested.

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Appendix A: Definitions and abbreviations

A1 Definitions

Cycle time (CT): The time a component spends on the shop floor after being released

Turn Around Time (TAT): The time a component spends in the system from accepting the order to completion

Release methods: Determine which order should be released when

Work In Process: The amount of work on the shop floor including

IAMCO components: Components from the Dutch defence department, which have a longer due date than other components

A2 Abbreviations

E&M:	Engineering and Maintenance
CS:	Component Services
WIP:	Work In Process
TAT:	Turn Around Time
CT:	Cycle Time
TH:	Throughput
A&A:	Avionics and Accessories
BMSS:	Base Maintenance and Support Shops
FIFO:	First In First Out
EDD:	Earliest Due Date
MS:	Minimum Slack
WM:	Waiting for material
WR:	Waiting for resources
OS:	Outsourced

Appendix B Organization charts

Source: website KLM corporate.klm.com

Figure B1 Organization chart KLM group

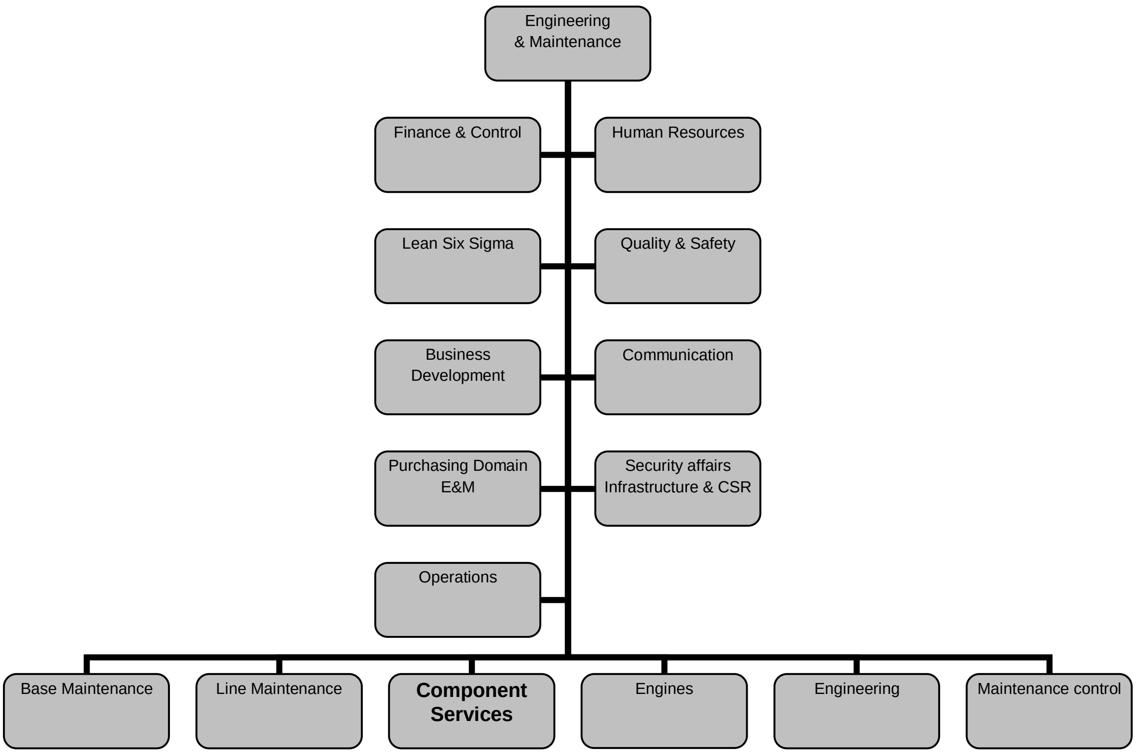

Figure B2 Organization chart Engineering and Maintenance

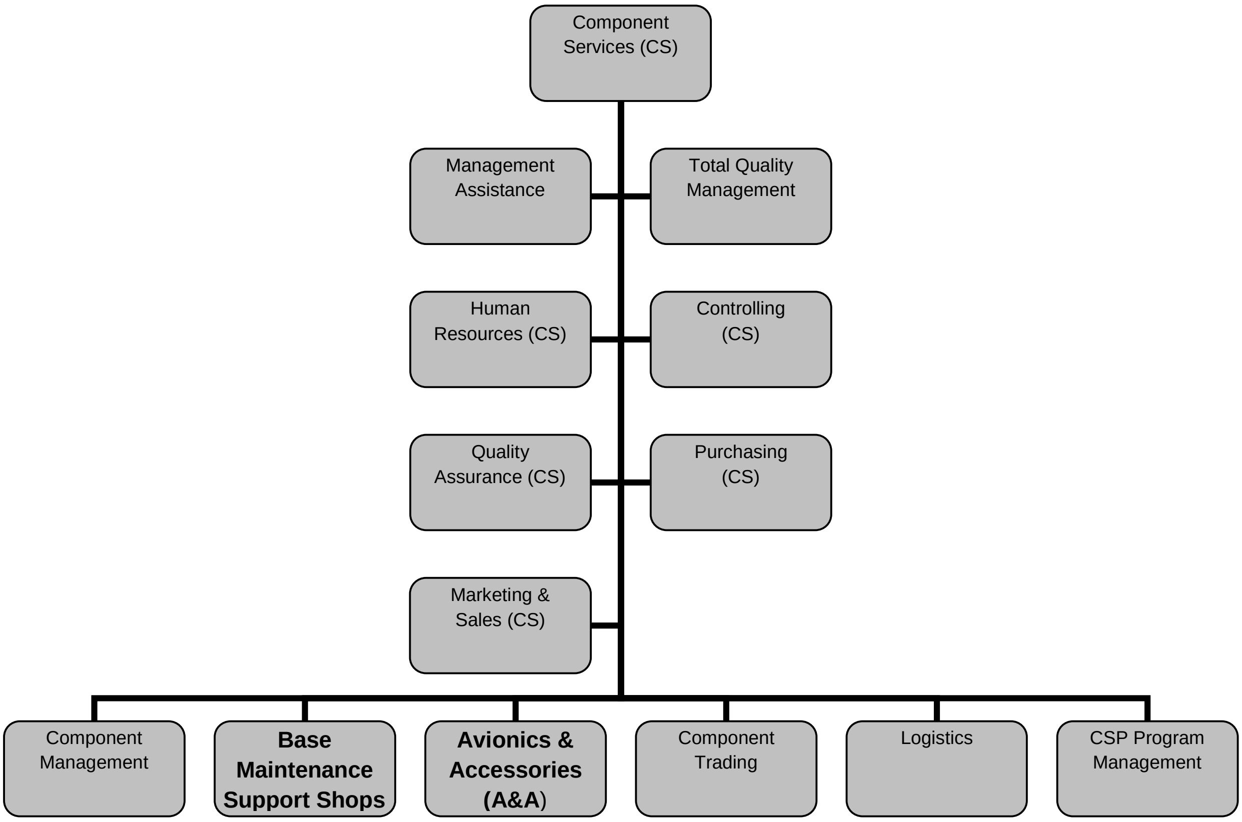

Figure B3 Organization chart Component Services

Appendix C: Literature review

Two databases are selected for the literature review: Scopus and Business Source Elite (BSE). BSE contains articles from 1985 through 2009 and Scopus contains articles from 1823 through 2009. For our search through these databases we searched for useful keywords. In figure B1 and B2 the keywords are displayed in bold. They are tested for relevance in the databases and if a relevant article came up the keywords of this article were tested as well. For BSE it was necessary to add free text words as well, because the keywords did not cover all the articles. The results of the search are displayed in figures C1 and C2.

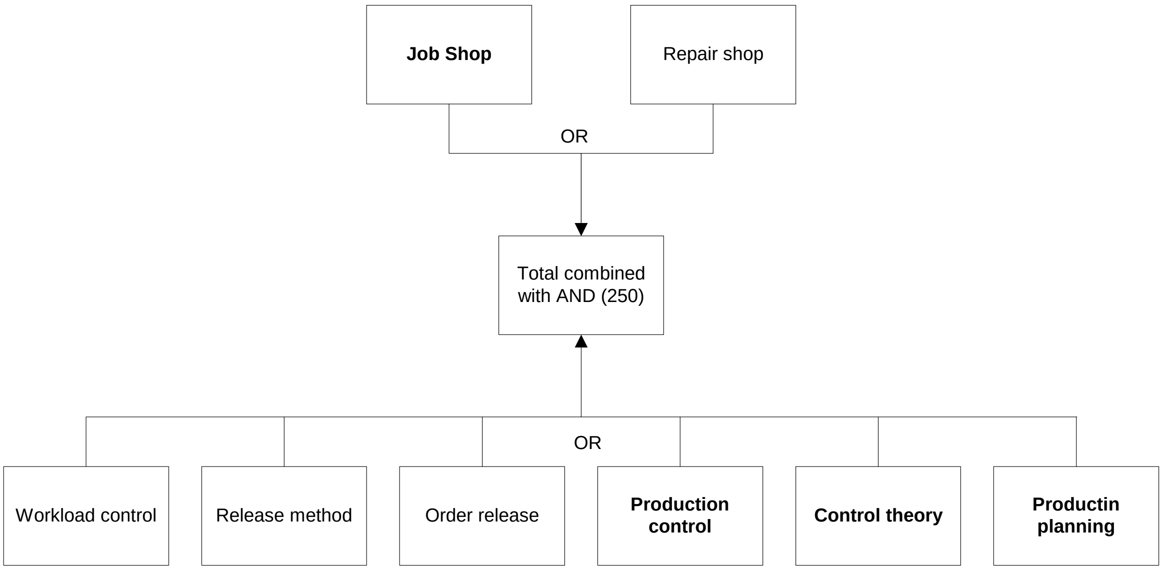

Figure C1 Flowchart search in Business Source Elite

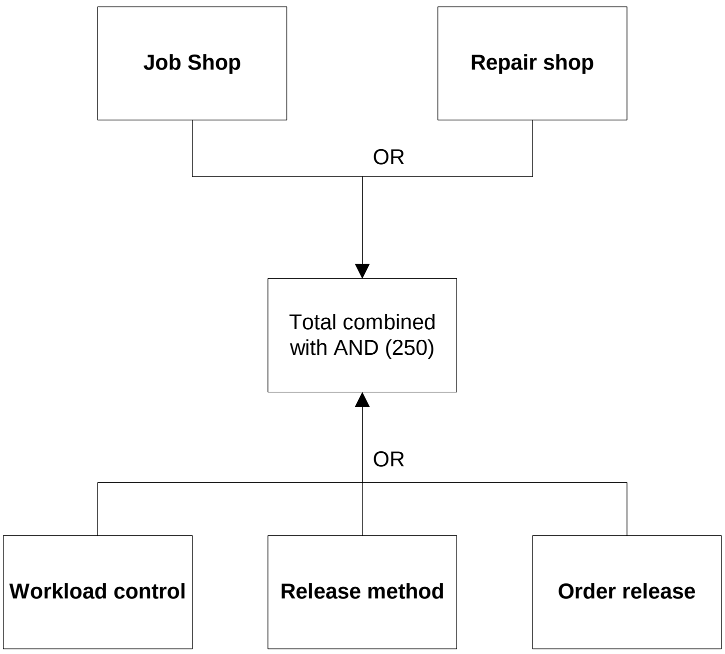

Figure C2 Flowchart search in Scopus

When both searches are combined and the duplicates are removed, 127 articles remained to be interesting. When reading the abstracts 49 articles remained to be interested. After reading these articles and checking the references 21 articles were selected. The references can be found in the reference list.

Appendix D: Steps of a simulation project

This text is copied from Law and Kelton 2007, page 66-70

1. Formulate problem and plan the study

This starts with a problem of interest stated by the manager. Next, one or more meetings are conducted in which the following subjects should be discussed:

- Overall objectives of the study
- Specific questions to be answered by the study (required to decide the level of model detail)
- Performance measures that will be used to evaluate the efficiency of different system configurations
- Scope of the model
- System configurations to be modelled
- Time frame for the study and the required resources

2. Collect data and define a model

The following steps will be considered in this stage

- Collect information on the system structure and operating procedures
- Collect data to specify model parameters and input probability
- Delineate above information and data in a written assumptions document
- Collect data on the performance of the existing system for validation purposes
- Interact with manager on a regular basis

3. Is the assumptions document valid?

Perform a structured walk-through of the assumptions document before an audience of managers and analysts. This will

- Help ensure that the model's assumptions are correct and complete
- Promote interaction among the project members
- Promote ownership of the model
- Take place before programming begins. to avoid significant reprogramming later

4. Construct a computer program and verify

Program the model in a programming language or in simulation software and verify (debug) the simulation computer program. Verification is the process of ensuring that the simulation model is built correctly and performs as the modeller intended. Verification is concerned with determining whether the assumptions document has been correctly translated into a computer program, in other words debugging the simulation mode.

5. Make pilot runs

Make pilot runs in order to validate the process.

6. Validate the programmed model

In this step the model should be validated. Validation is the process of determining whether a simulation model is an accurate representation of the system, for the particular objectives of the study. The following steps will validate the model

- If there is an existing system, then compare model and system performance measures for the existing system.

- The manager. experts and simulation analyst should review the model results for correctness
- Use sensitivity analyses to determine what model factors have a significant impact on performance measures and have to be modelled carefully

7. Design experiments

After the simulation model is validated, the system configurations of interest for comparing alternative system configurations should be specified. These consist of:

- length of each simulation run
- length of the warm-up period, if one is appropriate
- number of independent simulation runs using different random numbers

8. Make production runs

Production runs are made for use in the next step.

9. Analyze output data

- Determine the absolute performance of certain system configurations
- Compare alternative system configurations in a relative sense

10. Document, present and use results

- Documents assumptions, computer program and study's results for use in the current and future projects.
- Present study's results
- Use animation to communication model to managers and other people who are not familiar with all the model details
- Discuss model building and validation process to promote credibility
- Results are used in decision-making process if they are both valid and credible.

Appendix E: Determining the shop characteristics

To determine the shop characteristics that might influence the selection of release method, all the team supervisors and planners of the shops are interviewed. The following questions were asked.

1. Which shop floor control method is currently used and why?
2. Which characteristics make your shop unique in comparison with other shops and why?
3. Which shop characteristics influence the shop floor control method and why?

Underneath we describe all the shop characteristics that the team supervisors mentioned in the interviews.

The percentages of process disruptions
A component can have several disruptions in the process; the component needs to wait for material (WM) or resources (WR) or the component can be outsourced (OS). This leads to a decrease of the percentage of components delivered on time and an increase in the Turn Around Time (TAT). The chance on a process disruption differs per component type and per shop.

Restricted skill level
In order to repair a certain component of the shop, a mechanic needs to have a specific skill. Not all the mechanics in one shop have the same skills and so are not able to repair all the components of the shops. This leads to restrictions which component can be released next. In some shops the mechanics have a lot of different skills, but in other shops the skill level is more restricted.

Variance in Turn Around Times (TAT)
When a component arrives it is hard to determine what needs to be repaired and what the TAT will be. This makes the TAT less reliable to use for the release method. All the shops have some variance in processing time, but some shops have more variance than other shops.

Variance in arrival times
It is never sure when a component will fail, which makes it hard to determine when and how many components enter the shop. All the shops have to cope with this problem.

The number of mechanics working on the components
In some shops not all the required processing steps can be performed by one mechanic. This applies especially to the testing of the components. When more mechanics need to work on one component, the loading of these mechanics becomes more complicated. Not all the shops have this problem.

Differences in TAT agreements
The clients of each shop have agreements on when the component needs to be repaired (TAT agreementx). In some shops these agreements differ per component. In particular the shops that repair components for the defence department of the Dutch government (*IAMCO* components) have differences in TAT agreements. The TAT agreements for the *IAMCO* components could be up to half a year. This influences the decision on which component to release next. The

IAMCO components can wait a longer time before being released to the shop floor and still be on time.

Section 2.2.3 describes the shop characteristics that influence the selection of release method according to the literature. Underneath we repeat these two characteristics.

The workload of the shop
When the workload in the shop increases, the queues in the shop floor will increase as well, so the control of these queues becomes more important. The queues will grow especially when the workload is not in balance with the capacity.

The number of levels a component consists of
When a component exists of more than one level, the component needs to be disassembled and the disassembled parts of the component can be repaired by different resources. The parts need to be assembled again, which can complicate the scheduling of components and their parts.

Since we do not have the time to research the influence of all the above mentioned shop characteristics, a selection needs to be made. In discussion with the team supervisors, planners and the managers of Avionics and Accessories (A&A) and Base Maintenance Support Services (BMSS) the following shop characteristics are not further explored.

Variance in arrival times
All the shops have to cope with variance in arrival times. The differences between the variance in arrival times between the shops are minimal. For that reason we will not discuss this shop characteristic further.

The number of mechanics working on a component
This shop characteristic was not indicated by the team supervisors as a factor that had influence on the moment and order of the release of components.

The number of levels a component consists of
The components which Component Services (CS) repairs, mostly consist of more than one level. However, the parts from the components are most of the time repaired by the same mechanic. For that reason we will not discuss this characteristic further.

Variance in Turn Around Times (TAT)
The variance of the TAT per component is taken into account when determining the processing times for the minimal slack sequencing rule. For that reason we will not discuss this characteristic further.