Developing a management information tool

A study to determine the information that is needed for job card scheduling in aircraft maintenance

UNIVERSITY OF TWENTE.

KLM Engineering & Maintenance

Author:	M. A Schut
Student number:	s0167150
KLM number:	klm50657
Master program:	Industrial Engineering & Management
Specialization:	Production & Logistic Management
University:	University of Twente
Date:	24 October 2014
Examination committee UT:	Dr. Matthieu van der Heijden
	Dr. Leo van der Wegen
Examination committee KLM:	Perwien Meriwani
	Eric Bron
	Anne Vos

Abstract:

This report serves as master thesis for the master Industrial Engineering and Management at the University of Twente of M. A. Schut. The goal of this thesis is to enable future research on scheduling methodologies, by describing the information that scheduling processes and scheduling performance measurement would require. Based on this description, a management information tool was developed for the KLM Engineering & Maintenance, to enable it to improve its scheduling processes.

UNIVERSITY OF TWENTE.

Acknowledgements

This work embodies my last achievement at the University of Twente for my master Industrial Engineering and Management. The last seven years of my life have *flown* by, having a fitting ending at one of the most exciting workplaces I could have ever imagined. I write these acknowledgements to express my gratitude towards the people who made me into the person that I am today and to express my gratitude for their support throughout my thesis and my study.

I would like to start by thanking KLM Engineering & Maintenance, for creating such a great work environment for a graduate student. It is hard to describe how amazing it is, when you go to work and the first thing you see in the office is a Boeing 747. In particular, I would like to thank Perwien, Erik, and all the other members of the management team for accepting me as part of their team and giving me the opportunity to see how they handle such a large reorganisation. My thanks also go out to Ronald, Johan, Dimitri, Cees, Rob, and everyone else in the Front and Back Office, as I enjoyed working with all of you and could not have obtained the necessary information without your cooperation and support. I will never forget the interesting sayings you taught me (e.g.: *'er een ei over leggen', 'een blik russen naar de grens sturen',* or *'het net is even goed ophalen'*) and I wish you all the very best!

Matthieu, Leo, I thank you both for the support you gave me during my graduation assignment and during the other courses I took from you. Our discussions very much helped me to improve quality of my work.

I also would like to thank the people close to me. Mom, Dad, thank you for the support and care you gave me throughout my study. You always supported my choices and helped me in any way you could. Bruder, thanks for motivating me and providing the wanted diversion via sporting or watching soccer. Don, thanks for finding the time in your busy schedule to proofread my thesis and for being a great friend. The same holds for all you guys, whom I shared my years in Enschede with.

Deniece, special thanks to you as well. For putting up with me and my stress, for travelling back and forth to Ijmuiden, for pushing me to achieve greater results, and because you were and are always there for me.

Finally, I would like to thank my grandparents. Although it is not possible anymore to thank all of you in person, I do know that you are proud of me, as I am thankful for the love and care you give/gave me.

Mark Schut

Summary

Context

This research is intended to support the Royal Dutch Airline (KLM) in their efforts to improve the productivity of their Engineering & Maintenance (E&M) division for aircraft maintenance within hangars (KLM E&M VO-H), which is a goal of their overall reorganisation called – Securing Our Future (SOF). For this research, we examined the scheduling processes within one of the hangers of VO-H that is used for medium - to heavy aircraft maintenance on Wide Body airplanes. The main reasons for executing this research are: the demand for accurate and reliable schedules during maintenance for the success of several reorganisation projects, the possibility to influence the changes that VO-H is making to its IT system, and the necessity for understanding the scheduling processes, given the loss of scheduling experience that is expected after the reorganisation.

Objectives

VO-H desires to improve its current scheduling practices by using alternative methods for scheduling the job cards that are executed during maintenance. As VO-H had limited understanding of the current scheduling processes and was missing important information that is needed for scheduling job cards, this research aims to identify the absent information and present it in an accessible solution for the relevant stakeholders, being the planners of job cards and managers who are responsible for the productivity during maintenance checks.

Results

Forth realization of alternative scheduling methods, we found that KLM required insights into their current scheduling processes, into the measurement and evaluation of scheduling processes, and into the means for presenting the absent information (needed for scheduling and measurement/evaluation).

The scheduling processes that we reviewed focus on the scheduling of job cards within one maintenance visit. From literature, we deduced that we should focus on Rough Cut Capacity Planning (RCCP) and Resource Constrained Project Scheduling (RCPS), which translates to the scheduling of job cards as groups via scheduling blocks over the length of the maintenance visit or individually within a time window of three shifts.

We also deduced that scheduling processes on these levels require an aggregated and detailed description of *job cards, scheduling blocks, resources availability and requirements, generated schedules, and the status of the completed and remaining work.* From reviewing VO-H processes, we deduced that most of this information is currently not readily available. Commonly found problems that have the largest impact on both the scheduling and execution of job cards are the *incorrect descriptions of job cards* (e.g. absent processing time), the absent *description of resource requirements/processing time* when cards are *executed in different modes*, *the available resources that are not predicted accurately*, and *the current status* that cannot not be determined.

Regarding performance measurement, we determined that the by literature proposed indicators are of limited us to VO-H. The absent and incorrect information on job cards prevent VO-H from accurately measuring indicators as the resources used or the makespan of the project. Furthermore, it is not be possible to benchmark scheduling alternatives, given that there is no reference point to compare the schedules to. Assuming that the reorganisation projects would generate some of the missing information on job cards, this project should at least realise the benchmark-functionalities.

To solve the problems related to the scheduling of job cards and its performance measurement, a model was formulated that would retrieve and present the desired information to managers and planners. This model is designed to indicate possible sources of absent information of job cards, to present the current status of the visit, to describe resource usage, and to enable benchmarking for performance measurement. To achieve this, we designed a solution for a Management Information System (MIS) that would retrieve information from databases and automatically present the desired information to the users – the managers and planners within VO-H.

Based on the model, it was possible to develop a software tool. However, during the development we established that limited availability in the general maintenance information systems (Maintenix) affected the outcome of the tool. As it would require a significant effort to manually manipulate data files to compensate for this problem, we limited the functionalities of the solution from an automated Management Information System to a Management Information Tool that uses limited additional user interaction to generate the desired information. Due to these limitations, we could also not include the resource usage in the tool, as the required information could not be accessed or entered. The final result thus includes a tool that provides *desired status information of the visits*, together with the possibility for *benchmarking the progress of the maintenance visit*. The result is shown in Figure 1.

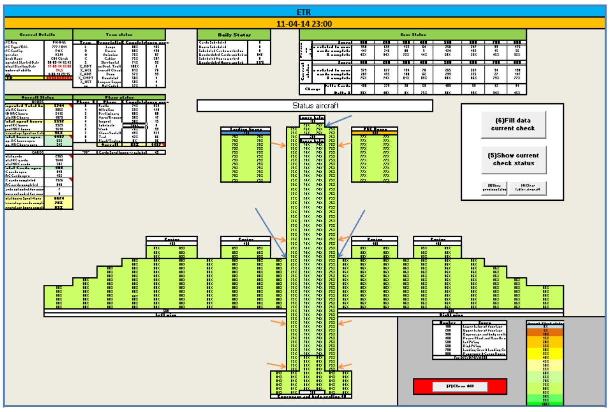


Figure 1: Overview of main user screen of management information tool

Conclusion & Recommendations

By developing the management information tool, we created the means for accessing and presenting the information that managers and planners need. By recording the status of the maintenance visit each shift, it becomes possible to compare the results of a generated schedule with the measured profiles of any airplane type. Additionally, the tool supports the management when they identify the deviations between the scheduled activities and the actual performance. By doing so, fewer unnecessary deviations from the scheduled job cards can be realised, therefore helping the realisation of improved schedules. The tool is thus the answer to the main research question.

However, the possibilities of researching new scheduling methods can only be accomplished, when the visit profiles are indeed stored into a database. We therefore recommend implementing the tool, by using it in the status updates in each shift to record the current status. By doing so, the managers and planners will also increase their understanding on what the current status means for operational control decisions (e.g. whether overtime is necessary). The first results showed that it indeed realised a greater understanding amongst the users. Furthermore, we recommend that VO-H continues the development of the tool after the finalization of the reorganisation, such that promised data access to resource availability and scheduled activities can also be included into the tool. Finally, for future research we recommend to analyze the possibilities of predicting Non-routine job cards and how they could be best scheduled using this additional information.

Table of Contents

List of Abbreviations

100% List	*List of materials that are known to be needed in check*
4Ms:	*Manpower, Machinery, Materials and Methods*
ADs:	*Airworthiness Directives*
AFI:	*Air France Industries*
AMM:	*Aircraft Maintenance Manual*
AML:	*Aircraft Maintenance Log*
AMP:	*Aircraft Maintenance Program*
AMS:	*Amsterdam Schiphol Airport*
AOG:	*Airplane on ground (negative)*
ATL:	*Aircraft Technical Log*
BM:	*Business Managers*
BMO:	*Base Maintenance officer*
BO:	*Back Office*
BOW:	*Bill of Work*
CML:	*Cabin Maintenance Log*
CMS:	*Crew Management System*
CSC:	*Customer Support Service*
DDs:	*Deferred Defects*
E&M:	*Engineering & Maintenance*
EASA:	*European Aviation Safety Agency*
EATL:	*Electronic Aircraft Technical Log*
EOs:	*Engineering Orders*
ETR:	*Estimated Time to Repair*
FAA:	*Federal Aviation Administration*
FTE:	*Fulltime employee*
FO:	*Front Office*
GWK:	*Grondwerktuigbouwkundige*
	Ground Engineer
IKB:	*Interne Kostberekening*
	Internal Cost calculation
IPC:	*Installed Part Catalogue*
JIC:	*Job Interrupt Card/Job Instruction Card*
JAR:	*Joint Aviation Requirements*
JSS:	*Job card Summary Sheet (IT Scheduling Tool – back office)*
KLM:	*Koninklijke Nederlandse Luchtvaart Maatschappij*
	Royal Dutch Airlines
LMO:	*Line Maintenance Officer*
LRP:	*Long Range Planning*
MAM:	*Maintenance Authorization Manual*
MC:	*Material Centre (formally MSSD/MSSC)*
MCC:	*Maintenance Control Centre*
MEL:	*Minimum Equipment List*
MO:	*Modification*
MOM:	*Maintenance Organisation Manual*
MOO:	*Maintenance Operations Officer*
MPD:	*Maintenance Planning Document*
MPID:	*Maintenix planning information document*
MPM:	*Maintenance Performance Meeting*
MPP:	*Master Production Planning*
MPP:	*Multi-Project Planning*

MPS:	*Maintenance Planning Schedule*
MPSM:	*Managerial Problem Solving-Method*
MRO:	*Maintenance, Repair, and Overhaul*
MSS-C:	*Material Support Service-Centralised*
MSS-D:	*Material Support Service-Decentralised*
MSM:	*Maintenance Shift Manager*
MSF:	*Maintenance Support Facilities (Contains all complaints)*
MTOP:	*Meetsysteem Technische Operationele Prestaties* *Measurement system Technical Operational Performance*
NRC:	*Non-Routine Cards*
OEM:	*Original Equipment Manufacturer*
OMP:	*Operator's Maintenance Program*
OVG:	*Overzicht Vliegtuigen aan de grond* *Overview Airplanes on ground (scheduled)*
PCG:	*Production Control Group*
PIB:	*Project Information Bulletin*
PM:	*Production Managers*
PUM:	*Production Unit Manager*
PPM:	*Production Maintenance Manager*
PP&C:	*Production Plan & Control*
PS:	*Project Supervisor*
PSG:	*Production Support Group*
RC:	*Routine Cards*
RCCP:	*Rough-Cut Capacity Planning*
RCPS:	*Resource Constraint Scheduling*
RCPSP:	*Resource Constraint Scheduling Problem*
SBs:	*Service Bulletins*
SOF:	*Securing Our Future*
SP:	*Spent (expressed in FTEs of work)*
SRM:	*Structural Repair Manual*
SSO:	*Single Sign Off*
TAT:	*Turnaround Time*
TM:	*Team manager*
TOR:	*Terms of reference*
VC:	*Voor gecalculeerd* *Pre-calculated (expressed in FTEs of work)*
VO:	*Vliegtuig Onderhoud – Naam voor: VO-H, VO-P & MCC* *Aircraft Maintenance*
VO-H:	*Vliegtuig Onderhoud – Hangaars* *Aircraft Maintenance - Hangars*
VO-P:	*Vliegtuig Onderhoud – Platform* *Aircraft Maintenance - Platform*
WBCU:	*World Business Class upgrade*
WVO:	*Werkwijze Vliegtuig Onderhoud* *Working Procedures Aircraft Maintenance*

JAR/EASA definitions:

Part M	The legal description for the operator of airplanes and how is responsible for the condition of the airplanes. In the research KLM Fleet Services/Engineering
Part 66	The legal entity for certifying staff to perform high quality maintenance checks.
Part 145	The legal entity responsible for performing the maintenance organisation, in the research KLM E&M c.q. VO-H

Developing a management information tool

1. Introduction

Information is the basis of any decision-making process, here, related to the information that is needed during aircraft maintenance checks for making scheduling decisions. By analyzing the information needs and problems that are related to these scheduling decisions, we attempt to support the Royal Dutch Airlines' Engineering and Maintenance division (KLM E&M), in their efforts to increase the productivity of their business unit Aircraft Maintenance – Hangars (VO-H).

This chapter is used to introduce the research that has been done within KLM E&M VO-H. First, we will present the context of this research in Section 1.1. We will then motivate the relevance of our work (1.2), followed by an explanation of the problem at hand (1.3). The problem definition will be used to define the goal (1.4), the scope (1.5), and the stakeholders in this research (1.6). Based on these sections, we then present our research questions in Section 1.7. The final section of this chapter is used to discuss the structure of this research and the research methods that we use.

1.1.Company description

This research was conducted at one of the hangars of KLM E&M. To explain the context of this research, we will first introduce the related organisation (1.1.1), followed by a general description of KLM E&M's maintenance processes (1.1.2).

1.1.1. Organisation & mission

KLM Engineering & Maintenance (KLM E&M) is the maintenance division of the Royal Dutch Airlines, from here on KLM. Together with Air France Industries (AFI), KLM E&M is one of the leading organisations in the airplane maintenance industry. Besides maintaining their own fleet, KLM E&M and AFI maintain the airplanes, engines, and components of about 150 customers worldwide. KLM E&M is the employer of roughly 4000 employees, who are all contributing in keeping these airplanes flying safely. The mission of E&M is divided into two main objectives. The first is to deliver superior maintenance support to KLM and the Air France KLM group via operational security, availability and reliability, and competitive cost pricing. The second is to be an important player on the Maintenance, Repair, and Overhaul market by generating earnings via external customers, e.g. other airline companies or aircraft producers (KLM E&M, 2013). This mission is derived from the strategy that is set by Air France KLM and is depicted in Figure 2 on the next page.

Figure 2: Linked Strategy Air France KLM & KLM E&M (KLM E&M, 2013)

KLM E&M's mission is carried out via the different business units that are highlighted in the organisational chart in Appendix 1. The hangars for which this research was performed are part of KLM E&M's base maintenance organisation, from here on VO-H[1]. VO-H is a part of the business units "Aircraft Maintenance", which is responsible for performing the maintenance checks on the airplanes within the hangars (marked red in Appendix 1). It consists of three hangars (**HI, HII, and HIII**[2]) that, amongst others, perform the different sizes of maintenance checks on Narrow and Wide Body airplanes during their maintenance visits. That is how VO-H generates revenues.

This research will focus on the maintenance activities that are executed within the hangars of VO-H. To introduce the concepts related to this scheduling of maintenance activities, we will now review how VO-H services the airplanes at Amsterdam Schiphol Airport.

1.1.2. Maintenance and scheduling process

The maintenance processes of VO-H are designed to support KLM's main purpose: flying passengers and cargo safely around the world. Every day, KLM operates its fleet of 203 airplanes all over the world (KLM, 2013). As airplanes only generate revenue in the air, KLM uses flight schedules that minimize the time spent on the ground. They thus minimize the time between the arrivals, the maintenance visits, and the departures. By doing so, KLM optimizes its yield per airplane. This is also why VO-H is operating 24/7 (with three shifts a day)[3]. By working 24/7, VO-H minimizes the required time for maintenance visits, therefore supporting KLM's yield strategy. Thus besides safety,

[1] VO-H is the Dutch abbreviation for *´Vliegtuig Onderhoud – Hangaar',* meaning Aircraft Maintenance - Hangar
[2] HI, HII, and HIII are made anonymous for confidentiality reasons and are explained in Appendix 1
[3] The only exceptions are the night shifts during the weekends and possibly some national holidays.

their objective is to finish these visits on time, thus creating a constant pressure on VO-H's performance, giving the limited available slack.

The maintenance visit itself consists of the mandatory maintenance activities that are determined by agencies as the European Aviation Safety Agency (EASA). The activities related to preventive maintenance are grouped into so-called letter checks, being the classification that is used to classify the quantity of maintenance work related to that letter check. In general, A-checks represent the light maintenance work that is performed on airplanes and have a mandatory repetition cycle of roughly 1500 flying hours. C-checks represent the heavier maintenance work that is performed roughly every 24 months[4]. When an aircraft visits the hangars for maintenance, VO-H executes one or multiple letter checks per visit, depending on which have been scheduled by E&M (e.g. when some light maintenance is performed, referring to a visit with an A01-check, or when heavy and light maintenance is executed simultaneously, for a visit with an C04- and an A06-check). By executing these letter checks before they go overdue, VO-H ensures that KLM can operate its fleet safely. The visits themselves generally follow the sequence that is displayed in Figure 3 below.

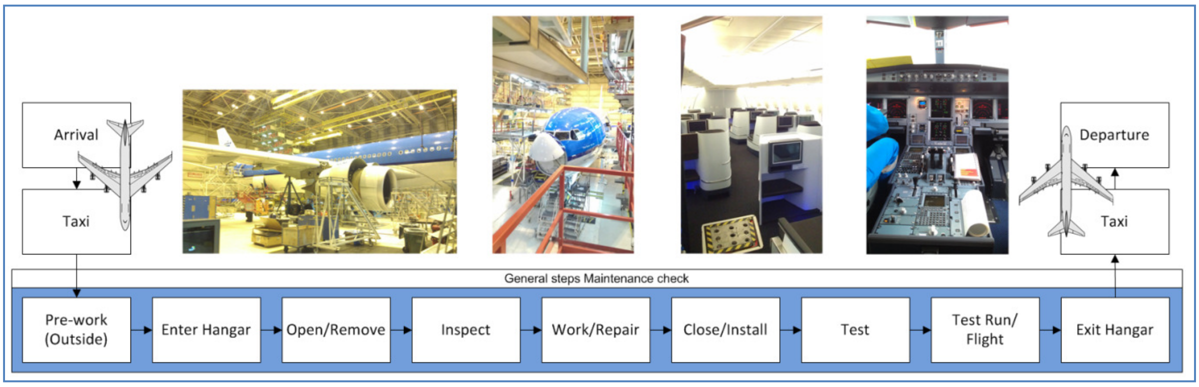


Figure 3: General sequence of main activity types in aircraft maintenance

The figure above applies to any set of letter checks that is executed during a visit. The major difference between light and heavy maintenance visits is the number of shifts executed per maintenance check. A-checks are normally completed within a day (3 shifts), while the C-checks are scheduled for a period of one or multiple weeks (15 shifts or more). As this research focuses on scheduling, let us now briefly introduce how maintenance activities are scheduled to follow this sequence.

When an airplane is due for one of the scheduled maintenance checks that is performed by VO-H, the airplane flies to Schiphol and is taxied to one of the hangars of VO-H for a maintenance visit. Based on the agreements that VO-H and the customers make beforehand (in this case between VO-H and KLM Fleet Services), different types of letter checks and/or modifications orders can be performed. The workload from these letter checks and modifications is described in tasks, which are known as job

[4] Besides A- and C-checks, VO-H performs also other checks, like are M-, and H-checks for a small specific set of tasks, or D-checks, which consists of the heaviest type of maintenance, however these are less relevant for this research.

cards. Job cards are known tasks that have to be performed during the maintenance check. These known job cards, called **Routine Job Cards (RCs)**, are scheduled in one or multiple shifts, depending on their characteristics with respect to their duration and/or their relation to other cards. They are scheduled according to a general base plan, which takes into account most of their complex relations. However, one cannot simply execute all these tasks according to the generated schedule. The scheduled sequence of cards is affected by disturbances, variability in the labour capacity, and the **Non-Routine Job Cards (NRCs)** that are generated from the known RCs[5]. Given that this variation affects the possibility of completing job cards, planners are forced to reschedule the sequence used to complete RCs and NRCs in the different shifts. Without rescheduling, it would not be possible to maintain the due date of the maintenance visit that VO-H had promised to the related customers. However, the (re-)scheduling of RCs and NRCs is a difficult process, as these cards have a high number of interdependencies, be it through their precedence relations, technical requirements (see example) or having shared resources. This makes it hard to find feasible schedules that fit the given due date, not even considering the sheer number of cards that have to be scheduled (ranging from 600/700 cards to over 3000 cards).

An example of a technical requirement is when welds are being reinforced in the fuel tanks. Work within the fuel tanks can only be executed when the airplane is not carrying electricity (due to safety regulations). Cards that require electricity, e.g. testing if the landing gear contracts correctly, can therefore not be executed simultaneously, which has to be taken into account when scheduling the cards in a static base-plan.

This section provided a global description of the aircraft maintenance process that VO-H is executing. Additional information on the letter checks and the regulations can be found in Appendix 3.

1.2. Motivation

The motivation of this research originates from ‘Securing Our Future (SOF)’, being the reorganisation of KLM E&M. For SOF, ten reorganisation projects have been initiated for VO-H, to realise the seven goals that are shown at the bottom of Figure 2. Amongst others, they aim to increase the productivity, the profitability, and the ability to complete maintenance visits on time. These projects try to reduce the waste in and around maintenance processes by ensuring that the 4Ms[6] that are needed for a job card are made available at the time the card is scheduled. For more information on these projects, we refer to Appendix 4. However, if VO-H wants these projects to succeed, it will be necessary to precisely control the outcome of the scheduling processes. To exemplify, without careful scheduling, it would not be possible to deliver the required materials in the correct shift. For that reason, VO-H desires to study the possibilities of improving the scheduling processes used during the maintenance

[5] An example of when a NRC is created from a RC is when the RC contains inspection tasks, often resulting in NRC repair activities.

[6] 4Ms are the Manpower, Machines, Materials, and Methods that are needed to executed the job card.

visits on Wide Body C-checks. It is necessary that these projects succeed, as the following performance indicators show that VO-H is underperforming.

- VO-H's utilization rate generates an operational loss (≈ 60% of work is paid for)[7]
- Maintenance visits are generally late (for C-checks, on average 1 shift)
- The number of deferred defects (DDs) keeps fluctuating outside of the control parameters for Wide Body airplanes.[8]

Another reason why a study on VO-H's scheduling processes is relevant, is due to the possibilities that VO-H has to influence the reorganisation of its IT-system. This could possibly prevent waste, when the new scheduling processes require (costly) changes to the IT-system. A final reason why a study on these processes is relevant is due to the expected loss of knowledge for VO-H. Due to the reorganisation and approaching retirement, mechanics that currently perform scheduling tasks will be limited to do so in the future.

1.3. Problem statement

The previous section motivated why VO-H desires to analyze the possibilities of improving the scheduling processes of maintenance activities. VO-H would like to study alternative methods of scheduling, to see whether which of these could help it to achieve its goals of the reorganisation. However, based on interviews with the stakeholders of the scheduling processes, we could not conclude that the current scheduling methods are underperforming. The information needed to determine that is currently absent or incorrect. This actually holds for the information that is needed for scheduling in general. For that reason we formulated the problem statement as follows:

VO-H cannot research new scheduling methodologies, as the information that is needed for executing and measuring the scheduling processes is currently absent or incorrect.

To clarify, any scheduling methodology bases its schedules on the input that is entered. This includes basic information on job cards, such as: duration time, the remainder of outstanding work, or the due date of the visit. When information is absent or incorrect, any scheduling methodology is likely to fail in producing accurate schedules. It thus explains why the information related to the execution of scheduling processes is necessary. The same holds for the information that is related to measuring the processes. As VO-H has limited understanding of its own scheduling processes (not knowing who is performing the activities, how schedules are created, and which information is used), VO-H is currently unable to measure the performance of these processes. It is thus not possible to compare the current performance with an alternative methodology. Finally, the limited understanding of the scheduling processes also prevents the search for alternative methods. Without knowing how the job

[7] See Table 6 of Appendix 5 for the utilization rates per hangar.
[8] Deferred defects (DDs) are non-critical maintenance problems that cannot be solved directly and have to be executed during a different visit or between flights.

cards are scheduled currently, there is no basis for selecting a methodology. We therefore have to develop a system or a tool that could present this information, enabling VO-H to analyze different scheduling alternatives.

1.4.Research Goal

The goal of this research is to identify the information needed in the scheduling processes during the maintenance visits, to identify the information that is absent or incorrect, and to generate a solution that will allow VO-H to access that information in future checks. By doing so, this research should support the current scheduling processes and enable future research on job card scheduling.

1.5.Research Scope

The focus of this research will be the scheduling processes before and during the maintenance visits. Assuming the dates of the visits and the scheduling content as given, we will only focus on the job cards and resources used for the visits. We will focus our efforts on the C-checks that are executed within the hangar HIII. Although we will be reviewing the information that is related to job cards, changing the content of these job cards falls out of scope, as that is part of one of the SOF projects. It is possible though, that the findings from this research will serve as recommendation for the related SOF projects. Finally, as this research takes place during the major reorganisation that KLM is implementing, we must take into consideration that the information we use in our analyses is based on the situation before the reorganisation, though the solutions that we will create are designed for the current situation (temporary, due to reorganisation) and future state.

1.6.Stakeholders

The problem statement in Section 1.3 is defined from the management perspective of KLM. The Vice President of KLM E&M[9] is responsible for attaining the increase of productivity for the SOF reorganisation projects. Without attaining the required increase in performance level, the unit manager of VO-H[10] will be held accountable by the executives of E&M and the board of KLM. This perspective is shared by the unit manager of HIII[11], who is responsible for the performance of the C-checks on Wide Body airplanes (e.g., expressed in productivity levels). These management levels are the problem owners. The middle management is responsible for realizing the required control over the scheduling process. They are the decision makers on how processes and roles are defined. The direct stakeholders are the people who feed the scheduling processes and perform the scheduled tasks. They consist of the planners and the mechanics that perform the scheduled tasks and face the problem of formulating daily schedules and finishing them on time, though they are not the problem owners that have need for realizing the desired increase in productivity.

[9] Highlighted green on Appendix 1
[10] Highlighted orange in Appendix 2
[11] Highlighted blue in Appendix 2

1.7. Research questions

Given the problem definition and the goals we presented above, this research aims to answer the following main research question:

How can the information issues in the scheduling processes of VO-H be eliminated, such that it would be possible for future research to analyze alternative scheduling methodologies?

To answer this main question, we will need to describe the size of the problem by analyzing what kind of information is absent in the current situation. As there might be different causes for the absent information, we must decide which causes to include within the model for the solution. Then, given these causes, it will be possible to formulate how the different informational needs can be solved. We should review the different means for solving this problem and try to combine that into a model. This model would then serve as the basis for the technical realization of the solution. This solution, together with an implementation plan, will solve the main problem of VO-H.

However, to execute these steps of analysing the problem, modelling the alternatives, and realising them in a solution, we will first need to address literature for suitable methods. As such, we present the following research questions, which structure this report and answer the main research question.

1. Which methods can be found in literature to analyse the informational needs in scheduling processes, can be used for measuring scheduling performance, and to present this absent scheduling information in a solution? **(Chapter 2)**

2. What are the informational needs in the current situation of the scheduling processes? **(Chapter 3)**
    - Regarding the scheduling content – the job cards?
    - Regarding the processes and methods that are used?

3. How can we ensure that the desired information is made available? **(Chapter 4)**
    - Regarding the information that is required for scheduling?
    - Regarding the information that is required for measuring scheduling performances?
    - What model would combine the possible alternatives?

4. How can the suggested model be realised into an implementable tool? **(Chapter 5)**
    - Regarding the constraints for the tool?
    - Regarding the functionalities of the tool?
    - Regarding the usage and implementation of the tool?

1.8.Research approach

The remainder of this research is structured as follows. Chapter 2 provides the scientific means for the current research. A literature study is conducted in order to help us formulate a method for describing the current scheduling processes, how the performance of these processes could be measured, and how the absent information could be accessed and presented. Chapter 3 then describes the scheduling processes within HIII, based on the earlier discussed literature. The analysis of these processes consists of observations that were made while participating in these processes and interviews with the related actors. These findings summarize which information is absent and incorrect. To access and present the absent and incorrect information, Chapter 4 is used to create a model that will solve VO-H's problems and to determine what is necessary to realise the proposed solution. Based on this model, we then propose our solution in Chapter 5. We discuss how the tool was developed, how it was validated, and how it was implemented. Finally, Chapter 6 presents the conclusions of the current research, as well as possibilities for future research.

2. Literature Review

This chapter discusses the literature that is available on scheduling processes, performance measurement of scheduling processes, and the means for presenting process information. These are our three main topics. We will start by presenting the search model that was used for accumulating the literature in Section 2.1, before consecutively discussing these three topics in Sections 2.2, 2.3, and 2.4.

2.1.Literature search model

In order to find literature on the main topics of this research, a literature review was conducted. This review was executed using the search engines of Scopus, University of Twente library, Sciencedirect and Google Scholar[12]. To ensure an efficient and systematic literature search on all three topics, we used the strategy that is depicted in Figure20 of Appendix 6.

The search model shown in Appendix 6 generated a total of *2983* results. These results were found by using one or more of the main topics in either forward or backward search. These were then either expanded or refined via the additional search terms and complemented by the suggested literature. From these results, a total of *72* results have relevancy for this paper, either contributing to the understanding of the scheduling processes or directly help in understanding the measurement of scheduling processes.

2.2. Scheduling processes and information

This section is used to present the literature on scheduling in general, such that we can define the related processes and the information these processes need.

2.2.1. Hierarchical Planning Framework

Herroelen stated: "*Scheduling and sequencing is concerned with the optimal allocation of scarce resources to activities over time*" (2004, p. 1). It is an activity of planning certain conditions, such that an event can take place. However, using the 4M expressing of VO-H, tasks can only be successfully executed, when the required Manpower, Machines, Materials, and Methods are available at the required time. Planning the availability of these 4Ms is normally done by different operational processes. Hans et al. (2007) captured this notion in their research on scheduling activities. They showed that scheduling is executed on either a *strategic*, *tactical*, or *operational* level, and that this is done for the *technological planning*, the *resource capacity planning*, and the *material coordination*. Their research was based on the work done by De Boer (1998) and Zijm (2000), who created frameworks that showed how these different levels of scheduling interact with one another. The scheduling of job cards can also be placed in these frameworks, given that one tries to match tasks

[12] Only used when the availability of articles was limited.

with available resources. The framework of De Boer (Figure 4) therefore helps to identify the processes that are related to job card scheduling.

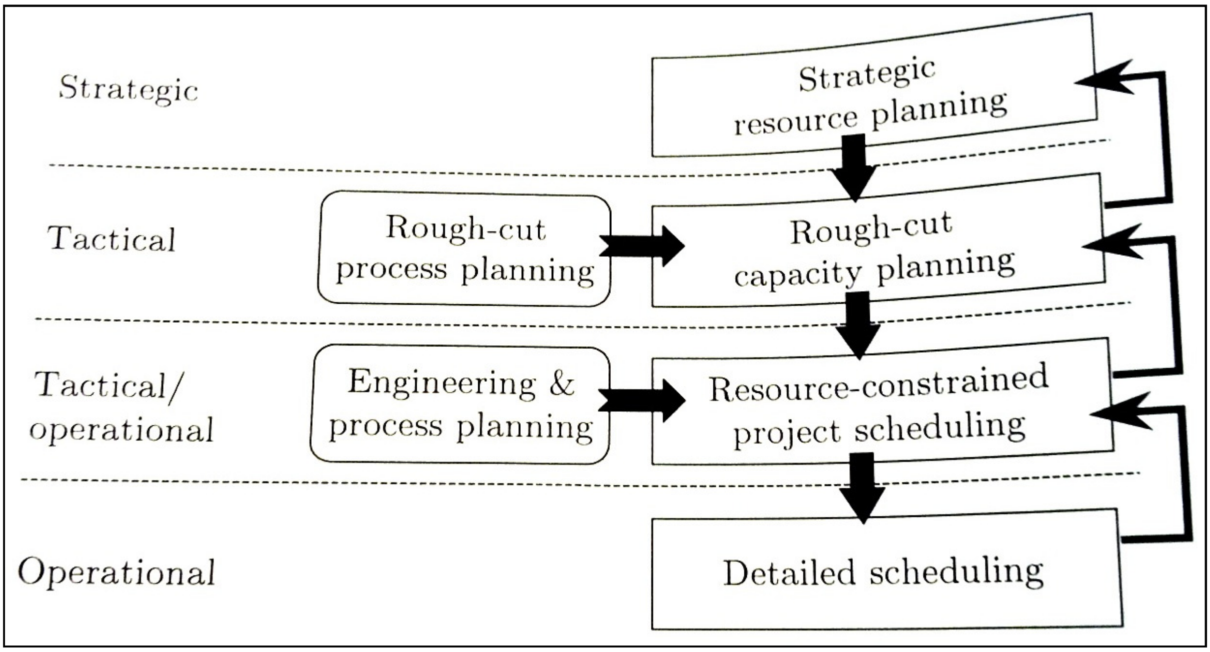


Figure 4: Hierarchical Planning Framework (De Boer, 1998)

The framework depicted above is comparable to the resource capacity planning of Hans et al. (2007), which is defined as Strategic Resource Planning, Rough Cut Capacity Planning (RCCP), Resource Constrained Project Scheduling (RCPS), and Detailed Scheduling. These levels of scheduling differ from one another on the scales of information availability and on decision flexibility. Anthony (1965) defined that strategic decisions are often based on aggregated information. Though the information is therefore less detailed, the larger planning horizon related to strategic decisions also provides additional flexibility for decision making. The exact opposite holds for the operational level of decision making. Translating this information to the result of the analyses of the processes of VO-H, four main processes can be identified of scheduling job cards:

- On a strategic level, the scheduling of visits and assignment of orders and checks to visits;
- On a tactical level, the scheduling of a set of related job cards[13] over the whole visit;
- On a tactical/operational level, assigning job cards to a day (3 shifts);
- On an operational level, the scheduling of cards within a shift.

For our research, we can establish that scheduling on a strategic or operational level are both out of scope. The strategic scheduling is out of scope, as the scheduling of modification orders and checks is not executed by HIII of VO-H, while the scheduling of visits only has limited effect on the operational performance during the visit (e.g. scheduling a visit to have additional days included, might guarantee the due date of the visit). The operational level of scheduling is out of scope, as within a shift, the possibility of scheduling is limited by the choices that were made on a higher level of scheduling. The

[13] In the next chapter we will explain how job cards are grouped for scheduling within VO-H.

scheduling on an operational level therefore has limited effect on the performance of the visit. The performance is mostly influenced by the execution of the chosen cards, not the order in which they are executed.

Given this scope, we conclude that we should focus on the tactical and tactical/operational level of scheduling (RCCP and RCPS). We will now discuss these levels of scheduling, by reviewing the sources of information that can be used.

2.2.2. Scheduling information

From literature we can derive that RCCP addresses medium term capacity planning. As Gademann and Schutten explained (2005), RCCP aims to allocate resources to work packages or jobs of a project over time buckets, such that the expected additional resources or overtime is minimized. Gademann and Schutten defined the term work packages/jobs as a set of activities, which coincides in our research with a set of job cards. Medium term or tactical scheduling is defined as the time window for which one aggregates information to counter the absence of details, while still having the flexibility to change the given capacity levels. One tries to create larger work packages of several activities, in order to aggregate the missing detailed information that is not available in the preparatory phase of scheduling a project. The goal of RCCP is either resource-driven or time-driven, assuming that either of these two is fixed, while the other can be extended for some form of additional costs (Herroelen, Demeulenmeester, & De Reyck, 1997).

For the RCCP, Gademann and Schutten (2005) assume that in a basic RCCP problem, certain aspects of the work package/jobs are known, being the *(resource) requirements per job* and *precedence relations between jobs*. We can also derive that, although the activities within jobs may not be defined, they do describe that the jobs will have their own *release* and *due dates*. These dates limit the *time-window* in which these jobs can be scheduled. Finally, the job descriptions also contain constraints, e.g. the *quantity of work that can be executed per resource, per time unit*. Given these job descriptions, the goal then is to find the *starting* and *completion time* of all jobs, such that the project is finished on time. The value for the goal function depends on the availability of resources. *Per resource category, per time unit*, one must thus know the *quantity of resources used* and *how many resources remain available*. Furthermore, as the usage of additional resources might have costs (hiring or overtime)*, the additional resources required* and *their costs* must also be known for the RCCP problem. This is also described by Masmoudi and Haït (2012), who use a different technique for solving the RCCP problem. Additionally, both articles describe that *variability* can be introduced to the basic RCCP for modelling reality more accurately. This is done by incorporating *uncertainty* that can be present in the characteristics of jobs and resources (e.g. *uncertainty on the release and due dates* or *the required/available amount of resources*). Though there are various techniques for solving the RCCP, the information presented above forms the required input for this scheduling level.

A final source of relevant information is related to in the constraints that one uses in the scheduling processes. Release dates, for example, are required to be set for each job/activity. These are determined by the start of the project, the delivery date of the required materials, and the precedence relations between other jobs (Gademann & Schutten, 2005). Though this type of information is not directly used in the scheduling processes, the information on these additional constraints (*material availability, resource restrictions,* and *precedence relations*) must at least be known and available for those who schedule, for else the dates that are used cannot be determined.

Unlike RCCP, where one still has the flexibility to generate additional resources by hiring extra resources or extending the available time, during RCPS, production orders are scheduled given a fixed constant and continuously available capacity. One tries to schedule a known set of activities, while minimizing throughput time of the found schedule (De Boer, 1998). This level of scheduling requires that more detailed information is available on the *required resources*, *the duration of activities*, and the *precedence relations* between them. Examples can be found in the work of Guldemond et al. (2008) and Möhring (1984), who described how the less standard time-constrained project scheduling problem could be solved. The different variations on the RCPS problem are explained in the work of Herroelen et al. (1997), who provided a classification on the information that is relevant in RCPS. This classification is depicted in Table 1. They have classified the RCPS problem via the characteristics of the resources (α), the characteristics of the activities (β) and the performance measure of the schedule or the goal function (γ). This is relevant for this study, as the different variations of the RCPS level of scheduling require the same type of information as the RCCP level of scheduling. These similarities are pointed out in Appendix 7, where we also explain the abbreviations of the different possibilities for the RCPS problem. The differences that exist are mostly related to the level of detail of the information (as explained in Appendix 7).

Type	Description	Possibilities
α1	# Resources	{o,1,many}
α2	Resource type	{o, 1, t, 1t, v}
α3	Res. Availability	{o, var}
β1	Pre-emption	{o, pre-emption}
β2	Precedence constraints	{o, CPM, Min, Gpr, Prob}
β3	Release dates	{o, rj}
β4	Duration	{o, cont, pj=p}
β5	Deadlines	{o, δj, δn}
β6	Nature resource req.	{o, var, disc, cont, int}
β7	Execution modes	{o, mu, id}
β8	Cash flows	{o, cj, c+j, per, sched}
γ	Resource/Time driven	-

Table 1: RCPS classification by Herroelen et al. (1997)

There are however expansions to and different methods for the standard RCCP and RCPS that require additional information. Multimode RCPS is an expansion of the basic problem that aims to schedule jobs that can be executed using various modes, therefore having *varying resource requirements* and *processing times*. This is for instance explained by DeBlaere et al. (2011) in their work on reactive scheduling for multimode RCPS. From their work we can also deduce that the *generated schedule* and the *current status during executing* are relevant for scheduling. By using this information, one can generate a new schedule for the *remainder of the work.* This reactive approach is a method that solves the RCPS problem by continuously selecting the next best job. The uncertainty that is present in the duration time of projects or the possibility of disruption is incorporated into the schedule, the moment that they become known. Alternatively, uncertainty can also be handled by incorporating it into the base schedule, as Herroelen and Leus (2001) described in their article on critical path scheduling with buffer management. By including *buffers*, a proactive approach aims to maintain the original schedule that realised the highest objective values. *The time between jobs or activities (slack)* is therefore also relevant for the scheduling problem. Besides the usage of different resource requirements, processing times, or slack, these expansions for solving the resource capacity planning problems do not appear to require other sources of information.

2.2.3. Conclusion

In this section we reviewed literature that can be used to identify and describe scheduling processes. Here we found that the *RCCP* and *RCPS* level of scheduling relate to the processes within VO-H. The methods used on these scheduling levels require the following information:

- Job and activity descriptions;
- Resource descriptions;
- Generated schedules;
- Status of finished and remaining work.

2.3. Scheduling performance

In the previous section we discussed the types of scheduling processes that are relevant for VO-H and determined the information these processes need. In this section we will discuss the literature that is available on the performance measurement of scheduling processes (2.3.1) and try to establish how we can incorporate performance measurement in the solution VO-H (2.3.2).

2.3.1. Performance criteria

Looking at the result of the review, we see that there are numerous papers prescribing how new scheduling techniques would perform via measurement of the scheduling processes and outcome they produce. As the following papers exemplify (De Boer, 1998) (Gademann & Schutten, 2005) (Guldemond, Hurink, Paulus, & Schutten, 2008) (De Reyck & Herroelen, 1999) (Leus & Herroelen, 2004), this is often done via benchmark-like techniques. The approach they use is to generate schedules and measure the performance via means of performance indicators (e.g. measure the required additional resource, the makespan or the running time for the algorithms). These indicators are then compared with other techniques that are applied to the same instance or, if possible, the optimal solutions that was found after enumeration. By benchmarking their results, they aim to determine the best possible sequence, process, and/or technique. Especially Kolisch & Sprecher

(1996) demonstrated this by extensively testing different algorithms and settings, comparing the outcome in terms of the scheduling solutions, and comparing the runtime to generate these solutions.

Pinedo (2009), who did research in the field of planning and scheduling, described that for the service industry, the following performance indicators are generally used:

- The makespan of a schedule;
- Setup costs[14];
- Earliness and Tardiness costs;
- Personnel costs (e.g. overtime or additional resources).

Others have also found that the makespan is commonly used for expressing the scheduling performance (e.g. Herroelen (2004), who used the same scheduling software as HIII to determine the makespan). In a different paper of Herroelen and Leus (2001), they state that the makespan is the primary objective for scheduling, while others can be used as additional objectives, e.g. the quantity of work in progress, the net present value, limited time for support activities, or minimizing the amount of rework. Though the latter group seems less relevant to the service industry of KLM (Pinedo, 2009), it does show that most literature favours makespan as the most important objective.

The research by De Boer (1998) provided additional insights, explaining that the RCCP level of scheduling (often used for order acceptance) should make decisions based on the reliability of due dates that schedules generate and how these schedules impact the prior accepted workload. Other indicators as the runtime of the scheduling process or the number of alternative schedules created can be identified as characteristics related of the actual scheduling process (regardless of the quality of the schedule) (Hurink, Kok, Paulus, & Schutten, 2011). De Snoo et al. (2011) explained in their paper however, that relatively limited research has been done on determining which performance indicators are most suited to measure the performance of scheduling processes. By means of qualitative research[15], they determined various indicators that can be used for measuring the scheduling processes, e.g. the number of scheduling errors, the cost of executing the schedule or the utilization rate reached). What they prescribe is indeed a categorization between the different indicators, displayed in Figure 5 on the next page.

[14] Setup costs are relevant for the scheduling processes at KLM, though more particularly for HI. In HI, the airplanes are repositioned between the maintenance docks that are available. For HIII, this only occurs as an exception, though setup costs can still be present, in the form of fuelling and jacking the airplane.

[15] Their conclusions are based on the interviews that were conducted with several managers/planners from different companies. These results were however not tested in an actual case study.

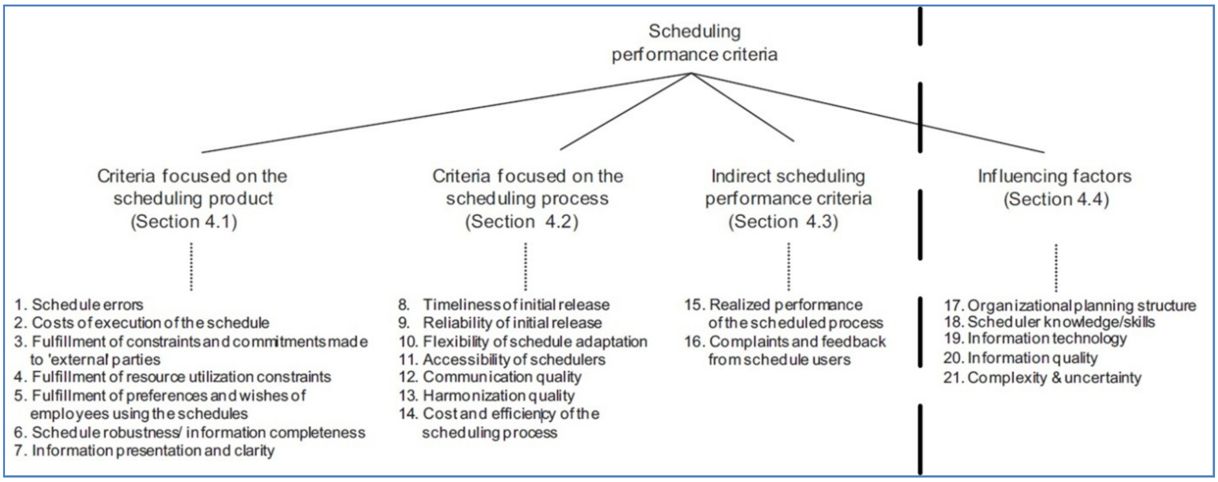


Figure 5: Adapted version of De Snoo et al.' scheduling performance measures framework (2011)

In the figure above, De Snoo et al. (2011) distinguished four types of criteria, of which three can be used for measuring the scheduling performance of an organisation. The fourth category they presented is not used for measuring performance, but is used to indicate factors that influence the performance of the schedule and/or scheduling process. The direct criteria found by De Snoo et al. (2011)support our findings from the works described above, being that the performance of scheduling processes and techniques can only be measured by benchmarking them against known optima or results generated by other techniques. However, besides looking at criteria that are focused on the scheduling product (e.g. the makespan [2]) or the criteria for the scheduling process (e.g. the run time [8-10][16]), they also include the actual performance that is realised by that schedule and the amount of feedback that is generated afterwards. Although these criteria can be used for measuring performance, it does bring the user onto a slippery slope. This is due to the none-scheduling related factors that affect the indirect criteria. It is for instance questionable whether the number of complaints is an objective measure, given that humans tend to complain in negative circumstances, compared to positive circumstances (e.g. the different phases of economic climate would generate more or less complaints on the same schedule) (Taylor & Gollwitzer, 1995). Then again, a schedule generated with a lower output score might be accepted in such a way that all the workers are extra motivated to work on it, increasing their productivity and in the end realizing better results. Therefore, if indirect measures were to be included into the performance measurement, then it must be important to control the circumstances in which the performance measurements take place for ensuring reliable results.

Based on the literature we described above, we can conclude that the performance of scheduling processes can be expressed via performance indicators, which can be compared to optima or benchmarked against performances of other scheduling techniques.

[16] Runtime impacts the flexibility that one has to generate new schedules and how much time one will have between generating the scheduling and its possible release, assuming that information will be available at the same point in time.

2.3.2. Measurement technique

The previous subsection provided a general description of the performance measurement of scheduling processes. Using literature on performance measurement techniques, we will now explain why it is necessary to limited set of performance indicators, better known as key performance indicators (KPIs).

KPIs are the results from measurements, used for analyzing the performance of business or processes (Eccles, 1991). They are the few indicators or criteria that signal the user, whether their processes are performing as desired, as Franceschini et al. (2007) describe while discussing the Tableau de Bord (Performance Dashboard) of Gaillard (1990). One uses a limited set of indicators, as the measurement of these indicators will cost resources. (E.g. measuring indicators that are not relevant for optimizing a process, would work counterproductive in improving the productivity.) Another reason for using a limited set of indicators is due to the loss of discriminative power it might cause. When applying KPIs in a benchmarking technique, one compares how several alternatives perform on different criteria (the KPIs). These multicriteria decision making analyses (MCDA) help to formulate one answer, when deciding which of the alternatives would perform best (Greco, Matarazzo, & Slowinski, 2001). By using too many criteria and/or weighing them incorrectly, one would lose the ability to clear distinct the different alternatives from one another. Analytical Hierarchy Process (AHP) is an MCDA that might beneficial for KLM. By relatively scoring how each alternative scores on each criterion and using a relative ranking system to add up the scores on different criteria, it will be possible to determine the schedule that performs best (Saaty, 1987). Important though, is that the chosen criteria a defined SMART, the abbreviation for indicators that are specific, measurable, achievable, relevant, and time-bounded (Piskurich & Piskurich, 2006). An obvious notion, though important, as this research is focused on the absence of information. When the chosen indicators cannot be measured or only are not specific enough, then it would be best to use other indicators.

In this research, we should thus select a few KPIs that VO-H could use for evaluating alternatives. While choosing these indicators, we should ensure that the information these indicators need is indeed available.

2.3.3. Conclusion

In this section we reviewed the literature on performance measurement of scheduling processes to determine how VO-H could compare alternative scheduling methods. We saw that most scheduling processes are evaluated by comparing the KPIs of the process, with the values of alternative methods or optima. We also established that KPIs should be for VO-H, based on the information that is available for the KPI and based on the relevance of the indicator for VO-H. The scores of the KPIs can be compared, using an MCDA, as AHP.

2.4. Accessing and presenting scheduling information

In this section, we will review literature to analyze the possibilities of accessing and presenting the information needed for scheduling job cards and measuring the performance of that process. We will first review the concept of Management Information Systems (MIS), before we review the methods for developing a possible tool.

2.4.1. Management information system

In the problem definition, we described that the information, which planners and managers within VO-H must access, will have three generic roles. First, there must be a function or process that stores the desired information on an accessible database. Then, a process should be in place to convert the stored information into the desired information output (e.g. present the summation of outstanding work for one resource). Finally, this output should be accessible again by the relevant user in the scheduling problem.

These three generic roles are comparable to De Boer's idea (1998) for using Decision Support Systems (DSS) to support a portfolio management team. DSS are a type of Management Information Systems (MIS) that assist managers in different decision making processes (Akoka, 1981). Mallach (1994) uses a comparable definition, describing DSS as information systems that support workers with information, such that they can make informed decisions. As described by Sprague (1980), these systems generally contain three basic elements: a database, some modelling software, and the software that is used as user interface. Using Alters Taxonomy (Alter, 1977), MIS can be ranked via a 7-layered hierarchy framework. The order in which they are ranked is based on their processing capabilities, ranging from systems that are limited to structure data items, to systems that would generate suggestions for using certain alternatives. It can thus be described as software that combines the available information into one database (lowest level) and depending on its intelligence, it can either only structure and present the information or use that information to make decisions and create schedules on its own. This ranking is also in line with the description that Millet and MawHinney (1992) use for describing the difference between MIS and Executive Information Systems. However, the performance of any version of MIS is dependent of the quality of information that it can use (De Boer, 1998). When the information from databases is incorrect or absent, it would be of significantly limited value for the users.

Keeping our objects in mind, the initial goal will be to develop a lower level MIS, which can structure and present the desired scheduling and process information, taking into account that it will have to work with limited/incorrect input.

2.4.2. Software development

The section above explained that MIS are suitable alternative for accessing and presenting the information that VO-H requires. Here, we will discuss the possible development techniques for creating MIS.

Software development methods can be categorized on the range from predictive to adaptive software development, respectively known as the Waterfall-approach and Agile Software development (Amrit, 2011). Both methods are used to plan the development of software from the initial idea to the (final) working product using roughly the same stages, though they have opposite approaches. The development stages of software development, or the Software Development Life Cycle (SDLC), describe how these steps are executed (Jirava, 2004). McDowell (1991) explains that the SDLC is used to develop software in roughly four phases. First, the requirements should be formulated, followed by an analysis of the possible alternatives. Then these alternatives should be used to design and develop the tool, whereas the final phase is used to test and implement the tool. This is the predictive approach, for which the entire cycle is traversed only once. In more recent days, the ridged sequential approach of the SDLC has often been adapted, such that developers can deal with changing demands, shorter lead times, and more adaptable for possible errors in the software. Instead of consecutively executing the four main phases, smaller cycles are executed, each being a stand-alone project that delivers working prototypes. This adaptive way of programming allows the programmer to build and expand small prototypes, making it is possible to gradually build the system that one initially plans for. This process is depicted in Figure 6.

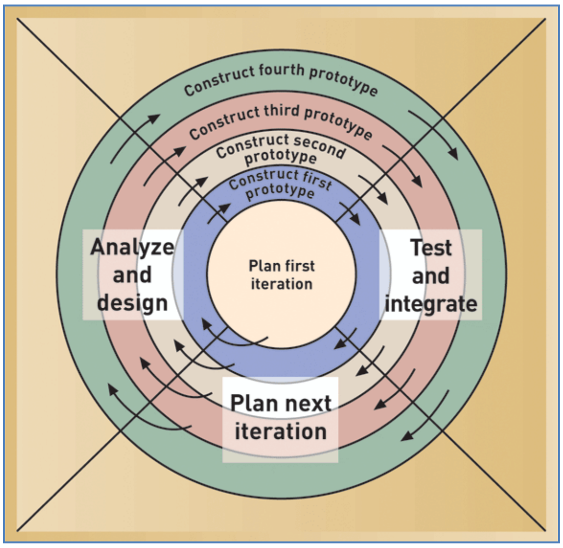


Figure 6: Adapted version of Software Development Life Cycle (adaptive) (Amrit, 2011)

The advantage of using the adaptive over the traditional approach is that practical problems in the design stage (e.g. desired information cannot be accessed) do not lead in major redevelopment efforts. Furthermore, using working prototypes over one final product increases the user involvement, an effect that would benefit the quality of the product (Anderson, 1985). We thus conclude that agile software development is the most suited developing the MIS.

2.4.3. Conclusion

This sector reviewed how the information that VO-H requires can be accessed and presented and how that solution could be developed. For accessing and presenting the desired information, it is possible to use MIS. During the development, one must however decide which functionalities it will have. This depends on the types of users and decisions it should make and the availability of the necessary information. For developing such a tool, it would be best to use the adaptive Software Development Life Cycle (SDLC) to continuously expand the working prototypes that are created each cycle.

2.5. Conclusion

In this chapter we performed a literature review to answer the research question that is stated below.

1. Which methods can be found in literature to analyse the informational needs in scheduling processes, can be used for measuring scheduling performance, and to present this absent scheduling information in a solution?

Here we found that we can describe the relevant scheduling processes within VO-H via the Hierarchical Planning Framework of De Boer (1998), limiting ourselves to the RCCP and RCPS level of scheduling. We also found that the related scheduling processes require information on the jobs and activities details (both aggregate and detailed), a description of the used and available resources, the generated schedules, and the status of the completed and remaining work. In the next chapters we can thus review, whether this information is available for these processes.

Based on the literature, we conclude that the performance of schedules and scheduling process should be expressed via performance indicators. These could be compared with optima or alternative methods, to evaluate the quality of the schedule/process in question (e.g. using AHP as method for comparing). Amongst others, De Snoo et al. (2011) provided several indicators that can be used for our measurement problem. However, we also established that only a few indicators should be used. We should therefore review in Chapter 3, whether the necessary information for the indicators is available and decide in Chapter 4, which for the indicators are most suited for solving VO-H's problem.

In the last section we reviewed how VO-H can access and present the information it requires and how this solution could be developed. We found that Management Information Systems are suited for accessing and presenting the desired information. By using an adaptive software development approach, we can ensure that the functionalities that are added are based on information that is correct and available, thus supporting in the development of the tool.

With this, we thus answered our first research question.

3. Current situation: Information and scheduling processes

In this chapter we discuss the current situation of the scheduling processes within HIII of VO-H. In Section 3.1, we will review the information that is available on job cards, before we analyze in Section 3.2 how these are scheduled. We thus determine which information is available and which is absent/incorrect, providing us the answer to the second research question.

3.1. Job card information

Before we explain how job cards are scheduled, we will first discuss the information that is available on job cards. This will be done by reviewing how job cards are created for a maintenance visit (3.1.1), by describing their known characteristics (3.1.2), and to determine when this information becomes available for scheduling (3.1.3). In Section 3.1.4 we will then summarize the problems that are found.

3.1.1. General overview

Maintenance visits are performed by completing the job cards for various types of maintenance activities. On the one hand, preventive maintenance is executed to secure the airworthiness of the airplanes via known Routine Cards (RCs). While on the other hand, corrective maintenance is used to repair the faults that are found either during inspections or during flight. There are therefore two types of maintenance activities that are executed during the maintenance visits, which are depicted in Figure 7 below. On the left, the largest part of the maintenance visit is depicted, consisting of the main letter check and additional orders from smaller letter checks or e.g. modification orders. On the right, activities generated from the current status of the aircraft are displayed. Let us now review the groups of maintenance activities that generate the job cards in the maintenance package of the maintenance visit.

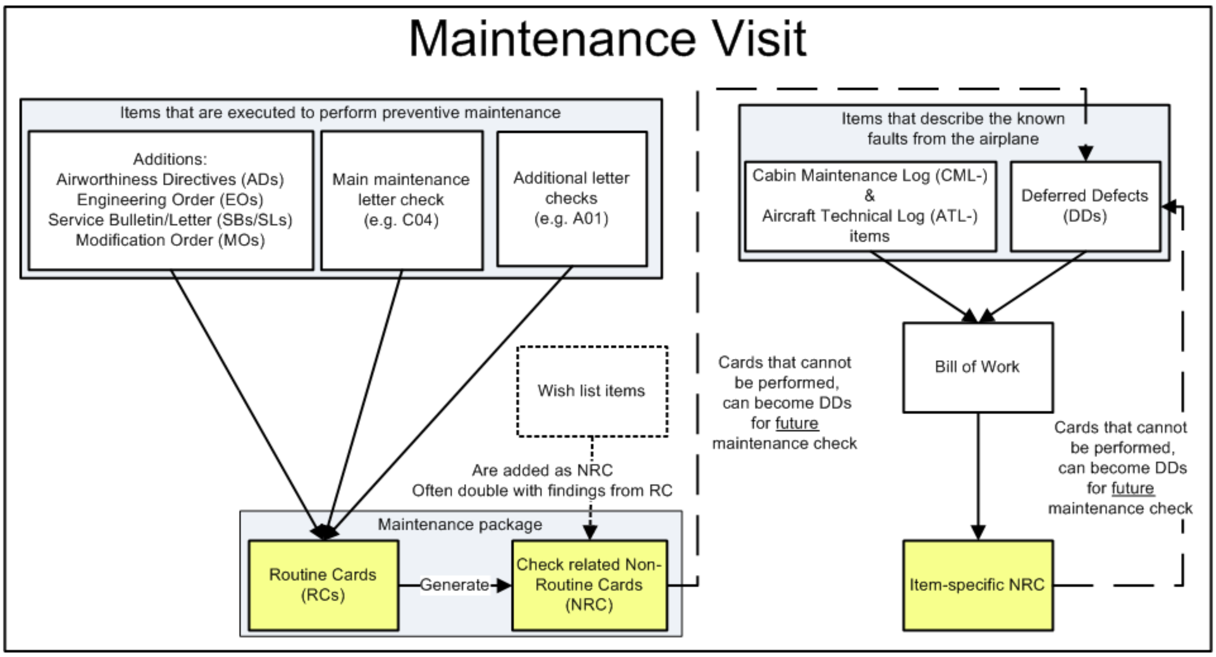


Figure 7: Overview of all the maintenance activities during a visit

Maintenance Package: Letter checks, ADs, EOs, SBs/SLs, and MOs

The *maintenance package* is the entire set of job cards that has to be completed during a visit. Most of the maintenance hours in this package are related to the main maintenance letter check. As explained earlier, the airplane can be scheduled to visit HIII for a C04-maintenance check. This means that all the job cards that are described as mandatory by legal documents that define the C04-check, are included into the maintenance package[17]. These cards should be completed during this visit, as they are required to be completed before a certain due date, expressed in a number of days or flight cycles. The number of cards in the maintenance package can grow by adding additional smaller letter-checks, e.g. an M-check, which mostly focuses on one engine system of the airplane. Additionally, job cards as those that make up the Modification Orders (MOs) or Airworthiness Directives (ADs) can be added to the maintenance package. Together, they form the known set of cards that can be scheduled during the maintenance visit.

Deciding when certain letter checks are due and combining them with the available maintenance visits is an important scheduling process. Although KLM E&M performs this scheduling activity, KLM Fleet Services is responsible for ensuring that the overall due dates on the letter checks and additional orders are met. How this process is relevant for this research is explained in Section 3.2. For now, it is important to know that some of these scheduling decisions are made right before or even during a visit, as we determined after analyzing the last 23 maintenance checks[18]. This deviates from the agreements that are displayed in Figure 8, later on in this section. As this information is made available to the planners in the final phase of the scheduling process, limited flexibility remains to change an earlier created schedule or to hire additional capacity.

CML/ATL, MEL, Deferred Defects, and the Bill of Work

Before we focus on the specifics of RC and NRCs, let us first describe the other set of maintenance activities that are executed during the visit. Not surprisingly, the condition of the airplane will deteriorate during flights and over time. Faults found during flight or at the gates are logged in the so-called Cabin Maintenance Log (CML) and Aircraft Technical Log (ATL). These logs contain items that should be reviewed for complaints and should be either be solved or defined as deferred defect (DD – a fault that is repaired in a later visit). When for instance a seat breaks down during flight, it is unlikely that a foreign airport will have a spare seat that can be installed between flights. Given that the fault is analyzed and it has been determined that it could not be repaired at that particular point in time, this fault will be defined as DD. These DDs are given due dates, depending on the severity of the

[17] The legal documents refer to the regulations that are described in the EASA/FAA regulations, see Appendix 3

[18] Between October 2013 and April 2014, 23 Maintenance checks were executed (not including modifications). To 17 of the 23 checks, a smaller M- or A-check was added just before or during the maintenance checks. (Slot & Kleijne, 2014). See Appendix 12

fault.[19] DDs are therefore objects that can be assigned or transferred to a particular maintenance visit, depending on the due date of the DD. The same holds for cards that are not critical for flight, which can receive extended due dates by Boeing or KLM Engineering and cannot be performed during that visit[20]. These cards might also become DDs, if the current visit cannot solve that particular fault.

Though most DDs are known beforehand and can be added to the initial schedule in the weeks before a visit, some of them will still be added at the start of the visit, given the latest findings during its last flights. The new and/or scheduled DDs, together with the latest CML/ATL-items, form the Bill of Work (BOW). The general agreement between Fleet Services and E&M is that roughly 30 man-hours are reserved for new CML/ATL-items. If more work is required, this will thus impact generated schedules and/or resource capacity expectations. This is a problem for VO-H, as we established from interviewing mechanics and cross-referencing it with the item information, that information on these items is often incorrect. In the limited analyses that we could perform on these cards[21], we found that roughly 25% to 50% of the items on these list were given duration times that were incorrect. These vary from incorrect job description, absent/incorrect duration time, or absent/incorrect material requirement information. As a logical consequence, these cards thus disrupt the sequence of the scheduled cards, possibly affecting the makespan of the maintenance visit. Furthermore, as the information related to these BOW-items is retrieved by the planners at the start of the maintenance visit (and not in the weeks before), again limited flexibility is available for altering the chosen sequences, hire additional capacity or materials.

Wish list items

Finally, there is one more group that generates orders for the maintenance visit. KLM Fleet Services executes its own quality assessment on the cabins of airplanes, which is not related to any of the maintenance checks. The items they inspect are not safety related, but focus on items related to aesthetics and customers satisfaction. During these inspections, findings are requested to be repaired during one of the maintenance visits and are referred to as wish list items. However, wish list items often generate duplicate job cards, as mandatory inspections in the regular letter checks also cover the same areas as the wish list items prescribe. Checking these items creates an additional administrative workload for the mechanics, which is counterproductive to the ‘hands-on-mental’ goal of the SOF-projects. Furthermore, the related demand for resources that the planners use is also doubled. This

[19] The severity of faults and their related due dates are defined in documents called MELs, Minimum Equipment Lists. These are documents that behold agreements between KLM Fleet Services and E&M (in case of the KLM MEL) and should always be better than the minimum requirements that were set in the Boeing/Airbus MELs.

[20] There are limited reasons for deferring findings. Only NRCs and ATL/CML-items can be defined as DDs, when there are no materials available, or when there is not enough time to complete that card. The creation of DDs is not a desirable outcome; therefore this will generally be avoided if possible. Most importantly, DDs are about deferring cards to other checks (or line maintenance), not simply postponing cards during the same check.

[21] It is limited, as the generated items on the list are very much depended on the condition of the aircraft, the previous flights it made, and previous maintenance activities. It is therefore advisable to conduct additional research on these deviations, to ensure that our initial findings are indeed accurate.

creates fictional demand levels for capacity, making it hard to estimate whether the due dates can be guaranteed or not. Interestingly though is the manner in which these items can be treated. Normally, a mechanic copies them onto a newly created NRC that is related to the letter-check. When this happens, it will become mandatory to execute this particular card. Also, the planners will not be able to differentiate between these NRCs and the letter check NRCs, making it hard to determine if these cards can be deferred or not. However, if they are not defined via letter-check related NRCs, then these items can still be ignored for this maintenance visit (as they are not safety related). Given that there are no clear agreements about how many of these items should be executed or what the urgency for completing these wish list items is, the planners are hindered in determining how much additional capacity is required.

3.1.2. Job cards – RC and NRC

Job cards can be defined as a formal assignment that will be executed by one or multiple certified employees, who perform one or multiple activities on a certain work area of the airplane. This could be for example: "Perform a detailed inspection on Door #4 in zone 450" (KLM E&M, 2013). This means that several activities – inspecting various aspects of that particular engine door – will have to be executed, before this job card is completed. When they are known beforehand, they are defined as routine cards, while non-routine cards are those cards that are generated from the findings during the checks (or via wish list). Examples of these two types of job cards can be found in Appendix 8, which show that job cards are defined via the following characteristics (except for the last point, this only holds for RC cards).

- Job card identification;
    - Barcode and numbers;
- Check identification;
    - Specifying which check and aircraft it belongs to;
- **Job description;**
    - Task type & Required skill;
    - The number of hours/men needed (sum over all activities);
    - Zone of activity;
    - Production phase ;
- List of activities;
    - Per item the description & related manuals ;
      (Stating which materials should be used and how it should be repaired);
- **List of access panels;**
    - Need to be opened/closed to complete this card;
- **Related NRCs;**
    - The NRCs that are generated from this RC cards.

From these characteristics, the job description, the list of access panels, and the related NRCs (bold) are the most relevant for the scheduling processes. The job description defines the activity, stating where, how long, and by whom this job should be executed. Via the production phase, the progress on a specific stage can be reviewed (e.g. the progress on all cards that are identified as inspection cards). The duration time of job cards is initially based on the suggested duration that the manufacturer provides for that job cards (e.g. Boeing suggests that the door inspection would take 3 hours). The suggested durations are reviewed by the support staff of VO-H and are adapted to a more reasonable expectation. These expectations can still deviate from the actual duration, as their estimates are less accurate than those of the mechanics who perform these job cards. Therefore, besides natural variation, large discrepancies are generated between the calculated and spent hours. These discrepancies occur more often, as not all the job cards are reviewed before they are included in a maintenance package. As seen in Table 7 in Appendix 5 and Tables 9 and 10 in Appendix 9 show, we calculated that roughly 20% of the job cards require one additional man-hours (versus calculated), which results in an additional requirement of 5 FTEs for a weekly visit. Discrepancies (both positive and negative) between the spent and calculated hours are sources of variation that has to be dealt with in the schedules. Though large discrepancies are exceptional, having better estimates for the job cards would help to increase the accuracy of the schedules and thus support the desired increase in productivity.

Besides discrepancies between the spent and calculated hours, the fact that job cards can be executed in various modes also complicates the scheduling process, while it is not specified which mode is indicated by the 3 man-hours that mentioned in the example above. KLM currently does not have a database that can be used to view different modes for executing job cards, while most do have multiple execution modes[22].

The list of access panels influences the precedence relations between cards, as all panels need to be opened, before that job can be started. This impacts the sequence of executing cards, just as the related NRCs might do. For NRCs, these characteristics are created by the mechanics that created that particular NRC. When the mechanic creates this NRC, he or she is responsible for filling in the correct information and determining its duration time. This duration time of NRCs is estimated and based on the experience of that engineer, as there are currently no databases available, which contain information on regularly found faults that could help in the estimation. The description of the NRC is often incorrect, as the description for solving the fault, the zone/team description, or the required hours are not filled in. Here we for instance found for incorrect duration time in a sample of 7 visits, that 5 to 15% of the NRCs had a duration time of 0.00 hours (varying from 20 to 100 cards on 200 to 500 NRCs). Without knowing the duration of job cards, the location, and/or the required resources, it becomes hard to schedule the cards effectively.

Important to know though is that one cannot derive all the precedence relations between the cards from the information that is on the cards. This is only indicated for the related NRCs, though they do

[22] Modes are defined as the manner in which the job can be executed. For scheduling, this means that by using a different amount of capacity to perform the job, different duration times can be achieved. As the capacity used and the duration time often do not have a linear relation (in this case, the relation is not even defined), it becomes very hard to find reliable and feasible schedules.

not represent actual precedence relations. The only useful precedence relations/technical requirements are given via the access panels. If these are not completed, then one cannot access the area of that particular job card, making it not possible to start and/or complete this card. The same holds for the absence of technical requirements. On the cards, this information is not given, making it hard to determine which cards can be executed simultaneously and in which order they should be executed[23]. The next section will explain how KLM does manage to schedule the cards.

3.1.3. The T-minus list

Taking the general overview and the job card characteristics into account, we see that the cards that are executed during a check are generated at different points in time. This is also visible in the so-called T-minus list that HIII uses to coordinate activities in the weeks leading to a maintenance check. These activities are expected be completed at specified times, in order to ensure that all the required preparatory work for that maintenance check can be executed on time (including the generation of schedules). Figure 8 on the next page is based on the T-minus list that will be used in the new organisation and is adapted to highlight when and which job cards become known for the scheduling processes[24]. This figure summarizes when cards are added to the maintenance package of the different visits, including those that are generated during the visit. Starting 26 weeks before the actual visit, the T-minus list shows per week the activities that will go due. It shows for instance, that the additional checks or Modifications Orders/Service Bulletins are expected to be added roughly five to ten weeks in advance (t-10 -> t-5). In reality, this still happens in the final week of the visit (t+1). As additional orders are generated close to (or during) the actual maintenance check, limited flexibility remains in finding optimal schedules and hiring additional manpower.

[23] Most of the needed technical requirements are defined in the different maintenance manuals. However, the information in these manuals is not linked with the scheduling systems.
[24] Appendix 10 and 11 contain the items of the old and new T-minus lists that KLM uses in the preparations for maintenance checks.

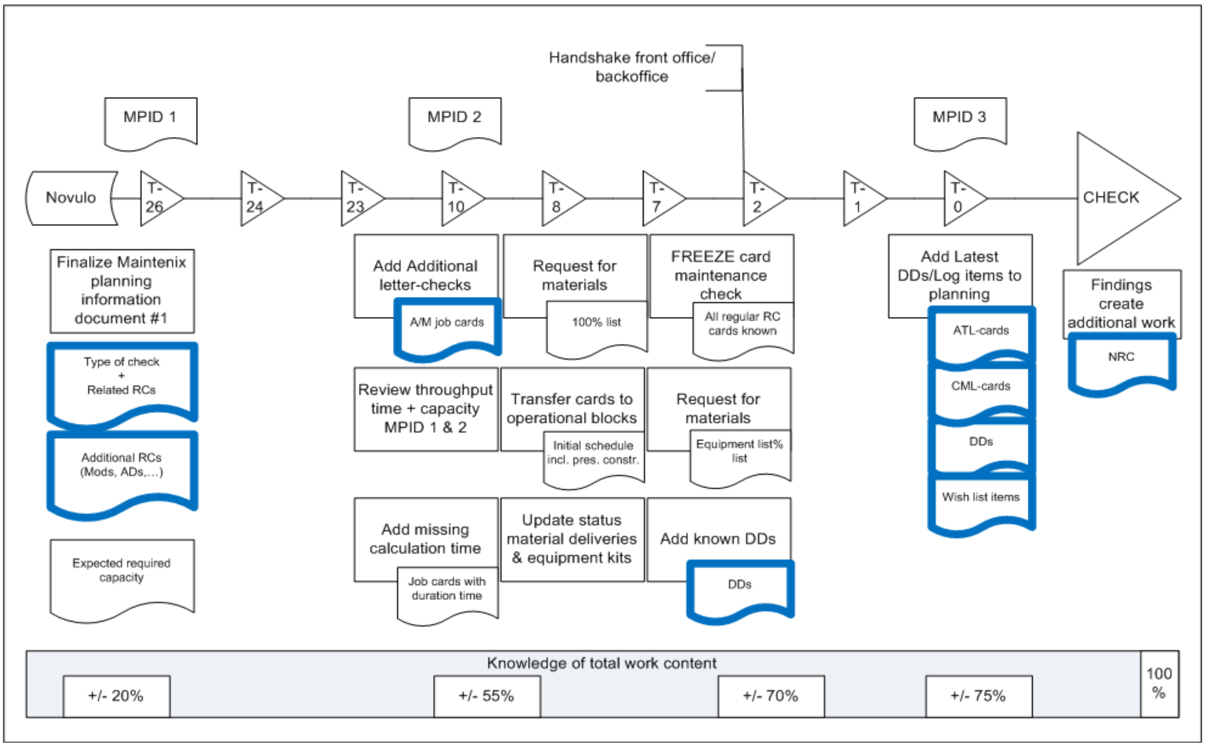


Figure 8: T-minus list Flowchart + work content progress (T-minus in weeks)

3.1.4. Summary of problems and where additional information is needed

The previous subsection showed that in the current situation, there are several problems in the availability of information related to job cards. We found that:

- Job cards are still being added to the maintenance package, right before the check is planned, limiting the possibilities for matching capacity and finding optimal schedules;
- Prioritization between jobs in the maintenance package is difficult, given the absence of prioritization agreements;
- Job cards lack vital information for scheduling;
  - Precedence relations between cards are not defined;
  - Technical requirements cannot easily be found;
  - The location (zones) and duration are not defined for some cards;
  - The capacity requirements and related duration when executing tasks in different modes is not defined;
  - The required time for cards is specified incorrectly;
- Wish list items form duplicate cards with regular job cards.

As we described in Section 2.2, scheduling processes require both aggregated and details description of the job cards. As these are often incorrect or incomplete, it explains why VO-H currently finds it difficult to generate job card schedules. This summarizes the problems that are related to job cards. The next section will review how job cards are scheduled and the problems that are related to that.

3.2. Scheduling processes and measurement

The previous section explained what job cards are, when they become available for scheduling, and which problems are encountered with respect to the information that is available on them. In this section we will discuss how job cards are scheduled during the maintenance visit and the problems that are encountered. We will first discuss the general scheduling processes (3.2.1), before reviewing the problems related to the RCCP (3.2.2), the RCPS (3.2.3) and the problems related to the performance measurement of schedules (3.2.4).

3.2.1. How job cards and scheduling blocks are scheduled

As we explained in the first chapter, the scheduling of job cards is not an easy assignment. With several hundreds or thousands of cards in a maintenance package, VO-H uses objects called scheduling blocks to schedule sets of job cards over multiple shifts of the visit. Scheduling blocks are defined via four different characteristics. They are identified via the code L_SH01_100_1, which indicate the team, the shift, the zone, and the production phase. Here, the team indicates a certain human resource type, the shift-code is currently not used by HIII, the zone indicates a specific working area of the airplane, and the production phases are linked to the general maintenance steps (open, inspect, NRC, etc...). The blocks themselves contain one or more job cards and are used to schedule the cards throughout the check, as Figures 9, 10 below exemplify.

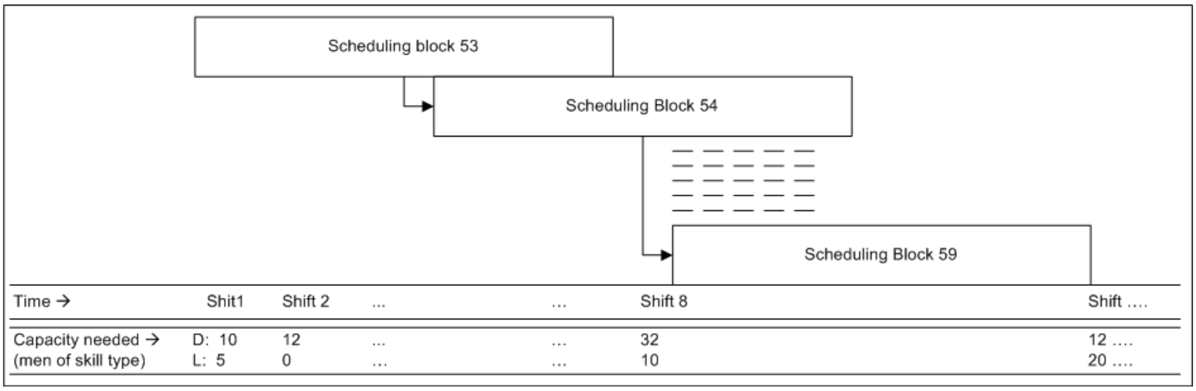


Figure 9: Example of generated schedule – zoomed at scheduling block level.

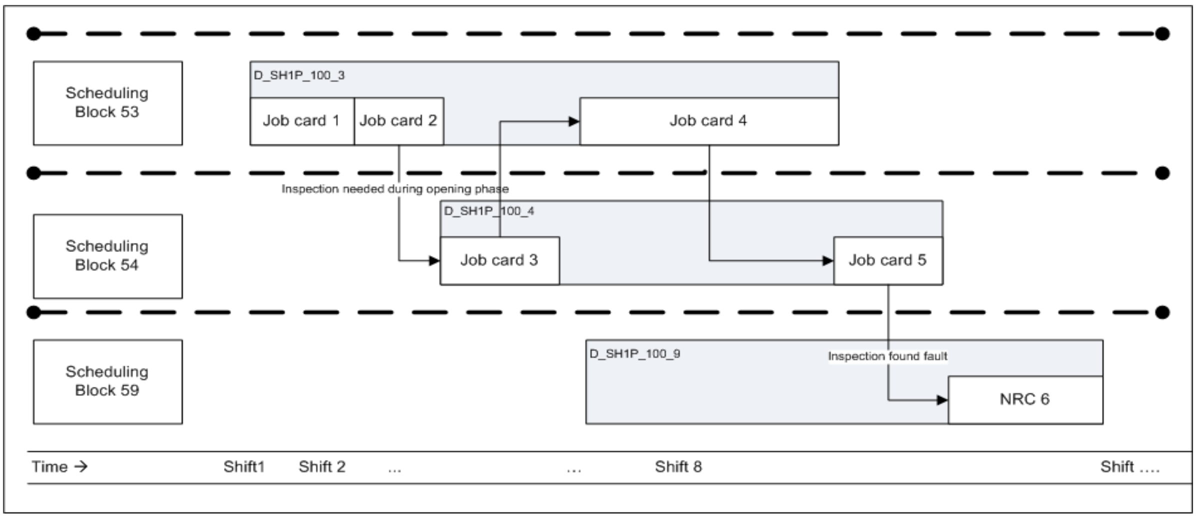


Figure 10: Example of same section, now zoomed to job card level

Figures 9 and 10 are illustrations of a partial schedule for the maintenance visit. The blocks shown in these examples above include the precedence relations that exist between the cards that they represent. These relations are manually added based on their content, as the job cards themselves do not contain accessible information on precedence relations (expect for panels and NRCs). A set of these scheduling blocks is related to only one zone and one team. In total, there are several hundreds of these sets of blocks, which may have hard precedence relations or only a preferred execution sequence. It is therefore possible to generate many different sequences, making it difficult to find the optimal schedule. Also, looking at Block 59 in Figure10, one can see that this NRC block is reserved for multiple shifts, while only after job card 5, an NRC is generated. If actual capacity were to be reserved during this time, the utilization rate of the production would decrease (given the absence of work). Vice versa, if capacity is not reserved, this could delay the rest of the scheduled cards.

As can be seen, these blocks are scheduled over the entire makespan of the visit. As a result, they create a selection of job cards that can be scheduling for a particular day. The scheduling of blocks (RCCP) and the daily assignment of cards to shifts (RCPS) are the two levels of scheduling we review. This might seem somewhat contrary to the standard RCCP, as one tries to aggregate information into a limited number of manageable scheduling blocks, reducing the error margin that a more detailed schedule creates (Gademann & Schutten, 2005). One might think it would therefore resemble the RCPS, which is less aggregated than the RCCP. However, the nature of aircraft maintenance makes that the full scope of to-be scheduled orders is still unknown, being a general requirement for RCPS. Though the high number of scheduling blocks is not standard for a RCCP, it is required to capture the complexity that is related to the different job cards. The same contradiction holds for describing the assignment of job cards to shifts as RCPS. Though for a standard RCPS, the set of activities should be known before they are assigned, for VO-H, NRCs are created and prioritized over the generated schedule. Then again, this does resemble the possibility of having rush jobs or breaks down, thus supporting our motivation for categorizing the assignment of job cards to shifts as RCPS.

Let us now review in details how blocks and cards are scheduled on these levels.

3.2.2. Rough Cut Capacity Planning: Visit-level block scheduling

Reviewing the scheduling techniques more closely, we see that days (3 shifts) are used as time buckets, to which planners assign portions of the scheduling block. With that they aim to complete the visit without any overtime and without hiring additional resources. In other words, by moving, increasing, and decreasing the scheduling blocks over the length of the visit, the planners intend that (a proportion of) one or multiple job cards are assigned to one or multiple shifts, via a certain execution mode. This process is mostly time-driven, as in the weeks before and even during the check, planners still have the flexibility to hire additional resources e.g. from other hangers. For this research, we assume that there is still flexibility if requests are made 24 hours in advance. To emphasize, this process is *mostly* time-driven, as there is also the option to extend the duration of the check if that were necessary. This is however the least favourable outcome, given E&M' mission to support KLM, by ensuring the dates that airplanes are available for flights (thus requiring the improvement of due date KPI). This option will therefore not be viewed as an admissible outcome at this level of scheduling. What is important to note, is that the planners adapt the originally generated plan every 24 hours, as new information becomes available on the progress that was made on the known cards and the NRC cards that were generated during one of the previous shifts.

Looking specifically to the alteration of blocks, this is dependent on the content of the blocks and its relations with other blocks. By increasing or decreasing the size of scheduling blocks, one assumes that the cards it contains can also be decreased or increased in duration time, if different capacity levels were used to execute them. However, Section 3.1 showed that the characteristics on executing cards in different modes are not known in the system. As a result, the planners do not use upper or lower bounds for which the scheduling blocks can be adapted. This results in the possibility that infeasible schedules are created. As this knowledge is not described on the job cards, this process depends very much on the experience of the planners and the mechanics they consult. Here one also assumes that there is enough flexibility to increase or decrease the demand for capacity during the checks. It thus more resembles resource-driven RCCP, explaining the tendency to see the due date of the check as flexible. On the other hand, if increasing the length of the block threatens the due date of maintenance check, then the planners would ask for additional capacity. By doing so, they try to minimize the need for hiring additional capacity per check.

Moving scheduling blocks forwards or backwards in the check, one must take into account the precedence relations between job cards. The planners have to consider two types of precedence relations. The first is created between job cards in blocks that differ only on their production phase. The second is between job cards in blocks that are given to different teams and/or working areas. The problem with these types of relations is that they are based on the precedence relations between cards and not between scheduling blocks. As the content of a block changes for every visit[25], its precedence relations with other blocks might also change. This makes it harder to generate feasible schedules, given the limited visibility on present precedence relations (as was explained in Section 3.1).

The changing precedence relations are not limited to different visits; they also affect the NRC blocks. NRC blocks have one major milestone linked that is linked to all of them, being that all NRCs are expected to be completed before the test phase starts. Though this might not be actually required[26], it does hold for all the NRC scheduling blocks that are used by KLM. Besides this one milestone, no

[25] Each visit, a set of order is given in the form of a main letter check and additional orders from MOs, ADs, etc... As different letter checks and different additional orders are assigned each visit, so will the specific job cards that are to a particular scheduling block.

[26] As said, the actual precedence relations are between job cards. Some cards could actually be performed, if not all the cards in the same block are completed before the testing milestone.

other precedence relations are normally entered in the schedule of the maintenance visit. However, NRC blocks that contain the different NRCs per team and working area do have the possibility to also have precedence relations with one another. For instance, the NRCs that require power to be on have to wait before all the power-off cards are completed. As mentioned in Section 3.1, these types of characteristics are not visible on the job cards, requiring from the planner to know at the detailed job card level, which precedence relations are currently active for this check. The planners therefore have to see all the connections between all the different blocks, which is not a task a realistic expectation for human beings. The missing precedence relations, together with the relations of job cards that cannot be predefined, negatively influence the scheduling performance. The knowledge of the precedence relations is closely related with having the information on the status of the airplane and having the knowledge of performing all the relevant cards. This was visible in the observations of the planners who created the RCPS schedules. The planners lack the information on the actual status of the visit[27], making it difficult for them to decide which cards should be selected for scheduling. Interestingly, the scheduling decision to move to Block X backwards instead of Block Y is not based on logical decision rules. In the discussions with the planners on how they executed their work, no prioritization rules were explicitly found, which supports their chosen sequences over others. They accept feasible sequences that are within the limits of the current due date of the check, not verifying whether this choice was optimal or not. Together with the issues related to precedence relations, it supports the VO-H assumption that the methods for scheduling could be improved.

The scheduling itself is executed via two important pieces of IT. The backbone of the system is the program called Maintenix, which contains all the job card information, including their status and how many hours there have been spent on these cards. Mechanics also use this system to create NRCs, which directly become available to anyone with the accessing rights for Maintenix. From there, the scheduling software Artemis retrieves the information of all the job cards, being their tool for scheduling all the different blocks. It displays the blocks, just as the example that was created in Figure 9 and 10 does. The planner uses this tool to determine the required capacity levels for the time buckets of 24-hours and try to estimate whether to Estimated Time to Repair (ETR), the due date of the visit, is still maintained. During the last six months, many upgrades have taken place on Maintenix, in the preparation of replacing Artemis by two scheduling tools that are included in Maintenix itself. However, HIII chose to deviate from this IT-decision, by still using Artemis, even after the reorganisation. As a result, the changes in Maintenix made that Artemis is unable to reliably retrieve the spent hours on job cards. Until the connection between Artemis and Maintenix is repaired, Artemis

[27] Though their scheduling tool does provide some insights on the current status, the information the plan uses appears to be not in line with the actual progress. This was caused by backlogged administration of job card, interface issues between the tool and VO-H information system Maintenix.

can only be used for visualizing the scheduling blocks over the length of the checks[28]. Required capacity levels currently have to be calculated manually, being a time consuming task for the two planners that HIII has[29]. As the IT changes related to the reorganisation projects only create additional disruptions in the IT environment, HIII now relies on the analogue working methods for scheduling cards. This brings us to how the scheduling blocks transfer into the actual scheduling of job cards. In the planning area for the mechanics, two walls are used to distribute all the scheduled and unscheduled job cards. One side contains all the unscheduled job cards, sorted per work area and scheduling block, while the other contains the boards for daily c.q. shift planning (relevant for the RCPS/detailed shop floor scheduling). Given the overall schedule that is used to manage the check, per time bucket, a selection of scheduling blocks can be made, from which cards will be selected for execution. This forms the input for the RCPS, in deciding which cards have to be scheduled. These boards also form an analogue backup of the current progress of the check. All incomplete and unscheduled cards are still present on these boards, while completed cards are archived. You could thus roughly derive the remaining workload that still has to be done. Then again, if the progress in terms of time is desired, this would require for the manual calculation of the remaining job cards. That would take up too much time, showing the need for a software tool like Artemis, which can calculate the remaining hours. Unfortunately, Artemis does not take into consideration how much time mechanics already have spent and how much time is still remaining on job cards, resulting in a significant difference in capacity requirements. It can only take into account the given calculated duration and how much time is already spent on those cards. This gap is currently also not filled by any self-made macro's, as their output did not match up with control values (although they are still used). The differences that were found could not be clarified by the planners, supporting the notion that these tools are not reliable. This thus explains why they cannot estimate whether the due date would be met. The tools needed to make the calculations are either absent or incorrect.

What was described above explains how the planners use the generated schedules leading up to the selection of job cards. The time buckets, in which a certain number of scheduling blocks are present, should lead to the choice of the to-be performed job cards. There are however some differences. Until the major change that is completed on the 31st of March, 2014, the planners only selected a set of scheduling blocks and highlighted the most important job cards. They expect that these cards are completed in that time bucket, though they do not prescribe a detailed list of all the job cards that should be performed within that time. This leaves the decision for choosing the exact job cards for the next three shifts to the mechanics, which is the RCSP level of scheduling. As this does not have to match the chosen schedule of the planners, it explains why the planners have to reschedule

[28] The decision to keep using Artemis over the Maintenix scheduling function was necessary, as Maintenix' scheduling capabilities are limited. Maintenix cannot handle precedence relations, thus requiring manual adaptations of schedules in order to make an operational schedule.

[29] Two additional planners are expected to be hired in the near future, though during this research, none of the positions were actually filled.

each day. As different information is available for the mechanics, they choose different sequences than the planner created in their schedules. The differences between the planners schedules and the choices that the mechanics make, lead to deviations in the required capacity levels each day. This could endanger the due date of the visit, though it can also help to repair any delays that were generated earlier, therefore protecting the given due date. When negative decisions are made, this is usually caused by the limited knowledge over the status of the entire airplane and which cards still remain to be scheduled. As planners thus have limited control over what is scheduled and executed, less clarity remains on what is causing the productivity problems, being either incorrect schedules or underperforming mechanics. As this is not logged, it is not possible to quantify the size of the problems. The latter is also the last problem that we found for the RCCP.

Summary of problems and where information is needed in the RCCP scheduling level

To summarize how this level of scheduling is executed, what is required for scheduling, and which problems were encountered, we see that the planners use historical information to schedule sets of job cards in different scheduling blocks. They maintain the created schedule by rescheduling scheduling blocks over daily time buckets of three shifts. These blocks might have predetermined precedence relations and can contain one or multiple job cards. The planners select the most important scheduling blocks that have to be performed, providing the input for the lower levels of scheduling in creating shift-level schedules. The following summarizes the potential improvements areas that are encountered during this scheduling process:

- There is a high number of scheduling blocks, while the precedence relations between them have to manually managed, increasing the number of wrongly scheduled cards;
- Artemis is not linked with Maintenix. Calculated and spent hours are loaded incorrectly, making it not possible to estimate the required daily capacity. As a result daily schedules mismatch available capacity;
- Given that it is not defined what the duration time is, when more or less capacity is used on a job card, it is not possible to check whether the cards are feasible, given a certain choice for capacity. Planners can therefore not verify whether their generated schedule is actually feasible or not[30];
- Besides the historically generated schedule, no scheduling rules are present to support the choices for a generated schedule. This might explain why on other levels of scheduling (e.g. the mechanics at the RCPS-level), other job cards are chosen for execution from the scheduling blocks, than what planners initially had scheduled;

[30] Though planners could ask mechanics, whether certain choices for capacity requirements would lead to feasible job cards, normally they do not know the capacity availability for which this should be true. This information only becomes partially becomes available during the start of the shift, used by the RCPS and detailed shop floor level of scheduling.

- Another explanation is that planners do not select which cards are executed. They only suggest a certain working order, which creates the possibility to deviate from the intended schedule. This could endanger the ETR;
- The planners lack the information on the status of the visit, making it hard for them to decide which cards should be selected for scheduling.

3.2.3. Resource Constraint Project Scheduling: Day-level job card scheduling

As was established in the previous chapter, the RCCP level of scheduling is focused on scheduling job cards (via the scheduling blocks) over the length of the visit. It determines which cards are executed within the next 24 hours. Unlike RCCP, where one still has the flexibility to generate additional resources by hiring extra resources or extending the available time, during RCPS, production orders are scheduled given a fixed constant and continuously available capacity. One tries to schedule a known set of cards, while minimizing throughput time of the found schedule (De Boer, 1998).

For VO-H, the RCPS level of scheduling uses the input that the planners generate and try to determine how these 24 hours should be spent. This again is different from a standard RCPS, as one does not schedule for one shift, but for three. Another major difference from the standard RCPS is that not all orders are known beforehand. As said, the planners select only the most important scheduling blocks. Job cards are selected from these blocks by planner-mechanics, who are free to choose additional job cards from the unscheduled-board (given that it is possible to execute them)[31]. All these job cards are selected from the unscheduled-card board, making it far from a standard RCSP. To define the differences that VO-H is facing at this level of scheduling, the classification of Herroelen et al. (1997) was used.

Table 2 on the next page displays how the aspects within VO-H can be described. Here, the first two columns display the type of aspect that is reviewed, followed by what is applicable to the situation within VO-H (see Appendix 7 for more information). The results from this analysis are explained below the table and are based on the current situation, which is before the major changes after the 31st of March, 2014. Although these changes also impact the scheduling processes (e.g. the number of resources are expected to change), these were not taken into consideration, as it is unknown how they will be executed.

[31] The planners and planner-mechanics currently have taken over this role from the mechanics either by splitting up the RCCP and RCPS levels of scheduling between each other, or by performing the processes completely by themselves. Though the actors have changed after the 31st of March, the actual process still remains the same.

Type	Description	Applicable
α1	# Resources	Many (4 skills and two level groups)
α2	Resource type	1 (renewable)
α3	Res. Availability	Variable availability
β1	Pre-emption	Pre-emption allowed
β2	Precedence constraints	Critical Path Method + General precedence relations
β3	Release dates	rj (material delivery date.)
β4	Duration	Continuous duration times
β5	Deadlines	δj, δn (milestones + project deadline)
β6	Nature resource req.	Constant/variable discrete + discrete function
β7	Execution modes	Multiple execution modes
β8	Cash flows	o - Not relevant
γ	Resource/Time driven	Resource driven

Table 2: RCPS processes within VO-H, based on the classification made by Herroelen et al. (1997)

As displayed in Table 2, the planners/planners-mechanics assign job cards to multiple types of resources (α1), being the labour groups of: mechanics, avionic mechanics, cabin mechanics and sheet workers, which have two different experience level clearances. These resources are renewable (α2), as a new group of mechanics will be available during the next shift. Finally, these resources are expected to be available 6.5 hours per shift, though this varies in reality. The issues indicated in Chapter 2 (e.g. health problems or relocated to different project), make that resources are generally for fewer hours available (being the current utilization rate[32]). Looking at how this affects the scheduling process, those who schedule have to schedule against an expected capacity level, though no information is available what the limitations are on this level. If information were to be available about the actual available capacity, a better match could be created for the scheduled work per shift.

In their choices for selection and assigning job cards to shifts, the planner-mechanics have to take into account that jobs can be continued over shifts, meaning that it can be stopped by unit of resource and continued again by another (β1). This does not have to be in consecutive shifts, making it necessary to know the exact status of each job card (how many hours spent -> % completed). As mentioned earlier, the status of cards is not always available, hindering the scheduling process at this level. During the review of RCCP, we already mentioned that the cards are scheduled via precedence relations (β2), related to either general technical requirements (power on/off) or direct precedence relations (opening panels before it is possible to inspect that area). Here, the same problem as in the RCCP level arises, given that not all precedence relations are known or visible. The choices for job cards are limited by the release dates that cards might have (β3)[33]. For instance materials that have delivery dates, they prevent job card from being executed, when the necessary materials still have to arrive. They also have general due dates, created by the manually added set of project mile stones (e.g. completing all

[32]Given the current utilization rates of roughly 60%, means that the workers are generally available for 4.8 hours a shift.

[33] This choice is also supported by the sequence in which the scheduling blocks are number. These were number according to the historically generated base plan, which already sequence the cards and their blocks in a logical order.

inspections before Friday) and hard dead lines like the ETR (β5). These help to limit and prioritize the choices from the scheduling board, though again, these insights are not displayed in one particular system that shows which cards are ready for scheduling and which cards are overdue. The duration of job cards (β4) and the different execution modes that they have (β7) were already discussed via the RCCP. They also apply to this level of scheduling. Not knowing the duration time of the card (only the expected man-hours) and not knowing how different modes would affect the exact duration time, negatively affect the performance of accurately scheduling job cards.

Finally, looking at the goal of this level of scheduling, we see that it is different from that of RCCP. Here the goal is resource-driven, where the planner-mechanics try to complete the suggested progress by the planners, without having to use any overtime (or simply delaying cards to the next shift). Similar is the absence of scheduling rules that support the choice of a set of cards over another. Besides the historical preferences that are used for generating the initial schedule and the technical constraints that are used to limit the number of cards that can be executed, we did not find additional rules for choosing one card over another. How can one therefore judge, whether there scheduling choices are accurate or if re-scheduling is actually needed? It thus explains why there is a tendency to reschedule during the detailed scheduling level, as one mechanic might disagree with the other, therefore choosing different cards, than his predecessor determined. The mechanics deviate from the chosen selection of cards, by simply selecting different cards from the unscheduled-card board, or prioritizing newly created NRC cards over the currently assigned job cards.

Summary of problems and where information is needed in the RCPS scheduling level

This analysis explicates the findings on this level of scheduling. It clarifies why maintenance managers (the floor managers each shift) have problems in explaining and knowing the progress that was made under the supervision of their colleagues in the previous shift. It also explains why there are many complaints made via the continuous-improvement meetings, about having to work on seemingly incorrect schedules. The following points summarize the information that is in needed of improvement:

- If more reliable expectancies of the available capacity were provided, a better match could be made between the workload per day/shift and the available workers;
- If the status of job cards and their precedence relations would be made visible, it would be easier to select cards that are available for production;
- If there would be a way to see all the job cards that are available for scheduling and their prioritization (e.g. given their due date), it would be easier to select job cards for a certain shift;
- If the duration times for different available levels of capacity were shown, then given a certain capacity level, better choices between the scheduling of job cards could be made.

All of these points would help to improve the scheduling performance, therefore reducing the need for rescheduling and thus helping to safeguard the ETR and the KPI for due dates and (indirectly) utilization. It again shows that information related to the job characteristics and related to the status of the job cards and/or the checks is required for the different scheduling processes.

3.2.4. Performance measurement and indirect problems

Besides describing the information that is needed for the RCCP and RCPS level of scheduling, we also described in Chapter 2 how performance measurement could be executed. Here we will analyse, whether it is possible to use the indicators we have discussed in Section 2.3, given the current state of the scheduling processes. We will also review some additional processes that impact quality of the generated schedules via their output.

In Section 2.3, we described that performance indicators are grouped as criteria that focus on the scheduling product, focus on the scheduling process, are indirectly related, or influence the process. Based on the interviews and our analyses we have conducted, we conclude that the later two groups are not suitable for VO-H processes. First, the realised performance of the scheduled process cannot be measured, given that it is unclear whether the schedule or the execution was not as desired. Second, the number of complaints cannot be used as well, as there currently is not a fixed schedule that should be followed. Finally, the indicators that are influencing factors cannot be used, as they are difficult to define and they are the same for every alternative. We should thus focus on indicators that express the scheduling product or the scheduling process.

For measuring these indicators, we found that the scheduling processes require roughly the same information as these indicators do. E.g. the makespan, this depends on the expected starting time of the first card and the expected completion time of the last. This information is currently not readily accessible, as job card are not actually scheduled during the visit (as explained in 2.3.3). As job cards are not actually scheduled to specific shifts, estimations for resource requirements would also be difficult. The latter would also require information on the availability of resources per shift, which is currently also not available, as we will explain later on in this section. Both the makespan and the resource requirement face the same problem, with respect to the variability that exists in job card duration. As VO-H currently cannot generate the distribution of variability per job card (and thus not for a visit), determining any time or resource related indicator would be limited at best. It would only be based on deterministic information, while Möhring (2001) explains that it should be based on the stochastic behaviour, as otherwise, one cannot for instance determine the expected number of shits that the visit will be overdue.

Furthermore, for measuring the current performance and/or comparing alternative scheduling methods, it must be necessary to create a benchmark of the scored values of the method or compare it to known optima. The benchmark would be based on the maintenance package (and/or current progress) of that particular visit. However, VO-H currently does not store its maintenance package overtime. The cards of that visit (and their status) must be manually retrieved from either Maintenix or a server, making it more difficult to create this benchmark. Given the complexity of the scheduling problem (NP-hard) and constant changes that are applied to the package, it is also not possible to calculate optima (at least, not in polynomial time). Finally, as the packages changes during the visits (e.g. added cards/NRCs), benchmark should also be based on the changing circumstances. The problem thus is, we have to benchmark the quality of schedule, while the input (the packages) is not available and no known optima can be generated. Thus if we would like to use this technique, we should at least store the status of the maintenance package (how it changes over time), such that objective comparisons can be made.

Although the influencing factors cannot be used as indicators, they do generate problems for the scheduling processes. For one, we determined that there are problems with the reviewing process of the maintenance package, with the control process on spent hours after the visit, and with the estimations of the required resources of the project.

The content of the maintenance package as input for the initial schedule is controlled as follows (with respect to processing time). Each (RC) job card is given a net production time, together with an additional buffer for retrieving materials and performing administrative tasks. These three durations are all vaguely determined, as for neither of them it is stated, whether the sum of these times provide the minimum production time needed for one employee, or e.g. if it indicates an average norm (regardless of the number of employees needed). This norm should be given to cards by the support-staff that works in the back office, though miscommunication created the false assumption that they are not responsible for doing so. As a result, job cards with duration time of 0-hour or 0.01 hour enter the maintenance package. Though the support-staff reviews the set of job cards for those types of cards, in each check, at least 20 cards can be found with deviating values[34]. This seriously impacts the performance of the scheduling process, as a job card of 100 hours that is entered as 0.01, seriously creates a gap in the original capacity estimations. Furthermore, the support-staff tends to misjudge the duration of certain cards. As a result, the job cards they expected to require fifteen minutes to complete, actually have a duration time of four hours (as an example). To avoid these problems, other administrative workers recalculate the deviation between the expected duration time and the spent hours for cards, though their control is not that strong. As is explained in Appendix 9, Table 9/10, by adjusting their control parameter, more cards will be reviewed by them. This is important, as checking an additional five to ten percent of cards per visit on their duration time, would result in several hundreds of hours each visits that could have been accounted for. Therefore, although the content of

[34] This is based on the review of 'Check details' excel files of the checks between 01-11-2013 and 01-05-2014. The 'Check details'-excel files contain most the available information that the Maintenix uses for managing the job cards and maintenance checks.

the job cards is reviewed, these processes could be used more effectively to improve the quality of the information.

Besides the difficulties in calculating RCs and recalculating all cards, one may doubt the forecasting process for the expected number of non routine hours per check. Currently, the expected demand for resources is based on the different known job cards and a forecast of the number of NRCs and their respective hours. This is based on a moving average of a number checks, while outliers are excluded based on experience and not on rules. The reason to question this method is because of the differences between the predicted NRC hours and the required NRC hours. A possible explanation for these discrepancies is given by Silver, Pike and Peterson (1998), who state that a drawback of using a simple moving average, is that the weight of the most recent check is as heavy as that of historical checks, thus assuming that the number of NRCs is independent of, for instance, the age of the airplane. Mechanics also provide another reason why a simple moving average is incorrect. Besides the age of the airplane, the condition of the airplane is also affected by the amount of time between it last D-check. Checks right before a scheduled D-check[35] are expected to have many more hours of NRCs than checks right after a D-check. Simply taking the average of the last view checks might thus not be the best model for forecasting the quantity of NRCs.

Summary of information problems for performance measurement and indirect processes

For the performance measurement, we found that the absent or incorrect descriptions of the job cards are preventing us from using the chosen criteria. Furthermore, the changing conditions of the maintenance package and the absence of a database in which these changes are stored, limited the possibilities for evaluating the performance of scheduling methods under different circumstances.

We also found that there are indirect processes that influence the correctness of the information that is used by the scheduling process, being:

- The review process of the maintenance package –incorrect job card information;
- The review of duration times after the completion of the visit – incorrect job card information;
- The estimation processes of expected work – incorrect resource availability.

[35] D-checks are the heaviest types of maintenance.

3.3. Conclusion

In this chapter we described the current situation of scheduling processes, with respect to the information that they need. Using the literature that we presented in Chapter 2, we were able to indicate which problems currently exist in the scheduling process, thus showing where information is needed. For the job cards, we found that additional is needed for the following problems:

- The job card description only contains basic formation (no variability, precedence relations, multimode);
- The basic information of job cards can be absent or incorrect (processing time = 0.01);
- The absence of basic and extended job card descriptions prevents the usage of performance indicators for scheduling (except for runtime).

For the scheduling processes and methods that are used, we found that information is needed for these problems:

- The resources that are calculated to be present deviate from the actual availability (for both the entire visit and for a 24-hour window), limiting the ability to assess the need for additional resources (when evaluating scheduling performance);
- The generated schedule is only accessible via a high level summary, limiting maintenance managers to prioritize tasks in case of rescheduling;
- The status of the visit (completed and unfinished job cards per work area/resource group/production phase) cannot be generated correctly, hindering the assessment whether the visit can be completed before the due date and whether additional resources are required;
- As the status of the visit, the related maintenance packages, and related schedule are not stored somewhere, it will not be possible to calculate the progress over time, thus preventing benchmarks to be performed on alternative scheduling methods.

VO-H needs these information problems to be solved to reach their goals for improving the scheduling processes and for enabling future research on alternative scheduling. In the next chapter, we will review whether and how these problems can be solved and how these can be modelled into one solution.

4. From Problems to Solution

In this chapter, we will describe how the information that VO-H needs can be made available. This is achieved by developing a model that describes how the need for information for each of the problems can be fulfilled (4.2). However, we will first present the scope for this model (4.1), as not all of the issues that we described in Chapter 3 can be solved by this research.

4.1.Scope

In Chapter 3 we determined that there are seven important areas of improvement that hinder the scheduling of job cards and the measurement of the scheduling performance. Related to the job cards, we established that:

1. Only limited information is available on the job cards;
2. The information on the card contains errors;
3. Additional information on the variability of the duration time of job cards is needed for several performance indicators.

Furthermore, related to the scheduling processes and methods, we established that:

4. Incorrect information on resource availability hinders managers in their assessment whether additional resource are needed;
5. Managers require more detailed information on the generated schedule, to be able to effectively prioritize job cards when needed;
6. There are no status reports containing the status of visit on a detailed level (only the overall progress on cards can be generated);
7. It is not possible to compare/benchmark schedules, as the status of visit, the related maintenance package and the related schedule are not stored.

For our model, we will not be solving the problems related to job cards (1, 2, and 3).). Currently, a different reorganisation project is already reviewing these cards on the correctness of their basic information. Given the absence of this experience for this research and that these problems are partially solved, we will not include these issues into our model. We will thus focus on presenting managers and planners with information that they can use the increase the productivity of the production process and improve the match between the generated schedules and the available work (4, 5, 6, and 7).

4.2.Model description

In this section, we will review the four problems we included within our scope and describe the requirements for solving them. At the end of this section, we will describe the design of a model that is based on these requirements.

4.2.1. Resource availability

The first problem that we discuss is the information that is absent on resource availability. The managers within VO-H require the information on resource availability, to determine whether the scheduled job cards can be completed in the given time period. For this, they would have to match the resource requirements of the job with, with the resources that are scheduled to be available. This information must be fairly detailed, as mechanics within one resource group, are still limited to perform tasks for which they are certified/skilled. Additionally, this information should be specified on shift level, as it will be used on a daily basis to decide whether additional resources are necessary.

4.2.2. Schedule information

The second problem is that of absent scheduling information. Managers currently do not have access to a detailed overview that explains which groups of job cards are scheduled and when certain milestones must be completed. This is currently only summarized in a highly aggregated overview. The managers require an overview that would specify on shift level, which scheduling blocks should be prioritized. This will increase the usage of the generated schedules.

This overview should also contain the information on resource requirements. Given the same degree as resource availability, the managers would then be able to decided, if there is a match between the supply and demand for resources.

4.2.3. Status reports

The third problem is that of the absent status overview. The status overview complements the generated schedules, as it helps the user to determine what the demand for resources actually is. For managers and planners, having real-time visibility of the progress that has been made, supports them in improving production control and select job cards while (re-)scheduling. The information that is used should thus reflect the actual status of the visit. The only format that VO-H currently has available for such a tasks, is the ‘Check Details’ list in Maintenix. However, this list is only as up-to-date, as the progress mechanics have made on their administrative tasks. This should thus be considered while using the tool.

The information that managers and planners need, should summarize the progress that has been made on the overall visit and should specify the same information for the progress per zone, per resource group, and per production phase. The overall information can be used by higher management for production control, whereas the detailed summaries are useful for the managers that have to decide on hiring additional resources. The additional control they attain should also be support by insights on the progress that has been made over time. It should be possible to compare two situations, to verify whether the current progress is as expected or that measures are required to increase productivity.

4.2.4. Benchmarking

The final problem is related to the absent benchmark functionality. In order to perform a benchmark, we should be able to load and store different schedules or performances in the tool. This is similar to the functionality of comparing the status of a visit over time. For benchmarking, one would have o store the 'profile' of an entire visit. Planners could then compare their generated schedules with the progress that the profile displays. However, we showed that the information for measuring indicators is limited. We should therefore focus on the indicators that can be derived from lists as 'Check Details'. Given that this list can be used to determine aggregated information on the check, as well as more detailed information (possible to job card level), this would provide important input for indicators as *resources used* or *makespan*. Important though is that we base the visit profiles on more than one maintenance visit. This means that comparable visits (same checks/type of airplane/amount of work) should be analyzed, such that averages can be determined. This would increase the reliability for comparing and benchmarking alternative scheduling methods.

4.2.5. Model design

Based on the requirements we discussed above, we can design the following model:

- The goal of this tool will be to improve the production and scheduling performance and to realise the performance measurement of scheduling processes;
- The tool will be designed for managers and planners;
- The tool will be a lower-ranked MIS, which structures information and calculates indicators for the users;
- For accessibility, the tool should:
  - Present the information on one main dashboard/user interface;
  - Have a dashboard that provides visual feedback on the information that is presented;
  - Use input that only requires the import of data by the user;
  - Have instructions available for using the tool;
- For functionalities, the tool should:
  - Present the job cards that are scheduled;
  - Present the aggregated status of the visit (#job cards & #hours completed/ remaining);
  - Present the detailed status per zone, resource group, production phase;
  - Present the information in absolute and relative numbers (e.g. remaining cards and percentage completed);

- Present the resource availability, per resource group (and skill-level), per shift.
- Store the general description of the visit;
- Provide insights in errors in the maintenance packages;
- Should format the status of the visit, to generate profiles for the progress over time;
- Should format the status of the visit, to analyze progress that has been made.

4.3.Conclusion

In this chapter we described how our model will ensure that the needed information will become accessible for the managers and planners of VO-H. They will be using this information to minimize the effects that the current information problems generate, thus making it possible to analyze alternative scheduling methods.

For the scheduling information, we described how a MIS could present the status of the visit to managers and planners. By presenting aggregated and detailed information on the progress that has been made on zones, resource group, and production phases, they will have better control over the scheduling/production process. The same holds for the visualisation that will help to in the prioritisation of cards and/or hiring additional resources.

The visualisations that are included are based on the detailed information of the zones/resource groups/production phases also make it possible to start benchmarking. By comparing two maintenance packages, the user will be able to analyse the scheduling method is performing better.

5. Management information tool

In the previous chapter we described how our model could be used for solving the information problems of VO-H. In this chapter, we use this model for the realization of a tool that VO-H can use. We first discuss the technical realisation of the tool, before discussing how the elements of the model were included into the tool. In Section 5.2 briefly describe how the tool was verified, before we explain in Section 5.3 how VO-H should implement this tool.

5.1.Technical realization

Using the Software Development Cycle we described in 2.4.2, we developed the tool in several steps. Here, our model serves as the software design. Based on this design, we determined how the information could be grouped and presented. This consisted of the desired buttons, the macros to operate them, the areas for entering information, an area for calculations, and of course, a page that would summarize all the information. Then, for each of these groups we coded their calculations, reviewed their correctness and added them to the Main User Interface. This process was repeated several times, such that we could include: the general information of the visit, the overall progress in terms of hours and job cards, the progress that has been made per resource category, production phase, and production zone, and finally the visualization of this progress in an interactive chart.

The information that is used by our MIS has to be based on the information that is available in either Maintenix or Novulo[36]. These are the only two information systems/databases that can be used by both managers and planners. The possibilities to export information from these systems are however limited. In Maintenix, it seems that only an Excel export of the maintenance package can be retrieved. As we cannot access the information via the tool, we must develop the function for importing data, such that the user easily (and without error) imports the data him/herself. The list, also called the 'Check Details' list, contains all the information on a job card level that VO-H currently records. These can be used in the calculation of the status of the checks and for providing insight in the quality of job card details. The coding on this job cards can even be used to fulfil the need for both an aggregated and detailed job card description. There is however nothing recorded here on how many resources are used for executing job cards – only the sum of the hours spent on this card. In Novulo, this information is also not available. We therefore cannot fulfil the need for information on resource usage and/or additional resources.

[36] Besides Maintenix, Novolu is used by VO-H for storing the information of visits online. This includes aggregated resource requirements and images that highlight important job cards in the schedule.

The result of this development process is presented below Figure 11: *Management Information Tool*.

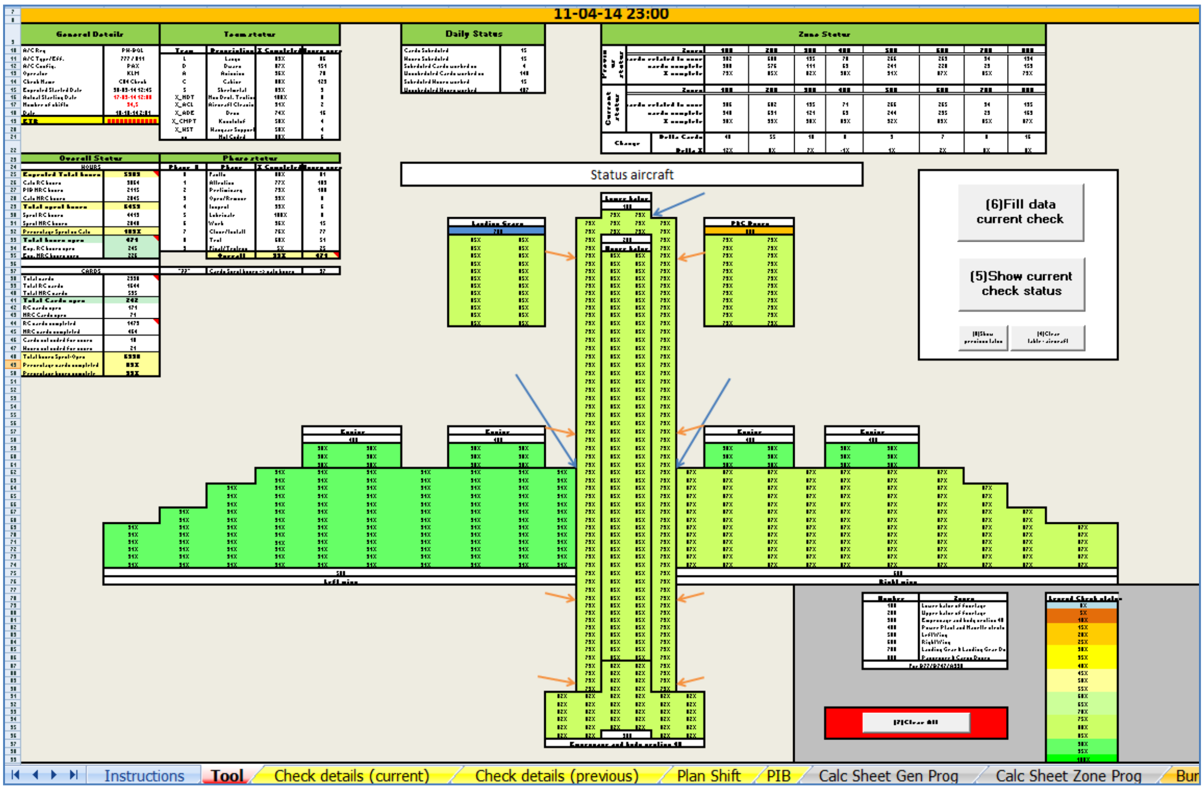


Figure 11: Management Information Tool (see large example in Appendix 13)

We will now discuss the various aspects of the tool. In Figure 11, one easily recognizes the airplane in the centre of the display. It has been divided into eight different zones, related to the main zones that OEMs defined for the aircraft. This screenshot was taken at a later stage of the check, showing that most of the work has been completed. The colour difference between the wings clearly shows that progress on the left wing is higher than on the right wing. It clearly visualises the progress of the maintenance check in one image[37]. The percentages on the wings are derived from the table in the right upper corner of the tool. It represents the percentage of cards that has been completed for the related zone and is used to colour the airplane. For this tool, it was decided to only show the results based on the main aircraft zones. This means that the progress on all the engines is reviewed as one category. The table for the zones is depicted below.

[37] Although all of the actors reacted positive towards the design of the tool (in the shape of a 4-engine B747), they did make the remark that the display was not interactive. With that they mean that it would be even more impressive, if the template could change from a 4-engine airplane to a 2-engine, which is true for the B777. These could of course be incorporated in the tool for future purposes, though for now, it suits its purpose in eliminating the negative factors that hinder the scheduling process.

Zone Status										
Previous status		Zones	100	200	300	400	500	600	700	800
		# cards related to zone	350	639	122	64	250	247	33	175
		cards complete	147	216	88	9	124	132	15	56
		% complete	42%	34%	72%	14%	50%	53%	45%	32%
Current status		Zones	100	200	300	400	500	600	700	800
		# cards related to zone	379	672	134	70	265	261	34	190
		cards complete	285	495	108	62	233	225	27	147
		% complete	75%	74%	81%	89%	88%	86%	79%	77%
Change		Delta Cards	138	279	20	53	109	93	12	91
		Delta %	33%	40%	8%	75%	38%	33%	34%	45%

Table 3: Table used in tool to display Zone Status

As can be seen, a comparison between a previous and current situation is included in this table. Depending on which check-details list are entered as input, one could for instance compare two consecutive shifts, two different days, or even two completely different checks. For the latter, the lower two rows would be less useful, as the total amount of cards is now based on two different maintenance checks. However, if one uses the buttons on the main interface to switch between the current and previous status, it is easy to visualize the progress data of both checks, as is displayed in the example of Figure 12 below (showing on the left, the progress in the beginning of the check and on the right, at the end of the check).

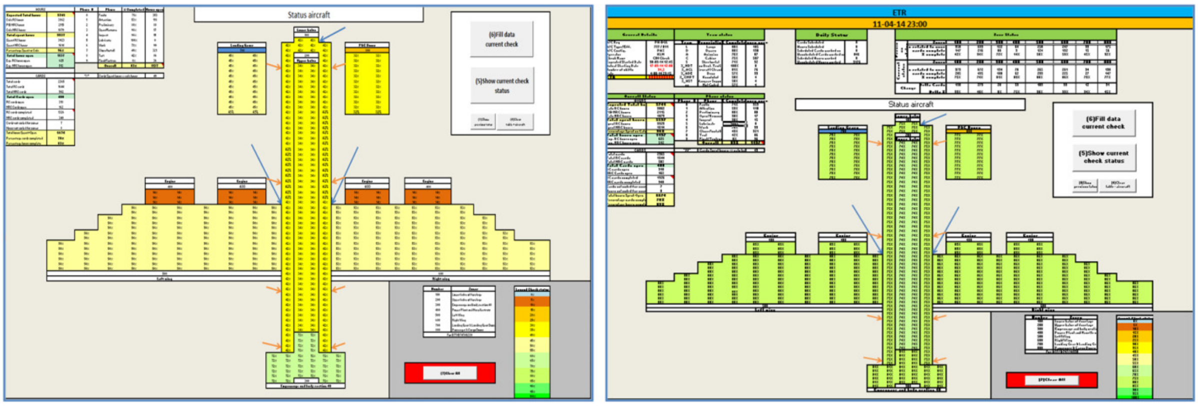


Figure 12: Overview of two progress images that can be used for comparing.

As said, the functionality to make this comparison is instantly accessible, by simply pressing one of the two ‘show progress’-buttons. To clarify the results displayed within the tool, a legend was added at the lower right corner of the display.

More important is the information that is displayed in the top left corner of the tool. Using four tables, the general information, the overall check progress, and the progress made per category are displayed. To clarify, these four tables are grouped and shown in the table below.

General Details	
A/C Reg	PH-BQL
A/C Type/Eff.	777 / 011
A/C Config.	PAX
Operator	KLM
Check Name	C04 Check
Expected Started Date	30-03-14 12:45
Actual Starting Date	17-03-14 12:00
Number of shifts	34,5
Date	5-08-14 17:08
ETR	11-04-14 23:00

Overall Status	
HOURS	
Expected Total hours	5741
Calc RC hours	3862
PIB NRC hours	2115
Calc NRC hours	1879
Total spent hours	5537
Spent RC hours	3923
Spent NRC hours	1614
Percentage Spent vs Calc	96%
Total hours open	1137
Exp. RC hours open	625
Exp. NRC hours open	512
CARDS	
Total cards	2365
Total RC cards	1644
Total NRC cards	502
Total Cards open	480
RC cards open	318
NRC Cards open	162
RC cards completed	1326
NRC cards completed	340
Cards not coded for zones	7
Hours not coded for zones	8
Total hours Spent+Open	6674
Percentage cards completed	78%
Percentage hours complete	83%

Team status

Team	Description	% Completed	Hours open
L	Langs	80%	185
D	Dwars	80%	198
A	Avionics	76%	87
C	Cabine	75%	507
S	Sheetmetal	71%	32
X_NDT	Non Dest. Testing	100%	0
X_ACL	Aircraft Cleaning	81%	76
X_ADE	Deco	57%	39
X_CMPT	Kunststof	50%	4
X_HST	Hangaar Support	50%	4
XX	Not Coded	57%	4

Phase status

Phase #	Phase	% Completed	Hours open
0	Faults	71%	353
1	Attention	53%	118
2	Preliminary	80%	88
3	Open/Remove	98%	17
4	Inspect	98%	15
5	Lubricate	100%	0
6	Work	78%	99
7	Close/Install	49%	321
8	Test	42%	86
9	Final/Testrun	0%	36
	Overall	83%	1137
"??"	Cards Spent hours => calc hours		49

Table 4: Four tables for General information, overall status, team status, and phase status[38]

To provide a brief explanation on these four tables that are displayed in Table 4, let us first review the *General Details*. Most of the information here is available on the check-details list. The areas indicated in red are however, not available in any digital format. It often occurs that the starting moment is different from that expected starting moment. This, together with the ETR, has to be entered manually. Additionally, the number can also be indicted here. This was added to complement the general information on the check that is performed, also to support the shifting mindset of a more scheduling-focussed control method. The ETR, often now forgotten by most, is also displayed at the top of the tool in the orange header. The information here is mostly for documenting the check correctly.

[38] The discrepancy between the total number of cards ≠ RC+NRC is due to the fact that there are other none-relevant categories. These can be found on the calculation sheet of the tool.

More interesting for the users is the *Overall Status Table*. Here the progress that has been made is displayed, split up in two categories. The top halve shows the progress made in hours, while the bottom halve shows the progress in terms of cards. It is important to review both, as the number of cards and the duration of cards is not evenly distributed. With this we mean the differences that exist between completing either 50% or 20% of the check, when 1 card of 100 hours has to be completed or when 4 cards of 25 hours still open. More importantly, it shows that the different groups that will be using this information must be made aware of the important differences between the given values. Related to 'Hours', we must take into consideration that only the calculated time and the time spent is given on the job card. The expected remaining time can therefore only be expressed as the gap between those two, assuming that the calculated hours > spent hours. If this assumption does not hold, thus spent hours > calculated hours, the remaining time would be unknown. That is also why in the bottom right corner, the number of cards that violate this assumption is indicated. This helps to trigger both the maintenance managers and the planners, to keep reviewing cards that possible are going out of control. If they like, they could easily sort out the barcode of the cards in question. In general, the percentage Spent vs. Calc also indicates this problem. More importantly, it is an indication of how much of the expected capacity is already used up by the check. This percentage is based on the expected RC and NRC hours, for which HIII caters a certain quantity of resources. If only 70% is completed (indicated below), while the Spent vs. Calc ratio is already close to 100%, then it is most likely that additional resources will be required. It also is a trigger for reviewing the performance on this particular check. It could for instance lead to the adjustment of the NRC calculation (if the number of NRCs were incorrectly calculated). In the 'Cards' section, the same review is done, showing the completed vs. the number of open cards, the total number of cards, and how many RC/NRC there are. It also is used to identify cards that have faults on them. Here, the cards that have no zone coding or for which no duration time is entered, are displayed for corrections. These can then be filtered from a check-details list, which otherwise would probably remain undetected.

On the right of Table 4, we see two tables that indicate per resource category (*Team Status)* and per production phase (*Phase Status)*, the progress that has been made. Each of the job cards is coded using four groups of characters. This makes it possible to structure the information and present it the way that we did. The column for '% Completed' compares the number of cards that are completed for each of the categories. The 'Hours open' column determines the remaining hours, based on the gap between the calculated and spent duration times. Again, it must be emphasized that a small error exists in the general variation of the duration time and for those cards that are calculated incorrectly, thus having 0 open hours, while they have not yet been completed. The sum of both tables is displayed in the total open hours. Here the cards that are not coded, should be added to the sum of the lower table, in order to add up to the 1137 we used in the example. This concludes the review of the different elements within the tool. Additional information on the usage of the information is discussed in the next section.

5.2. Verification of tool

For testing the correctness of the model and whether it would function desirably, we used several of the verification techniques[39] that Law (2007) described on building valid and credible simulation models. By using the development life cycle for developing working prototypes, letting workers of HIII test it, and by reviewing the results that were generated by tool with the actual circumstances, we were able to generate a reliable tool.

To clarify, by developing working prototypes it is possible to continuously debug the miscalculations that might exist. By letting untrained users review the tool, we could verify whether the user interface was working properly (including the instructions that were added for users). We used traces to test where the programmed coded behaves properly. By controlling the results and manually recalculating the generated outcome, the used calculations and codes could be tested. The same holds for comparing the generated results with the expected outcome of the planners, the maintenance managers, and in general the perceived status of the maintenance check. The latter was done for most days of two consecutive maintenance visits (same airplanes) and testing using check details of different airplanes, thus testing the results under various circumstances, which the final techniques we applied.

5.3. Implementation and additional options

To ensure the value of the tool, we must ensure that users of VO-H are able to use it. We therefore use this section to describe how this tool should be implemented and how additional development could be used to increase the value of this tool.

5.3.1. Implementation

The tool was at foremost designed for the maintenance manager and planners within KLM. They should use this tool for additional control of the production processes and to provide them with accurate and up-to-date information of the visit. As an introduction to the users, we first presented the tool during a general demonstration. Here, the different functionalities that are included in the tool were presented and it allowed them to see the ease and possibilities of the tool. Then, we made sure that these users could access the tool by placing it on a shared database. They could use the tool, based on the instruction that were also embedded in the solution. The instructions we stored within the tool as manual and some are also displayed in Appendix 13.

However, using the tool and understanding its possibilities are two different things. To realise the benefits of the tool, the users must gain familiarity and experience with the numbers that are generated. This is quite different from their current mindset on operational control, making this step especially important. We propose that they should gain this familiarity, based on the progress updates that one can make with the tool. By recording how maintenance visits progress over several checks,

[39] For this research we used Techniques 1, 2, 3, 4 5, and 6.

these users can see what it for example means if 7% of the inspections still would have to be completed. The tables and graphs that were added can be used for visualizing these results.

Storing the progress of maintenance visits also creates the possibility of creating maintenance visit profiles. By determining how compared maintenance visits should behave (in terms of total hours used, the moments NRCs are created, when production phases are completed), it is possible to start creating the benchmark tool for performance measurement. The output of a scheduling tool could thus be used in comparison with the average/worst/best performance on that particular visit. Although it might take some years to realise reliable visit profiles (given the limited data entry points that are created by a limited number of visits per year per airplane & visit type), this would be the simplest way for accessing the required performance measurement indicators.

For now we can conclude that the managers and planners are indeed following this implementation plan, as the tool is still being used, almost 6 months after the tool has been demonstrated to these users. By using it only a daily basis, it helps them to solve issues related to the status updates of the visit and to clarify the interpretation of information.

5.3.2. Additional development options

We also would like to point out that there some possibilities for already expanding the tool, if certain changes in IT were completed in the planned reorganisation projects. In the current model, it was not possible to compare how well the production adhered to the generated schedule. We were promised however that the changes in Maintenix, together with the new approach for assigning jobs, would make it possible to digitally compare the scheduled and executed job cards. The functionality is already built into the tool via the 'Daily Status' table that is depicted below.

Daily Status	
Cards Scheduled	0
Hours Scheduled	0
Scheduled Cards worked on	0
Unscheduled Cards worked on	846
Scheduled Hours worked	0
Unscheduled Hours worked	3176

Table 5: Additional function that can be used to compare the scheduled work and the executed work

As can be seen in Table 5, the *Daily Status* contains an overview of how many cards/hours were scheduled, how much of the scheduled work was executed and how much additional work was executed. These calculations are based on the manual export from the scheduling section within Maintenix. Depending on whether a decent export will be added and whether the functionalities will be supported by the way the processes are executed, it could be possible to make the comparison between these two. This would help to objectify the performance of the production, compared to that of the schedule. For now, as this link currently does not exist, the values are still presented as 0.

5.4. Conclusion

The model that we created in Chapter 4 was used to create the tool that we presented in this chapter. Although not all the desired improvements could be realised due to the limitation in the IT systems, we did create a tool that will help VO-H to:

- Determine the status of the visit that is both accurate and up-to-date;
- Identify and prevent some of the job description problems in the Check Details lists;
- Provide the insights that help to match resource requirement with unfinished work;
- Take the first step to realise performance measurement for scheduling processes;
- Provide insights into the areas or resources that should be prioritized.

In the six months after its initial demonstration, the tool already has shown it benefits, thus being a success for the production and scheduling processes. If the data that is used also is stored, then future research should be able to use the tool for finding alternative scheduling methods.

6. Conclusion & Discussion

In the final chapter of this research, we summarize our findings and formulate how this research solved the presented problems of VO-H. This is done in Section 6.1, together with the recommendations that we have for VO-H. In Section 6.2, we will review the limitations that must be taken into account, before we discuss the possibilities for future research in Section 6.3.

6.1.Summary, Conclusion and Recommendation

This research was conducted to support KLM E&M VO-H in their efforts to improve the scheduling activities of job cards in maintenance visits for Wide Body airplanes. The goal is to improve their scheduling processes, as their current processes can improve on the delivery of accurate schedules that are needed for the success of their reorganisation projects. Here we found that this goal cannot be attained, as the information that is needed for both creating schedules and measuring scheduling performance is currently absent or incorrect. To help VO-H achieve this goal, we formulated the following main research question:

How can the information issues in the scheduling processes of VO-H be eliminated, such that it would be possible for future research to analyse alternative scheduling methodologies?

Chapter 2 was used to analyse the literature that was needed for performing this research.

- We found that the scheduling processes could be reviewed via the Hierarchical Planning Framework of De Boer (1998) and that we should limit the description of required information to the RCCP and RCPS level of scheduling;
- We also found that the related scheduling processes require information on the jobs and activities details (both aggregate and detailed), a description of the used and available resources, the schedule that is generated, and the status of the completed and remaining work;
- Performance measurement of scheduling requires the same sources of information for performance indicators as the scheduling processes do. The indicators, together with computation time can be used in an MCDA, to benchmark current or alternative scheduling methods;
- Finally, we found that Management Information Systems are suited for accessing and presenting the desired information. However, during the development process, it must still be decided how supportive this tool will be (given the availability of information).

In Chapter 3, we reviewed the current situation to determine the information that VO-H needs. For the job cards, we found that additional is needed for the following problems:

- The job card description only contains basic formation (no variability, precedence relations, multimode);
- The basic information of job cards can be absent or incorrect (processing time = 0.01);

- The absence of basic and extended job card descriptions prevents the usage of performance indicators for scheduling (except for runtime).

For the scheduling processes and methods that are used, we found that information is needed for these problems:

- The resources that are calculated to be present deviate from the actual availability (for both the entire visit and for a 24-hour window), limiting the ability to assess the need for additional resources (when evaluating scheduling performance);
- The generated schedule is only accessible via a high level summary, limiting maintenance managers to prioritize tasks in case of rescheduling;
- The status of the visit (completed and unfinished job cards per work area/resource group/production phase) cannot be generated correctly, hindering the assessment whether the visit can be completed before the due date and whether additional resources are required;
- As the status of the visit, the related maintenance packages, and related schedule are not stored somewhere, it will not be possible to calculate the progress over time, thus preventing benchmarks to be performed on alternative scheduling methods.

In Chapter 4, we formulated a model that should solve the information issues.

- We concluded that it is only possible to generate a solution that would express the current status of the visit and make it possible to create a performance measurement tool. Here we excluded the improvement of job card details, as this should be covered (at least partially) by one of the reorganisation projects;
- The solution would support managers and planners in their effort to schedule jobs and allocated the available resources. For this, they would need to have the aggregated information on the current status of the visits, in detail the current progress on zones, production phases, and resource groups, information on the usage of resources, and graphs to make comparisons between progress levels and/or scheduling results;
- This would be achieve by using a Management Information System that uses the databases in other information systems to import and present the information, when the users make a request for it.

In Chapter 5, we used this model to create the solution we presented as answer to our main problem

- We found that not all features could be included into the software tool, as the available sources of information prevent the automatic access to its databases. Furthermore, the usage of resources cannot be included, as this in currently not stored in a format that is exportable;
- Using the Software Development Life Cycle, it was possible to create the management information tool that is displayed in Figure 13 on the next page.

By implementing the tool we suggested, we believe that most of the information issues will be resolved (or at least controlled). We recommend that the planners and maintenance managers will use this tool each shift, such that a database can be created for improving their experience and to make the benchmarking of scheduling techniques possible.

With this, we eliminated the problems that any scheduling alternative would have, making it again useful to execute a research on new scheduling techniques.

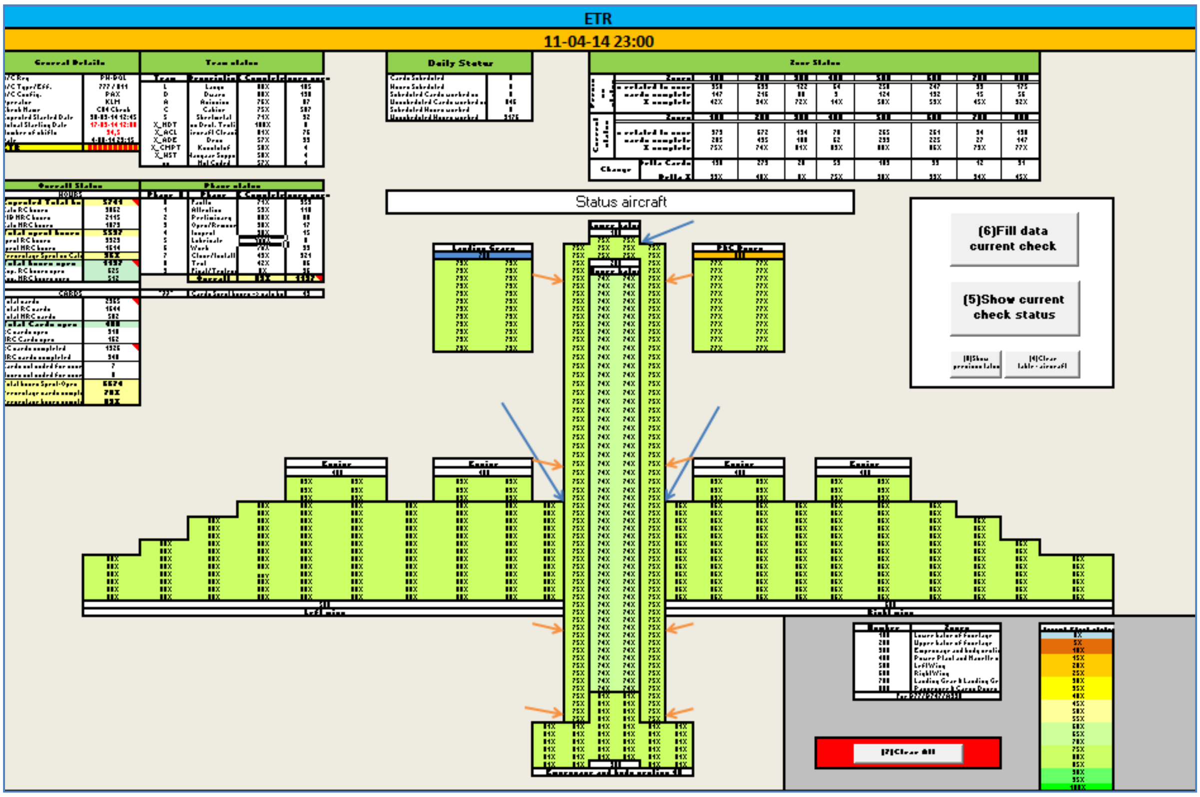


Figure 13: Management Information Tool (see large example in Appendix 13)

6.2.Limitations

This research was conducted within one of the maintenance hangers of KLM E&M VO-H. Unfortunately it faced a number of limitations that even forced to change the course of the initial research. First of all, the results of this research are based on an organisation that is in the middle of a large-scale reorganisation. As a result, one has to take into consideration that some of the problems that were identified at the start of this research, might already be solved at the end of this research. We therefore did not focus on improving aspects that are covered by the reorganisation projects, though some overlap will always be present. The proposed recommendations therefore are not a final solution to the problems that HIII is facing, but merely a first step in the right direction.

Second, the information issues that HIII is facing made that this research also had to rely on qualitative information. Observing the daily operations within HIII and interviewing the related actors only provides a limited certainty on how correct some findings were. Being part of an operation for six months leads one to generate his own preconceptions about the operations, even though one attempts to remain impartial. However, the cross-references between interviews, observation, and literature should have protected the objectivity of this research.

A final limitation of this research was its dependency of the airplanes that were scheduled for maintenance. Having a limited amount of aircrafts also implies that the observations that were made during this research might not represent a production cycle within HIII. There were serious issues with the timely delivery of materials for the modification-line of HIII. As a result, the behaviour that was displayed by mechanics and managers might not be representative for the actual situation within HIII. However, as comparable problems could still occur in during future visits, this exception could be considered as events that trigger 'normal' behaviour.

6.3.Future research

As a final part of this research, we would like to point out some opportunities for future research from both an academic standpoint and that of KLM.

In the research, we found that the current scheduling process is not only troubled by the lack of information. Though currently solved by the experience of the current planners, we found that there are no scheduling or prioritization rules for any of the scheduling processes. Assuming that the tool will lead to the possibility of measuring scheduling performance, we would hope that VO-H would now be able to analyze the possibilities of alternative scheduling methods. The most important directions for finding new alternatives would seem the development of a mathematical model of the scheduling problem. By doing this, it might become possible to expand the MIS tool into a Decision Support System for recommending scheduling alternatives.

Another possibility for future research would be the analysis of NRCs. By analyzing the behaviour of NRCs in maintenance packages, VO-H might be better able to handle them in future maintenance visits, thus improving the predictions of resources requirements and/or determining matching labour-rosters. From an academic perspective, scheduling unknown objects is also a relatively unscratched topic. Most work that has been created describes how one can handle uncertainty with known jobs, not when the job itself is unknown.

Finally, we would like to point out that the design of a measurement tool on scheduling performances has not yet been described in literature. Though a first attempt has been made by this research to realise performance measurement, the creation of a standard performance measurement tool for scheduling performances would certainly support both research and practice in finding better scheduling alternatives.

References

Air France Industries KLM E&M. (2013, September). *Aircraft Airframe Maintenance fo AFI-KML.* Retrieved November 6, 2013, from Air France Industries KLM E&M Web Site: http://www.afiklmem.com/AFIKLMEM/en/g_page_tabs/GlobalSolutions/Airframe/Airframe.html

Akoka, J. (1981). A Framework for Decision Support Systems. *Information & Management* , 133-141.

Alter, S. L. (1977). A Taxonomy of Decision Support Systems. *Sloan Management Review* , 39-56.

Amrit, C. (2011). *Lecture1_OverviewOfSystemDevelopment.* Enschede: ISDM, University of Twente.

Anderson, E. E. (1985). Managerial Consideration in Participative Design of MIS/DSS. *Information & Management , 9* , 201-207.

Anthony, R. (1965). *Planning and control systems: a framework for analysis.* Division of Research, Harvard Business School.

De Boer, R. (1998). *Resource-constrained Multi-project Management - A hierarchical decision support system.* Enschede: University of Twente.

De Reyck, B., & Herroelen, W. (1999). The multi-mode resource-constrained project scheduling problem with generalized precedence relations. *European Journal of Operational Research , 119*, 538-556.

De Snoo, C., Van Wezel, W., & Jorna, R. J. (2011). An empirical investigation of scheduling performance criteria. *Journal of Operations Management* , 181-193.

Deblaere, F., Demeulenmeester, E., & Herroelen, W. (2011). Reactive scheduling in the multi-mode RCPSP. *Computer & Operations Research , 38*, 63-74.

Eccles, R. G. (1991). The Performance Measurement Manifesto. *Harvard Business Review , 69* (1), 131-137.

European Aviation Safety Agency. (2012, August 01). *Rulemaking Regulations - Consolidated version of Regulation (EC) No 2042/2003.* Retrieved November 6, 2013, from European Aviation Safety Agency Web Site: http://easa.europa.eu/regulations/regulations-structure.php

Franceschini, F., Galleto, M., & Maisano, D. (2007). *Management by measurement : desiging key indicators and performance measure systems.* New York: Springer.

Gademann, N., & Schutten, M. (2005). Linear-programming-based heuristics for project capacity planning. *IIE Transactoins , 37* (2), 153-165.

Gaillard, C. (1990). Tableau de Bord à la blibliothèque de l'université de Paris VI(. *LA BU DE PARIS VI* , 302-30.

Greco, S., Matarazzo, B., & Slowinski, R. (2001). Rough sets theory for multicriteria decision analysis. *European Journal of Operational Research* , 1-47.

Guldemond, T. A., Hurink, J. L., Paulus, J. J., & Schutten, J. M. (2008). Time-Constrained Project Scheduling. *Journal of Scheduling , 11* (2), 137-148.

Hans, E., Leus, R., Wullink, G., & Herroelen, W. (2007). A hierarchical approach to multi-project planning under uncertainty. *Omega, International Journal of Management Sciences , 35* (5), 563-577.

Herroelen, W. (2004). *Project Scheduling - Theory and practice.* K.U. Leuven, Department of Applied Economics, Leuven.

Herroelen, W., & Leus, R. (2001). On the merits and pitfalls of critical chain scheduling. *Journal of Operations Management* , 559-577.

Herroelen, W., Demeulenmeester, E., & De Reyck, B. (1997). *A classification scheme for project scheduling problems.* Research Report, Catholic University of Leuven, Department of Applied Economics, Leuven.

Hurink, J. J., Kok, A. L., Paulus, J. J., & Schutten, J. M. (2011). Time-constrained project scheduling with adjacent resources. *Computer & Operations Research* , 310-319.

Jirava, P. (2004). System development life cycle. *Scientific papers of the University of Pardubice. Series D Faculty of Economics and Administration.* , 58-62.

KLM E&M. (2014, January 5). *DD-control chart Wide Body airplanes*. Retrieved January 05, 2014, from Meetsysteem Technische Operationele Prestaties KLM E&M: https://www.klm.com/corporate/myklm/web/engineering-maintenance/performance-mtop

KLM E&M. (2013, July 9). *E&M Beleid.* Retrieved November 12, 2013, from KLM Corporate Web site: https://www.klm.com/corporate/myklm/web/engineering-maintenance/e-m-beleid1

KLM E&M. (2013). *Maintenix Report of Jobcards for the next maintenance check of the PH-BQN.* Schiphol Ooost: KLM.

KLM E&M. (2013, February). Organogram H14 februari 2012. Schiphol Oost, Noord-Holland, Netherlands. Retrieved November 3, 2013

KLM E&M VO-H H14. (2013). *Summary of Checkdetails vs. TotalManhourPrognosis AKA/AKB/AKD/BFC.* Schiphol: KLM.

KLM E&M VO-H. (2013). *PM3 VO-H Week 43 Verz Deft.* Schiphol Ooost: KLM E&M.

KLM. (2013, Marc 19). *KLM Annual report 2012.* Retrieved November 12, 2013, from KLM Corporate website: http://www.klm.com/corporate/en/images/Annual_report_2012_tcm729-436908.pdf

KLM. (2013, 10 16). *Organizational Charts KLM E&M*. Retrieved November 3, 2013, from KLM Corporate Web site: https://www.klm.com/corporate/myklm/web/engineering-maintenance/organogrammen1

Kolisch, R., & Sprecher, A. (1996). PSPLIB - A project scheduling problem library. *European Journal of Operational Research , 96*, 205-216.

Law, A. M. (2007). *Simulation Modeling and Analysis* (Fourth ed.). Boston: McGraw-Hill Education.

Leus, R., & Herroelen, W. (2004). Stability and resource allocation in project planning. *IIE Transactions* , 667-682.

Mallach, E. (1994). *Understanding Decision Support System and Expert Systems.* Chicago: Irwin.

Masmoudi, M., & Haït, A. (2012). Fuzzy uncertainty modelling for project planning: application to helicopter maintenance. *International Journal of Production Research , 50* (13), 3594-3611.

McDowall, R. D. (1991). The systems development life cycle. *Chemometrics and Intelligent Laboratory Systems: Laboratory Information Management , 13*, 121-133.

Millet, I., & MawHinney, C. H. (1992). Application - Executive Information Systems - A critical perspective. *Information & Management , 23*, 83-92.

Möhring, R. H. (1984). Minimizing Costs of Resource Requirements in Project Networks Subject to a Fixed Completion Time. *Operations Research , 32* (1), 89-120.

Möhring, R. H. (2001). Scheduling under uncertainty: Bounding the makespan distribution. *Computational Discrete Mathematics: Advanced Lectures* , 79-97.

Nelis, A. (2014). *Overview FTEs actual vs Budget.* Schiphol Oost: KLM.

Pinedo, M. L. (2009). *Planning and scheduling in manufacturing and services.* New York: Springer.

Piskurich, G. M., & Piskurich, J. F. (2006). *Rapid Instructional Design: learning ID fast and right .* San Francisco: Pfeiffer.

Saaty, R. W. (1987). The analytical hierarchy process - What it is and how it is used. *Mathematic Modelling* , 161-176.

Silver, E. A., Pike, D. F., & Peterson, R. (1998). *Inventory Management and Production and Scheduling*. New York: Wiley.

Slot, K., & Kleijne, P. (2014). *KLM Internal E&M OVG B747/MD11/B777A330.* Schiphol Oost: KLM.

Sprague, R. H. (1980). A Framework for the Development of Decision Support Systems. *MIS Quarterly* , 1-26.

Taylor, S. E., & Gollwitzer, P. M. (1995). Efet of Mindset on Postive Illusions. *Journal of Personallity and Social Psychology , 69* (2), 213-226.

Van Rijn, L. (2013, September). Informatiesessie Business Management Vliegtuigonderhoud Hangaars. Schiphol Oost, Noord Holland, The Netherlands. Retrieved November 3, 2013

Zijm, W. (2000). Towards intelligent manufacturing planning and control systems. *OR Spectrum , 22*, 313-345.

Appendices

Appendix 1: Organisational Charts KLM

The figure below depicts KLM's organisational chart. Here, KLM E&M is highlight in white, the VP of E&M in green, and VO-H in red.

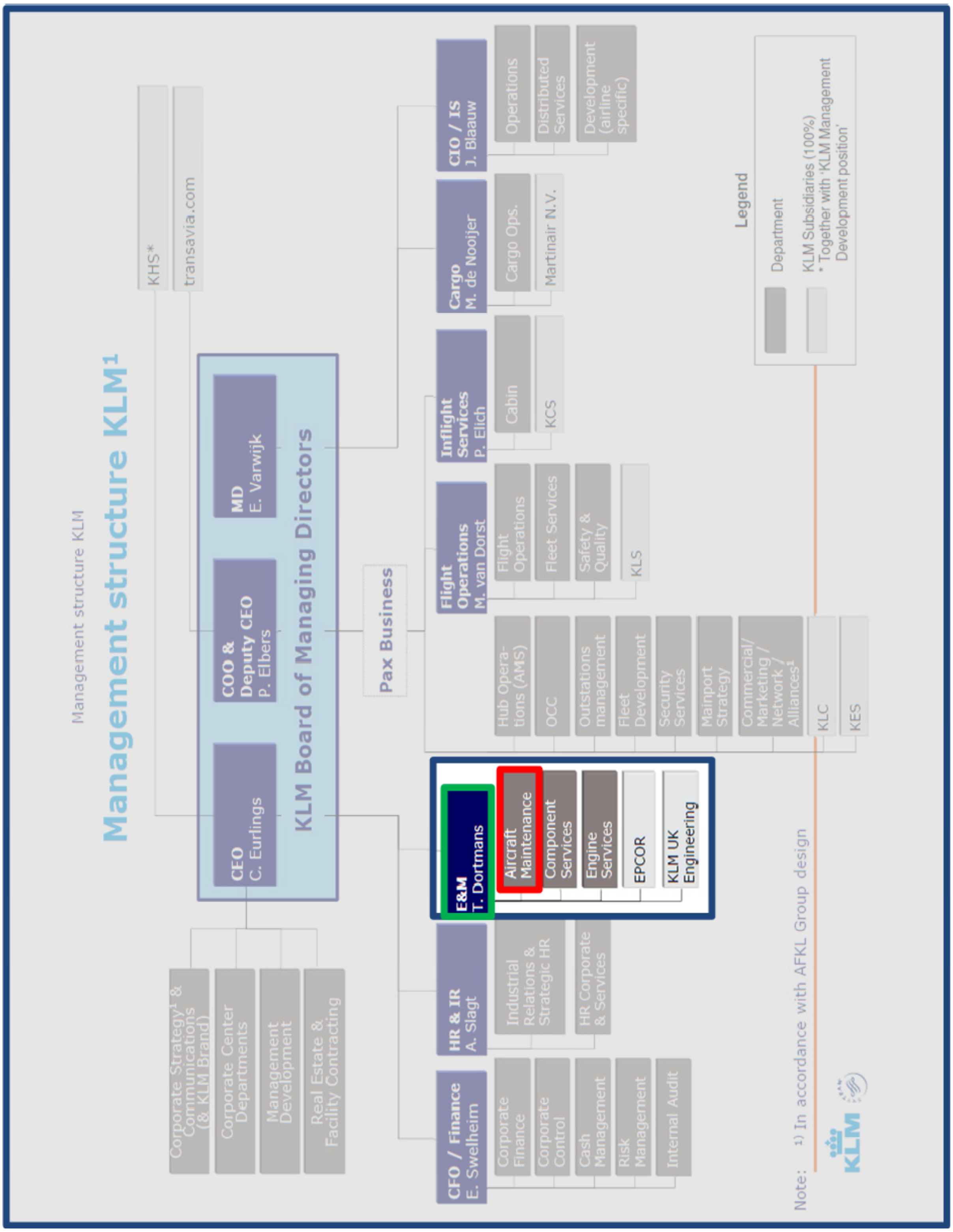


Figure 14: Management Structure KLM (KLM, 2013)

Appendix 2: Organisational Charts KLM E&M VO-H

Below, the organisational chart of VO-H is presented. It is based on the organisational structure after the SOF reorganisation. In orange, we highlighted the VP of VO-H, and in blue, the Production Unit Manager of HIII

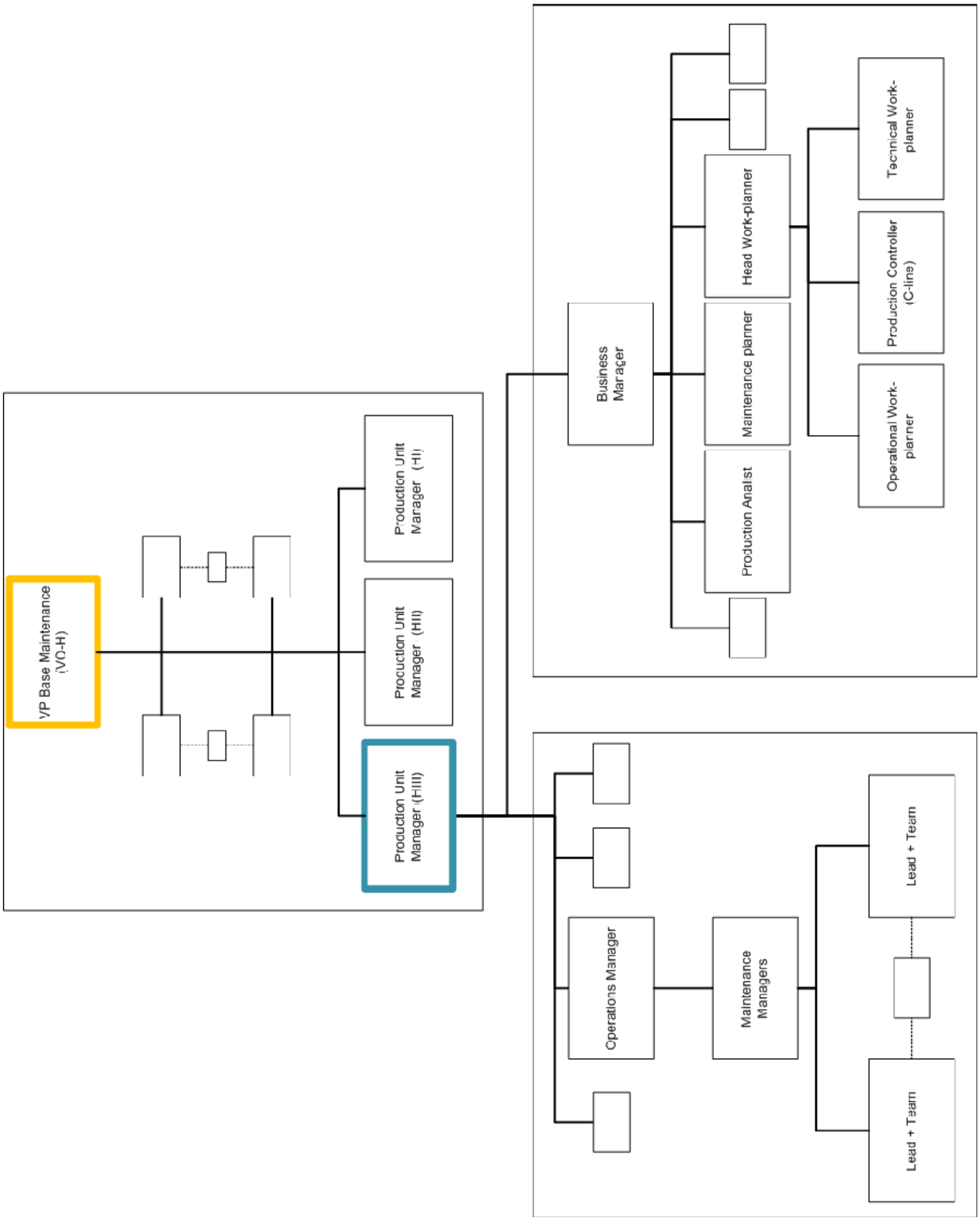


Figure 15: Organisational Chart VO-H, new design (Van Rijn, 2013) (KLM E&M, 2013)

Appendix 3: Background information on maintenance checks.

Aircraft maintenance is strictly regulated by the different governmental agencies. The Federal Aviation Administration (FAA), the European Aviation Safety Agency and National Aviation Authorities have determined in various regulations, when aircrafts are allowed to fly, which organisations are certified to do maintenance, what certifications employees need, and so on... In the aircraft MRO-industry, the term "Article 145" is known for determining all these requirements. It determines for KLM E&M VO-H, which types of maintenance checks can be performed. This is done in the three hangars that VO-H operates, Hangar 10, Hangar 11/12, and Hangar 14, which are names HI, HII, and HIII throughout the thesis.

The maintenance checks that are required to guarantee the airworthiness of the aircraft are split up over 4 types of checks – A, B, C, D – checks. Each of these checks is segmented into sub-parts, explaining the type of maintenance that is performed on that aircraft (e.g. C01). KLM E&M uses the term 'A-line' for all the different A-checks that can be performed on an airplane. Therefore, when the term C-line is used, it will imply that the information given will be applicable for all the C-checks in general. The same applies when C-checks are mentioned without any specific identification. VO-H currently executes the A and C checks for different aircrafts at Schiphol. The D-line is executed at external MROs, like Malaysian Airlines in Kuala Lumpur, Malaysia. Together, they form a sequenced maintenance program that ensures the aircraft' security, e.g. via an A01, C03, A03, and D-check. To clarify the difference between these three checks, each of them well now be briefly discussed. (Air France Industries KLM E&M, 2013) (European Aviation Safety Agency, 2012)

A-line:

The A-line consists of the shortest types of maintenance checks and is indicated as light maintenance. The checks are predefined and only cover certain critical areas of the airplane. The different types of checks (e.g. A01 to A10) cover additional parts of the airplanes, where a full set of A-checks cover all the parts of the B-checks. This is probably one reason why KLM currently only performance A, C, and D-checks.

For Narrow Body airplanes, like the smaller Boeing 737, the A-checks are performed in Hangar 10. Hangar I0 (HI) completes this servicing overnight. Hangar 11/12(HII) performs the A-checks on the Wide Body airplanes. Airplanes, like the Boeing 747 or 777 are much larger than the 737 and take more time to be serviced. These A-checks are therefore scheduled to take 24 hours. The total work related to an A-check is roughly 200 to 300 hours.

C-line:

The C-Line consists of light to heavy maintenance work. It covers most parts of the airplane and therefore requires more man hours, than for instance, the A-check. For the C-check, the airplane is scheduled to be in the hangar for a period of 5 days to a little over 2 weeks. The Narrow Body C-checks are again shorter and can be completed in a week by HI, while the Wide Body checks are performed at Hanger 14, HIII. The Wide Body airplanes take roughly two or three weeks, depending on the type of C-check and the additional modifications that are scheduled. The hours spend on a C-check vary roughly between the 1.500 and 3.000 individual man-hours, with the larger ones even reaching 6000 hours.

D-line:

Though D-checks are not within the scope of this research, they do form an import part of the maintenance sequence. D-checks consist of heavy duty checks, completely overhauling the airplane. The airplane is stripped to its bare minimum, serviced from top to bottom, therefore normally taking about two months to complete. These checks used to be performed by HI and HIII, though being one of the consequences of the reorganisations, is now conducted in at external partners. After the completion of the D-check, the airplane is fully refreshed for the next maintenance sequence, starting again with the smaller A-checks. The workload related to d-checks varies between 4 to 8 weeks of work, being roughly 50.000 man-hours for a standard D-04 check.

Other checks:

Besides A/B/C/D checks, additional checks are executed during aircraft maintenance. E.g. M-checks are used for an engine relate check. M- or H-checks are added to a larger check, as they generally too small to be executed independently.

Appendix 4: General background information Securing Our Future:

Securing our Future is about changing KLM to realise cost savings, increased productivity, and additional revenue across all the business units. For KLM E&M VO-H, the main goal of Securing Our Future is to realise a 30% improvement on their productivity. This figure is based on the inefficiencies that are present in many areas of the organisation.

The general problem can be divided in three sections. The first problem is found in the execution of processes and their costs. The operations of VO are too expensive, making it an unattractive partner for external operators and KLM. The costs of the operations are too high, as only 3.5 of the 6 declarable hours are currently transferable to the customers (Nelis, 2014). The main reason why only 60% of the costs for labour hours are transferable to the customer is due to the inefficiencies in the productions. Production workers spend too much time waiting for materials or on other tasks, on administration, and on hold-ups caused by the incorrect information that is linked to the work packages. Inefficiencies are not only present in the direct labour. Supporting processes are also executed with too much inefficiency. They are designed to support production, though they also spend too much time on e.g. finding the correct information. The second problem lies in the motivation to execute the necessary improvements. The expectancy for improvement projects is low, due to the numerous projects that have been started in the past. Though they have been communicated and many have spent time and effort on these projects, most of them were stopped, before they were completed. It is therefore very important that Securing Our Future is fully implemented and secured. The final problem lies in the IT that should facilitate the production and supporting activities. Paper pushing and disconnected systems and databases fire the inefficiencies in the processes. They force employees to find workarounds and create additional efficiencies for something that should actually improve their productivity. Therefore, the reorganisation of processes should also embrace additional changes to matching IT system. Solving these three problem should lead to the desired increase in productivity.

Based on lean principles, the general idea is to enable the 4Ms for the process at the right place, at the right time, with the right quantity. This visualizes in the match between the 4Ms and the process in the figure on the next page. As can be seen in Figure 16, the process is divided over the business and the operational management (BM & OM). Simply stated, the BM is responsible for the back office (the supporting activities to production), while OM is responsible for the production and the front office (support during production). This is the result of the organisational design, created for the ten reorganisation projects. These projects divide the work needed to realise this new organisation. What they contributed is describe below.

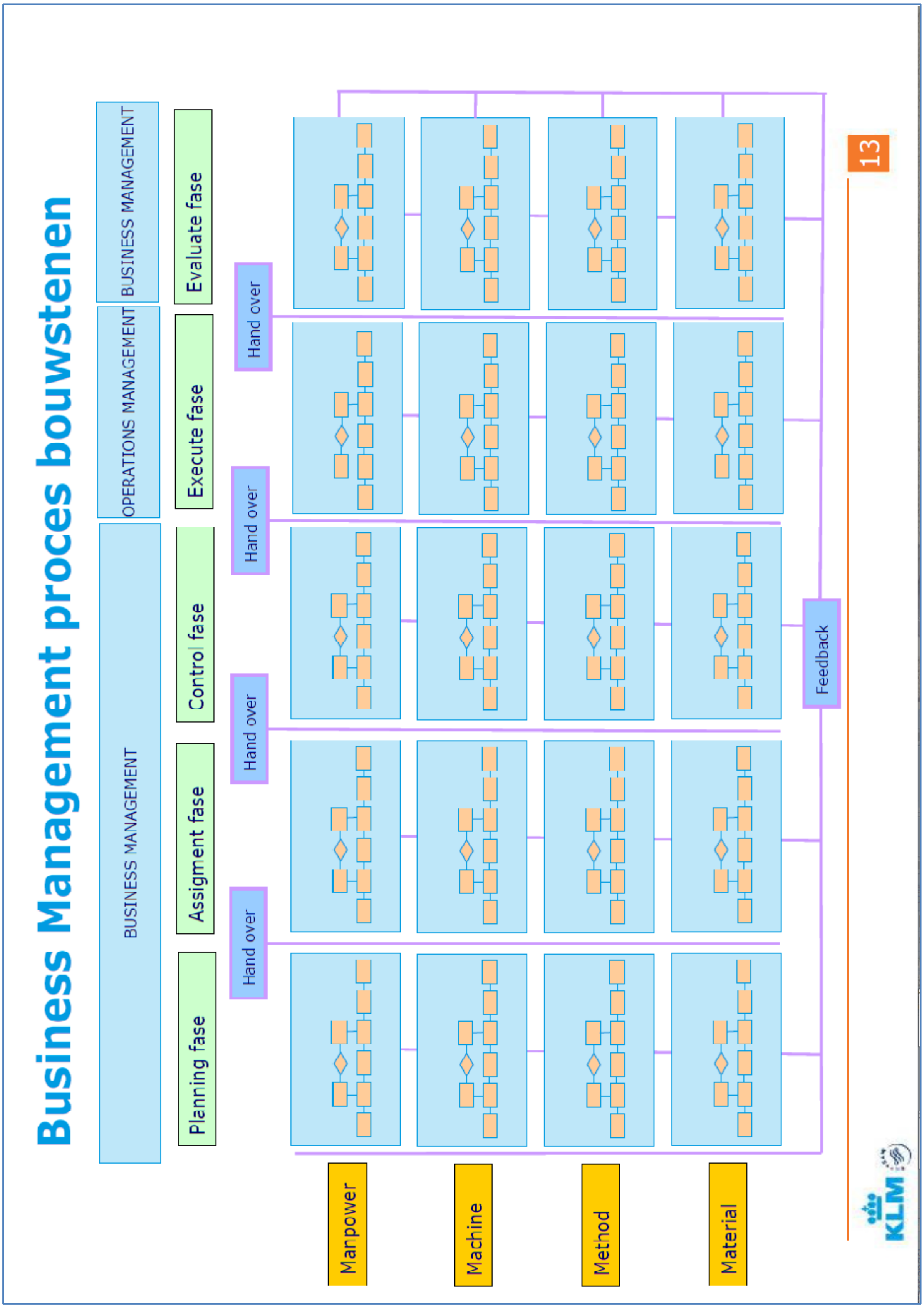


Figure 16: Overview organisational matrix 4M vs. process flow (Van Rijn, 2013)

10 Major Improvements Project KLM E&M VO-H:

1. Work preparation and shaping back office.
    - This project is used for designing the processes and the organisation within back office. It is responsible for defining the processes that deliver the work preparation and for designing the organisational units that create this work preparation.
    - The goal of this project is to deliver standardized, executable work packages that are tailored to the different shifts. It should provide the information on when the 4Ms should be made available in the production.
    - The box in the lower left corner of Appendix 2 shows the new organisational design for the Business Management c.q. back office.
2. Shift-based working and shaping front office
    - This project is used for designing the processes and the organisation within the front office. It is responsible for defining the processes that control the daily scheduling of tasks and the control over the different production teams.
    - The goal of this project is to improve the scheduling of tasks per shift, the rescheduling of tasks due NRCs and abnormal disruptions, the distribution of tasks to teams, and to control over the execution of tasks. This should result in a predictable and reliable production process, ensuring the completion of project within budget and on time.
    - The box in the right left corner of Appendix 2 shows the new organisational design for the Operation Management c.q. front office/production.
3. Materials & equipment around the aircrafts
    - This project is part of the solution that directly controls one of the 4Ms, making sure that the materials and equipment needed to perform a certain tasks are delivered to the process at the right time, place, and quantity. To realises these actions, it must be necessary to update and eliminate the errors in the IT and administration of materials, equipment, and tasks. Additionally, the processes that control the logistical flow to the airplane need to be redesigned and enforced.
    - The goal of this project is to create savings via reduced inventories, eliminate the time spent searching for and (re)ordering materials. It should also a visible aspect that reinforces the feeling amongst the workers that the current reorganisation is effective.
4. Teams
    - This project focuses on the workers and their work methodology. The intention is that, by creating balanced team that start together, work together, and finish the day together, that teams are more involved with their work. The usage teams should create a sense of responsibility amongst workers to complete their tasks more efficiently and with more care. This project has been dissolved in Projects 1, 2, and 9.
5. Lead, combined functions, and problem solving
    - This project is designed to create the organisational structure in the production needed to work in teams, to secure control and to stimulate continuous improvement. This project has been dissolved in Projects 1, 2, and 9.
    - The goal of the project is to secure the improved work ethics that should be created by the new organisation. It should also ensure that the organisational changes are secured as well as the effectuation of continuous improvement.

6. Craftsmanship and capability
    - The project is designed to optimize the utilization of the production employees. By releasing the restrictions that KLM has set on their skills and lowering it to the legal standards, it should become possible to increase the productivity of the workers.
7. Visible progress & visual communication Connected Balanced Score Card
    - This project focuses on effectuating key performance indicators. In the current situation, it is hard to understand how hangars are performing, if projects are nearing their completion or if workers are actually performing as they should. As this information is lacking, it is very difficult to control these processes. For that reason, agreements and definitions are needed on the performance indicators and tools are needed to visualize these indicators.
    - The goal of this project is to provide the organisation the tools needed to steer on performance. By visualizing the current status of maintenance projects, VO-H hopes to motivate people to increase production and to support control to increase the production.
8. A safe, clean, and light work environment – Hangar improvements
    - The three hangers that are operated by VO-H are in need of improvements. The original hangars lack the standardized safety markings for non-essential personnel and the dark lighting lowers the environmental factor in productivity.
    - By improving the hangers, marking/painting the floors and walls, changing the lighting and investing in standardized (safety-) equipment, KLM hopes to increase the productivity of the workers and to visualize the projects of Securing Our Future.
9. Governance and Maintenance Manager
    - The ninth project is designed to realise the actual transition into the new organisation. This project is not about defining processes, as it is more on defining the roles of functions in the organisation and finding suitable employees for these functions. Figure 16 shows how the governance within the new organisation is distributed. A Product Unit Manager will lead the hangars, supported by the business and operational manager. The BUs and OMs are responsible for the functional areas indicated in Figure 16. The organisational chart that is a result of this new organisation is shown in Appendix 2.
    - The goal of this project is to create the organisation, define the roles for each function, and to create the educational support process to ensure growth of the individuals in those particular functions.
10. Using IT
    - As mentioned, the problem with not functioning IT is one of the major organisational problems. By providing the production and management with linked IT systems that are intuitive to use, VO-H plans to eliminate unnecessary actions in the organisation and provide additional means to eliminate waste. For this some major IT systems will be updated and implemented as E-signature, Single Sign-off, Maintenix update, Novulo update, and Workflow.

Appendix 5: [CONFIDENTIAL] Overview utilization rates VO-H and performance WB C-line checks

Images and text were removed for confidentiality reasons.

UNIVERSITY OF TWENTE.

Appendix 6 Literature search model

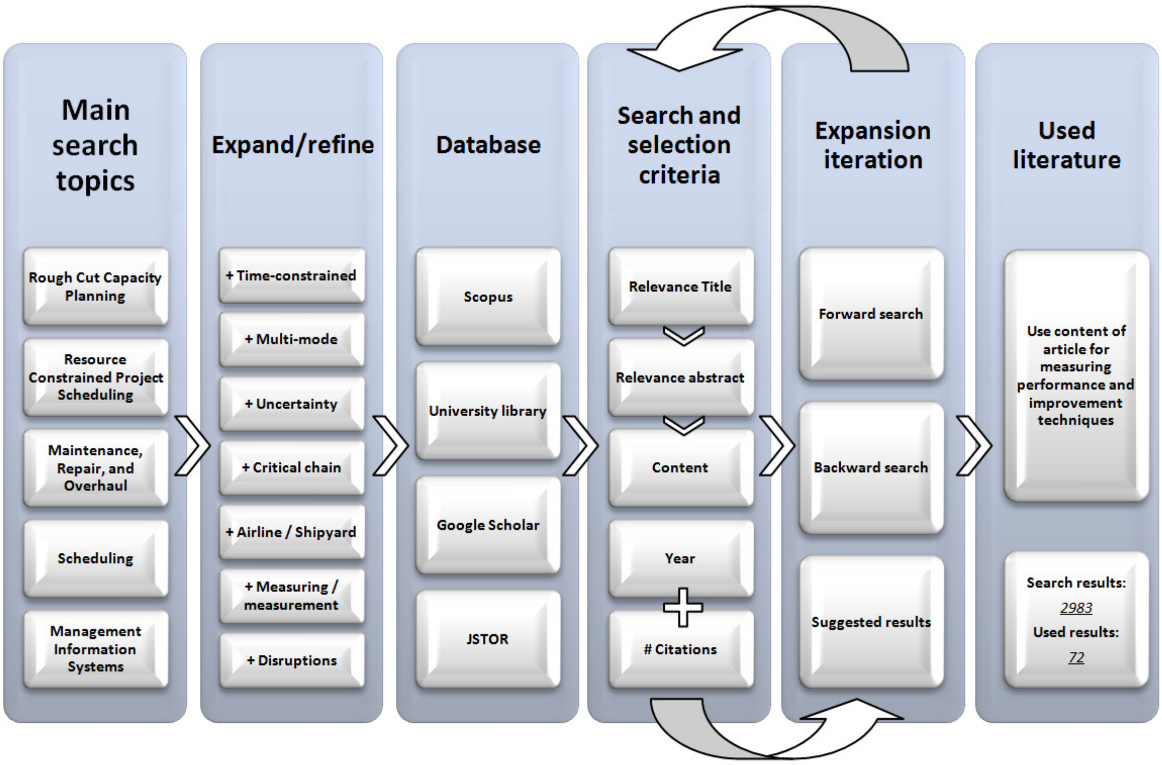


Figure 20: Literature search model (including most relevant topic and expansions)

Appendix 7 Background information RCPS classification Herroelen et al.

In Chapter 2 we established that the RCPS problem can include several variations. Depending on the characteristic of the resources (α), the characteristics of the activities (β), and the objective you try to achieve (γ), different scheduling methodologies can be applied to achieve better scheduling results (Herroelen, Demeulenmeester, & De Reyck, 1997). To capture these variations, Herroelen et al. (1997) formulated a framework that would capture all the varying aspects of the RCPS problem. This framework is displayed in Table 8.

Type	Description	Possibilities
α1	# Resources	{o,1,m}
α2	Resource type	{o, 1, T, 1T, v}
α3	Res. Availability	{o, va}
β1	Pre-emption	{o, pmtn}
β2	Precedence constraints	{o, cpm, min, gpr, prob}
β3	release dates	{o, rj}
β4	duration	{o, cont, pj=p}
β5	deadlines	{o, δj, δn}
β6	nature resource req.	{o, vr, disc, cont, int}
β7	execution modes	{o, mu, id}
β8	cash flows	{o, cj, c+j, per, sched}
γ	Resource/Time driven	-

Table 8: RCPS classification framework by Herroelen et al. (1997)

Herroelen et al. (1997) divided the aspects of the RCPS into the three categories we described above, being: α, β, and γ. Now, we will now briefly describe each of the aspects and which possibilities there are in the RCPS problem, to provide a legend for Table

For the characteristic of the resources (α), there are in three different aspects, the number of resources (α1), the type of resources (α2), and the way these resources are available (α3). The number of resources is expressed as: absent (o), one resource type (1), or m different resource types (m). The resource might be without a resource type specification (o), might be renewable for each time unit (1), might be non-renewable over the entire project (T), might be a mixed renewable and non-renewable (1T), or might be partially non-renewable, meaning that they are only renewable in certain time buckets (v). Finally, these resources might be available in a constant amount (o) or they might vary over time (va).

For the characteristics of the activities (β), there are in total eight aspects that can be defined for the RCPS. For this scheduling problem, we might consider activities that can be pre-empted (β1), which could have precedence constraints (β2), which might have release dates (β3), for which the duration time is defined (β4), for which deadline might apply (β5), for which a specific resource requirement might be necessary (β6), which could be executed in different modes (β7), or could related to a specific cash flow (β8). To clarify some, precedence constraints might be defined via critical path method (cpm), have precedence relations with minimum time lags (min), which might have generalised precedence relations (gpr), or could be of the probabilistic type (prob), meaning that the relations between activities might change through the project. The duration might be arbitrary continuous (cont) or equal to *d* time units (dj=d). The deadlines that might be there, could apply to a single activity (δj) or for the entire project (δn). The resource requirements can be of a constant discrete amount (o), could be variable discrete (vr) or could be defined as a discrete- (disc), continuous- (cont), or an intensity/rate-function (int).

Finally, the objective of the RCPS might either be resource- or time-driven (γ), depending on which of these two is known/fixed and which one serves as variable.

Appendix 8: [CONFIDENTIAL] Example Routine & Non-Routine Card

Images and text were removed for confidentiality reasons.

Routine Card:

Figure 21: Example RC from C03-check on PH-BVA containing 1 activity

Non-Routine Card:

Figure 22: Example NRC from C03-check on the PH-BVA

Appendix 9: [CONFIDENTIAL] Summarized data analysis performance after calculation

Images and text were removed for confidentiality reasons.

Table 9: Summaries accuracy after calculation Boeing

Table 10: Summaries accuracy after calculation Airbus

Appendix 10: [CONFIDENTIAL] T-minus x list old organisation.

Images and text were removed for confidentiality reasons.

Table 11: Copy of old T-minus list

UNIVERSITY OF TWENTE.

Appendix 11: [CONFIDENTIAL] T-minus x list new organisation.

Images and text were removed for confidentiality reasons.

Table 12: Copy of new T-minus list

Appendix 12: [CONFIDENTIAL] KLM internal E&M OVG B747/MD11/B777/A3

Images and text were removed for confidentiality reasons.

Figure 23: OVG First half 2014 (Slot, 2014)

Appendix 13: Manual for using measurement tool

Below you can find the Dutch manual that was added for the usage of the tool. It is included in the actual tool, such that the users would always have access to it. It explains for all users what the functionalities are of each tap, how they should use the tool, and how the major fields of the tool should be interpreted. This explanation is followed by a set of print screens, showing each of the taps on the tool and describing how the information should be inserted into the tool.

Uitleg voor Tool

TABS

Bevat:
Instructions, Tool, Check details (current), Check details (previous), Plan shift, PIB, Calc Sheet Gen Prog, Calc Sheet Zone Prog, Burndown

Kleur betekenis:
Rood: Overzicht met informatie
Geel: Hier de informatie in plakken
Grijs: Rekensheets, niet bewerken
Oranje: Voor het maken van charts (data analist)

BURNDOWN

Bevat:
Tabellen en charts van de status over meerdere dagen.

Door middelen van het laden verschillende check details, kan men per uur, dag, shift, verschillende team/phase statussen uitdraaien. Hiermee kan ook de benchmark gebouwd worden, als deze date in een database worden gezet. Hiermee kan vergeleken worden of de huidige status op de zones goed is. Of er dus achter- of voorgelopen wordt, vergeleken met vergelijkbare checks.

TOOL - BUTTONS
(hoe deze tool te gebruiken)

Stap 1:
Download vanuit maintenix de check details die je wilt gebruiken.
Plak de laatste versie in current en eventeel voor vergelijking in previous **(NODIG!)**
Plak eventueel de selectie van plan shift **(Opt.)**
Plan eventueel de PIB **(Opt.)**

Stap 2:
Gebruik de knoppen om de informatie in te laden, te laten zien, of te verwijderen
(6) Fill data current check
Na het plakken van de informatie in de gele tabs, druk op deze knop en alle tabellen worden gevuld en door gerekend.
(5) Show status current check
Laat de status zien in Aircraft Status, voor de current check details tab
(8) Show previous status
Laat de status zien in Aircraft Status, voor de previous check details tab
(4) Clear table + aircraft
Verwijdert niet alle data, alleen de tabellen en het vliegtuig. Knoppen blijven werken
(7) Clear ALL
Verwijdert alle data. Andere knoppen werken hierna niet meer voordat de tabs weer gevuld zijn.

(x) - geeft aan welke macro bij deze button hoort

TOOL

Bevat:
General details, Overall status, Team status, Phase status, Daily status, Zone Status, Aircraft status, Buttons, Legend.

General details:
Hier staat de algemene informatie van de kist. Het meeste wordt uit de check-details gehaald, maar de daadwerkelijke ETR, start moment en het totaal aantal shiften moeten handmatig ingevoerd worden

Overall status:
Hier staan de algemene details over de status van de kist in verwerkt, verdeeld over de status in uren en de status in job cards. In het groen staan dik gedrukt de belangrijke waarden over wat nog moet komen, terwijl in het geel uitgedrukt is waar we nu staan. In de notes staat verwerkt, wat er in de verschillende waarden verrekend zit.

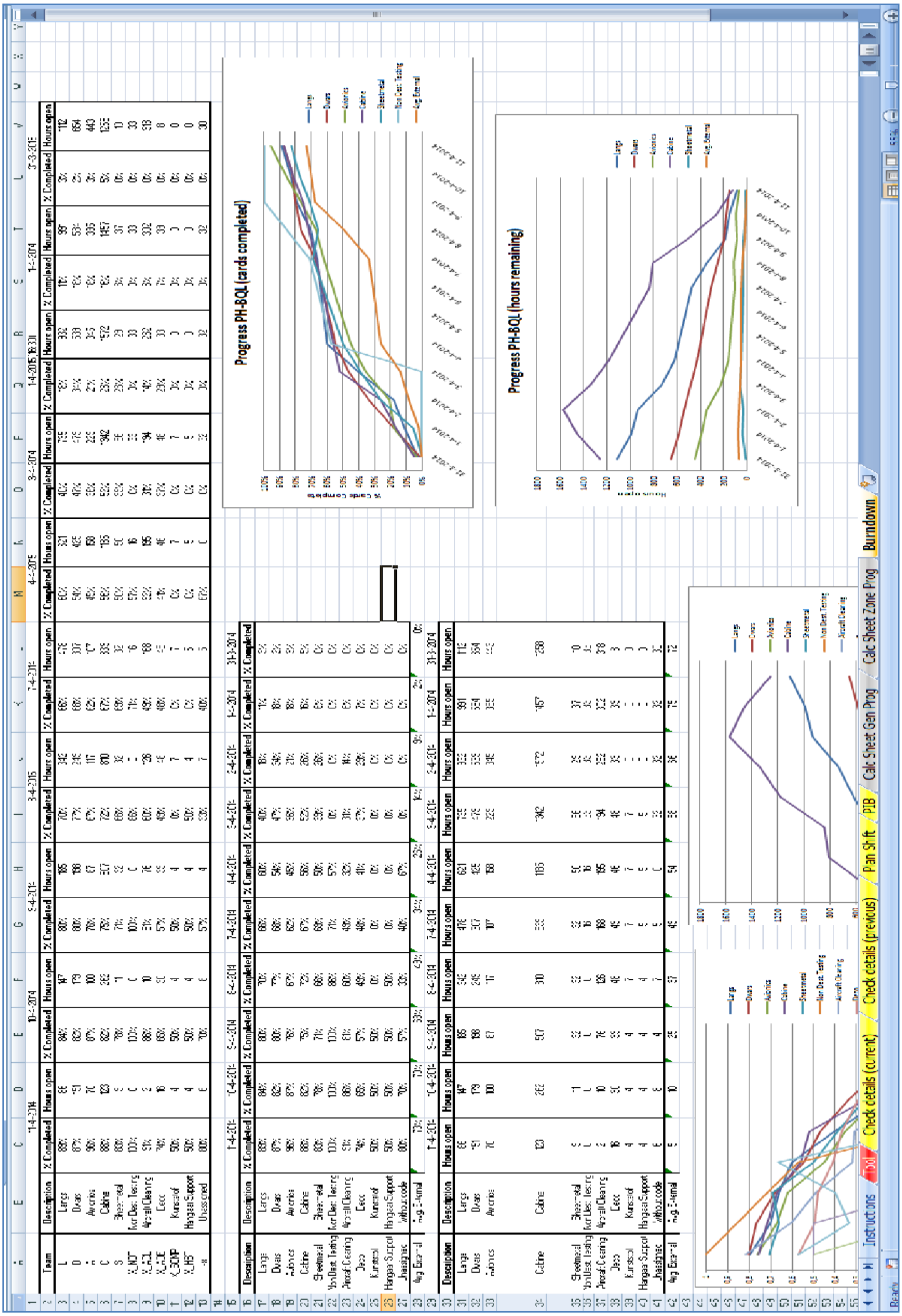
Team status:
Jobcards bevaten de codering Team_Shift_KLMZone_Produtie phase. Gegroepeerd per team(langs, dwars,NDT,...) laat deze tabel de huidige status zien. De kaarten waarvoor 'xx' is aangemerkt, hebben geen codering meekregen, maar zouden wel uitgevoerd moeten worden (niet gecancelled/unassigned in maintenix). De kolom '**% completed**', geeft het percentage job cards dat klaar is voor dat team. De '**Hours open**' geeft het resterende aantal uren weer (die bekend zijn -> Spent>Calc!)

Phase status:
Net als de team status, is gegroepeerd per productie phase, de status van de kis hier te vinden. Ook hier geld dat % completed voor het aantal kaarten is en de hours open gerelateerd aan de open staande uren is. Onder phase status staan het aantal taakkaarten die nog wel open staan, maar waarop meer gespendeerd is dan calculated. Hiervan is in het systeem niet te zien hoeveel daarvan nog open staat.

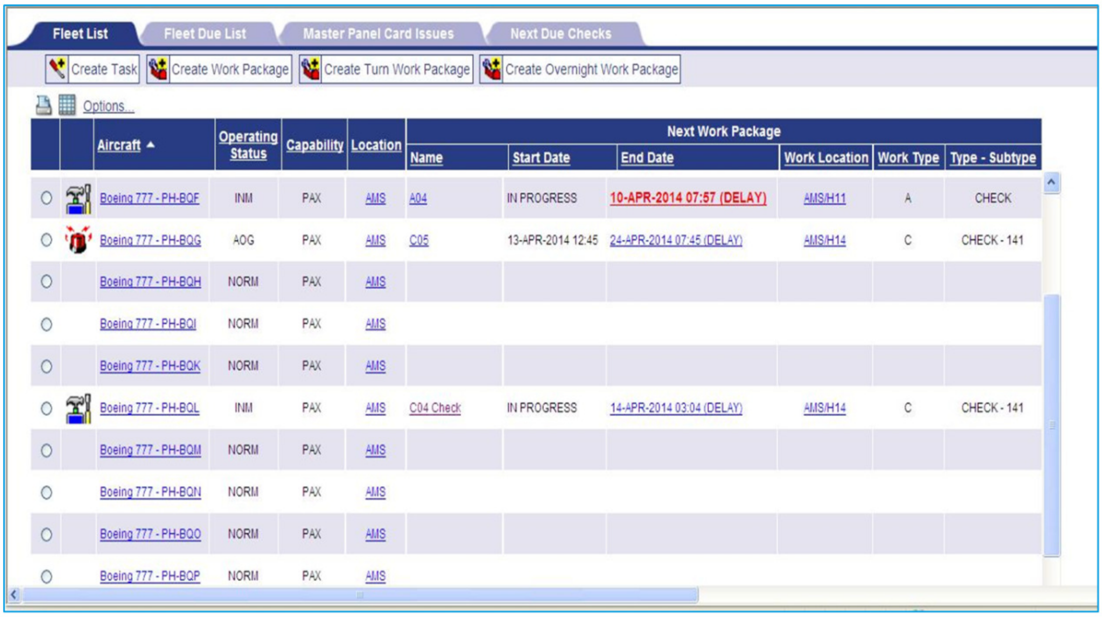
Daily status: (WERKT NOG NIET)
Met het huidige systeem kan alleen handmatig een selectie van de geplande taken gemaakt worden via de maintenix functie: Plan shift. Als men de hele tabel handmatig selecteerd en kopieerd, dan kan alsnog zichtbaar gemaakt worden op barcode niveau hoeveel uur we gewerkt hebben en/of deze taken gepland waren of niet. Als er een excel export in maintenix komt met dezelfde format, dan zal dit makkelijker uitgevoerd worden. Ook moeten men dan wel de taken in maintenix op de juiste tijden zitten.

Zones status:
Naast de klm-zones die wij aan taakkaarten meegeven, heeft iedere taakkaart ook de OEM-zones meekgeregen. Voor airbus/boeing zijn de hoofdzones hetzelfde en wordt gebruikt om de status van het vliegtuig inzichtelijk te maken. Per taakkaart zijn alle gerelateerd zones genoteerd en geven in '**Status Aircraft**' de huidige status weer. De tabel geeft de status van 2 check details weer, de huidige (current) en voorgaande (previous). Via de buttons voor de current en previous status (5 en 8), kan het vliegtuig de verschillende statussen laten zien. De delta sectie werkt alleen als het om 1 visit gaat.
NB: percentages zijn op kaart niveau, niet uren!

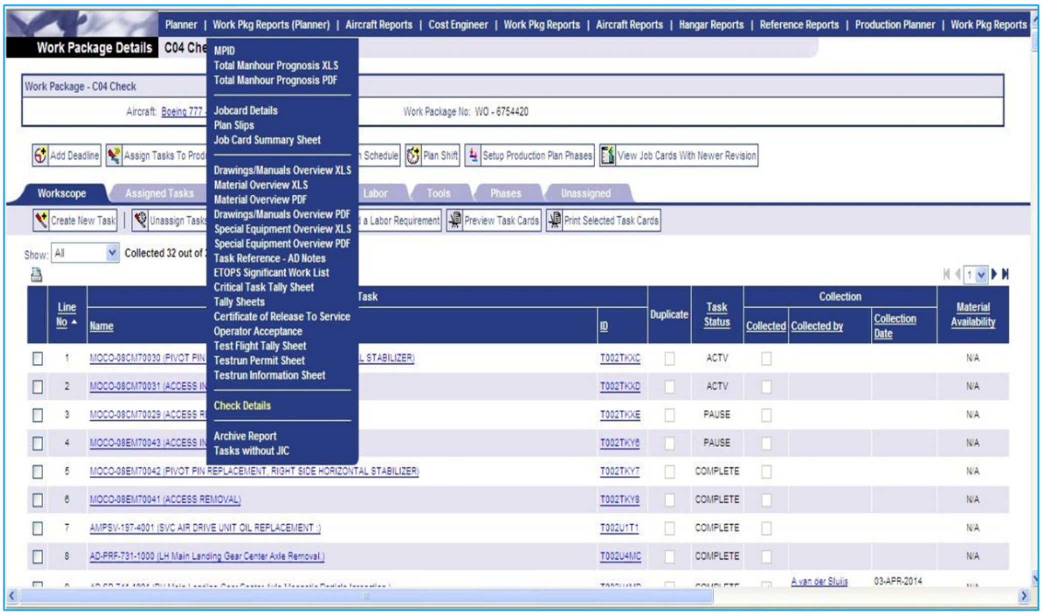
Status aircraft:
Hier staat per hoofdzone de status van het vliegtuig. Voor de onderstellen en deuren (700/800) zijn 2 tabellen naast het vliegtuig ingeruimd en geven de status voor alle deuren. Dit geldt ook voor zone 400, de motoren, als in, hier is geen onderscheidt gemaakt tussen de linker motor(en) en rechter motor(en).


Progress PH-BQL (cards completed)
Progress PH-BQL (hours remaining)
Instructions
Check details (current)
Check details (previous)
Plan Shift
PTB
Calc Sheet Gen Prog
Calc Sheet Zone Prog
Burndown

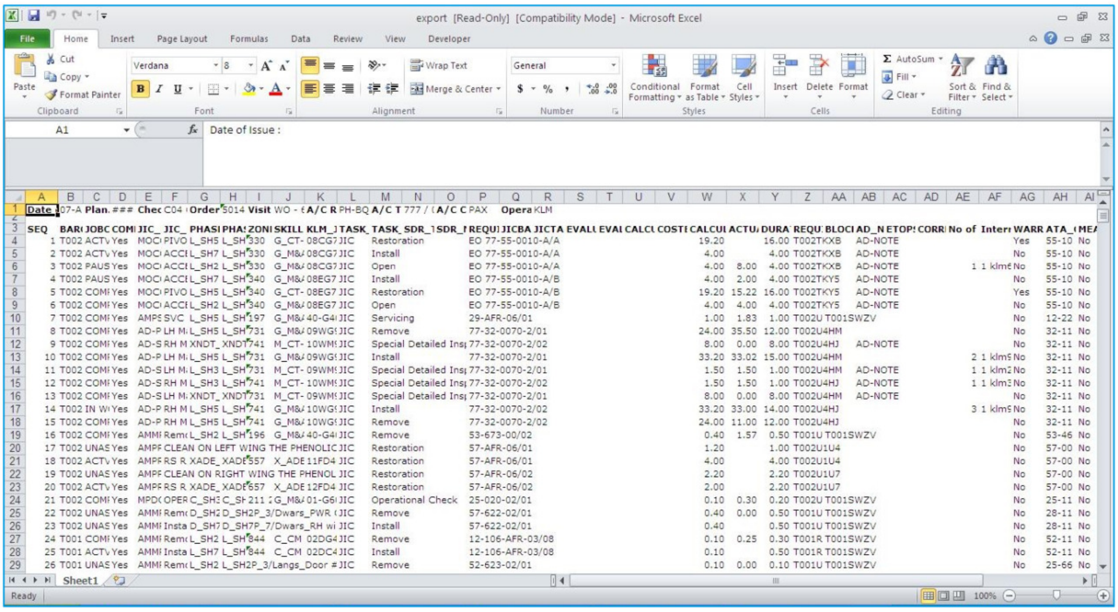
Step 1: Maintenix – planner_to do list



Step 2: Generate check details



Step 3: Copy check details in tool



20

ETR

11-04-14 23:00

General Details

A/C Reg	PH-BQL
A/C Type/Eff.	777 / 011
A/C Config.	PAX
Operator	KLM
Check Name	C04 Check
Expected Started Date	30-03-14 12:45
Actual Starting Date	17-03-14 12:00
Number of shifts	34,5
Date	3-10-14 17:09
ETR	**11-04-14 23:00**

Team status

Team	Description	% Completed	Hours open
L	Langs	89%	86
D	Dwars	87%	151
A	Avionics	96%	70
C	Cabine	88%	123
S	Sheetmetal	83%	9
X_NDT	Non Dest. Testing	100%	0
X_ACL	Aircraft Cleaning	91%	2
X_ADE	Deco	74%	16
X_CMPT	Kunststof	50%	4
X_HST	Hangaar Support	50%	4
xx	Not Coded	80%	6

Daily Status

Cards Scheduled	15
Hours Scheduled	15
Scheduled Cards worked on	4
Unscheduled Cards worked on	148
Scheduled Hours worked	15
Unscheduled Hours worked	407

Zone Status

Previous status	Zones	100	200	300	400	500	600	700	800
	# cards related to zone	382	680	135	70	266	263	34	194
	cards complete	300	576	111	63	241	228	29	153
	% complete	79%	85%	82%	90%	91%	87%	85%	79%
Current status	Zones	100	200	300	400	500	600	700	800
	# cards related to zone	386	682	135	71	266	265	34	195
	cards complete	348	631	121	63	244	235	29	169
	% complete	90%	93%	90%	89%	92%	89%	85%	87%
Change	Delta Cards	48	55	10	0	3	7	0	16
	Delta %	12%	8%	7%	-1%	1%	2%	0%	8%

Overall Status

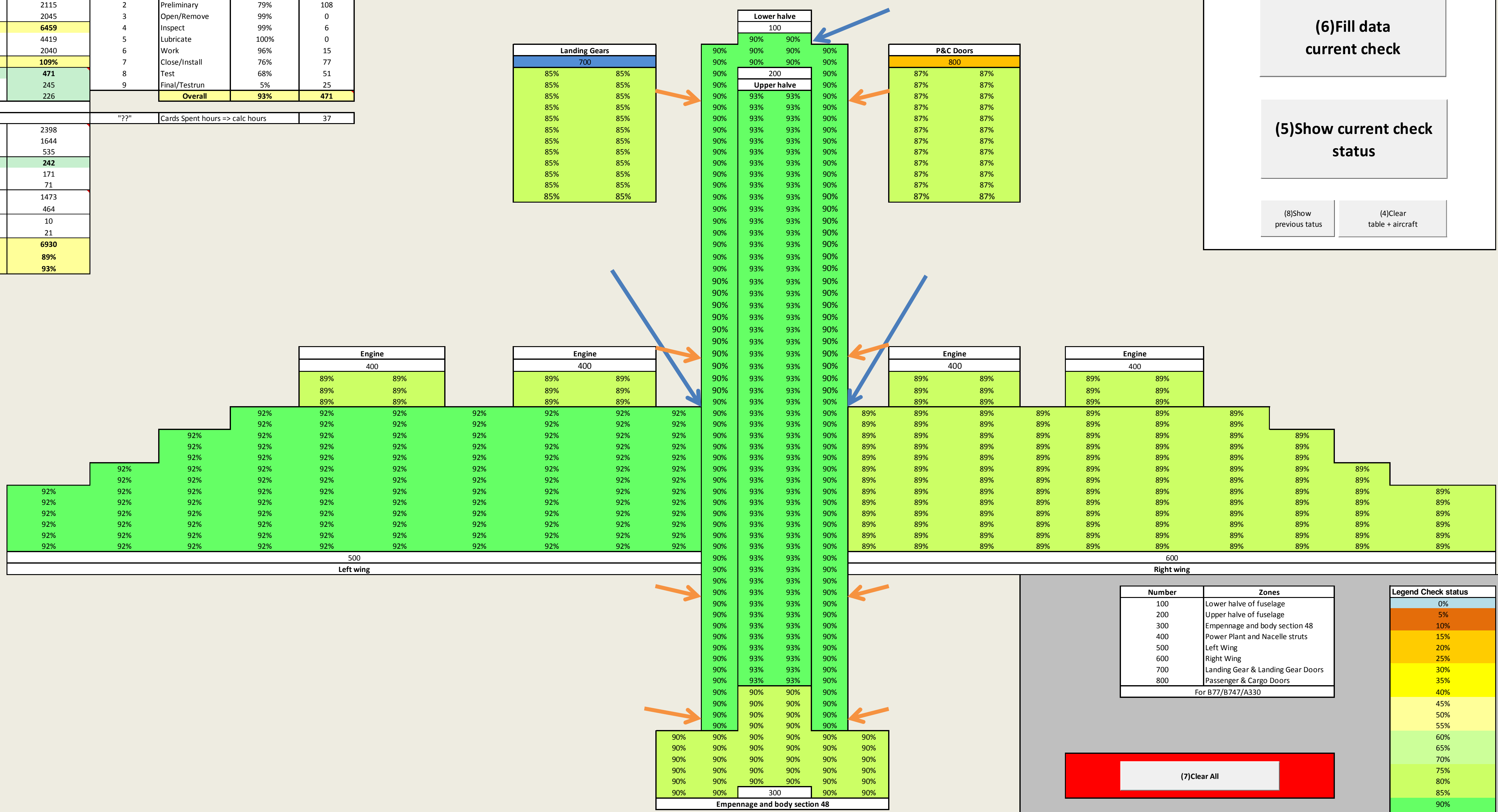
HOURS	
Expected Total hours	**5909**
Calc RC hours	3864
PIB NRC hours	2115
Calc NRC hours	2045
Total spent hours	**6459**
Spent RC hours	4419
Spent NRC hours	2040
Percentage Spent vs Calc	**109%**
Total hours open	**471**
Exp. RC hours open	245
Exp. NRC hours open	226

CARDS	
Total cards	2398
Total RC cards	1644
Total NRC cards	535
Total Cards open	**242**
RC cards open	171
NRC Cards open	71
RC cards completed	1473
NRC cards completed	464
Cards not coded for zones	10
Hours not coded for zones	21
Total hours Spent+Open	**6930**
Percentage cards completed	**89%**
Percentage hours complete	**93%**

Phase status

Phase #	Phase	% Completed	Hours open
0	Faults	88%	81
1	Attention	77%	103
2	Preliminary	79%	108
3	Open/Remove	99%	0
4	Inspect	99%	6
5	Lubricate	100%	0
6	Work	96%	15
7	Close/Install	76%	77
8	Test	68%	51
9	Final/Testrun	5%	25
	Overall	**93%**	**471**
"??"	Cards Spent hours => calc hours		37

Status aircraft



(6)Fill data current check

(5)Show current check status

(8)Show previous tatus

(4)Clear table + aircraft

Number	Zones
100	Lower halve of fuselage
200	Upper halve of fuselage
300	Empennage and body section 48
400	Power Plant and Nacelle struts
500	Left Wing
600	Right Wing
700	Landing Gear & Landing Gear Doors
800	Passenger & Cargo Doors
For B77/B747/A330	

(7)Clear All

Legend Check status
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%
100%