# POTENTIAL IMPROVEMENTS IN THE PLANNING AND SCHEDULING CHAIN AT KLM AIRCRAFT SERVICES

Master Thesis Industrial Engineering and Management


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*"Plans are of little importance, but planning is essential."* – Winston Churchill

# Preface

I have been amazed in the last six months. Where my Bachelors and Masters prepared me to improve any logistics problem, it did not prepare me for organizational bureaucracy, politics, and behavior. KLM needs 32,000 employees to keep 202 aircraft in the air. The number astonished me, 145 people per aircraft. KLM just has enough airplane seats to transport their whole personnel base.

All that everybody kept saying was “welcome to the real world”. The most amazing thing is that the KLM functions reasonably good. Despite a resigning CEO, a major strike by Air France pilots, and news about massive lay-offs, KLM still made an operational profit in the last quarter of this year. In retrospect it has been a great experience. The difficulty was not to find potential solutions or collecting relevant data; it was the vast organization and communicating my ideas that gave me the most valuable experience I could have had during my master thesis.

At KLM I would like to thank Mark Bovenkerk for giving me this “real world” experience. The discussions, thesis feedback, but also the regular talks on the train home were valuable to me. I would like to thank Elizabeth Brunsting for her daily supervision of my internship. You were always ready to answer questions or start a discussion, but above all, you always kept your patience while I was trying to run at full speed. I want to thank Iwi and Marian for being great colleagues and the discussions about everything that was not related to my thesis, and for attending a classical concert that I was doing with Collegium Musicum Leiden. And of course I want to thank Tony for always being there, questioning my arguments, and always being ready to help out.

At the University of Twente I would like to thank Marco Schutten and Leo van der Wegen for their structural monthly support. Your feedback helped me in structuring my thesis, asking the right questions, and guiding my through the landscape of academics and practical application. Furthermore, I thank Marco for his visit to the KLM, which helped a lot in giving my thesis the right direction.

Finally, I would like to thank family and friends for their support. Discussing my internship and sharing my frustrations about it has been very helpful. Furthermore, I would like to thank all my friends with whom I make music and do long distance running. Music and running kept me calm and focused, and were the greatest contributors to the quality of this thesis.

# Summary

## Motivation

For Refueling, the current planning and scheduling chain at KLM Aircraft Services (AS) results in a workload prediction that is different from the workload during execution. The differences between planned and actual workload either result:

- in a personnel shortage that leads to lower on time performance (OTP) and aircraft delay costs
- in an overcapacity of personnel that results in higher operational costs.

AS does not have the tools to understand the differences between planned and actual workload. Therefore, current personnel scheduling is experience based in which AS schedules personnel to cover for more or less than the expected workload.

## Research Goals

The first goal in this research is to identify and understand of the current discrepancies between the planned and actual workload. The second goal is to propose potential improvements for the planning and scheduling chain to deal with the current discrepancies between planned and actual workload.

## Current Situation

The current planning process considers one flight schedule for which it makes one workload prediction in the form of a workload profile. This workload profile is built from a deterministic optimized refueling schedule. This schedule uses standardized plan norms that describe the required fuel task time for each aircraft type.

AS does not use this schedule during execution. The schedule that Refueling executes is updated every 30 seconds for all tasks in the upcoming four-hour time interval. Refueling operates in a dynamic environment that depends on changing flight links (the assignment of aircraft to specific flights), early and late arrivals of flights, incidental tasks, disturbances in the process, and fuel requirements by airlines and pilots.

During the planning process, AS assumes time-windows to service aircraft. These time-windows are different from the time-windows that AS has during execution. Furthermore, the plan norms have less time than the actual needed time to execute a task. This is because needed driving times are underestimated and obligatory vehicle inspections are not included.

## Potential improvements

We recommend that AS reconsiders its planning norms. AS must include vehicle inspections to the norms, and should consider the use of a driving time matrix that is based on historical data. Furthermore, AS should consider planning and scheduling with 50$^{th}$ percentile norms for scheduling flexibility, i.e. a norm that covers for 50% of all historic instances.

To cope with incidental tasks, severely delayed aircraft, and longer tasks duration we recommend that AS schedules buffers between tasks such that enough capacity is available to deal with these factors. The amount of time buffer depends on Aircraft Services goals. AS must determine whether the OTP target is a minimum requirement or an ambitious goal. We also propose that AS does not schedule for 100% personnel utilization, and that personnel utilization must be in accordance with scheduling flexibility. For

this, we propose an idle-time buffer, i.e., the scheduled time that personnel does not work. In this way AS not only has enough capacity to execute all tasks, but also enough flexibility to reschedule tasks in case tasks get disturbed or an incidental task arises.

The output of the planning process must consist of two workload profiles, one for bowser and one for dispenser planning. These type of vehicles serve different aircraft parking positions on the airport. AS must be aware that workload can switch between the two vehicle types. Furthermore, we recommend that the workload profiles show turnaround times of aircraft related to the tasks, and the amount of scheduled buffer time across the working day. These workload profiles must be sufficient for a personnel-scheduling decision.

During operations, AS must reconsider the use of its CHIP system. It is very nervous and has the potential to reschedule all tasks every 30 seconds. We propose that CHIP not only considers a new solution, but also repair possibilities of the current solution. In addition, we propose that dispatchers do not only consider to schedule tasks as early as possible, but also schedule for personnel utilization. Balancing personnel utilization provides a situation in which incidental tasks, longer process duration, and severely delayed aircraft are handled equally across the working day.

The feedback regarding the planning and scheduling chain must not only consist of performance measurements, but also regular checks in which norm times, personnel utilization, and buffer usage are considered.

## Implementation

On the short-term AS can start the use of two workload profiles, one for dispensers and one for bowsers. AS also knows that current planning norms do not suffice and the amount of buffer time is very limited. It could therefore at least justify scheduling more personnel than the current planning process recommends. Furthermore, for the weekly performance meeting we recommend the following: Do not only discusses daily performance measures, but also the use of buffers and personnel utilization across the working day.

On the long-term AS needs to consider its position in the planning process. AS controls the input of the planning process and is responsible for its performance, but cannot alter the way the planning process plans and schedules. This is far from ideal. In addition, AS must be enabled to use database data instead of manmade observations for norm times. Furthermore, AS should determine new norms and needed buffer capacity.

AS must also monitor the improvements, and consider whether the current norms and buffers result in a wanted OTP, or that they should be altered to better reflect the situation. We did not identify all processes that influence the execution of refueling, and it is possible that the norms need new elements, or that a new type of buffer is necessary.

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# 1 Introduction

The competition and passenger growth in the airline industry have led to shorter ground times for aircraft year by year. During these ground times, aircraft need several services. This is to make sure that the aircraft is ready for departure on time, i.e., turned around within the scheduled time window. At Amsterdam Airport Schiphol, KLM Aircraft Services (AS) provides services to 350 aircraft of KLM and her partners on a daily basis, which includes refueling, cleaning, catering, and water services.

At AS, there is a need to have a planning and scheduling chain (at KLM, in Dutch: “planning, roostering, en indelings keten”, or “PRI keten”) that provides reliable capacity planning and personnel scheduling, such that their services are performed on time and within budget. Furthermore, there is a need for a better understanding of the discrepancies between the planned and actual needed capacity, such that AS can explain and control the discrepancies between the two.

Therefore, the aim of this master thesis is to research how this planning and scheduling chain currently results in differences between the expected workload and actual workload, and how AS can reduce and/or deal with these differences. This research adds value by proposing potential improvements across the planning and scheduling chain that improve the personnel scheduling decision.

This chapter introduces KLM, KLM Aircraft Services, and earlier research at AS (Section 1.1), the motivation for this research (Section 1.2), the scope of this project (Section 1.3), and the research goals and questions of this research (Section 1.4).

## 1.1 Organization

This section describes KLM organization (Section 1.1.1), the AS organization as part of KLM Ground Services (GS) (Section 1.1.2), planning and scheduling of AS (Section 1.1.3), and recent research done at AS that is relevant for this research (Section 1.1.4).

### 1.1.1 KLM

KLM is the oldest airliner flying under its original name. KLM started as an airliner in 1919 to connect the Netherlands to its former colonies. Nowadays, KLM has 202 aircraft in service (March 2014, including Cityhopper, Transavia, Martin Air, excluding Air France), an employee base of 32,000 people, a yearly turnover of 25 billion euros, and is part of the Air France KLM group since 2004. With Amsterdam Schiphol as its hub airport, KLM serves more than 100 destinations.

### 1.1.2 KLM Ground Services and Aircraft Services

KLM Aircraft Services is part of KLM Ground Services (GS). GS manages all hub operations at Schiphol Airport. Hub operations are all the operational services (excluding technical maintenance) relating to the passenger, baggage, and aircraft on the airport. AS then operates all services related to the aircraft. Figure 1 summarizes the organizational chart of GS and AS. Appendix B contains the complete organizational charts.

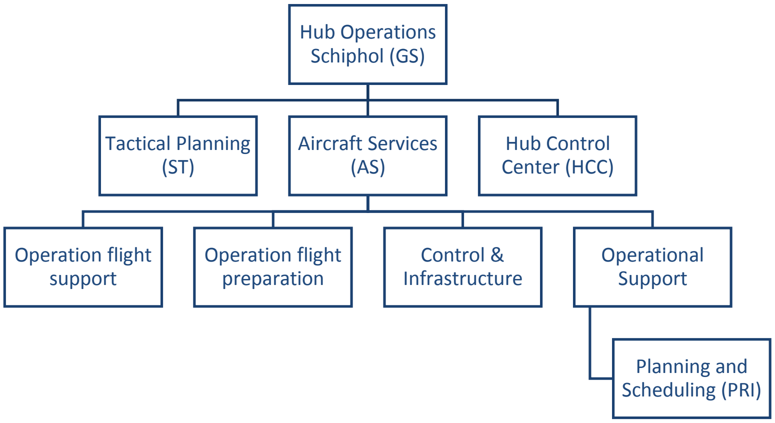



*Figure 1: Summary of Aircraft Services as part of Ground Services*

The summary in Figure 1 displays all the departments that are involved in AS:

- Tactical Planning (ST) has the responsibility for the capacity planning of all the services under GS.
- The Hub Control Center monitors and supports the execution of all ground services.
- Operation flight support operates services that are part of the flight process.
- Operation flight preparation operates services that make an aircraft ready for departure.
- Control & Infrastructure controls the daily operation.
- Operational support coordinates the services, provides personnel scheduling based on the capacity planning from ST, analyzes all processes under AS, and does contract management for AS.

This research takes place at Planning and Scheduling. PRI connects the schedules from ST to the daily operation, and provides analysis about the planning and scheduling chain and the related service execution.

### 1.1.3 Planning and scheduling of Aircraft Services

The planning and scheduling chain of Aircraft Services consists of five main phases, which results in the execution of an aircraft service:

- Operational Planning Cycle (OPC): This cycle, performed by ST and PRI's resource planners, determines whether the proposed seasonal (winter or summer) flight schedule fits the available capacity at AS, using planning principles upon which AS and ST agreed. For the busiest week of the season in the KLM flight schedule, ST determines the workload across every workday, and AS determines the needed shiftset (Dutch: dienstenset) to handle the workload. The shiftset determines the start times and needed personnel for different eight-hour shifts. This results in a basic personnel schedule for KLM employees during the season.
- Rolling Planning: ST makes a monthly update of the expected workload and needed capacity based on the latest information regarding the flight schedule. AS updates the basic personnel schedule to cover the expected workload.
- Weekly forecast: Last adjustments to the workload by ST. AS can adjust the personnel roster if necessary.

- Workforce Scheduling: Business managers and personnel coordinators of AS hire flex workers, such that enough personnel are available on the day of execution. AS accounts for the latest changes in the flight schedule and illness of its personnel.
- Day of execution: Online operational scheduling, i.e., scheduling tasks during the day of execution with available personnel and equipment. AS uses a software tool called CHIP that automatically optimizes all necessary tasks across the available personnel and equipment of AS. Dispatchers monitor the daily operation, and adjust the timing and assigned operators of tasks in the CHIP system when necessary.

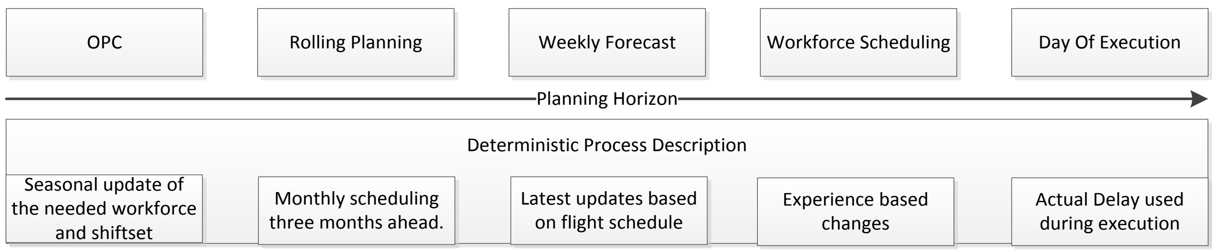



*Figure 2: Current Planning and execution of Aircraft Services*

### 1.1.4 Earlier research

Earlier research by Dekkers (2010) provided insight in the design of the planning and scheduling chain. This was done by designing a new planning and scheduling chain based on constraints at AS. One of the main conclusions was that AS makes most decisions regarding capacity too late or without the required information; this leads to capacity adjustments that are not ready on time or in line with actual demand. (Dekkers, 2010)

Definitions:

- *The workload is the total number of tasks that AS performs at a certain moment in time.*
- *A workload profile is a representation of workload over time, representing the workload across a 24-hour day for 5 minute time intervals.*

Furthermore, Dekkers (2010) made clear that different norm times, i.e., norms describing the time that a service needs to perform a task, serve different purposes within AS. AS, however, does not describe the relationship between different norms sufficiently, making it hard for staff to determine how and which norms should be used during planning, execution, performance analysis, evaluation, etc. (Dekkers, 2010)

Research by Harmsen (2012) provided "insight into the effect of uncertainty and unforeseen events on the dynamics of personnel capacity planning, related to the performance of KLM Aircraft Services". He focused on the tactical planning level, meaning that his method allocates resources to meet strategic set targets. The research focused on a planning horizon from six months to one day in advance. (Harmsen, 2012)

The research by Harmsen (2012) used a robust planning technique. He incorporated factors influencing the aircraft service process into the planning method by using their statistical distributions. He used a "solution robust" planning technique, i.e., providing a solution that remains near optimal for different scenarios, but not necessarily feasible for many different scenarios (Mulvey, Vanderbei, & Zenios, 1995). This technique plans such that the number of operators available can handle the specific workload at every moment during the day with a degree of certainty, combining the workload and number of personnel into a workload profile. Using this technique, he made robust predictions on how much workforce AS needs every moment during the working day. He included factors that could predict arrival punctuality on the long term, such as average lateness per month, average lateness across the working day, average lateness for European and Intercontinental flights, and average lateness per aircraft type. For the aircraft service itself, the disturbances and service time per aircraft were included.

We also learned that workload “peaks”, or busy moments during the day of execution, lead to needed personnel that is redundant before and after these peak times, because personnel works eight hour shifts. According to the law of variability buffering, AS needs extra capacity (personnel in this case) to buffer against variability, when inventory or time is not available (Hopp & Spearman, 2008, p. 309). For some services, inventory buildup is possible, e.g., it is possible to build up a water reserve such that an aircraft does not need water servicing every new flight. It is however not common to do so and does not apply to most aircraft services. Harmsen (2012) found that time is available for the services under the flight preparation operation, since AS can start between an earliest and latest start time to perform their service. Spreading workload across available time reduces workload “peaks”, leading to a more balanced workload and less needed capacity (operators) at peak times.

## 1.2 Motivation

This section describes the motivation for this research. Section 1.2.1 then describes the objectives AS has with this research.

Nowadays, the differences between the planned workload and actual workload lead to two problems during execution:

- Lower on time performance (OTP) and costs related to flight delay due to capacity shortage of workforce.
- Higher operational costs due to excess capacity of workforce.

Currently AS and ST do not have the tools to understand all the differences that exist between the planned workload and actual workload. Therefore, AS does not have a structural method for scheduling personnel that accounts for these differences. This makes it difficult to make educated decisions about personnel scheduling when regarding the workload profile. So, in order to cope with variability in the business operation, AS takes decisions they cannot substantiate.

The business manager and personnel coordinators of an aircraft service determine the number of operators they need the next week. They use the result of the rolling planning/forecast to do so, and look at several factors such as the weather and the performance of the last few days to determine their needed workforce. Based on their experience they deviate from the rolling planning recommendation by hiring or canceling flex workers.

However, there is a lot of variability in airline operations that results in deviations from the planned time windows and process times. Examples of factors that cause variability are the influence of weather, technical malfunctions of aircraft and supporting equipment, delays in ground processes, and runway capacity due to air traffic control restrictions (Fricke & Schultz, 2009). Delays and early arrivals influence the actual workload across a working day at aircraft services. Then, there is variability in the operation of aircraft services: An aircraft service needs more or less time than scheduled, has broken down equipment, or is delayed due to other processes at the airport that influence his operation. These factors also influence the actual workload.

Earlier, this led to the development of the robust planning technique by Harmsen (2012). Harmsen (2012) only tested this method for one average month, and ST did not implement the results into their current tactical capacity planning. In addition, Harmsen (2012) suggests that lots of uncertainty experienced by AS can be reduced by breaking down planning norm times into sub processes such as driving time, setup time, and task time.

Moreover, Harmsen (2012) suggests that scenario planning, i.e., using different states of factors that influence the execution of services to make a workload profile, makes the workload predictions more precise. AS could do this by making several workload profiles in advance that are based on different settings of several factors, such as the airport landing capacity and the weather. He then suggests the use of dynamic planning that changes the workload profile in accordance with the change of circumstances. (Fricke & Schultz, 2009; Harmsen, 2012)

AS or ST, however, did not implement these kind of solutions to cope with variability that influences the total workload of a service, and Tactical Planning (ST) still uses deterministic plan norm times in all their planning phases.

Therefore, to sum up the current situation, the capacity planning with its current deterministic plan norms results in differences between the planned expected workload and actual workload. Due to the nature of airline operations, there is a delay or early arrival of each aircraft and variability in the needed process time of an aircraft service. AS cannot explain all differences between the planned and actual workload, but has experience with variability across its business operation, and takes experience based decisions to deviate from the workload profile that ST provides. Currently, this situation leads to unexplained excess capacity or capacity shortage of workforce during daily operations, which then leads to good or bad performance.

### 1.2.1 Aircraft Services objectives

In the current situation, AS first wants to understand what the differences are between the planned and actual workload and what the reasons are for these differences. When AS gains insight in these reasons, AS wants to account for these differences in their planning and scheduling chain. To measure the effects of these improvements, AS wants to consider both the cost of personnel and on time performance of departing aircraft, such that AS has a constant performance. Therefore, AS has the following two objectives:

***The first objective of AS is to understand what the discrepancies are between the planned workload and the actual workload, and what the reasons are for these discrepancies.***

***The second objective of AS is to provide reliable personnel schedules in which they consider and/or reduce factors that now lead to discrepancies between scheduled and actual workload, on time performance of departing aircraft, and associated costs.***

## 1.3 Scope

This section describes the scope of the project. This section first relates AS to other departments within KLM. Then it determines the scope of this project, based on the relations that AS has with different departments.

ST provides the workload profiles to AS. In this context, AS provides the planning norms that ST should use. Also, ST and AS have to agree on the planning principles. These planning principles do not discuss the planning method that ST uses, but the tasks that ST needs to and does not need to include in the workload profiles. In this way, AS can deliver input that ST needs to use in their planning method. Furthermore, AS advises on how they could benefit from changes in the planning method.

ST controls the planning process. Every improvement in the planning method from which AS benefits, AS communicates towards ST. AS delivers planning norms and discusses principles that build up the workload profile. AS does not change the planning process that ST manages, but AS can both advise ST on changes in the tactical planning process and can build solutions based on the workload profiles that ST provides.

During daily execution, the Hub Control Center (HCC) is responsible for the online scheduling of all services, i.e., they make sure that AS's operational employees perform all the necessary tasks. The CHIP system automatically schedules tasks; dispatchers monitor the process and reschedule tasks if necessary. This department of GS, however, is not part of AS. Currently, the HCC only knows which tasks they need to schedule and which personnel they have available; they do not use a predetermined schedule.

While AS makes personnel schedules based on the expected workload, they do not make a detailed operational schedule in advance of operation. ST does provide a weekly workload forecast that contains all expected tasks, but the HCC does not consider this as valid input for their online operational schedule. However, it is AS's responsibility and in their best interest to provide enough workforce such that dispatchers at the HCC can schedule all tasks.

We can relate the scope of this project to several planning levels: the hierarchical structure of Hans, Van Houdenhoven, and Hulshof (2012) discerns between different planning and control levels, considering strategic, tactical, offline operational planning, and online operational planning (Hans et al., 2012). In relation to AS the following decisions at each level are relevant:

- Strategic decisions: The long term decisions KLM, GS, and ST take, e.g., long term decisions about flight availability and market penetration around the world, buying new aircraft for KLM, and buying new equipment at AS.
- Tactical decisions: Making a flight schedule that fits the strategic goals set by KLM, relating this schedule to available equipment, allocating available budgets to the different departments, hiring extra staff, and match basic personnel schedules with the expected workload.
- Offline operational (proactive) decisions: Making detailed schedules for aircraft services, updating the basic personnel roster, and hiring or canceling flex workers.
- Online operational (reactive) decisions: Adapting schedules for unforeseen or unanticipated events, adjusting the schedules to match the current circumstances.

AS is not involved at the strategic level of KLM, but is involved in buying its own new equipment and educating its own personnel, which is a strategic decision. Then, the tactical level involves ST and AS; the deterministic planning method that AS and ST use, predicts the expected workload and results in a basic personnel roster. In the scope of the online operational level, HCC schedules and reschedules tasks during execution. This system is reactive and responds to events influencing the service real-time.

While Harmsen (2012) showed that his method would provide more transparency for the tactical planning level, he also stated that the current tactical planning method is working reasonably well. Furthermore, his technique could be experienced as complicated and currently ST does not use it.

We, however, want to connect the tactical planning level provided by ST and the online operational scheduling provided by HCC, such that AS takes a personnel scheduling decision that results in a constant and reliable performance. Currently, it is at the tactical and offline operational level that these decisions are taken; the resource planner of a service needs to decide how much personnel he needs during the next season (tactical) and the business manager of a service needs to decide the number of personnel he needs next week (offline operational). These decisions are now based on the provided workload profiles from ST. In this report, the scope is on how the tactical and offline planning processes on the one hand, and the execution and feedback regarding the execution on the other result in discrepancies between the expected and actual workload. Furthermore, we discuss improvements in the planning and scheduling chain to reduce and/or deal with these discrepancies. The improvements describe what changes AS needs, these are not technical descriptions regarding how AS and other departments should perform its planning and scheduling. In addition, these improvements focus on the planning and scheduling chain of AS, and do not necessarily relate to other KLM operations.

It is important to know that the degree of freedom deteriorates as the planning level comes closer to the day of execution. Therefore, if a bandwidth represents the possible decisions about making resources available for the execution of the process, this bandwidth is reduced for each planning level closer to the execution, but the available accurate information increases. When AS executed a process, all information is available, and AS is able to evaluate and give feedback to the several planning phases (see Figure 3).

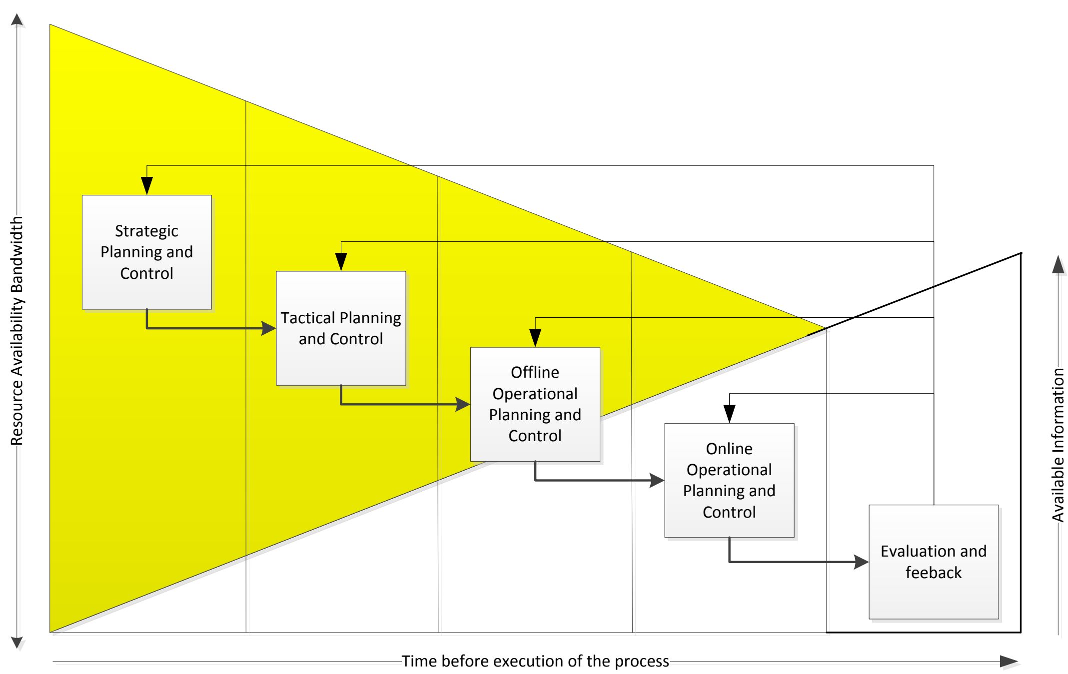



*Figure 3: Resource versus information availability, based on Hans et al. (2012)*

## 1.4 Research Goals and Questions

The first goal in this research is to identify and understand the current discrepancies between the planned and actual workload. The second goal is to propose potential improvements for the planning and scheduling chain to deal with the current discrepancies between planned and actual workload. This results in the following main research question:

What are the current discrepancies between planned and actual workload, and what are potential improvements to deal with these discrepancies?

To answer this main research question, there are four research questions.

1. What is the current situation of the planning and scheduling chain? (Chapter 2)

We first describe the current situation at Aircraft Services. To do so, we first reduce the problem size by choosing a suitable service for this research. Then, we give a description of the current planning and scheduling chain for this service. Finally, this chapter describes the discrepancies that currently exist between the planned and actual workload for the selected service.

a. Which aircraft service is the most suitable for this research?

The answer to this sub-question reduces the size of this research. We select the service that could benefit most from solutions that match scheduled personnel with the actual needed capacity, and for which the solutions are generalizable to other services. To answer this question, we use earlier research, KLM's databases, and interviews with AS management.

b. How does the planning and scheduling chain for the selected service result in execution of the service?

The answer to this sub-question describes how the planning and scheduling chain works, and how this results in the execution of the service. Information for this question comes from interviews and conversations with personnel involved in the planning and scheduling chain, historical data from databases, and analysis of software packages that are used.

c. What are the current discrepancies between the planned and actual workload for the selected service?

This question describes the kind of discrepancies that now occur between the planned and actual workload. For this question we use databases that relate to the planning, scheduling and execution of AS.

2. What literature is available related to the discrepancies between the planned and actual workload? (Chapter 3)
    a. How can the scheduling problem at Aircraft Services be described?

As background to the problem, we discuss literature that AS could use to describe its scheduling problem.

b. What is the role of airline delays in Aircraft Services operations?

Since airline delays are the main influence on the operations of AS, and since AS can cause airline delays, we discuss airline specific literature and databases. This will provide insight in the environment that AS acts in.

c. What is the value of information during the planning and scheduling chain?

Since all planning processes deal with imperfect and incomplete information, we discuss the value of information during planning processes.

d. How should AS create robustness against variability during execution?

For several types of variability, this question discusses how AS should create robustness against it. It discusses the use of statistics, planning for unlikely events (contingencies), coping with incidental tasks, and the use of time buffers to cope with all sorts of variability.

3. What are potential improvements for the current planning and scheduling chain (Chapter 4)?

Chapter 4 describes potential improvements for the planning and scheduling chain. This question uses Chapter 2 and Chapter 3 to describe potential improvements in the planning and scheduling chain.

a. What are potential improvements for the input of the planning and scheduling chain?

This question discusses what input AS and other sources need to facilitate for the planning and scheduling chain, such that all input is available to create the desired output.

b. What are potential improvements for the output of the planning and scheduling chain?

This question answers what output the planning and scheduling chain should provide prior to execution of the process, such that AS can make the right personnel scheduling decision.

c. What are potential improvements for the planning and scheduling chain during execution?

During execution, AS monitors and schedules tasks to all available personnel. This question discusses possible improvements.

d. What are potential improvements for feedback regarding the planning and scheduling chain?

This question discusses potential improvements regarding the feedback that AS provides towards the planning and scheduling chain.

4. How must AS implement the potential improvements in the planning and scheduling chain? (Chapter 5)

The answer to this question describes the improvements that we recommend. First, before discussing implementation at all, the chapter discusses whether changes are necessary. Then the chapter continues with changes on the short and long-term, before the question discusses how the implemented improvements must be monitored. Finally, this question discusses how the findings of this report can be generalized to other aircraft services.

a. Is there a necessity to change the planning and scheduling chain immediately?

Before starting the implementation of improvements, this chapter discusses whether it is necessary to implement improvements in the planning and scheduling chain.

b. What are the possibilities in the short-term?

Not all potential improvements can be effective immediately. This question answers what changes are possible on the short-term and could be effective in a few weeks.

c. What are the possibilities in the long-term?

This question discusses possible changes in the long-term and what AS needs for them in the organization.

d. How can AS ensure continuous monitoring regarding the planning and scheduling chain of AS?

This question answers how AS must monitor its planning and scheduling chain after they implemented several improvements. The fact that something is an improvement now does not mean that it will always remain an improvement. This question answers how AS should monitor their improvements proactively.

e. How can AS use the main findings at other aircraft services?

After the selection of a department in Chapter 2, this question answers how AS can use the findings of this research at other aircraft services.

# 2 Current Situation

In this chapter, we first select a service to reduce the problem size (Section 2.1). For this service, the chapter then describes how for the whole planning and scheduling chain workload profiles are made, and what the function of each workload profile is (Section 2.2). The next sections describe the execution of the refueling process (Section 2.3), and the discrepancies between the scheduled and actual workload (Section 2.4).

## 2.1 Selection of an aircraft service

Of all aircraft services, we select one that is suitable for our research, because with limited time we cannot solve the problems for all the services. This section first describes the service that AS performs, then describes the relevant characteristics our service must have, and continues with how aircraft services relate to the flight operation of KLM, before selecting a service for research. A detailed description and comparison of all aircraft services is in Appendix C.

The aircraft services that AS performs are in Table 1.

| Service | Description |
|---|---|
| Airside Handling Support | Connecting the aviobridge to the aircraft, crew transport and crew briefings |
| Board supply | Changing and distributing the non-food supplies of the aircraft (pillows, blankets, etc.) |
| Catering distribution | Changing the catering supplies of the aircraft (unloading the old and loading the new supplies) |
| Cleaning | Cleaning the interior of the aircraft |
| De-icing | Remove ice from the aircraft (de-icing) and applying a fluid that prevents freezing (anti-icing) |
| Flex tasks | Cooling and heating the cabin, giving jet starts and docking of mobile staircases on buffers |
| Pushback | Pushing an aircraft back from the gate, since aircraft cannot taxi backwards by themselves (performed by Towing) |
| Refueling | Refueling the aircraft with a specific amount of fuel, based on the flight destination |
| Security check | Checking the interior of the aircraft for unsecured objects or unsafe situations |
| Toilet service | Emptying and flushing the toilet tanks of the aircraft |
| Towing | Moving aircraft between hangars, gates and buffer positions |
| Water service | Filling or refreshing the water supplies of the aircraft |

*Table 1 KLM's aircraft services*

In this research, the focus is on providing reliable personnel scheduling that accounts for discrepancies that nowadays exist between the planned and actual workload, so these discrepancies should be visible for the service we analyze. In addition, the service should make use of the workload profiles that ST provides, such that we can analyze the service and use the findings for this service at other services as well. Then, we want a service that has a different workload profile if the actual flight schedule changes due to external factors and processes, such that improvements in the planning and scheduling chain can be of benefit. In addition, AS wants to have full control over the service that we analyze. Therefore, we need a service for analysis with the following characteristics:

- The aircraft service must not be outsourced, which means that GS and AS have full management over the operation.
- The service must make use of the workload profiles provided by ST.
- There are external factors and processes that affect the needed aircraft service capacity.

Support services are an integral part of the flight process, where preparation services prepare an aircraft for departure. As there is a clear distinction between the two (see Figure 4), we know whether a service has a strict or a flexible time window in which AS needs to perform their service. Figure 4 displays how AS performs services in time windows of several aircraft simultaneously, which depend on the actual in block time (AIBT), i.e., the actual arrival at the gate, and target off block time (TOBT), i.e., the estimated departure from the gate. The AIBT mainly depends on the landing time of the aircraft and the taxi in time (EXIT), i.e., the driving time of the aircraft after landing. The TOBT depends on the AIBT, other ground services like baggage and passenger handling, and the services performed by AS.

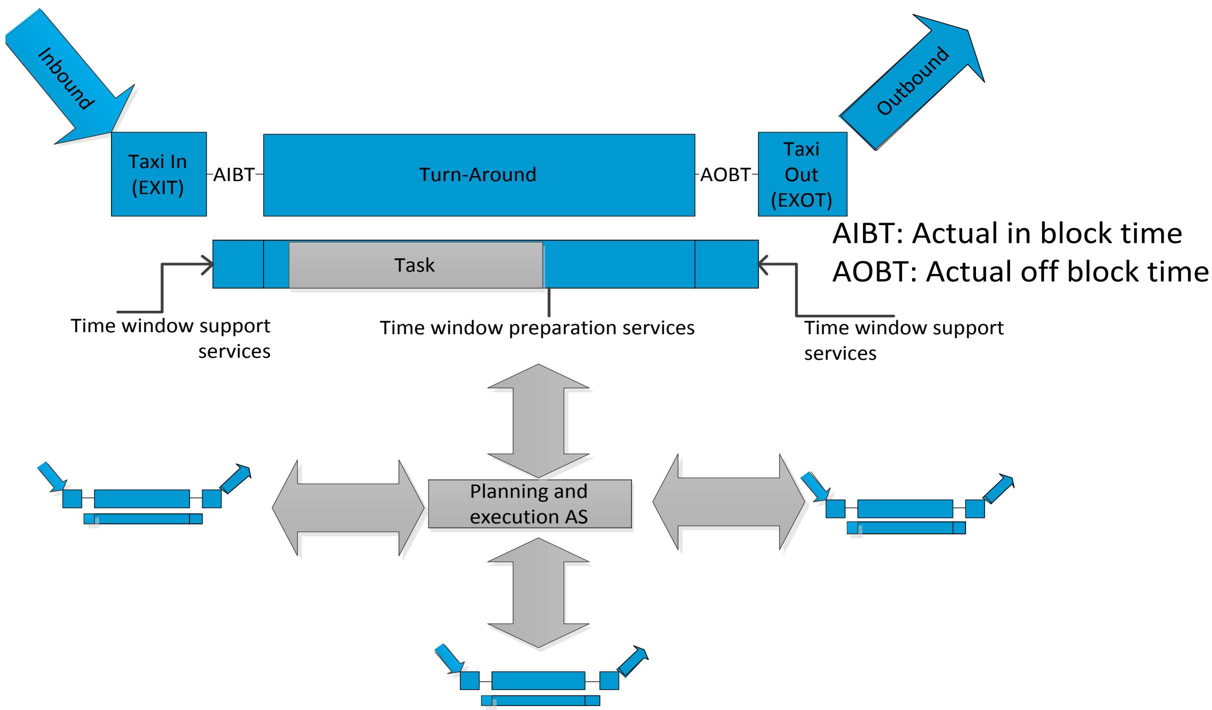



*Figure 4: Planning and executing aircraft services, based on Harmsen (2012)*

This research does not analyze Catering, Board Supply, and Cleaning, since AS outsourced these activities. Furthermore, we do not choose Security Check, since it is a service that either the cleaning companies or the airport authorities perform, and is not performed before each flight, and thus not making use of the workload profiles by ST.

Support services have a direct impact on the flight's delay, because they are an integral part of the flight. This results in delays for either arriving or departing aircraft, e.g., the passengers and crew cannot leave before an aviobridge or staircase is attached to the aircraft. For departing support services, it also holds that they can only start when all other services have executed their tasks. In addition, lateness here directly results in a flight delay for the departing aircraft, e.g., a pushback truck that starts five minutes later than scheduled, results in a delay of five minutes. Furthermore, because these services need to be performed directly after arrival or directly before departure, their workload is highly varying and depending on the actual flight performance of the airliners. However, support services are not valid in the scope of this research:

- Towing and Pushback has not used workload profiles from ST in the last few years, so we do not have data for our research to compare workload profiles from ST with the actual workload experienced.
- For Airside Handling Support there are workload profiles, but the resource planners currently do not base their personnel schedules on these directly. Furthermore, Airside Handling Support has a new work portfolio, which led to organizational changes in the last few years.
- De-icing is a seasonal and weather dependent process, only needed when ice forms on the wings of aircraft. This means that we cannot use findings for this service at other aircraft services, since it is a less general service. Furthermore, it is not a service that works with standardized workload profiles that AS can use for comparison.

We want to choose a service for which we know that other processes and factors influence its varying needed capacity the most. Since we excluded all outsourced and support services, we need to choose a remaining service that makes use of the workload profiles. These could be Water, Toilet, and Refueling services. All have a similar coefficient of variation (see Appendix E) considering their process duration. The main difference is the process duration, which is largest for the Refueling service. This leads to more workload peaks at Refueling, since it is harder to balance workload flexibly over a period. This is due to an earlier start time in the total turnaround time window for each task when compared to water and toilet tasks. Therefore, when AS covers the scheduled workload peaks for Refueling with personnel, a change of timing of the workload peak due to delays could result in excess capacity of personnel during the scheduled workload peak and capacity shortage during the actual workload peak.

Due to workload balancing at Water and Toilet services, there is a more constant workload and more flexibility to provide all needed services with a constant number of personnel. Therefore, other processes and factors have a larger effect on the varying workload and need for personnel at Refueling. Also, if Refueling starts later than scheduled, the risk of delays is higher than at Water or Toilet services, since there is less buffer to cope with a late start of the service. For these reasons, we choose to analyze the Refueling service. We summarized our selection in Table 2.

In this section, we chose to analyze the Refueling service for this research. It is a service that is under the full management of AS (opposed to Catering, Cleaning, and Board Supply), and makes use of the workload profiles provided by ST (opposed to the Towing and Pushback service). Furthermore, there is less flexibility than at Water and Toilet services; this leads to a varying workload that is prone to changes in the flight schedule and has a higher risk of flight delays if performed later than scheduled.

| Comparison | Support or Preparation service | Outsourced | Service uses the workload profiles | External processes and factors influence the varying need of the service's capacity |
|---|---|---|---|---|
| Airside Handling Support | Support | | No | Yes |
| Board supply | Preparation | X | | |
| Catering distribution | Preparation | X | | |
| Cleaning | Preparation | X | | |
| De-icing | Support | | No | Yes |
| Pushback | Support | | No | Yes |
| Refueling | Preparation | | Yes | Yes |
| Security check | Preparation | | No | Not so much |
| Toilet service | Preparation | | Yes | Not so much |
| Towing | - | | No | Yes |
| Water service | Preparation | | Yes | Not so much |

*Table 2: Comparison of Aircraft Services*

## 2.2 The planning and scheduling chain at Refueling

This section describes the planning and scheduling chain at Refueling. First, Section 2.2.1 describes which data they need to make these workload profiles and schedules, second, Section 2.2.2 describes the equipment and task types that are used at Refueling, and then Section 2.2.3 describes how ST and AS make workload profiles and personnel schedules.

### 2.2.1 Input data for the planning and scheduling chain

The input data that AS and ST use for the planning and scheduling chain consist of the flight schedule, budget constraints, planning principles (in Dutch: plannings uitgangspunten, or PUG), available personnel, and norm times per combination of aircraft and airline.

The flight schedule denotes all flights that KLM and her customers perform, linking them to all available aircraft. KLM calls this a flight link, e.g., an aircraft arrives at Amsterdam from New York, and has a link to Bangkok on its next flight. ST determines the flight links for all aircraft to create workload profiles. These flight links, however, are not the actual flight links that Flight Operations performs, but a model in use for the Operational Plan Check (OPC) and rolling planning. This model determines the flight links on a first in, first out (FIFO) principle: ST links a flight to the right aircraft type that has been on the ground at Amsterdam the longest.

The budgets are determined once a year. In cooperation with the head office, GS management determines the money that is needed to perform all ground services in collaboration with AS. AS does not consider this budgets during later planning phases.

The planning principles contains all the major agreements and rules that ST and AS use in the OPC and rolling planning. This includes the agreed upon planning norms and the report of contracts, which contains the fueling contracts that Refueling has with different airliners. The remainder of the planning principles is a summary of available equipment to perform the service, major changes in fueling procedures, and ST's procedures to make the workload profiles.

The planning norms are representing the times needed to perform the fuelling tasks per airliner, aircraft, and ground time combination. Jansen (2013) used a bootstrap methodology that uses 10 to 30 observations for each aircraft type in which he included unavoidable disturbances. For each airline, aircraft type, fueling equipment, and ground time combination, there is a specific plan norm. He bases these norms on task observations for everything that takes place on the parking position. The 50$^{th}$ and 80$^{th}$ percentiles of the observations plus an average driving time define the plan norm with the following formula:

$$50th\ percentile + \frac{1}{2} * (80th\ percentile - 50th\ percentile) + average\ driving\ time$$

Next season (winter 2015) a driving time matrix for all locations is in use, linking task locations with the distance based driving time.

Furthermore, the norms state the starting and finishing times after AIBT (actual in block time) or before AOBT (actual off block time), the number of employees needed to fuel an aircraft, the equipment type used, and the expected duration. Currently, they plan each such that only one employee is assigned to a task. Some aircraft can be pre-fuelled (see 2.2.2), meaning that they receive a base amount of fuel, before receiving their final fueling. For these tasks, planning norms exist as well.

### 2.2.2 Equipment and task types

The equipment of KLM Refueling consists of 3 large bowsers of 80m$^3$, 15 small bowsers of 40m$^3$ (see Figure 5), and 21 operational dispensers (see Figure 6). The dispensers do not carry fuel themselves, but connect their equipment to the hydrant system of underground pipelines that is available at most parking positions.

All equipment together delivers 2.5 million m$^3$ of jet fuel on a yearly basis. Table 3 describes all the task types that the CHIP system registers and operators must perform at Refueling. These tasks are split in flight schedule related, unrelated to the flight schedule, and incidental tasks.


*Figure 5: a bowser*


*Figure 6: a dispenser*

### 2.2.3 From flight schedule to workload profile

Table 4 gives a summary of the planning and scheduling chain. This section describes the several processes.

| **Task Type** | **Description** | **Flight schedule related, flight schedule unrelated, incidental** |
|---|---|---|
| Final fuel | Operators fuel the amount of kilograms requested by the pilot. Refueling performs a final fuel for each flight. | Related |
| Pre-Fuel | Fueling long distance flights to a minimal required amount of kilograms, such that the final fuel task takes less time. Refueling performs this task when equipment and ground time is available. | Related |
| Extra Fuel | If the pilot requests extra fuel after the final fuel task, an operator performs an extra fuel task. | Incidental, unrelated |
| Refill | This task refills the bowsers with fuel. | Unrelated |
| Maintenance | This task concerns tasks to make aircraft ready for maintenance. | Unrelated |
| Defuel | Defuel is done if an operator overshoots the requested amount, or if an aircraft breaks down after pre-fueling or final fueling. Defueling requires a bowser. After defueling an aircraft, the bowser needs to empty its tank, because the tank is polluted. | Incidental |
| Break | A task in the system that gives breaks to the operators. | Unrelated |
| End of Shift | This task gives time at the end of a shift for operators to end their shift, such that they do not get a new fueling task and they finish their shift on time. | Unrelated |
| Shift Elsewhere | A task denoting that an operator is performing his shift elsewhere. | Incidental |
| Storm Fuel | Operators must perform these tasks in case of a storm. Aircraft need fuel as extra weight to anchor them when it is storming, such that they do not lift off the ground due to their aerodynamic shape. Refueling has a storm procedure in place to fuel aircraft up to the required weight for different wind speeds. | Incidental |

*Table 3: Tasks types at Refueling*

The purpose of the Operational Plan Check (OPC) is check the feasibility of and to agree on the proposed timetable. This agreement exists between Ground Services and Network, the department connecting all the operations that depend on the flight schedule that Flight Operations of KLM wants to fly.

Before GS can come to an agreement, ST and resource planners of AS discuss the principles and planning norms that they use for planning. Then ST checks whether they have enough capacity and budget to perform all necessary tasks for the proposed timetable. ST does this by taking the busiest (OPC) week of the season and compares it to the available capacity. If this is possible, GS and AS agree upon the flight schedule that Network proposed for the next season.

| Moment of execution | Planning and Scheduling | Goal | People/departments involved |
|---|---|---|---|
| 2 times a year (3 months before the start of the season) | OPC: Operational Plan Check. Making workload profiles for the busiest week of the upcoming season. Using agreed upon planning norms and principles, the flight schedule, and FIFO principle for flight links. | Check for feasibility of the proposed flight schedule (in terms of gate availability, personnel, and equipment).<br>Create basic and personnel rosters.<br>Budgeting | Flight Operations<br>Network division<br>ST tactical planning<br>AS resource planners<br>Business manager |
| Every 4 weeks | Rolling Planning: The rolling planning is updated every 4 weeks for the three months ahead based on the latest information from the flight schedule. FIFO principle for flight links. | Adjustments to the schedule based on the latest information for the three months ahead (summer or winter), updating the workload profiles and the personnel rosters. | ST Tactical Planning<br>AS resource planners<br>Business manager |
| Every week | Forecasting: By using the actual flight schedule, the most actual workload profile is created. FIFO principle for flight links. | Weekly forecasting for the upcoming month, updating the workload profiles and basic roster to the latest information. | ST tactical planning<br>AS resource planner<br>Business manager |
| Every week | Short-term personnel scheduling: Using the rolling planning, forecasts, and experience based decisions to cover the expected workload with personnel. | Adjust personnel capacity to latest trends and information by hiring or canceling flex personnel from an employment agency. | Business manager<br>Personnel coordinators |
| Day of execution | Online Scheduling: Scheduling in CHIP with actual demand and actual capacity, no other input. | Optimize the schedule on the day of execution. | Business manager<br>Shift leader<br>Operators<br>Hub control center |

*Table 4 Planning and scheduling chain, and execution at KLM Aircraft Services*

ST then makes a workload profile for every day of the OPC week. These workload profiles depict the following information:

- All pre-fuel and final fuel tasks that Refueling needs to perform, split out in KLM contracts and SHELL contracts.
- Flight schedule unrelated tasks (except breaks, see 2.2.2) that ST denotes as deltas.
- Lunch breaks and coffee breaks.

The example in Figure 7 displays the workload profile coming forth from the agreements made in December 2013. ST schedules all refueling tasks in accordance to the aircrafts scheduled arrival and departure time, e.g., the task for a 737-800 starts at the earliest 1.5 hours before departure, and finishes at the latest 10 minutes before departure. The duration of the task then has a set norm time. ST schedules in such a manner, that they minimize the number of needed personnel. Furthermore, Refueling delivers both fuel to aircraft that have a contract with KLM or SHELL for refueling. The deltas in these OPC workload profiles predict the average extra needed extra fuel, refill, and maintenance tasks for the dispensers and small bowsers. ST did not include these deltas for the large bowsers, but did include extra time in their pre and final fuel tasks to account for their refill tasks.

Then AS resource planners make a shiftset (Dutch: dienstenset) that best covers the workload profiles. This set contains the following information:

- Start times and duration of KLM personnel shifts and flex worker shifts.
- A gross personnel roster based on KLM personnel employed and needed shifts across the OPC week.
- A net personnel roster based on the gross personnel roster, average absence factor of KLM employees, and needed extra flex workers to fulfill the expected workload across the OPC week.

This results in a basic roster, denoting the needed personnel for each shift across the week. AS splits this to a set of individual rosters that denote the start time for an employee for each day during the week. Figure 8 is an example of such rosters, e.g., if an operator is assigned line 3 in the table, he works the night shift from Tuesday until Friday.  AS assigns all these lines in the basic roster to KLM employees working at Refueling, which results in the personnel roster for KLM workforce at Refueling.

Next, AS updates the workload profiles from the OPC, adding the net presence of personnel. They adjust the presence in such a manner that it accounts for ‘end of shift’ tasks.

In the next phase, ST and AS uses a rolling planning with a three-month horizon to update the workload profiles. This results in deviations from the basic roster. ST makes a rolling planning on a monthly basis, such that AS can match the expected actual workload with a personnel roster. Then, every week ST makes a more precise forecast for the month ahead, incorporating the latest flight schedule changes into the workload profile.

## 2.3 Execution of the refueling process

This section describes the processes that Refueling performs. First, Section 2.3.1 describes how the workload profile and personnel schedules are used in the operation. Second,  Section 2.3.2 gives the task description of the hub control center, then, Section 2.3.3 describes the impact of the airport layout on the Refueling process, to finish with how a refueling task is performed in Section 2.3.4

### 2.3.1 Using the workload profile for personnel capacity planning and scheduling

It is the role of the business manager and personnel coordinators of the service to translate the expected workload to an actual personnel capacity schedule. For KLM employees, their working roster should be available two weeks in advance of the start of their roster. To manage deviations from the basic roster, the business manager of Refueling hires extra flex workers a few days in advance to match the expected workload, or cancels flex workers if they expect less workload. He performs this task every week and bases his needed workforce on the rolling planning, forecast, and his experience.

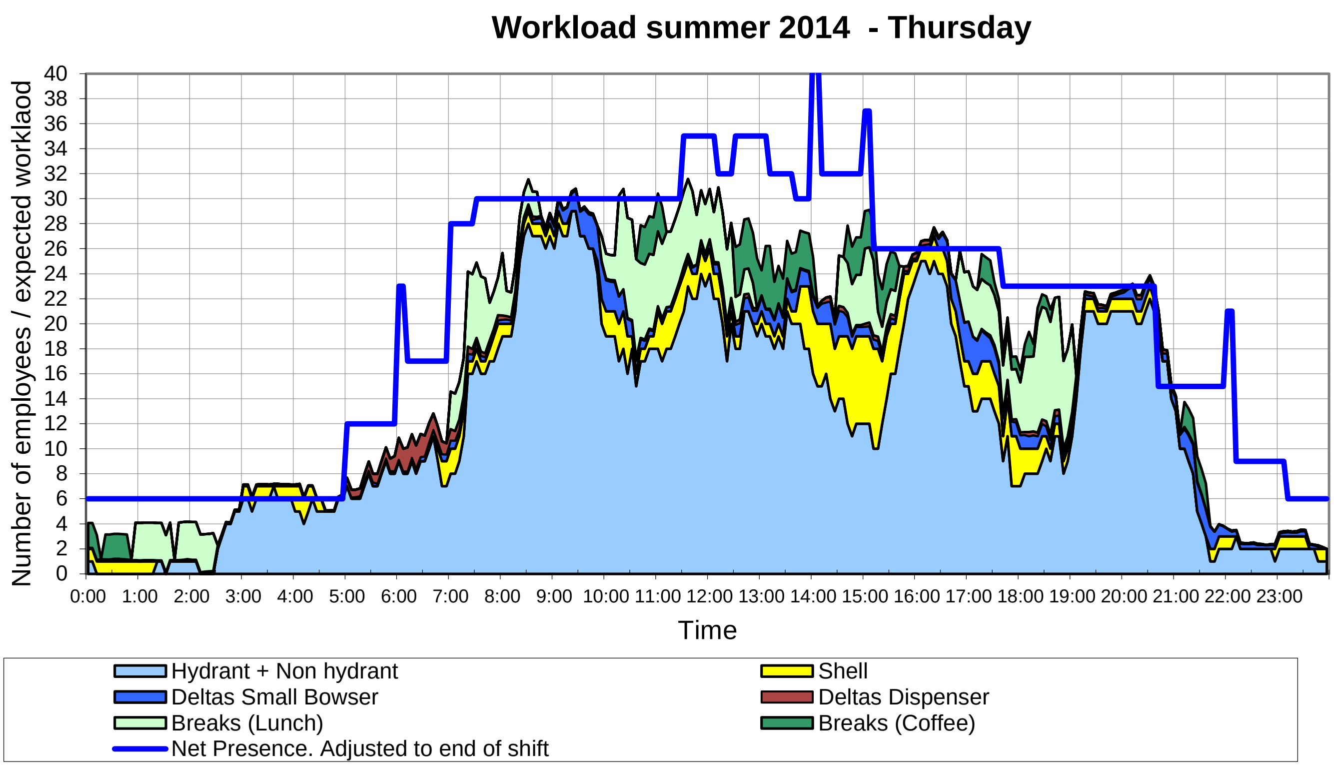



*Figure 7: OPC workload profile for the Thursday of summer 2014*

| Line | MO | TU | WE | TH | FR | SA | SU |
|---|---|---|---|---|---|---|---|
| 1 | 1400 | 1400 | 1400 | === = | === = | 0700 | 0700 |
| 2 | 0700 | 0700 | =070A | === = | 0600 | 0600 | 0600 |
| 3 | === = | R2200 - R | R2200 - R | R2200 - R | R2200 - R | === = | === = |
| 4 | 1400 | 1400 | 1400 | === = | 0700 | 0700 | 0700 |
| 5 | 0700 | =070E | === = | 1400 | 1400 | 1400 | 1400 |
| 6 | === = | === = | 0700 | 0500 | 0500 | === = | === = |
| 7 | 0600 | 0600 | 0600 | 0600 | === = | 2200 - | 2200 - |
| 8 | 2200 - | === = | === = | 1500 | 1500 | 1500 | 1500 |
| 9 | === = | === = | 1400 | 1400 | 1400 | === = | === = |
| 10 | 0600 | 0600 | 0600 | 0600 | === = | 0500 | 0500 |
| 11 | 0600 | 0600 | === = | =070E | 0700 | 0700 | 0700 |

*Figure 8: Different individual working rosters at Refueling, for each line in this table AS assigns an employee to generate a gross personnel roster.*

### 2.3.2 Hub control center

The operators of the fueling trucks execute all necessary tasks in cooperation with the hub control center, where dispatchers coordinate the operations at the airport in consultation with the shift leader and the business manager.

At the hub control center, a dispatcher monitors the Refueling process, using the CHIP system. CHIP contains all tasks that refueling operators need to perform across the working day. Furthermore, CHIP holds live information on which it bases the assignment of tasks:

- Equipment in use.
- Personnel assigned to the available equipment.
- Personnel skill levels for different tasks and aircraft.
- Expected actual arrival and scheduled departure time.
- Location of personnel and equipment, and driving time between tasks.
- Pre-fuel and final fuel amount requirements.
- Priority of each task.
- Time window of each task.

CHIP does not use the planned start and finish times from the rolling planning, but uses decision rules applied to the above information. Personnel and equipment can only fuel an aircraft type if they are both qualified. In addition, CHIP knows whether personnel are limited in their work due to medical reasons.

Then, for each task type there is an earliest start and latest end time requirement that is related to the actual landing time and scheduled departure time, e.g., Refueling uses the timeslot with arrival time + 0 minutes and departure time – 10 minutes for a final fuel task of a Boeing 737-800 that performs a normal turnaround. Each task type also has a standard priority setting, indicating its priority in relation to other tasks. Dispatchers need to schedule tasks manually if it they do not fit within the time-window

In addition, CHIP continuously gets actual flight and fueling information from the Flight Information Royal Dutch Airlines system (FIRDA). Based on this information, CHIP includes the driving times between the parking positions and calculates the actual fueling time based on the requested amount of fuel and the fueling speed for the related aircraft type.

For making a schedule, CHIP uses an algorithm that tries to assign tasks to available personnel and equipment combinations by choosing the minimum cost from a cost matrix. This algorithm runs every 30 seconds. The external developer of CHIP does not explain the workings of this algorithm any further, apart from that it is preferred over other optimizers when used with different optimization criteria. The most important criterion for Refueling is the end priority, penalizing tasks if planned towards the latest end time. The second most important criterion used now is the priority of tasks.

CHIP creates a schedule for the next four-hour time window. As this window moves with time, every time a new task or information update is included in the four-hour window, the CHIP system accounts for these in the next schedule, while CHIP did not account for it in earlier schedules. The cost parameter for switching tasks between resources is set to zero for Refueling. In addition, the parameters that give employees equal workload and an equal number of tasks are not used. These settings make the schedule prone to task assignment changes. CHIP reconsiders all tasks that did not start and are in the current optimization window every 30 seconds.

CHIP cannot schedule tasks to an employee that starts a shift in the future, if there is currently no equipment available in the parking lot. This equipment only becomes available to CHIP when personnel on duty finish their shifts and sign off their equipment. The effect is that CHIP tries to schedule all tasks to personnel that is now on duty. When this does not fit, CHIP needs to unschedule tasks with the lowest priority. Therefore, CHIP has settings that discern between priority and urgency of a task (tasks that need to start earlier than other tasks).

In the current settings, however, priority of a task is a factor 100,000 more important than its urgency. Therefore, a task that needs to finish in four hours is almost as important as a task that needs to finish in 20 minutes. Since intercontinental flights have a higher priority than European flights, the current settings lead to the unscheduling of tasks that need to start within fifteen minutes. An example of this is in Appendix G.

The dispatcher monitors the process and can adjust the schedule if necessary. These adjustments can be to freeze a task start time and/or resource, such that CHIP cannot change these. In addition, the dispatcher can reschedule tasks and assign extra breaks. Furthermore, the dispatcher communicates with the operators on the ground and the shift leader of the service by telephone in case of disturbances, missing personnel, or unexpected events.

### 2.3.3 Airport layout

The airport layout influences the performance of tasks. At the fueling platform, the “Jet-plein”, personnel start and end their shift, refill their bowser with fuel, and have their lunch break. This platform is not near the passenger terminal and has a connection to the terminal via a tunnel below the “Kaagbaan” runway. For coffee breaks, the operators also have a parking south of and close to the terminal at the B-platform. So in the agreements that AS uses, a lunch break takes 50 minutes, of which 20 minutes is driving time. For a coffee break, ST schedules 10 minutes of driving time, since the operator is closer to the B-platform location. For the end of shift tasks, AS considers the driving time to the fueling platform, such that operators finish their shift on time. Appendix I contains a map of the current situation.

### 2.3.4 Standard refueling task

For refueling an aircraft, an employee uses a PDA and a dispenser or bowser. He performs his task with remote supervision from the hub control center. The PDA communicates the next task an operator needs to perform, giving information about the aircraft’s position, registration number, its requested amount of fuel, and its standard time of departure (STD). We split the execution of a task in two phases: see Figure 9.

Phase 1: The operator confirms this task on his PDA, which registers the confirm time of the task in CHIP, such that the dispatcher at hub control knows that the operator initiated his task. When the operator is ready and checked his vehicle (only done for first task that an operator performs on a bowser or dispenser), the operator drives his equipment to the position the PDA displays. When the operator arrives, he informs CHIP via his PDA that he arrived at the aircraft’s position. The dispatcher now knows that the operator is at the position of the aircraft.

Phase 2 takes place at the aircraft’s position: First, the operator prepares a fuel receipt (in Dutch: tankbon) for administrative purposes, checks the aircraft, and prepares his equipment for fueling. The operator informs CHIP that he starts, and executes his fueling task. When he finishes the fueling task, he disconnects the fueling hose, after which he notes the total fuel in kilograms that the panel on the aircraft’s wing displays and the total amount in cubic meters that the fueling equipment displays. He writes these numbers on the fuel receipt and into his PDA, which implicates the ready time of the fueling task. He then delivers the fuel receipt to the aircraft’s cockpit for the pilot’s and airline administration.

The operator returns to his vehicle and finishes his task on his PDA, which CHIP administrates as the finish time of the task.

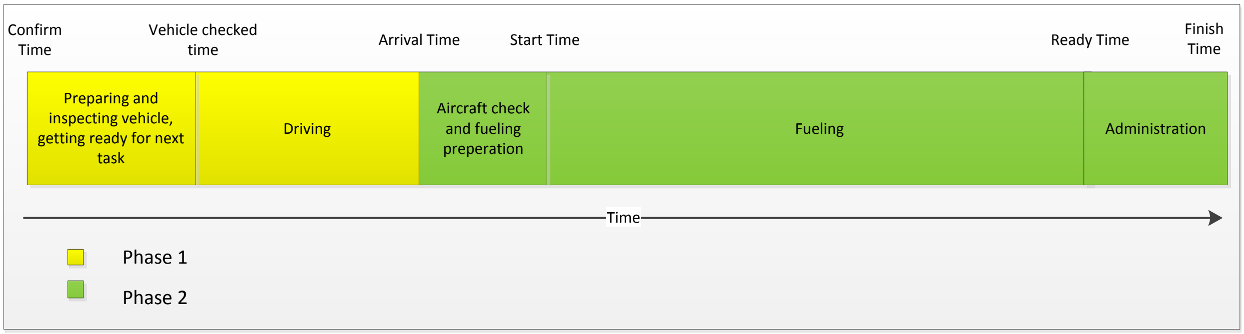



*Figure 9: The timeline of a fuel task*

## 2.4 The discrepancies between the scheduled and actual workload

Currently there is a deterministic planning method in place, where every workload profile is based on plan norm times. This method deals with uncertainty in a uniform way. With the planning principles and input that AS delivers, the planning process at ST generates workload profiles that do not necessarily match the actual needed capacity, and do not account for different scenarios.

To show this behavior, we analyzed the Refueling Service over the months July 2013 and February 2014, representing the summer and winter season. During the summer, there is more flight traffic due to the holiday season, while during the winter season the chance of bad weather influencing flight and ground operations is higher.

Two workload profiles (Figure 10 and Figure 11) display a daily average of the actual performed work and planned workload in these months. Furthermore, Figure 12 displays the average on time performance for the Refueling Service for five-minute time intervals. In these intervals, the tasks that started in the interval are included.

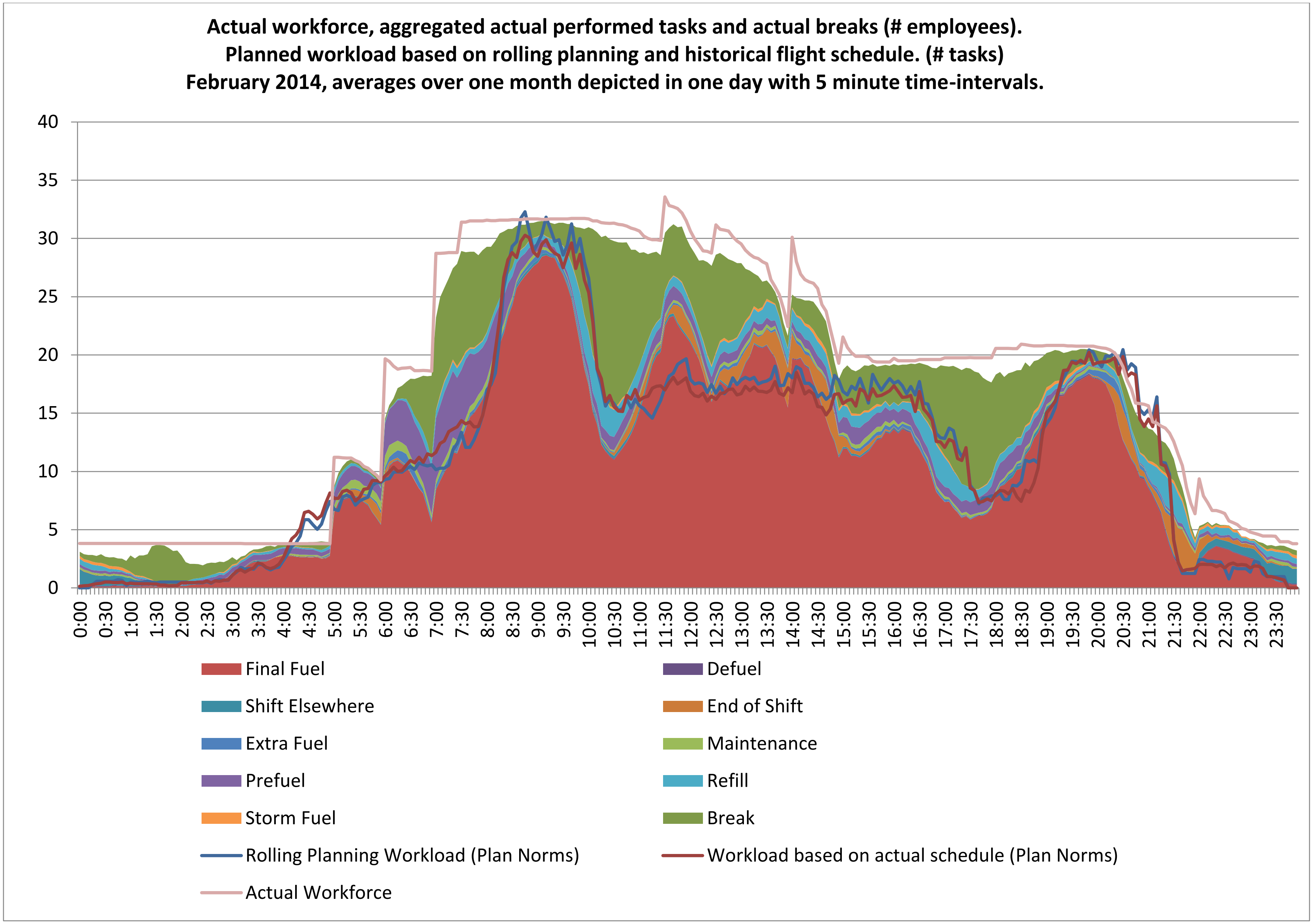
Figure 10 and Figure 11 first depict the workload profile as planned by ST using their planning norms, both prospective (blue line) and historic (red line). The first perspective uses the flight schedule as was expected by ST during the rolling planning; the second perspective uses the flight schedule as was actual on the day of operation. ST translates this actual schedule to a workload profile using the same planning norms and principles, not the actual task durations.

Next, the graph displays the actual work as experienced in the operation, such that we can compare the deviations between the actual performed work and planned workload. The actual workload is an aggregated area chart of the several tasks (including breaks) performed at the Refueling Service. Finally, a pink line depicts the average actual present personnel across the working day.

We observe the following effects of deviations between the actual work and scheduled workload profile:

- The changes in the flight schedule cannot account for the deviations between the workload profile by ST and the actual workload. Although there are small differences between the prospective and historic workload profiles by ST, the historic workload profile that ST makes does not reflect the actual workload experienced at the Refueling Service. It even holds that the historic perspective shows less workload than the rolling planning perspective. This is partly because the historic perspective deletes tasks if the actual ground time is shorter than the task duration.

- The current planning and scheduling chain cannot explain that Refueling on average performs more work than planned between 11:00 and 14:00.
- The comparison between the two months shows that the excess and capacity shortage situation has a similar pattern across the working day, especially between the morning and evening peak.
- The on time performance (OTP) is an average 87% for the whole month February 2014 (target is 90% for European flights, and 85% for Intercontinental), but for longer periods of the day, the performance drops well below 80% (see Figure 12). Furthermore, if we analyze 2013, the target for European and intercontinental flights was not met for respectively 243 and 155 days. A daily target does not reflect a constant performance; furthermore, it is not clear whether the (lack off) OTP is due to external factors, or factors within the service.


Actual workforce, aggregated actual performed tasks and actual breaks (# employees).
Planned workload based on rolling planning and historical flight schedule. (# tasks)
February 2014, averages over one month depicted in one day with 5 minute time-intervals.
40
35
30
25
20
15
10
5
0
0:00
0:30
1:00
1:30
2:00
2:30
3:00
3:30
4:00
4:30
5:00
5:30
6:00
6:30
7:00
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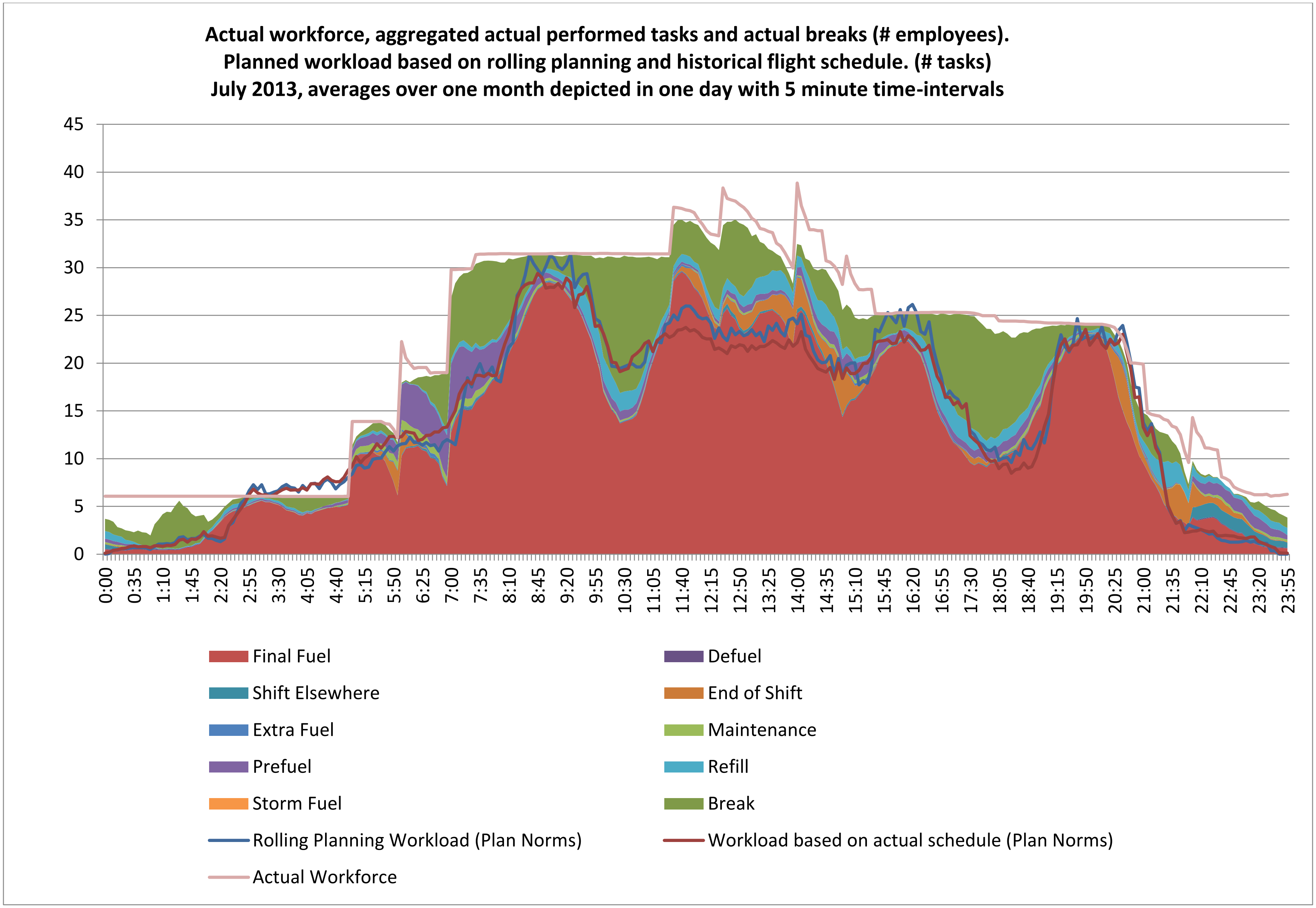
17:30
18:00
18:30
19:00
19:30
20:00
20:30
21:00
21:30
22:00
22:30
23:00
23:30
Final Fuel
Defuel
Shift Elsewhere
End of Shift
Extra Fuel
Maintenance
Prefuel
Refill
Storm Fuel
Break
Rolling Planning Workload (Plan Norms)
Workload based on actual schedule (Plan Norms)
Actual Workforce

*Figure 10*


Actual workforce, aggregated actual performed tasks and actual breaks (# employees).
Planned workload based on rolling planning and historical flight schedule. (# tasks)
July 2013, averages over one month depicted in one day with 5 minute time-intervals
45
40
35
30
25
20
15
10
5
0
0:00
0:35
1:10
1:45
2:20
2:55
3:30
4:05
4:40
5:15
5:50
6:25
7:00
7:35
8:10
8:45
9:20
9:55
10:30
11:05
11:40
12:15
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13:25
14:00
14:35
15:10
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16:20
16:55
17:30
18:05
18:40
19:15
19:50
20:25
21:00
21:35
22:10
22:45
23:20
23:55
Final Fuel
Defuel
Shift Elsewhere
End of Shift
Extra Fuel
Maintenance
Prefuel
Refill
Storm Fuel
Break
Rolling Planning Workload (Plan Norms)
Workload based on actual schedule (Plan Norms)
Actual Workforce

*Figure 11*

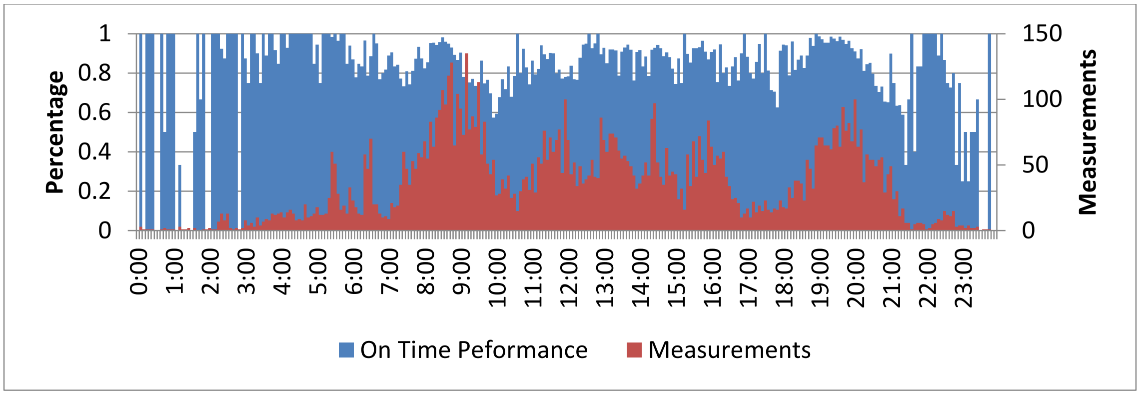


*Figure 12: On Time performance, 5-minute intervals, average over February 2014, tasks are included in the interval in which they start. The number of measurements (the number of aircraft serviced during that interval) for each bar is included.*

The buildup of the expected workload in the tactical planning is different from the buildup of work during the online operational planning phase. Both make use of input in the form of a flight schedule, both use norms and business rules to generate tasks, and both generate schedule, but these all differ. Figure 13 displays the differences and connectedness between the tactical and online operational planning phase.

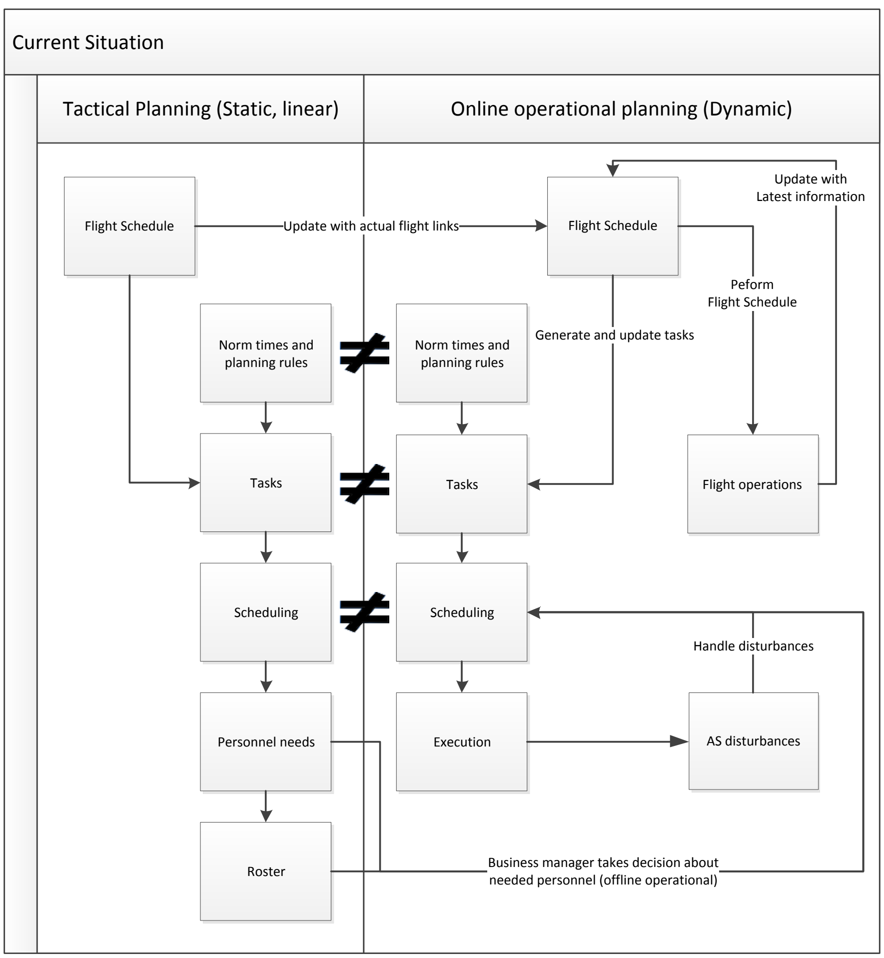


*Figure 13: Tactical planning and online operational planning*

The following sections explain structural differences in the buildup:

- The differences between the flight links assumed by ST and the actual flight links (Section 2.4.1).
- Not performing the tasks that ST planned and new tasks that ST did not plan, due to changes in the flight schedule and different norms (Section 2.4.2).
- Deviations between the actual and norm task times (Section 2.4.3).
- Performing tasks at different times than originally scheduled (Section 2.4.4).
- Deviations between the actual and scheduled personnel, due to decisions of the business manager and absence of personnel (Section 2.4.5).
- Arrival and departure performance that influences the time-window for a task (Section 2.4.6).
- The static behavior of the tactical planning method versus the dynamic behavior of its execution (Section 2.4.7).

### 2.4.1 Flight links

Flight links describe which aircraft KLM uses for which flights. Where KLM is limited to the number of landing and departure slots at Schiphol, they are free to change their flight links at any moment in time. The current workload profiles do not use the most actual flight links, but a first in, first out (FIFO) calculation as discussed in Section 2.2.1. Therefore, it is assumed that an aircraft that is on the ground the longest performs the next flight for that aircraft type. The actual flight links at KLM, however, do not follow a FIFO principle. The flight links constantly change due to broken aircraft, maintenance tasks, gate availability, number of passengers, etc. For the month February 2014 the numbers in Table 5 hold.

| **Aircraft type** | **Total number of departures** | **<24h before departure (%)** | **<4h before departure (%)** | **<1h before departure (%)** |
|---|---|---|---|---|
| Total | 7072 | 39.8% | 7.9% | 1.4% |
| Commuter | 3263 | 59% | 12% | 3.1% |
| European | 2902 | 21.3 | 4.1% | 0.5% |
| Intercontinental | 907 | 28.1% | 5.3% | 0.8% |

*Table 5: Flight link changes in hours before departure, KLM aircraft, February 2014*

If a flight link changes, the associated ground time changes, and this has an impact on the Refueling service. For example, Refueling performs a final fuel of a Boeing 737-800 between arrival time + 0 minutes and departure time – 10 minutes. Due to a change of flight links, the ground time changes from two to one hour during the morning rush hour. This means that buffer time to perform the task ahead or after the rush hour is gone.

The flight schedule does not change, so on average the ground time is the same as in the FIFO principle; this is because the total ground time over a day for aircraft of KLM will remain equal. However, when Flight Operations changes the flight links, they do increase the spread of ground times. Some aircraft have a shorter stay, others a longer than originally planned for. Furthermore, sometimes a broken aircraft is fueled before it is reported broken. In February 2014 there were 28 defuel tasks and 25 flight links changes after the standard departure time, in July 2014 there were 26 defuel tasks and 12 registration changes after standard departure time.

### 2.4.2 Canceled and extra tasks

Due to canceled and extra tasks, the planned workload is different from the actual workload. ST bases the planned tasks on the planning principles and the slot file, which contains the flight schedule of all flight on Schiphol. ST receives this file monthly from the airport authorities, while the airliners change their schedules more frequently. This means that the number of final fuel tasks deviate from the planned number of tasks. Furthermore, some tasks, such as refills of aircraft, extra fuels, and maintenance fuels are incidental or unrelated to the flight schedule, but occur every day. For tasks unrelated to the flight schedule, AS determined averages over historic data in each time-interval. These averages are added to the workload, but these tasks are not specifically scheduled.

Then, CHIP does not base its pre-fuel tasks on the planned pre-fuel tasks that come forth from the planning norms, but on the expected ground time. For every airplane that is eligible for pre-fuel, CHIP generates a pre-fuel task twelve hours before departure when the ground time exceeds two hours. Pre-fuel tasks have a low priority in CHIP and operators do not perform pre-fuel tasks if there is higher priority workload. This design in CHIP leads to both extra pre-fuel tasks that ST did not schedule, and canceled pre-fuel tasks that they did schedule.

Finally, in February 2013, five storm days resulted in storm fuel tasks, which AS does not include in the rolling planning because of non-normal operational conditions. Next, the rolling planning only plans for one lunch break and one coffee break per shift. Operators often get one additional break when the dispatcher does not have tasks on hand. The coffee break can also be together with the refill task of a bowser, which means that an operator combines two tasks at the same time.

### 2.4.3 Deviations from the norm times

The plan norm times that ST uses are less than the actual needed time in operations. These norms should account for varying needed times such that there is slack that accounts for uncertainty in the Refueling process (see Section 2.2.1).

The registered task time that an operator needs, is not necessarily the actual time that an operator performs a task. If we recall Figure 9, the task starts when the operator confirms his task in his PDA. This does not mean that he starts his task, because:

- The aircraft did not arrive at his parking position.
- The aircraft is not ready for fueling due to other processes.
- The operator does not initiate his task, because of a late task deadline, or a disturbance to his equipment or in his direct surroundings.
- The airliner or pilot did not file the requested amount of final fuel.

Because of this deadline, operators sometimes have some buffer time in their task. This means that the measured task duration in CHIP includes idle time of the operators, which is not included in the ST plan norms.

Furthermore, ST uses a planning norm that relates to an equipment and aircraft type. The aircraft's destination, the change of aircraft type, and change of parking positions (hydrant/ non-hydrant parking position) can change these. Finally, an aircraft that ST planned for pre-fuel might not get a pre-fuel on the day of execution. When a dispatcher cancels a pre-fuel task, a final-fuel task takes considerable more time, and vice versa.

Despite a formula for the plan norms that should ensure a plan norm that takes sufficiently more than the average task duration, the total time to perform a task takes longer for all equipment types (see Table 6 and Table 7).

| February task deviations | Dispenser (extra time, in %) | Number of Measurements | Large Bowser (extra time, in %) | Number of Measurements | Small Bowser (extra time, in %) | Number of Measurements |
|---|---|---|---|---|---|---|
| **Pre-Fuel** | 10.85% | 128 | 11.18% | 34 | 8.48% | 66 |
| **Final-Fuel** | 12.84% | 6759 | 35.78% | 51 | 9.64% | 2758 |

*Table 6: Total task duration deviation from plan norm February 2014*

| July task deviations | Dispenser (extra time, in %) | Number of Measurements | Large Bowser (extra time, in %) | Number of Measurements | Small Bowser (extra time, in %) | Number of Measurements |
|---|---|---|---|---|---|---|
| **Pre-Fuel** | 3.62% | 140 | -10.06% | 28 | 25.42% | 55 |
| **Final-Fuel** | 12.83% | 8993 | 23.00% | 35 | 10.28% | 3640 |

*Table 7: Total task duration deviation from plan norm July 2013*

However, if we look at the lead-time of solely phase 2, i.e., the part of the task at the aircraft's parking position (recall Section 2.3.4), the planned tasks on average holds enough slack time, except for final fuel tasks that Refueling performs with a large bowser (see Table 8 and Table 9).

| February task deviations | Dispenser (extra time, in %) | Number of Measurements | Large Bowser (extra time, in %) | Number of Measurements | Small Bowser (extra time, in %) | Number of Measurements |
|---|---|---|---|---|---|---|
| **Pre-Fuel** | -13.92% | 128 | -3.99% | 34 | -18.05% | 66 |
| **Final-Fuel** | -4.75% | 6757 | 5.61% | 51 | -6.14% | 2757 |

*Table 8: Phase 2 task duration deviation from plan norm February 2014*

| July task deviations | Dispenser (extra time, in %) | Number of Measurements | Large Bowser (extra time, in %) | Number of Measurements | Small Bowser (extra time, in %) | Number of Measurements |
|---|---|---|---|---|---|---|
| **Pre-Fuel** | -12.21% | 140 | -22.54% | 28 | -5.69% | 55 |
| **Final-Fuel** | -1.83% | 8983 | 6.87% | 35 | -4.91% | 3638 |

*Table 9: Phase 2 task duration deviation from plan norm July 2013*

The average driving time derived from the data is 6.5 minutes, while the planning norm contains driving time of either five minutes for European or six minutes for intercontinental flights. Adding to this number, there is a vehicle inspection of the used dispenser or bowser at the start of a shift and after each break that translates in three extra needed minutes on average. This means that on average, it takes 3.5 or 4.5 more minutes than planned to arrive at the aircraft.

The witnessed difference in percentages is because of the average task duration. For example, currently the norm for an Embraer 90 aircraft is 26 minutes, and the added driving time is 5 minutes, leading to difference between scheduled and actual needed times (see Table 10).

There are several causes for the differences:

- The plan norms do not account for driving times from the "Jet-plein" to the passenger terminals and back. These are included in the lunch breaks, but are not included in tasks that CHIP assigns to operators that start their shift. Also, operators that need to use the tunnel to fuel cargo aircraft next to "Jet-plein", need extra driving time. With the use of the driving time matrix, Refueling covers this next season.
- The planning norms do not consider vehicle preparation and inspection prior to their tasks in any way, while this is part of the work of fueling operators.
- AS did not configure CHIP in such a way that idle time of operators is registered.
- The plan norms do account for unavoidable disturbances during phase two, but not for disturbances during phase one. To discern from avoidable disturbances, avoidable disturbances are those that AS can prevent by better process control, e.g., not sending equipment to an aircraft that is not there, not able to fuel because the pilot did not file the requested amount, etc.

| | **Phase 1 and Phase 2** | **Phase 1** | **Phase 2** |
|---|---|---|---|
| **Norm time** | 31 minutes | 5 minutes | 26 minutes |
| **Actual average time needed** | 31.68 minutes | 9.2 minutes | 22.48 minutes |
| **Minutes difference** | 0.68 minutes | 4.2 minutes | -3.52 minutes |
| **Percentage difference** | 2.3% | 84% | -13.7% |

*Table 10: Differences between task phases for Embraer 90 aircraft in February 2014*

In the analysis of disturbances, we found that if not considered, the plan norms have more slack time. During phase 1, 5.3% of all tasks were disturbed with a median of 6 minutes and an average of 7.9 minutes in February 2014.

### 2.4.4 Deviations from the start time during execution

ST bases start times of the planned tasks on two principles, focused on scheduling the least amount of personnel for the expected workload:

- The task is performed within the time window associated with the planning norm.
- All tasks are started at moments in time that result in a minimum requirement of personnel to fulfill all tasks.

CHIP and dispatchers have other principles, focused on the minimization of departure delays:

- Tasks with a high priority are scheduled first.
- CHIP schedules tasks in such a way that the earliest start and latest end times for a task are not violated.
- Pre-fuels are only executed when there is available capacity.

Consequently, dispatchers give available work to an operator such that they minimize the number of delayed aircraft. If we recall Figure 10 and Figure 11, we can derive that dispatchers assign operators to a task for almost all moments during their shift, i.e., the aggregated performed work plus breaks is almost equal to the amount of available personnel.

Due to the pre-fuel's low priority, the dispatcher mainly assigns these tasks ahead of peak times. Figure 14 displays this further: The averages over February 2014 show that actual pre-fuel tasks are not in line with the timing in the rolling planning. Dispatchers have freedom in choosing which pre-fuel task to schedule and perform; they are not bound to the plan rules for pre-fueling in the rolling planning. So before the first peak, when operators start their shift (6:00, 7:00, or 8:00), there is most capacity for pre-fuel tasks. Pre-fueling ahead of the first peak leads to less delays across the working day.

For final-fuel tasks, the deviation from the start time is much smaller. There are several reasons for this:

- A final-fuel task needs to receive the required fuel amount, so starting too late could result in a delay.
- A final-fuel task depends on the ground time. For most flight links, the ground time is such (see Table 11) that there is not much room for deviating from the start time of the fuel task.

| **Total KLM outbound flights February 2014** | **8541** |
|---|---|
| **Actual ground time ≥ 1.5 and < 2 hours** | 1125 |
| **Actual ground time ≥ 1 hour and < 1.5 hours** | 2116 |
| **Actual ground time < 1 hour** | 1604 |

*Table 11: Ground time for KLM aircraft at Schiphol February 2014*

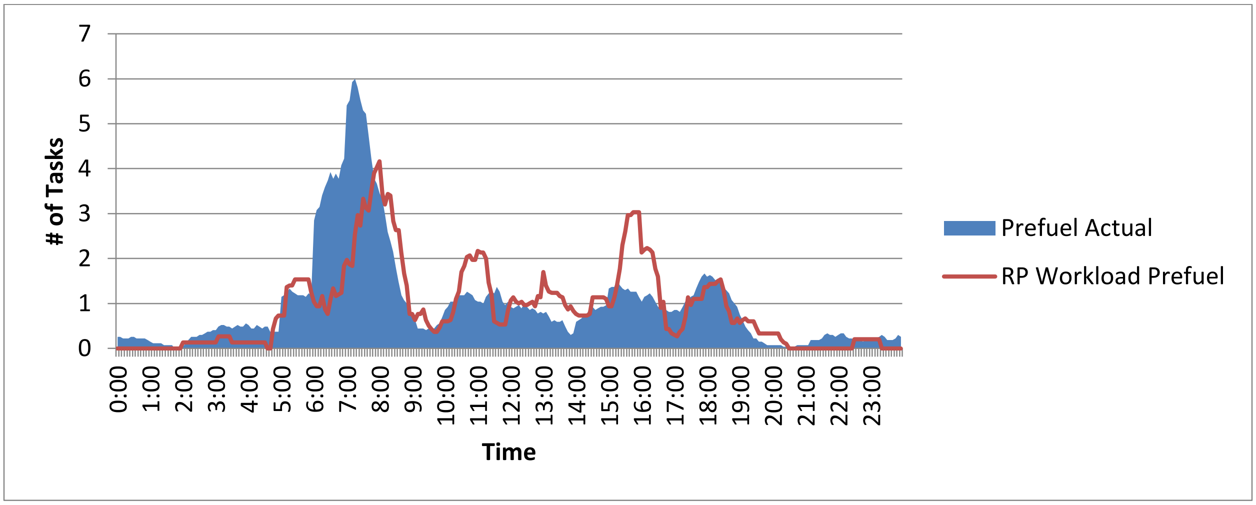


*Figure 14: Prefuel tasks in the rolling planning and actual prefuel tasks performed, average February 2014*

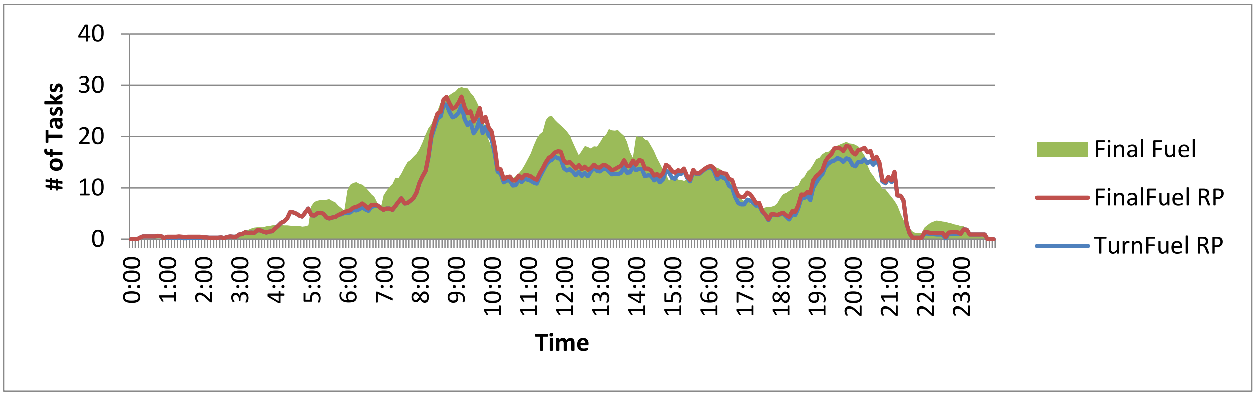


*Figure 15: Final fuel (turnfuel is a final fuel without pre-fuel) tasks in the rolling planning and actual tasks performed, average February 2014*

Therefore, the final fuel start time is on average 10 minutes earlier than planned in February 2014 and 2.5 minutes earlier than planned for July 2013, both with a standard deviation of 75 minutes. This is still a wide spread of start time deviation. Figure 16 shows a histogram of tasks actual start time deviation from what the rolling planning originally planned for ten-minute time intervals.

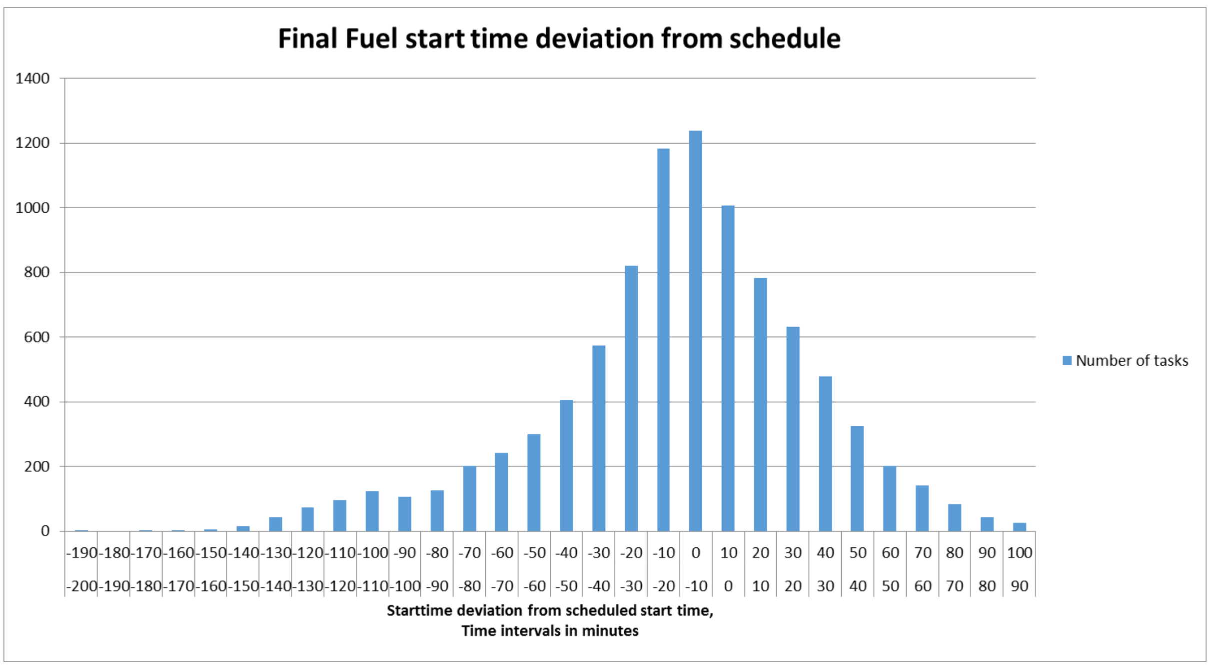


*Figure 16: Start time deviation from rolling planning scheduled time, February 2014, expressed as number of tasks in time interval*

For pre-fueling, the standard deviation is respectively seven hours for February and six hours for July. In combination with the number of canceled and new tasks (see Section 2.4.2), this confirms that for pre-fuels Refueling does not follow the schedules coming forth from the rolling planning.

The consequence of not adhering to the scheduled times as proposed in the rolling planning is that the buildup of the actual workload profile versus the buildup of the rolling planning workload profiles is different. The current rolling planning only shows one possible outcome of a working day, while the dispatcher and CHIP are free to generate any schedule that seems most suitable under the circumstances of that day.

### 2.4.5 Available versus scheduled personnel

The personnel coordinator and business manager are responsible for a personnel schedule that matches the expected workload during execution, which might be different from the workload that the rolling planning predicted. They update the shiftset to cover the workload peaks, accounting for the expected absence factor of KLM personnel. A few days in advance of operations, they also hire extra flex workers in case of absent personnel, expected bad weather, or bad performance during the last few days. The combination of scheduled KLM personnel, flex workers, and ill personnel then make up the available personnel during execution.

The measure that AS communicates is the surplus or shortage of personnel compared to the rolling planning. AS only relates this surplus to the rolling planning, and despite a surplus, the execution can still result in delays for departing aircraft, while a shortage of personnel can still result in a perfect on time performance for all tasks. Following the rolling planning's personnel recommendation does not guarantee a good OTP.

### 2.4.6 Arrival and departure performance

Currently, the rolling plan does not cover for the arrival delays and early arrival of aircraft, while their behavior is essential to available ground time in which Refueling can perform its services. During operations, when an aircraft arrives late, Flight Operations sometimes sets a new departure time (EBDE). This EBDE is set such that all ground services can perform their tasks and the aircraft has a more realistic departure time.

Commercially it is not viable to set an EBDE for all delayed flights, since it leads to a perception of bad service to the customer. Therefore, only some flights with expected unavoidable late departure get an EBDE.

Table 12 shows the number of days of a month KLM achieved the arrival punctuality (A0, aircraft arriving on time) target and average percentage. The first column shows the target KLM wants to achieve on a daily performance. The third and fourth column show the number of days KLM met this target, and the average performance during these months.

The departure performance of departing aircraft should be similar to A0 if all ground processes are on time. There are two measures, the aircraft departed before their set departure time (either the scheduled departure time or the EBDE), and aircraft departed within fifteen minutes from their departure time, which are the measures D0 and D15. Table 13 shows data for these measures.

KLM cannot always make its departure performance target, and for the intercontinental flights, the targets seem unrealistic. Flight Operations has the option to delay aircraft by using the EBDE such that they meet their targets, but Table 13 indicates that KLM does not use the EBDE to give all ground operations more breathing space such that more flights make D0, since departure performance is worse than arrival performance.

| Aircraft type | Arrival performance target (A0) | A0 July 2013 (# of days of the month target was met; average over the month) | A0 February 2014 (# of days of the month target was met; average over the month) |
|---|---|---|---|
| KLM Commuter | 72% | 23; 78% | 23; 82% |
| KLM Europe | 71% | 24; 80% | 20; 78% |
| KLM Intercontinental | 69% | 22; 72% | 21; 71% |

*Table 12: Arrival performance and available ground time*

Harmsen (2012) already showed that a log-normal distribution describes the arrival performance. This has an impact on the time-windows, and the starting time of tasks. It holds that 30% of all tasks have a later starting time than originally planned, but also that 70% of all tasks can start on time or earlier than planned. In the rolling planning, it is assumed that all aircraft arrive on time. In combination with changing flight links, it is by definition not possible to schedule and execute tasks as in the rolling planning schedule.

| Aircraft Type | Departure performance target (D0) | Departure performance target (D15) | D0 (# of days of July 2013 target was met; average of month) | D15 (# of days of July 2013 target was met; average of month) | D0 (# of days of February 2014 target was met; average of month) | D15 (# of days of February 2014 target was met; average of month) |
|---|---|---|---|---|---|---|
| KLM Commuter | 50% | 84% | 10; 49% | 27; 90% | 16; 55% | 26; 92% |
| KLM Europe | 49% | 86% | 6; 41% | 24; 88% | 10; 49% | 23; 91% |
| KLM Intercontinental | 33% | 77% | 1; 21% | 14; 74% | 1; 22% | 4; 72% |

*Table 13: Departure performance targets, average performance, and number of days of the month that targets are met*

### 2.4.7 Static planning versus dynamic rescheduling in CHIP

The current tactical planning method schedules all tasks as if all information is accurate and known before execution. During execution, CHIP reschedules all tasks every 30 seconds based on the latest information as if it were a new instance of an offline schedule. This is necessary because of dynamic developments during the day.

This has implications during execution. Consider the Gantt charts in Figure 17. These charts depict two time moments of a schedule in which there are three operators, a schedule of future tasks associated to aircraft, and tasks that Refueling currently executes. Furthermore, the yellow and red task have a deadline that we depict with a vertical line. At time t + 1, the dispatcher receives information that the green task on aircraft PH-CKC needs 20,000 kg more fuel, and thus will take longer. The yellow task on PH-BQL will take shorter due to less fuel requirements. The consequence is that the red task results in a departure delay for the associated aircraft PH-EZY. If the dispatcher had received this information at an earlier time, the dispatcher would have interchanged the red and yellow task, because the yellow task now has a shorter duration. Since AS is not allowed to preempt tasks, this is not possible. So due to dynamic changing information "exact methods provide an optimal solution for the current state, but do not guarantee that the solution will remain optimal once new data becomes available" (Pillac, Gendreau, Gueret, & Medaglia, 2013).

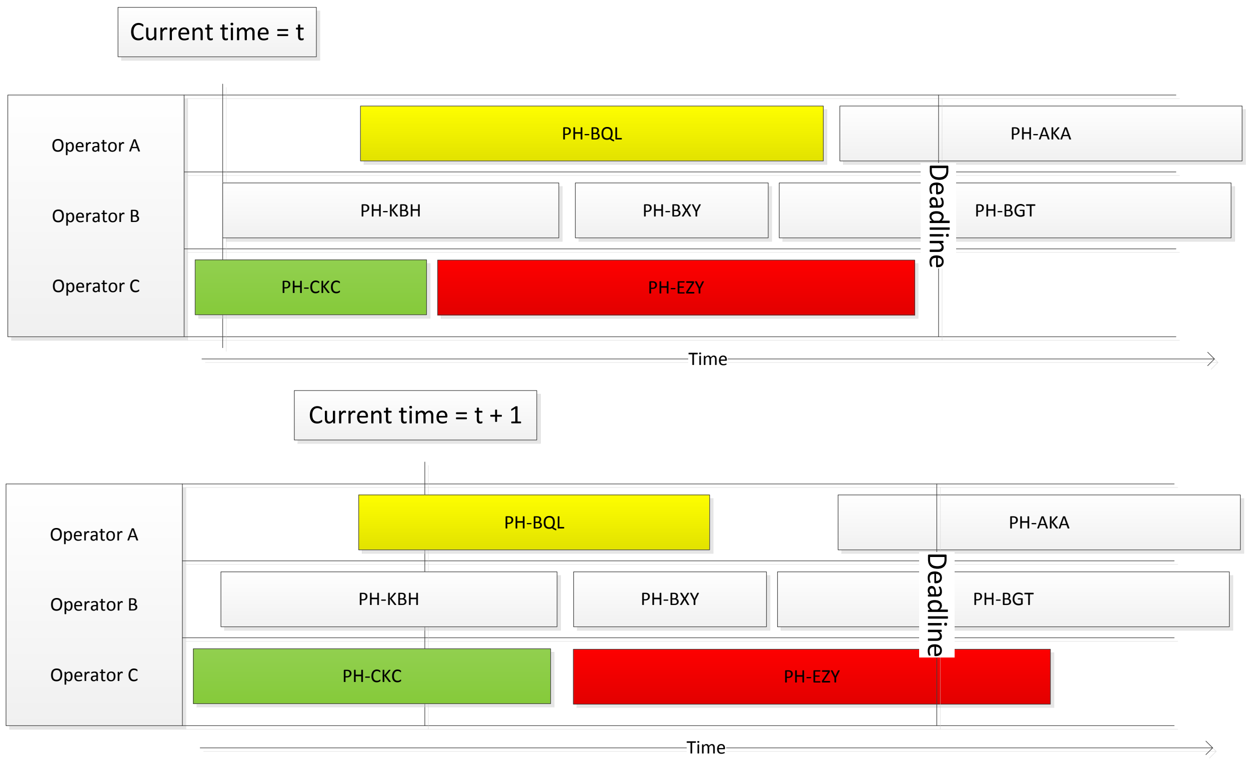


*Figure 17: Gantt charts of the same schedule with three operators at time t and time t+1*

A simulation in the CHIP system showed for June 1 2014 that the CHIP system could plan 360 tasks for the static instance (having all information before execution), and 335 tasks for the dynamic instance (getting all information as was actual during the day). This is an indication that information updates, and thus duration and time-window changes of tasks, results in the effect that CHIP schedules less tasks.

This does not mean that Refueling was unable to perform all demand: On the actual day, Refueling completed 493 tasks. This led to a loss of performance. The actual on time performance for Refueling was around 80%, except for non-KLM intercontinental flights, which was 72%. The hub control center, however, did not report any difficulties specific for the Refueling department on that day. There are several possible reasons for these differences:

- In the simulation, task durations take the planned time, not an actual time. Therefore, CHIP did not benefit from early finishing tasks nor had problems with late finishing tasks.
- All performed tasks were on time in the simulation, but CHIP was not able to schedule tasks purposefully with a delay, while in reality only a little over 80% of tasks were finished within their allowed time-windows.
- Due to the fact that CHIP cannot schedule tasks to future shifts if it currently has no equipment for them, this results in unscheduled tasks that need to start now (see Section 2.3.2 and appendix G).

- In the simulation, no dispatcher was monitoring and altering the schedule.

## 2.5 Conclusion

This chapter first selected the Refueling department as service for analysis in this research. Then, the chapter described the planning and scheduling process at Refueling, the execution of Refueling, and the dispatchers and software supporting the Refueling department during task execution. The chapter ended with differences between the buildup of the planned workload and the actual workload.

The main findings are the following:

- 40% of flight links change less than 24 hours before departure. The rolling planning assumes a FIFO principle. This means that ground times in the rolling planning differ from actual ground times before each flight.
- Many planned pre-fuel tasks are canceled while many non-planned pre-fuel tasks are executed. Furthermore, the rolling planning does not consider incidental tasks.
- Planning norms do not cover the needed time to perform a task. This has several reasons: Idle-time of operators is not known, on average driving takes longer, before driving there is a vehicle inspection that has never been included in the plan norms, and disturbances before phase 2 are not included in the norms. If only phase 2 of the fueling task is considered, the norms are sufficient.
- The starting time of a task in relation to the rolling planning starting time deviates. Final fuel-tasks on average start 10 minutes early, but has a standard deviation of 75 minutes. The standard deviation for pre-fuel tasks is so high that the planned and actual start time are not related.
- Following the rolling planning's personnel recommendation does not imply a good OTP during execution. Furthermore, a shortage or surplus in personnel does not necessarily imply a bad or good OTP.
- An arrival performance of 70% in combination with changing flight links makes it impossible to adhere to the schedule coming forth from the rolling planning.
- The dynamic environment in which information becomes available gradually has impact on the performance of CHIP, and results in performance loss when the dispatcher does not intervene.

# 3 Literature Review

This chapter reviews literature relevant to this research. Section 3.1 discusses scheduling problems that relate to the scheduling problem at AS. Section 3.2 provides background on factors that influence the airline operation in general, and specific factors that influence the aircraft service. Then, Section 3.3 provides literature about the value of information in planning processes. Section 3.4 provides background on robustness against variability.

## 3.1 The scheduling problem at Aircraft Services

This section discusses scheduling problems that are similar to those at AS. AS schedules tasks with a variable and stochastic duration in time-windows that also variable. Next to cost reduction, AS tries to schedule tasks such that aircraft leave without delay.

The scheduling of Refueling tasks can be characterized as a vehicle routing problem (VRP), first introduced by Dantzig and Ramser (1959) as the truck dispatching problem. In the original VRP, however, there are no constraints of time-windows. Furthermore, a fixed fleet size handles all tasks across different locations. The problem could also be characterized as a dynamic repairman problem (see Bertsimas, Van Ryzin, & Bertsimas, 1989; Tsitsiklis, 1992), in which service demands arise in certain areas that need to be serviced. Most service demands, however, are known beforehand.

The second aspect of scheduling Refueling tasks is that it has an earliest start time, a process time, and a latest end time. The earliest start time is a hard constraint; fueling cannot begin before the aircraft is at its parking position. A violation of the latest end-time must be avoided and is a soft constraint that can result in a penalty of a delay. The three time factors are all varying, due to external factors influencing the arrival process of aircraft, factors influencing the process time of each tasks, and factors influencing the scheduled departure time of an aircraft. Furthermore, information about these varying parameters becomes gradually available. Each time that new information becomes available, another schedule could hold better results. Therefore, the scheduling problem is a dynamic one. If we look back at Figure 4, we can connect the flight network to get an integral picture of all processes that influence the time factors at Refueling (see Figure 18).

Finally, due to the nature of Schiphol Airport, Refueling finishes all tasks such that at the end of the day there is no backlog. Every day starts with an empty system, i.e., no occupied operators that are fueling an aircraft. So when scheduling, Refueling can see each day as independent.

So, the scheduling problem at Refueling contains properties of a stochastic demand VRP (VRPSD), a VRP with time windows (VRPTW), a VRP with service times, and a dynamic VRP. Pillac et al. (2013) defines this kind of VRP as a dynamic and stochastic one: In these problems, “part or all of their input [is] unknown and revealed dynamically during the execution of the routes, [for which] exploitable stochastic knowledge is available on the dynamically revealed information”. Pillac et al. (2013) discuss that service times have not been explicitly studied, but that it is possible to add service times to the driving times.

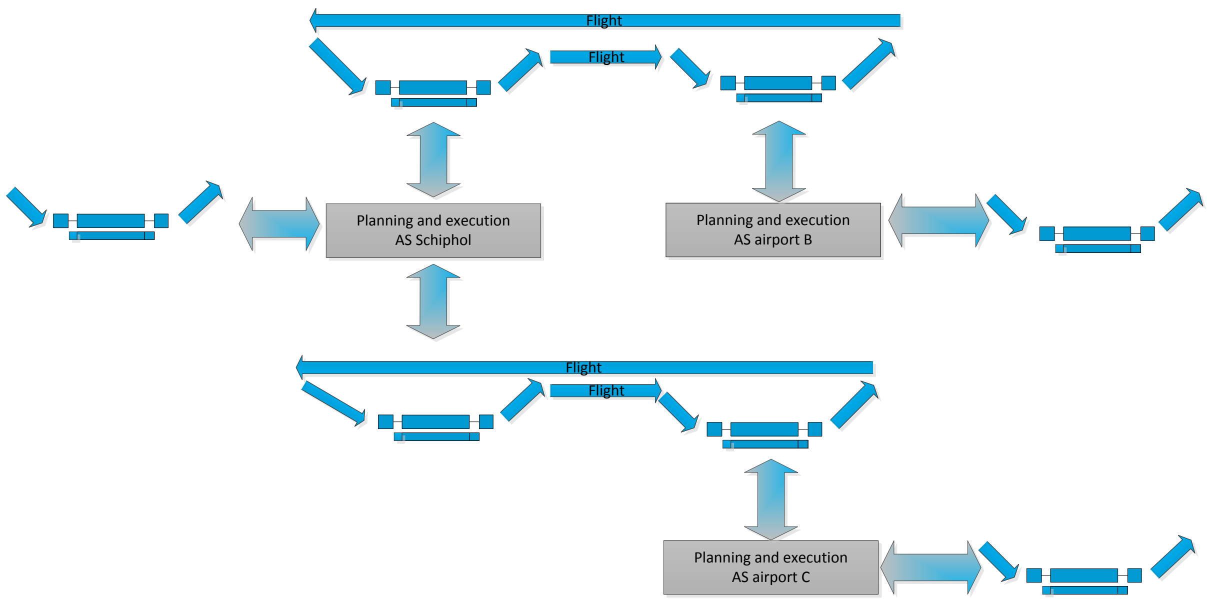


*Figure 18: Interconnectedness of the flight network and execution of aircraft services at different airports*

Psaraftis (1988) discusses the dynamic vehicle routing problem with regard to static instances of the problem. In his research, there are several differences of importance:

- Information about the future is imprecise or unknown. While information about current events is precise, the quality of information deteriorates gradually into the future.
- Tasks that are executed in the near future are more important. This means that the commitment of resources to near future tasks holds better results since more information about these tasks is available. Committing resources to tasks further in the future is less desirable, because such decisions lead to suboptimal resource dedication due to changing circumstances of these tasks.
- Information update mechanisms are essential. In a dynamic setting, the scheduling system must process information such that it updates its schedule accordingly.
- Decisions about resequencing and reassigning tasks are justified. With gradually becoming available information, this results in better schedules when used.

Li, Tian, and Leung (2010) discuss vehicle routing problems with time windows that include stochastic travel and service times, or a combination of the former, SVRPTW. They, however, use fixed time-windows, and their primary optimization objective is vehicle minimization. In addition, this kind of method does not deal with the dynamic change of available information about the process.

Novoa and Storer (2009) consider customer demand with a known probability distribution, solving the VRPSD in real-time. However, demand here is related to vehicle capacity, not to service times, so that if upon arrival demand exceeds the vehicles available supply, the vehicle needs to return to the depot. (Novoa & Storer, 2009)

Several authors discuss the use of ant colonization techniques, first proposed by Dorigo, Maniezzo, and Colorni (1996). Gambardella, Taillard, and Agazzi (1999) propose this technique for VRPTW, in which they simultaneously reduce the number of needed vehicles with one ant colonization algorithm, and reduce the total distance for the minimum of needed vehicles found with another. Montemanni, Gambardella, Rizzoli, and Donati (2005) solve the DVRP problem with service times. They rerun the optimization algorithm for a number of time slices during the planning horizon, rescheduling the remainder of the planning horizon based on information that the system obtained during the last time slice.

To solve dynamic routing problems there are two reoptimization techniques, periodic and continuous. Periodic updates in a dynamic environment can use static routing algorithms based on the current state of the system. A periodic update takes place for fixed time-intervals or every time new information becomes available. A disadvantage of such methods is that all optimizations take place before the routing plan is updated, causing delays in real-time updates of the schedule. By using continuous reoptimization, the schedule is continuously prone to changes. This leads to a system that continuously shows the algorithm's best solution, possible worse than solutions of more complex periodic algorithm implementations, because it uses less time to calculate solutions. (Pillac et al., 2013)

Modeling stochastic demand behavior could either be done via stochastic modeling or sampling. Sampling relates to generating scenarios with probability distributions, while stochastic modeling technically formulates the stochastic behavior in the models. Sampling is relatively easy, but leads to massive generations of scenarios. Stochastic modeling could fully capture the stochastic behavior of a VRP, but due to the mathematical complexity need to compute possible solutions efficiently. (Pillac et al., 2013)

Mitrović-Minić, Krishnamurti, and Laporte (2004) discuss the value of information that a dynamic instance holds versus the related offline instance in which all information is known beforehand. This is the gap that exists between the dynamic solution and the offline solution.

Cowling and Johansson (2002) discuss that in case of using real-time information, not only the quality of revised schedules must be considered, but also the disruption that is caused by revising the schedule. Local adjustments to a schedule (schedule repair) generates less disruption than full rescheduling of all tasks after a planning system obtains real-time information. The authors consider this as utility and stability. Utility is defined as the change in the objective function, where stability considers the changes in the schedule, i.e., the more changes, the less stable the schedule. (Cowling & Johansson, 2002)

## 3.2 Delays

This section discusses delays in the airline industry. For this section, we use airline specific literature and information sources. For all influences that contribute to delay, The International Air Transport Association (IATA) designed a code set that indicates what kind of delay a flight is experiencing; EUROCONTROL makes an annual report for these kinds of delay. We summarize the causes for aircraft delay in Table 14.

Xu et al. (2008) give a visualization of delay generation and absorption at airports and during flights in Figure 19.

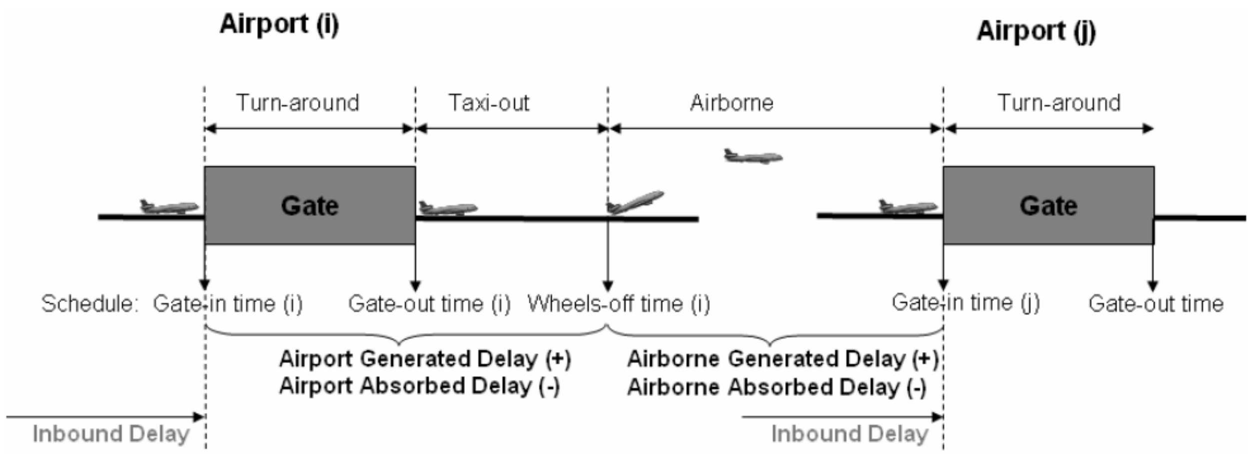


*Figure 19: Delay generation and absorption, derived from Xu et al. (2008)*

Important factors regarding the Refueling department are the AIBT (Gate-in time in Figure 19), the published departure time, the disturbances on the airport that affect the fueling process, and process time and disturbances in the refueling process itself. The IATA delay codes in combination with Figure 19 give information about these factors. The most important code in this research is code 36: Flight delay induced by fueling operations.

- The AIBT could depend on all factors that affect the aircraft prior to this moment. This could either be a:
    - Reactionary delay as a result from an earlier flight.
    - Problems at the airport of departure.
    - Problems en route.
    - Problems at the airport of arrival (Schiphol).
- The process duration could depend on:
    - Disturbances during driving.
    - Disturbances around the aircraft.
    - Equipment disturbances.
    - Fuel task type.
    - Used equipment.
    - Destination.
    - Departure weather.
    - En route weather.
- The published departure time could depend on:
    - Late arrival of the inbound flight.
    - Other processes that significantly delay the departure of the flight.

| Type of Delay | Description plus IATA delay codes | Examples |
|---|---|---|
| Airline | Passenger and Baggage 11-19 | Problems with check-in and boarding of the aircraft, lateness of passengers. |
| | Cargo and Mail 21-29 | Problems with documentation and lateness of cargo. |
| | Aircraft and Ramp Handling 31-39 | AS is mostly included here. Problems with equipment, lack of staff, aircraft documentation, and loading problems with cargo. Code 36 denotes delays due to fueling. |
| | Technical and Aircraft Equipment 41-49 | Defects, non-scheduled maintenance, late release from scheduled-maintenance |
| | Damage to Aircraft & EDP/Automated Equipment Failure 51-58 | Damage to aircraft and/or technical problems with automated systems. |
| | Flight Operations and Crewing 61-69 | Late crew boarding, crew shortage, and late completion or change of flight documentation. |
| | Other Airline Related Causes Others | |
| Airport | ATFM due to Restriction at Destination Airport 83 | |
| | Airport Facilities 87 | |
| | Restrictions at Airport of Destination 88 | Closed runway, industrial action, staff shortage, political unrest, noise abatement, night curfew etc. |
| | Restrictions at Airport of Departure 89 | Closed due to weather (ATFM only), industrial action, staff shortage, political unrest, etc. |
| En-Route | ATFM due to ATC En-Route Demand / Capacity 81 | Capacity problems |
| | ATFM due to ATC Staff / Equipment En-Route 82 | |
| Governmental | Governmental Security and Immigration 85-86 | |
| Weather | Weather (other than ATFM) 71-79 | Weather conditions at departure, arrival airport, or during flight. De-icing. airport snow, ice, or sand removal. |
| | ATFM due to Weather at Destination 84 | |
| Miscellaneous | | |
| Reactionary | Late arrival of aircraft, crew, passengers, or load from earlier flights 91-96 | Awaiting passengers, crew, or aircraft for next flight. Rerouting, diversion, or aircraft change. |

*Table 14: Delay types, derived from (EUROCONTROL, 2013)*

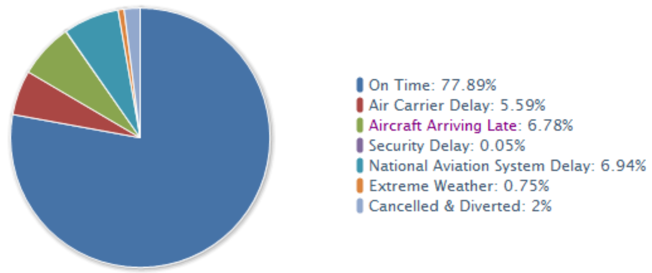


*Figure 20: Distribution of arrival delays U.S. June 2013 - April 2014 (derived from The Federal Aviation Authority (2014))*

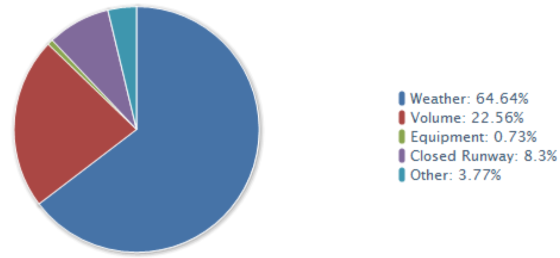


*Figure 21: Factors causing national aviation system delays, June 2003 - April 2014 (derived from The Federal Aviation Authority (2014))*

40-50 % of flight delays is caused by the reduction of capacity in the flight system, the remaining percentage is due to airline operations, of which 20 to 30 % is reactionary, and 10% comes forth from technical failures. (Wu, 2008)

The United States Federal Aviation Administration (FAA) records information about flight delay. For the period June 2003 to April 2014, 77.89% of U.S. flights were on time. Delays (aircraft arriving at least 15 minutes later than scheduled) are either attributed to system delay (less capacity than demand in the flight system), aircraft arriving late (reactionary), and air carrier (airline operations) delay (The Federal Aviation Authority (2014)). Figure 21 splits out the factors that result in system delay. Weather is the main cause for delay in the system. Then a flight volume that is higher than the system capacity is the second reason for delay. Limitations in runway availability come in third.

Also for the European flights, there are statistics. Ranked from high to low, the main causes for delay are Reactionary, Airline, Air Traffic Flow Capacity Management (ATFCM) airport, weather not related to ATFCM, ATFCM en-route, Government, problems at airport not related to ATFCM, and ATFCM due to weather. (EUROCONTROL, 2013)

ATFCM related delays are all due to a reduction of capacity for air traffic, e.g., a reduction in runway capacity is an ATFCM airport delay, and a reduction in security check capacity is an airport delay not related to ATFCM.

For scheduling reasons, it is important to know whether aircraft arrive on time, and how the deviation from the expected arrival time is distributed. EUROCONTROL (2013) describes a distribution of arrival punctuality over 2012 and 2013 for European airlines (see Figure 22). Harmsen (2012) described such a distribution for an arbitrary month of KLM operations and different type of aircraft, such that he could simulate the impact of arrival delay on the performance of Refueling.

Costs of delayed aircraft are essential to ground services of each airliner. If the cost of scheduling more personnel does not outweigh the incurred cost of delayed aircraft, scheduling extra personnel results in unwanted over capacity. Extensive studies by Cook and Tanner (2011) for EUROCONTROL show delay costs for airliners during all phases of flight for several aircraft type. Their study describes fuel, maintenance, fleet, crew, and passenger costs in relation to aircraft delay, and delay effects that propagate through the airliner's flight network. Small delays have little effect on the passengers and often do not result in propagated delays throughout the flight network. Increasing delay times, however, result in non-linear higher costs to the airliner. Cook and Tanner (2011) described a low-cost, base, and high-cost scenario. The base scenario in Figure 23 shows incurred costs for an airliner that has a delayed aircraft standing on the ground.

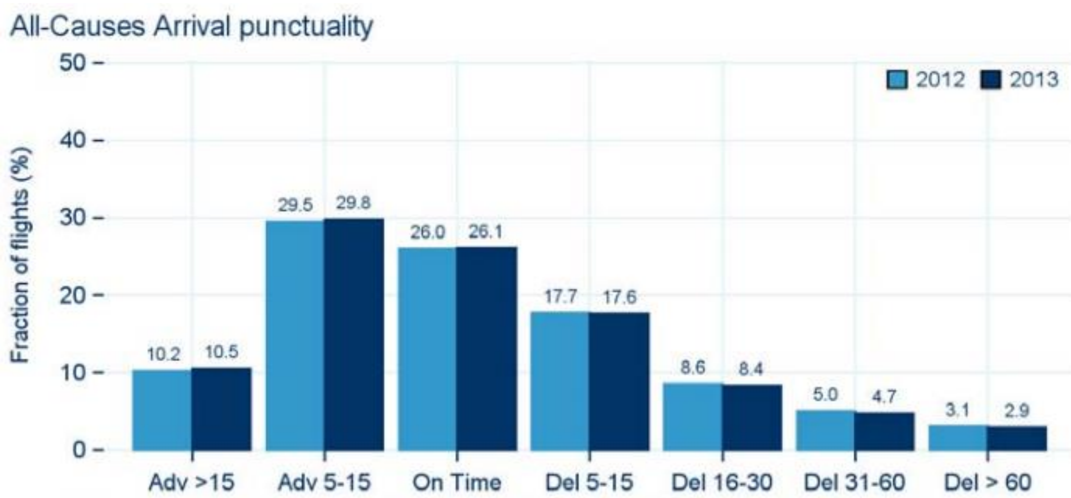


*Figure 22: Average aircraft delay in the European region, in fraction of arrivals, derived from EUROCONTROL (2013)*

Harmsen (2012) estimated the shift cost around 238 euros. For the base scenario, any 15-minute delay coming) is already more expensive than the average personnel costs of a one person shift. AS, however, can only justify an extra shift when they expect the current schedule to result in a delay induced by one of its services.

| Delay (mins) | 5 | 15 | 30 | 60 | 90 | 120 | 180 | 240 | 300 |
|---|---|---|---|---|---|---|---|---|---|
| B733 | 70 | 340 | 1 010 | 3 250 | 6 350 | 10 140 | 19 700 | 31 820 | 46 350 |
| B734 | 80 | 370 | 1 110 | 3 630 | 7 150 | 11 440 | 22 330 | 36 140 | 52 710 |
| B735 | 70 | 310 | 920 | 2 930 | 5 720 | 9 120 | 17 700 | 28 570 | 41 590 |
| B738 | 80 | 410 | 1 230 | 4 010 | 7 910 | 12 670 | 24 740 | 40 060 | 58 440 |
| B752 | 90 | 470 | 1 460 | 4 850 | 9 620 | 15 460 | 30 290 | 49 150 | 71 810 |
| B763 | 130 | 690 | 2 150 | 7 170 | 14 240 | 22 900 | 44 920 | 72 920 | 106 570 |
| B744 | 190 | 970 | 3 050 | 10 240 | 20 400 | 32 850 | 64 520 | 104 840 | 153 310 |
| A319 | 70 | 340 | 1 020 | 3 320 | 6 540 | 10 480 | 20 450 | 33 110 | 48 300 |
| A320 | 80 | 380 | 1 150 | 3 770 | 7 460 | 11 960 | 23 390 | 37 900 | 55 330 |
| A321 | 80 | 430 | 1 350 | 4 490 | 8 920 | 14 360 | 28 170 | 45 730 | 66 850 |
| AT43 | 40 | 160 | 430 | 1 260 | 2 390 | 3 750 | 7 140 | 11 400 | 16 460 |
| AT72 | 50 | 190 | 540 | 1 660 | 3 200 | 5 060 | 9 720 | 15 580 | 22 590 |

*Figure 23: At gate delay costs for different aircraft type in euros, derived from Cook and Tanner (2011)*

## 3.3 Value of Information about Future Events

Psaraftis (1995) discusses the development and perception of information over time. His notion about dynamic routing problems adheres to the dynamic situation of Refueling: “It is impossible for an optimal route to be produced in advance. At best, what can be produced is a policy, specifying what action should be taken as a function of the state of the system.” (Psaraftis, 1995) Most scheduling problems, however, do not develop as in the dynamic traveling repairman problem, where service demands arise with certain probability in certain areas. Therefore, we give the information taxonomy by Psaraftis (1995) that describes several attributes of available information:

- Evolution of information describes whether information is a static or dynamic input to the system. Static information is known during the whole planning process and does not change; dynamic information will be revealed and updated as the planning, scheduling, and execution of a process develop.
- Quality of information describes whether information is deterministic, a forecast, or probabilistic. The quality of information can change over time, e.g. when the realization of a probabilistic value is revealed, it could either become deterministic or an uncertain forecast.
- Availability of information describes whether information is known globally or locally, i.e., information is available to the whole planning process, or information is only available to operators that execute the process.
- Processing of information describes whether the used information is used in a centralized or decentralized manner.

Most information that AS knows is a forecast at best, i.e. all inputs in the planning process have some form of uncertainty in it. The flight schedule is a reliable forecast and the amount of final fuel tasks can be deduced from it. For forecasts, however, the following three laws hold:

- “Forecasts are always wrong.
- Detailed forecasts are worse than aggregate forecasts.
- The further into the future, the less reliable the forecast will be.” (Hopp & Spearman, 2008, p. 441)

Tasks that are unrelated to the flight schedule, are more difficult to plan and schedule, since their information is either missing or of probabilistic nature. So, in a planning chain, this imperfect and incomplete information must result in scheduling decisions. It is imperfect because the information contains uncertainties itself, and it is incomplete because information about possible events is missing.

De Meyer, Loch, and Pich (2002) describe the effects of uncertainty. They discern in four types of uncertainty: Variation, foreseen uncertainty, unforeseen uncertainty, and chaos. Variation describes how small influences may affect an expected activity. These small influences can be buffered for. Foreseen uncertainty are influences that the planner understands and has identified, but for which he is not sure they will occur. Unforeseen uncertainties, or “unknown-unknowns”, are very unlikely events, or the planner is really unaware of its possibility. (De Meyer et al., 2002)

Due to the non-deterministic nature of information, there are variations in the expected outcome. Furthermore, due to unforeseen and foreseen uncertainty there are contingencies, i.e., “future events or circumstances which are possible but cannot be predicted with certainty”. ("Oxford Dictionaries," 2014)

Since information and its quality changes over time, there is a need to reevaluate the possible outcomes during execution. In the case of foreseen uncertainty, this results in contingent actions that were predetermined, e.g., what to do in case of an extra task or incidental task. In the case of unforeseen uncertainty, a new contingent action plan must be made once the unforeseen uncertainty arises, e.g., what to do in case of a storm or winter weather. Information becomes available in the form of a forecast, and, based on such a forecast, the desired action should be taken. (De Meyer et al., 2002)

## 3.4 Robustness against variability

In this research, we extend the meaning of robust planning and scheduling at the offline planning and scheduling level. “Data are usually subject to measurement errors” and despite a dynamic and stochastic world “the world of mathematical programming models is generally assumed to be deterministic”. Therefore, if a model is deterministic with measurement errors, is formulated by “best-guessing” unknown values, and is solved with mean-value problems, a model does not capture all the effects of variability in the real world. This results in sensitivity analysis to examine the effects of uncertainties after execution. This, however, is a reactive approach, where a proactive approach could be robust to these real-world uncertainties and not in need of sensitivity analysis. Proactive approaches, or robust planning techniques, are a balance of feasibility (model robust) and optimality (solution robust), i.e., more costs create more feasibility at the cost of optimality, while less costs create more optimality at the cost of feasibility. (Mulvey et al., 1995)

The second notion on robust planning is that, while decision makers try to avert risk, most models ignore the distribution of an outcome and do not capture the risk attributes that the decision maker considered. (He & Huang, 2008; Mulvey et al., 1995)

Robustness could be described as buffering against variability such that it is safe to say that a set target is made. In general, this is done by adding slack, e.g., slack is reserve space in a container to fit larger than average objects, or reserve time to fit tasks that have a longer than average duration. We express this with the following formula, where $\beta$ denotes the amount of variance that is captured.

*Planned time* = $\mu + \beta * \sigma$

With this formula, however, only the expected varying duration of a task is captured. Orders (tasks) are contending for the same resources with variability in their time-windows and process durations. A robust schedule needs to deal with more sources of variability, such as incidental tasks, resources with an unexpected lower capacity, and changing time-windows due to delays.

Harmsen (2012) therefore decided to capture robustness with simulation experiments, running experiments that deviated from the expected arrival time and process times with theoretical fitted distributions based on historical data.

The remainder of this section describes how robustness against variability could account for incidental tasks (Section 3.4.1), using statistics in robust planning (Section 3.4.2), and contingency planning (Section 3.4.3). Then Section 3.4.4 describes the role of time buffers against all kinds of uncertainty.

### 3.4.1 Incidental tasks

To cover for incidental tasks, there is not only the need to plan extra capacity, but also available time during execution to perform it. The question is whether capacity or personnel should be solely reserved to handle all incidental tasks, or that incidental tasks should be handled within the normal schedule. For example, in hospitals, there is a choice to either handle emergency surgery within designated emergency theatres or handle emergency surgery within regular operating theatres (see Figure 24). If regular operating theatres handle emergencies, the schedule needs to be such that an emergency can always start within a reasonable time, and each individual theatre needs extra buffer time to handle potential emergencies. (Hans & Vanberkel, 2012)

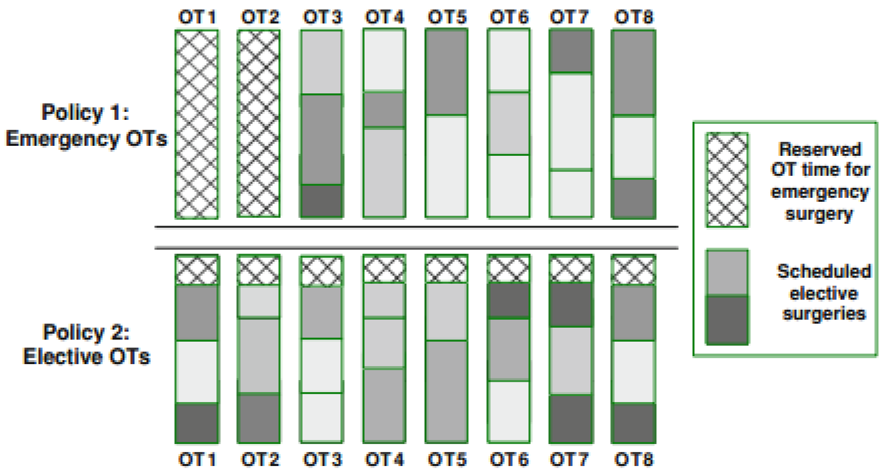


*Figure 24: An emergency theatre versus regular operating theatre setup, derived from (Hans & Vanberkel, 2012)*

Furthermore, we want to ensure that incidental tasks start in reasonable time. This gives the time that it takes before a task is finished must be minimized, i.e. the spread of break-in-moments must be such that waiting time is minimized. In this manner, it takes at most the difference between two break-in-moments before an incidental task can start; see the example in Figure 25. (van der Lans et al., 2006)

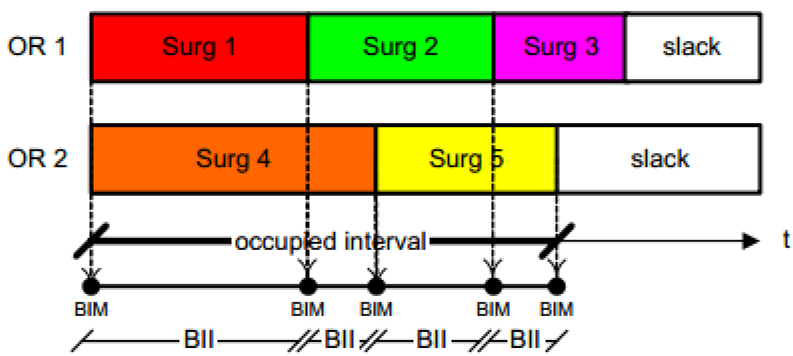


*Figure 25: An example of break in moments (BIM) and break in intervals (BII) derived from van der Lans et al. (2006)*

Operating theatre scheduling, however, does not deal with the strict time-windows Refueling has. Therefore, one incidental task cannot just move all scheduled tasks for one operator forward in time, despite potential free capacity at the end of all planned tasks. In the current situation, there is no design for handling incidental tasks. During the tactical planning phase, AS sees the incidental tasks as an add-on to the expected workload, while during execution, present personnel that are also working the regular workload, handle incidental tasks.

To cover for incidental tasks, AS needs to reserve capacity for incidental tasks. Furthermore, AS needs to assure that the schedule is such that an incidental task has a minimal waiting time. These concepts can help in designing and making the schedules robust for incidental tasks.

### 3.4.2 Statistics

This section describes the impact of variability on any process. It does so by explaining basic statistics in relation to time-windows (for further reference regarding statistics see for example Doane and Seward (2005)). Time-windows are the operational windows in which tasks must be performed. Each time-window is variable due to deviations of the expected arrival times and because of flight link changes. This performance, or expected lateness, can be captured in a robust planning process. Only using the average (the means, or first moment) however, implicates a fixed deviation from the scheduled arrival time. Larger moments describing the variance, skewness, and kurtosis reveal a lot more information about the deviation from the expected landing time.

Variance and kurtosis both are measures for the spread of values in a distribution. Variance describes the spread of values around the mean. Kurtosis describes the peakedness of the distribution and/or fatness of its tails. With a higher kurtosis come more extreme values that explain the variance of a distribution. The variance tells how values are spread around the mean, the kurtosis describes that this spread can be explained by a few extreme values or a more smooth distribution around the mean.

A positively skewed distribution has a median that is smaller than the mean. This means that more than 50% of all values are smaller than average. In a positively skewed distribution, the expected values at the right side of the median are more spread than on the left side. EUROCONTROL (2013) indicates a positively skewed arrival process in 2012 and 2013 (see Figure 22), and Harmsen (2012) showed a positive skewness for the arrival performance of KLM in June 2011. In terms of arrival delays: If an aircraft is delayed, the chance that it is extremely delayed is more likely than the chance that if an aircraft is early is extremely early.

Consider that 16% of all flights in 2013 were delayed more than fifteen minutes, i.e., the right side of the lateness distribution (EUROCONTROL, 2013). The positive skewness thus says that if an outcome of a probability function is above the median then the probability of it being a more extreme value is higher, while if an outcome of the probability function is less than the median it has a tendency to be closer to the median. While AS gains a little more flexibility due to larger time-windows of early arrivals, the late arrivals reduce flexibility such that the task start time is not flexible anymore. Figure 26 shows a schematic representation in which we placed tasks in their respective time-windows. In the expected time-windows, we need one operator to handle the workload. In the realization, where we have one large, one small delay and three early arrivals, we need a second operator to fulfill demand.

### 3.4.3 Contingency planning and risk management

Contingency planning is done to plan for possible outcomes that have non-negligible influence on the execution of a process. Examples for AS are extreme weather such as storms and winter conditions changing the workload. Also volcanic outbreaks, and the effect on flight operations should be considered, since it could result in a reduction or a full stop of flight traffic. When an unlikely scenario arises, the validity of proposed plans and schedules could be in danger.

It is not clear when to throw away the existing schedules and plan for new ones. To give an example for such a scenario: There is a 20% chance of a storm in three days that could last between three and six hours, and is quite severe when occurring. In the case of Refueling this means that more delays are imminent, and that aircraft will need storm fuel when there weight is not sufficient to cope with the winds

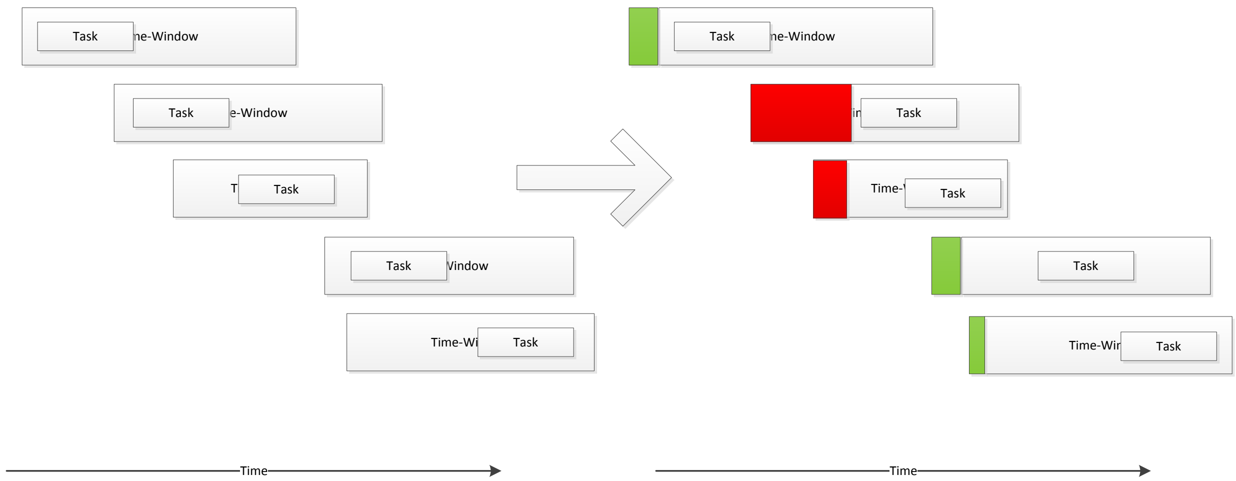


*Figure 26: Effects on workload of a positively skewed arrival performance, from planning with standard arrival times towards the actual realization. Red means a delay, green an early arrival. Schematic representation, not the actual impact..*

Jüttner, Peck, and Christopher (2003) did research into supply chain risk management, and came up with four kinds of constructs relating to risk: Risk sources, risk consequences, risk drivers, and risk mitigating strategies. Risk sources are those environmental variables that cannot predicted with certainty. Risk consequences discuss the variable outcomes due to these uncertainties. Risk drivers are those decisions to improve competiveness while exposing the organization to risk, i.e., "calculated risk". Risk mitigation strategies are actions taken to explicitly protect an organization for identified risk. Within these constructs, supply chain vulnerability is defined as "the propensity of risk sources and risk drivers to outweigh risk mitigating strategies, thus causing adverse supply chain consequences". (Jüttner et al., 2003)

Managing the risk of unforeseen uncertain events is much harder than for foreseen uncertainty. Krause, Fox, and Judson (1993) say that for many systems established statistical methods are available to assess risk and run simulations to observe their behavior. Often, the problem with risk assessment of possible outcomes is that:

- It "may at best cover a very wide range of possible values.
- Point value estimates conceal the uncertainties inherent in risk estimates.
- Judgments based on the comparison of point values may be quite different from those based on the comparison of ranges of possible values.
- in very many cases the spread of possible values for a given risk assessment may be so great that a numerical risk assessment is completely meaningless." (Krause et al., 1993)

Therefore Krause et al. (1993) focus on qualitative risk assessment, using quantitative data if possible. To assess the risk of uncertain events, uncertainty of events can be expressed using propositions concerning the risk assessment. For these propositions, both pro and contra arguments can be formulated using linguistic, instead of numerical, qualifiers. For example, Elvang-Gøransson, Krause, and Fox (1993) describe that propositions can be eithder:

- Open if the proposition can be constructed, but not necessarily any arguments in favor can be constructed.

- Supported: If any argument for it can be constructed, possibly based on inconsistent data.
- Plausible: If a consistent argument for it can be constructed, but it is still possible to construct arguments against it.
- Probable: If a consistent argument can be constructed for it and no consistent argument can be constructed against it.
- Confirmed: The same as probable. In addition no consistent arguments can be constructed against any of the premises used in its supporting argument.
- Certain: Self-explanatory.

A risk report for our example would then be constructed as such:

- The storm will occur: *plausible,* since there are enough scenarios that contradict the chance of a storm, but we can also argue for it.
- The storm will have impact on the operation: *confirmed,* because we can construct a consistent supporting argument for it: it will generate extra workload.
- The storm will be quite severe: *probable,* because we have a consistent argument that predicts the severity of the storm. The forecast used, however, is not always reliable, therefore making the proposition not confirmed.

This is a mere example of risk assessment in qualitative fashion. The following step is to take action based on the information from the qualitative assessment, and that is either to manage or mitigate the potential risk. McManus and Hastings (2005) built a framework (Figure 27) to understand uncertainty, define related risks and opportunities, mitigate against those risks, and then define the outcome of the system.

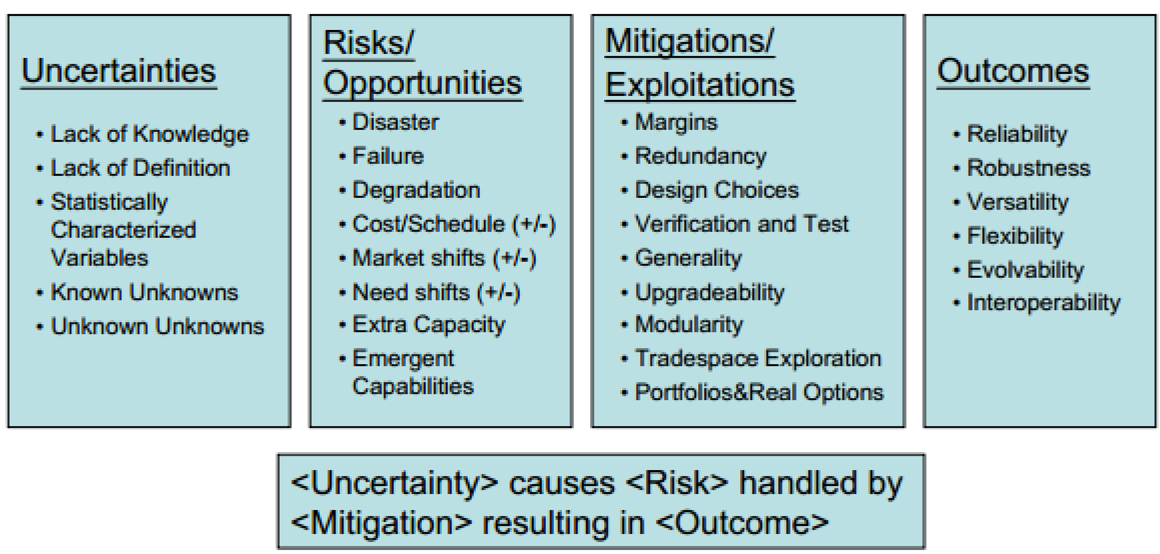


*Figure 27: This framework defines uncertainties, its related risks, possible mitigation strategies, and outcomes in complex systems. (derived from McManus and Hastings (2005))*

This framework allows identification of uncertainties and risks, the possible mitigations to cope with this risk, and the outcome, or capabilities, the system possesses. As we until now only defined robustness, McManus and Hastings (2005) extend this view. A system is versatile when it can handle jobs that were not in the requirements definition, and a system is flexible when it can be modified to handle jobs that originally were not part of the system.

Figure 28 shows a potential use of the framework to cover for known unknowns in which risks are identified, and potential mitigations are used to come to a reliable and robust outcome.

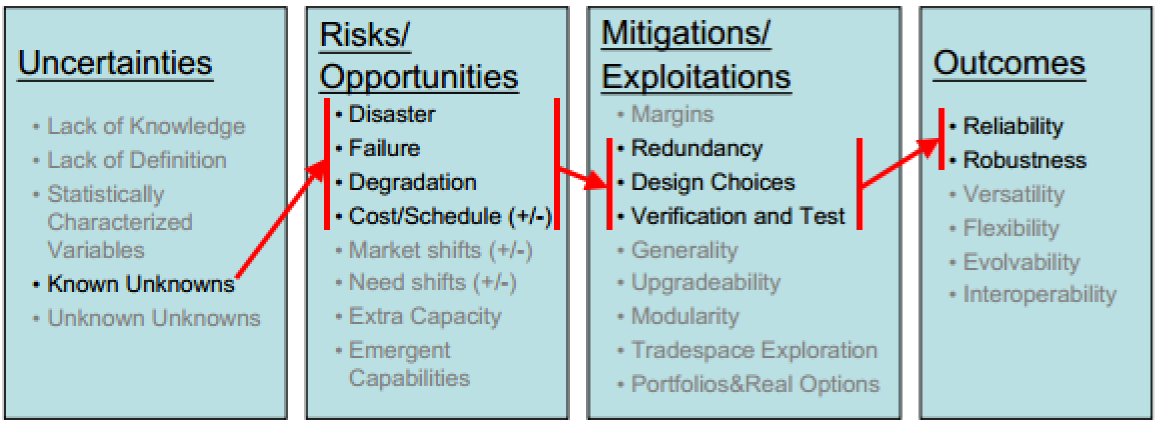


*Figure 28: Potential use of the framework by McManus and Hastings (2005)*

### 3.4.4 Time buffers

Section 3.3 discussed that buffers must be in place to handle small variance in the process, such that planning systems can handle foreseen uncertainty. Schedules, therefore, should hold slack capacity for variance and foreseen uncertainties, and should be designed to handle unforeseen uncertainties when they arise.

The possibility of schedule repair or complete rescheduling as discussed in Section 3.1 avoids that the schedules need to anticipate for every kind of variability on the single operator level. In systems where all resources are able to perform the same kind of tasks, variability can be handled on a global level.

Currently, AS handles process duration on the single operator level by trying to plan more time than the median duration for a task. In this way, more time of the available time-windows is used to schedule a task. This method gives limited insight in planning for process variability, and can only capture one type of variability in the process.

This method therefore leads to a problem when in reality Refueling needs more time when AS optimized the planning such that there is limited time available. Section 2.2.1 discussed that plan norms are larger than the 50$^{th}$ percentile. Consider Figure 29 with three operators and seven tasks under the current scheduling rules. If a task delays due to a severe disturbance, the red task with the vertical line as deadline cannot be rescheduled.

Furthermore, Goldratt identified that despite planning tasks with a longer than average duration, tasks still finish late due to two conditions. The student's syndrome tells us that people start a task as late as possible to make their deadline. Parkinson's law says that we purposefully delay or pace tasks at hand. So despite planned buffers within a task, people still tend to overshoot deadlines. (Goldratt, 1997)

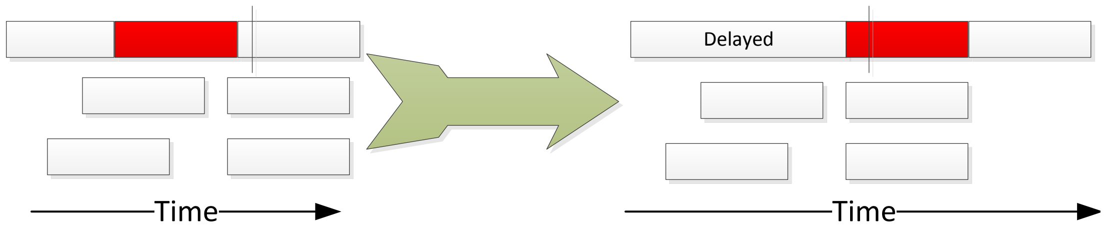


*Figure 29: Impact of scheduling with plan norms >50th percentile. The red task has a deadline denoted by the vertical line.*

Therefore, buffers need to be separated from tasks, such that if a set deadline is overshot, there is enough capacity left to reschedule the affected tasks. It is not possible to place a buffer at the end of all tasks to absorb variability when all tasks have a deadline that is earlier than the planning horizon. Using the median as the plan norm and buffers between each task gives the new example in Figure 30 in which the planning system plans tasks to each resource, or the example in Figure 31 in which one employee is standing by to cover for unexpected events.

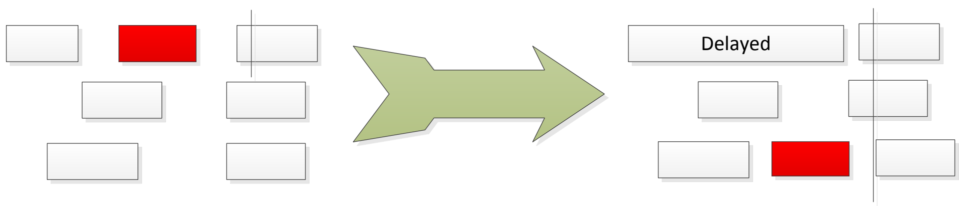


*Figure 30: Using the median for scheduling, effect of delayed task. The red task deadline is denoted by the vertical line.*

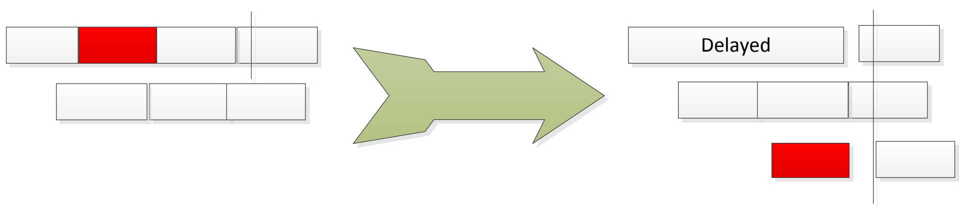


*Figure 31: Using the median for scheduling, having one resource as reserve capacity. The veritcal line denotes the deadline for the red task.*

The planning process must also schedule buffers for incidental tasks, arrival performance, and the effect of changing flight links. These buffers between tasks must thus be such that the performance does not drop in case of an incidental task or the need to reschedule.

There is one danger in scheduling with the 50th percentile. If the scheduled task is at the end of the time-window, the chance that the task does not make the deadline is then 50%. A missed deadline does not necessarily imply a code 36, since the deadline is set earlier than the actual departure time. In addition, when there is buffer time between each task, most tasks will not start at the latest possible moment. This is because these time buffers work both ways: During execution, they can both be used for longer process duration and an earlier start of tasks; see Figure 32 as an example.

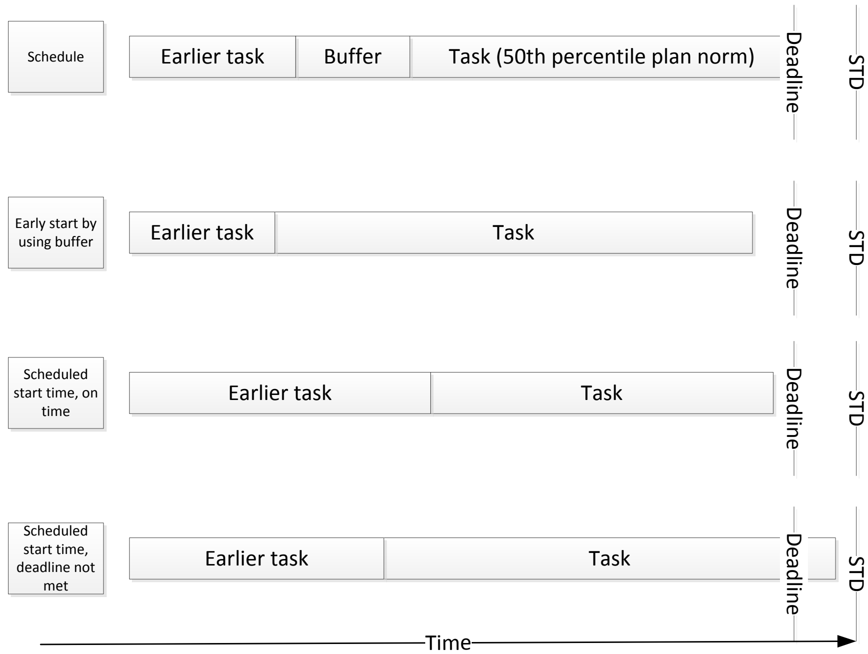


*Figure 32: Rolling planning schedule and multiple possible executions of task.*

Finally, personnel cannot be utilized 100% and must be underutilized during the planning phase. Hopp and Spearman (2008) have a law regarding utilization and cycle times: “If a station increases utilization without making any other changes, average work in progress and cycle time (the time from the moment the task could start until it is finished) will increase in a highly nonlinear fashion”. Goldratt, Cox, and Whitford (1992) state that machines need to sit idle sometimes: Utilization of 100% imply an increase of queues, i.e., if there is always work at hand, the amount of work is growing faster than it can be processed. Any implied 100% utilization, such as Figure 10 and Figure 11, suggests that this is indeed happening at AS. The following statement by the business manager adds strength to this argument: “If we do not pre-fuel enough aircraft before the morning peak, we will feel this throughout the day in our performance”. This means that if the queue, or aircraft available for fueling, is not managed, this results in unwanted delays.

Underutilization should inherently happen outside peak hours due to excess capacity that is needed during the peaks. During the peaks there is also a need to buffer against variation and uncertainties. Figure 12 suggests that on time performance drops gradually through the morning (8:00-10:00) and evening peak (19:00-21:00), which indicates that as the peaks come in a later phase, the performance drops.

Then, there is a tendency that people underestimate the needed time. There are soft laws describing these tendencies:

- Murphy’s second law: Everything takes longer than you think.
- Hofstadters law: It always takes longer than you expect, even when you take into account Hofstadters Law. (Hofstadter, 2000)

There is a full research body on planning underestimations, also known as the planning fallacy (Kahneman & Tversky, 1977): “The tendency to hold a confident belief that one's own project will proceed as planned, even while knowing that the vast majority of similar projects have run late, has been termed the planning fallacy." (as cited in Buehler, Griffin, & Ross, 1994)

## 3.5 Conclusion

This chapter discussed literature about scheduling problems that relate to the scheduling problem at Refueling, discussed flight delays and their costs, touched upon the value of future information, before discussing robust planning. The main findings regarding the scheduling problem are:

- The scheduling problem can be described using the vehicle routing problem (VRP) or the dynamic repairman problem.
- The scheduling problem consists of variable time-windows with a hard earliest start time constraint and a soft latest end time constraint, which makes it a dynamic scheduling problem
- The scheduling problem contains properties of a stochastic demand VRP (VRPSD), a VRP with time-windows (VRPTW), a dynamic VRP, and a VRP with service times.
- When using VRP, service times can be added to the driving times in the problem to reflect the need of service times.
- For dynamic VRPs, information about the future is imprecise and sometimes unknown, tasks in the near future are more important than tasks that take place later in time, information update mechanisms are essential, and decisions about resequencing and reassigning tasks are justified, because information becomes available gradually.
- The stochastic behavior of dynamic VRPs can be modeled mathematically, or be modeled by using sampling techniques.
- It is important to know the solution gap between the static VRP and dynamic VRP.
- Not only the quality of rescheduling tasks must be discusses, but also the stability of a schedule, to avoid that the schedule does not completely change all the time.

The main findings concerning flight delays are:

- The IATA has a code system for assigning causes of delays to airlines.
- Delay can be classified in airport and airborne generated or absorbed delays.
- Flight delays induced by refueling have delay code 36.
- Most delays are caused by system delays, i.e., a reduction in flight system capacity. The main reason for system delays are weather related.
- Arrival punctuality, both for KLM (one month, Amsterdam), and EUROCONTROL (general arrival data for European carriers at European airports) show an average early arrival of aircraft, but also a significant percentage of aircraft that arrive more than one hour late.
- Costs of delay at the gate increase non-linear over time.
- The cost of one shift at Refueling is less expensive than a 30-minute delay of a 737-300 aircraft.

The main findings concerning value of information about future events are:

- For dynamic VRPs it holds that: "It is impossible for an optimal route to be produced in advance. At best, what can be produced is a policy, specifying what action should be taken as a function of the state of the system." (Psaraftis, 1995)

- It important how information evolves over time, what the quality of information is (deterministic, a forecast, or a probability), to whom the information is available, and how the information is used and/or processed.
- Forecasts are always wrong, detailed forecasts are worse than aggregate forecasts, and the further into the future, the less reliable the forecast.
- There are four forms of uncertainty: Variation, foreseen uncertainty, unforeseen uncertainty, and chaos.

The main findings about creating robustness against variability are:

- With robust planning there should be a balance between feasibility (model robust), and optimality (costs, solution robust).
- Most models ignore the distribution of an outcome and do not capture the risk attributes that the decision maker considered.
- A robust schedule needs to deal with more sources of variability than just longer process duration.
- Creating robustness for incidental tasks means that extra capacity must be scheduled such that during execution, enough capacity for incidental tasks is available, and the waiting time for incidental tasks is minimized.
- Statistics can be used to describe the behavior of processes that influence AS. In terms of arrival punctuality, the distribution is positively skewed, i.e., If an aircraft is delayed, the chance that it is extremely delayed is more likely than the chance that if an aircraft is early is extremely early.
- The problem with risk management is that possible outcomes often consist of a wide range of values, point estimates often conceal the uncertainty inherent to risk management, and numerical assessment could be completely meaningless.
- Time buffers are used to handle uncertainties. Scheduling time buffers for uncertainties results in a situation that can cope with a certain amount of uncertainty.
- Time buffers must be separated from planned tasks, such that insight in scheduled tasks and scheduled time buffer is created.
- A schedule in which personnel is utilized 100% must be avoided at all times.

# 4 Potential improvements in the planning and scheduling chain

This chapter discusses potential improvements in relation to the current situation and the literature review.

The input that AS delivers to the planning process is once a season, a tactical decision that determines which information the planning process should use. Other input, such as flight schedules, are not only used once a season, but also more regularly to create a daily workload profile. The output and personnel scheduling regarding the planning and scheduling chain, therefore, is both tactical and offline operational. Once a season the planning process provides tactical output on which AS bases general work rosters and workload profiles. Once a week, the planning process generates offline operational output, which AS uses to correct for the expected situation during execution.

First, Section 4.1 describes which input AS needs to gather and provide to the planning process. Section 4.2 describes what other input the planning process should use. We do not discuss how the planning process works and operates. Section 4.3 describes the output the planning process should give. Section 4.4 discusses personnel scheduling and Section 4.5 discusses potential improvements in the current online scheduling situation. Finally, Section 4.6 discusses potential improvements regarding the feedback that AS now provides after the full planning and scheduling chain has been performed. Figure 33 outlines the structure of Chapter 4, in which we also address the planning levels as discussed in Section 1.3.

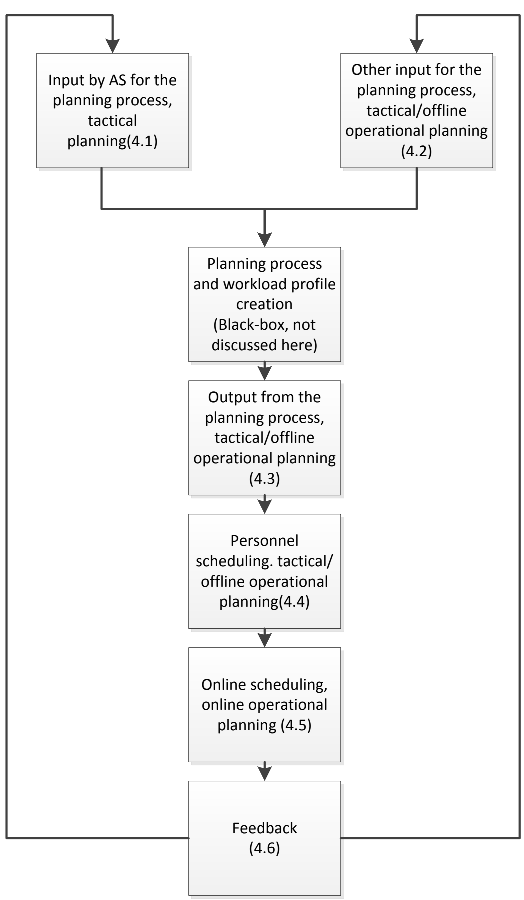


*Figure 33: Outline of Chapter 4, connected to the planning levels*

## 4.1 AS input for the planning process

We learned in Chapter 2 that AS provides input for the planning process that ST uses. In this, AS is responsible for the plan norms (Section 4.1.1), information concerning the planning of incidental tasks (Section 4.1.2), and tasks unrelated to the flight-schedule (Section 4.1.3). In addition, AS needs to account for personnel utilization (Section 4.1.4). Furthermore, we discuss planning rules concerning pre-fuels (Section 4.1.5), and we discuss shiftsets (Section 4.1.6).

### 4.1.1 Plan norms

We showed in Section 2.4.3 that the plan norms are large enough for phase 2 (see Figure 34) of the fuel task, but that the total plan norms are shorter than the actual needed time, because operators sit idle during task and/or need to perform a vehicle inspection. In addition, the current system does not give fuel operators hard deadlines for safety reasons, such that operators are never in a hurry when they perform their work. Operators, however, do know the STD or EBDE of an aircraft via their PDA. This time is later than the fueling deadline. If operators focus on this time and we include the student's syndrome and Parkinson's law, operators will often overshoot the deadline due to unnecessary idling and procrastination of tasks.

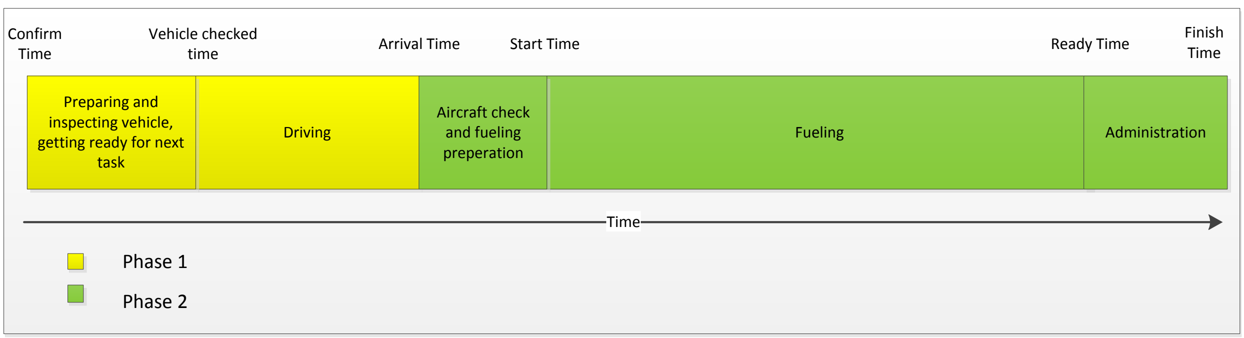


*Figure 34: The timeline of a fuel task*

Currently, the norm times do not account for a vehicle inspection. AS must calculate the needed time for vehicle inspection based on historical data or manmade observations, and include them in the planning norms such that an inspection of the vehicle can be included for all relevant tasks.

Furthermore, AS does not make plan norms with available database data, but with a limited number of manmade observations. We assume that personnel has the tendency to work faster when under observation. In addition, the limited number of observations results in a statistically unacceptable margin of error. We also concluded in Section 2.4.3 that most idle time occurs before the operator arrives at the aircraft. Therefore, the use of a driving time matrix that ST bases on distance between parking positions, and not on historical data, underestimates the actual driving time. A better estimation is the use of historical information to calculate needed driving times.

In addition, disturbances should not be part of plan norms. During execution, Refueling should be ready to handle a disturbance by rescheduling tasks if necessary. Only adding average disturbance times to a plan norm does not add flexibility, because if a disturbance occurs, it probably takes longer than the average that AS added to the norm. Therefore, AS should handle disturbances as incidental tasks (see Section 4.1.2).

Plan norms should also account for destination. A variable component in the task duration for Refueling is the fuel requirement, especially for aircraft capable of intercontinental flights. Table 15 shows the departure of four 747 aircraft and two 777 aircraft within a time range of fifteen minutes. All these aircraft require significant amounts of fuel, ranging from 89,000 to 119,000 kilograms. Their related final fuels took between 1 and 1.5 hours, since none of the aircraft were pre-fueled. The deviation in these times also depends on the fuel that was still available after the previous flight and idle time of the operators. AS now bases the plan norms per aircraft type on a fuel flow per aircraft type and its average intake. If this information is available, there is a possibility to make plan norms that combine aircraft type and destination.

| Destination | Flight | STD | ATD | Aircraft Type |
|---|---|---|---|---|
| San Francisco | KL605 | 9:50 | 9:56 | 747 |
| Curacao | KL735 | 9:50 | 9:54 | 747 |
| Los Angeles | KL601 | 9:50 | 9:58 | 74M |
| Houston | KL661 | 10:00 | 10:07 | 74M |
| Quito | KL751 | 10:05 | 11:04 | 777 |
| Sao Paulo | KL791 | 10:05 | 10:05 | 777 |

*Table 15: Wide body departures between 9:00 and 10:00 on 11th of September 2014, derived from Flightstats (2014)*

The current planning system sees the plan norms as if they have buffers. When optimizing the workload, there are no buffers between tasks in the current setup. We discussed in Section 3.4.4 that buffer time can be separated from task duration to create more scheduling flexibility. Therefore, norms should be such that they are based on the 50th percentile, and not a higher percentile such as discussed in Section 2.2.1. Another advantage of this setup is that buffer size can be adapted to handle all other sorts of variability. Furthermore, the norms thus consist of three parts: A vehicle check, driving time, and the actual fueling task (see Figure 35).

Using the 50th percentile for norms and buffers between tasks results in:

- Creating more flexibility for interchanging and rescheduling tasks.
- Separation of idle-time from actual task duration.

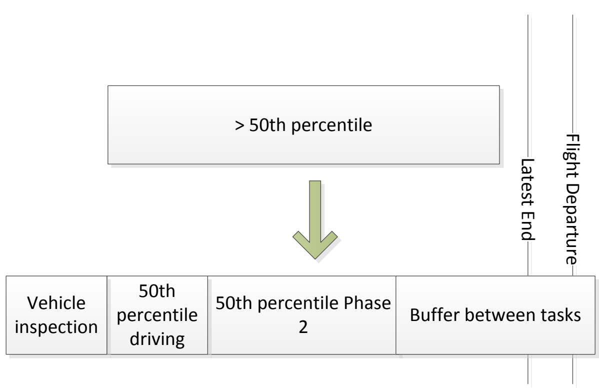


*Figure 35: Buffer should not be related to a task, and the buffer should account for more than just process duration. Also, plan norms consist of three building blocks.*

Disturbances, however, are not explicitly scheduled for these new norms, and longer than 50$^{th}$ percentile process durations are not accounted for, so there should be a buffer to cover for them. These buffers should be scheduled between tasks, and not on top of regular workload. We recommend this setup because in current operations all personnel on shift perform tasks; there is no reserve pool of employees on standby to handle incidental tasks or irregular work.

In this section we discussed that:

- The effect of Parkinson's law and the student syndrome are present with the standard time of departure as reference, while the actual fueling deadline is earlier.
- There should be a separate norm for vehicle inspections, such that the planning process can use these.
- AS should not base the driving matrix on distance, but on historic data, because driving time does not solely depend on distance.
- Disturbances are incidental, and should be handled as such.
- Norms should account for destination.
- There should be a time buffer between each task. The purpose of this buffer is to cope with different kinds of variability.

### 4.1.2 Incidental tasks

Incidental tasks occur infrequently and do not relate to the flight schedule or standard operations of KLM (see Section 2.2.2). AS can express the behavior of incidental tasks with statistical distributions. The occurrence of disturbances during a fuel task, extra fuels, and defuels could be expressed with binomial distributions. In this manner, AS relates the number of incidental tasks to the number of scheduled fuel tasks. Other distributions are needed to determine the needed process time for an incidental task.

For storm fuel tasks, these statistical distributions, or the chance of occurring depends on the storm's severity and the fuel already in the aircraft's tanks. Figure 36 describes what should be determined when planning for incidental tasks. For each identified type incidental task, we describe what needs to be determined after the colon.

The next step is to determine if and how AS wants to buffer against incidental tasks. Therefore, AS needs to determine the costs and benefits of buffering against incidental tasks. Since extra fuel and defuel tasks are related to the number of departing aircraft, the chance that incidental tasks occur around workload peaks is more likely than outside peak hours. It is for these peaks that AS needs to decide whether extra personnel needs to cover for potential incidental tasks.

AS needs to use historical data to calculate the need for enough extra capacity. From historical data, AS could determine for each day how many incidental tasks took place in relation to the number of departing aircraft. AS could then calculate the need of extra capacity to cope with a certain amount of all possible incidental task situations, e.g., if AS covers for three incidental tasks between 8:00 and 8:30, they have enough capacity to handle incidental tasks 80% of the time. This does not mean that AS should add extra capacity on top of the workload during the planning phase, but that buffers between tasks are such that there is enough capacity to reschedule regular workload and perform the incidental tasks.

We made an example with three incidental tasks that need to be scheduled, and a task that gets a disturbance (see Figure 37). Because we have buffers between tasks with flexible time-windows, we are able to schedule incidental tasks and reschedule other tasks if necessary.

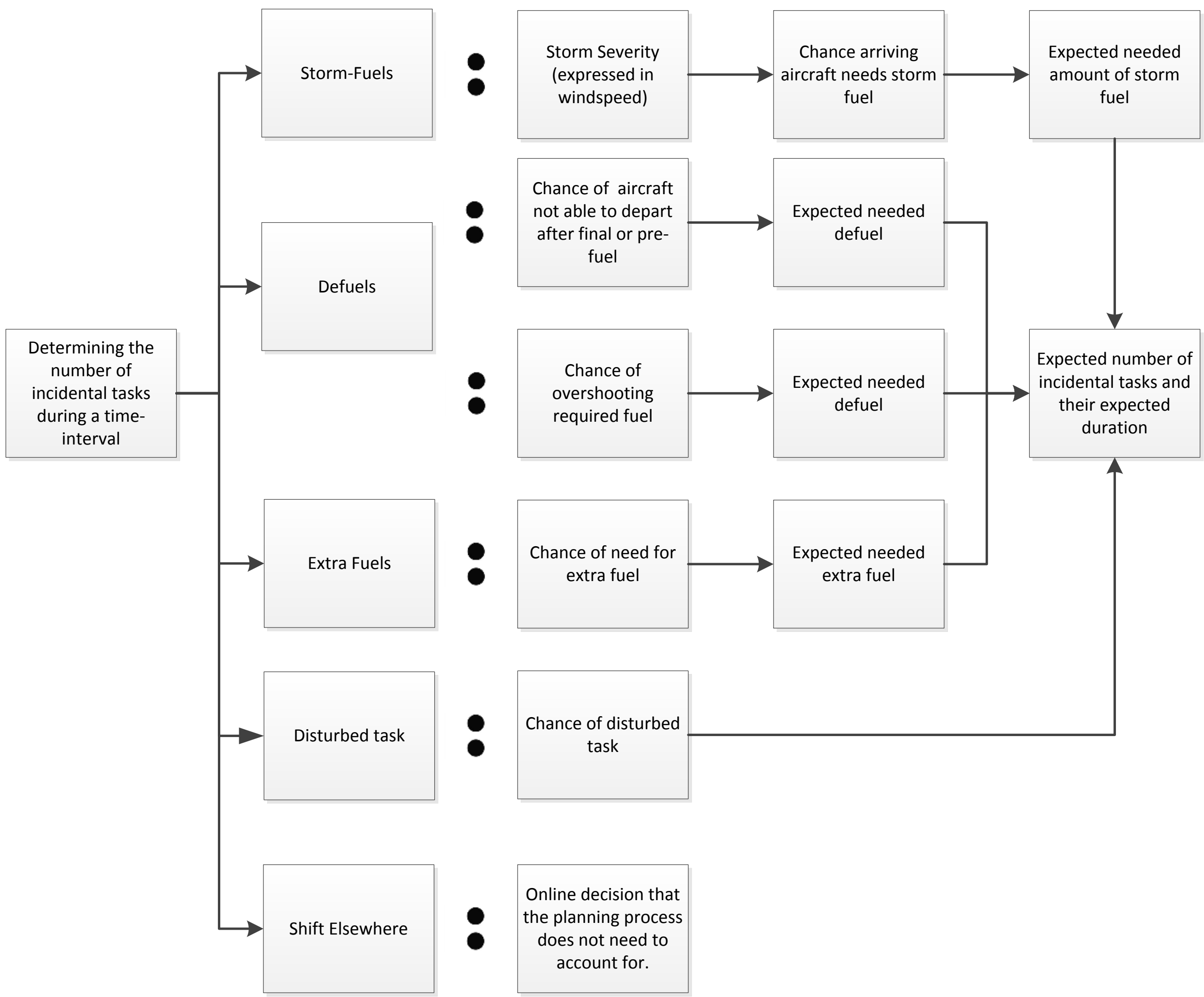


*Figure 36: Determining number and duration incidental tasks during a certain time interval. After each colon follows what needs to be determined for that type of incidental task.*

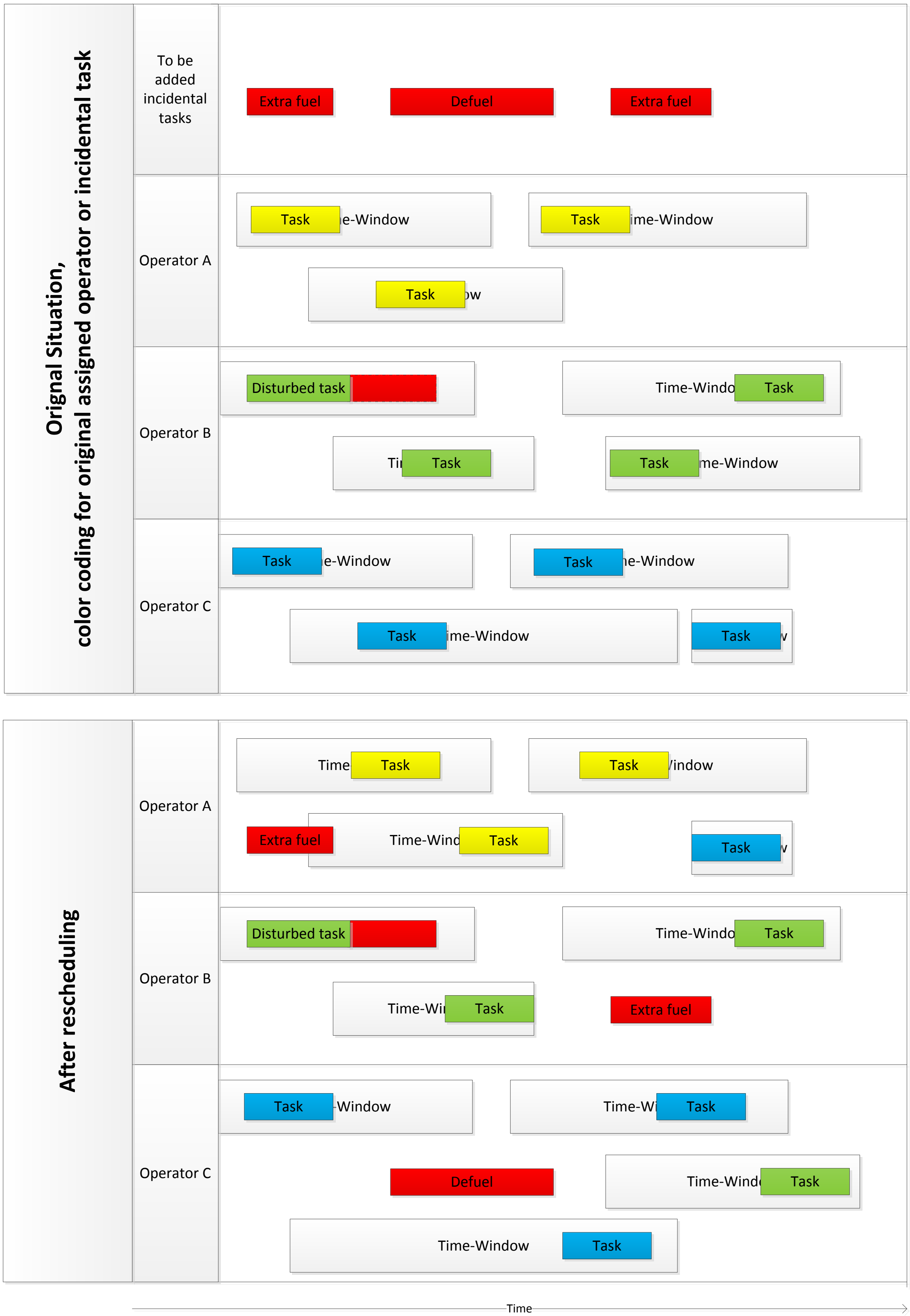


*Figure 37: Time buffers between tasks are needed to schedule incidental tasks and reschedule normal tasks.*

### 4.1.3 Tasks unrelated to the flight schedule

For breaks, maintenance tasks, refills, and end-of-shift tasks, the flight schedule does not provide information. Breaks are regulated through the collective labor agreement (in Dutch: CAO), and are scheduled accordingly.

Maintenance tasks depend on the engineering and maintenance department, demanding fuel for aircraft that go into maintenance. AS currently schedules maintenance tasks as an average occurrence within each time interval, but maintenance tasks should be handled similar to incidental tasks, basing the chance of occurrence on the maintenance schedule, the number of arriving aircraft, or historical data.

AS needs to schedule refills of bowsers, since AS knows the amount of fuel that bowsers can hold. The planning process should calculate whether after a task a bowser needs a refill. In the current situation, AS bases refills on historical averages. This results in extra workload that is disconnected from the actual workload of bowser operators. The danger in the current setup is that despite the extra capacity to perform refills, AS does not know whether the bowser operators themselves have enough capacity to refill their bowsers without delaying other tasks.

Refueling now schedules 30 minutes for an end-of-shift task. This correctly reflects the needed time to finish a shift. The planning process is now optimizing workload, such that the number of tasks fitted in a shift are maximized, but this is not happening during execution. Due to a four-hour planning horizon in which CHIP tries to handle all variability, during most shifts operators will perform less tasks than originally planned for. This leaves that some capacity is lost, for which the current planning system does not account. This loss could be covered if AS adjusts the length of an end-of-shift task accordingly.

### 4.1.4 Personnel utilization

Buffers do not only depend on extra needed capacity for incidental and flight schedule unrelated tasks, but also on scheduling flexibility. If all flights become quick turnarounds (QTA) and time-windows are reduced to the size of the task duration, tasks need to start when the aircraft arrives, and there is no scheduling flexibility for these tasks anymore. If AS loses this scheduling flexibility, AS must underutilize its personnel more. We express underutilization with idle-time buffer. The less scheduling flexibility AS has, the more idle-time buffer AS needs. Figure 38 shows an example with scheduling flexibility in which an incidental task fits. Figure 39 shows an example that has enough buffer capacity for an incidental task, but has no possibility to reschedule tasks such that the incidental task fits. This example therefore would need more buffer in the form of idle-time.

### 4.1.5 Planning for pre-fuels

Section 2.4.4 discussed that pre-fuels take place at other times than originally planned, due to a lack of capacity at certain moments during the day. Pre-fuels mainly take place prior to the morning peak, and take place less during the remainder of the day.

The current executed pre-fuels prior to the morning peak suggests that within the current planning and scheduling chain AS does not schedule enough personnel during the morning peak to cover for all tasks. It also suggests that not all pre-fuel possibilities are considered.

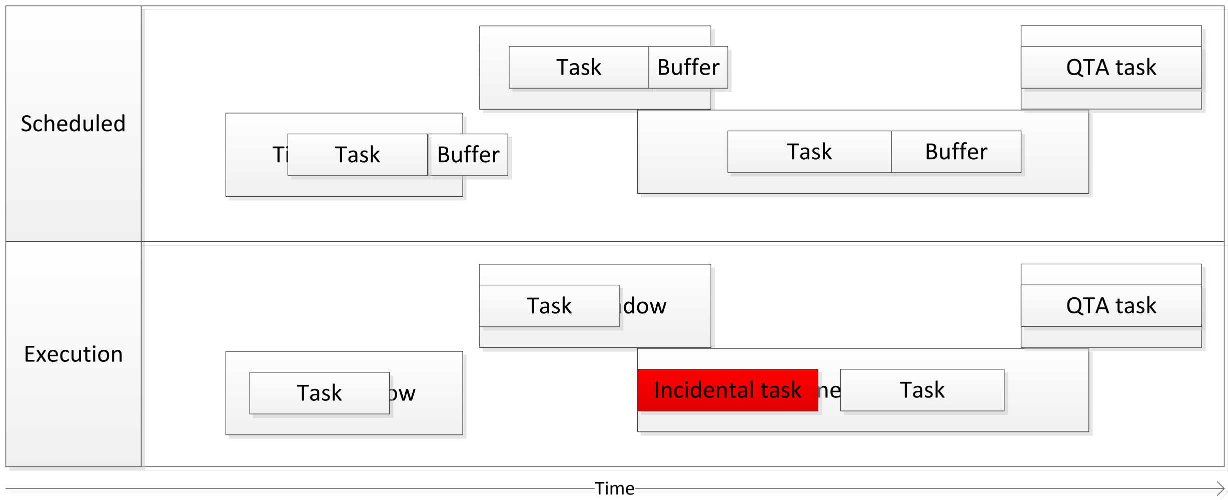


*Figure 38: Schedule flexibility and buffers give enough capacity for an incidental task to be scheduled*

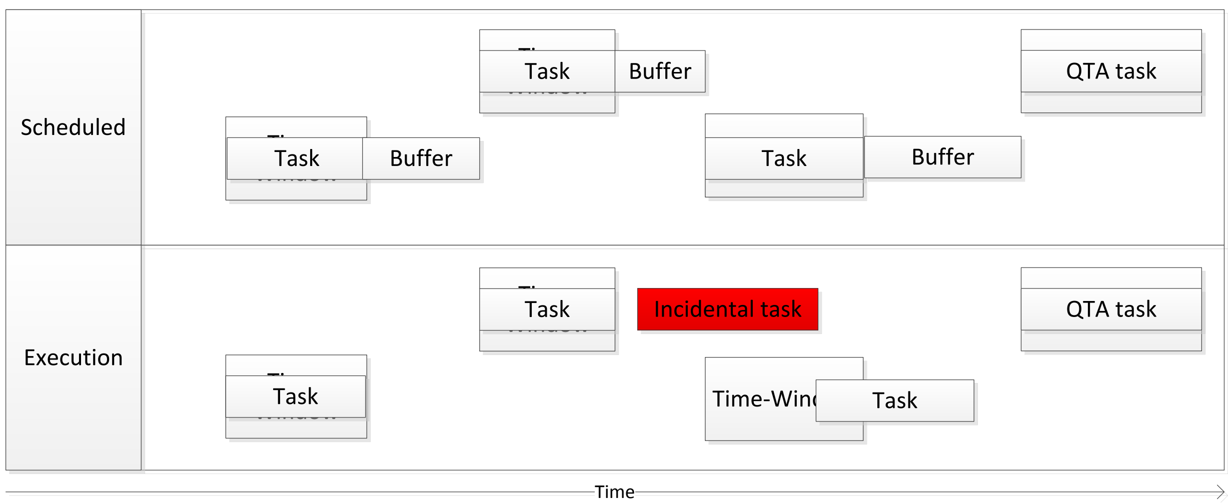


*Figure 39: No schedule flexibility due to QTAs give problems in scheduling the incidental tasks, despite enough buffer capacity between tasks*

The goal of pre-fueling is to reduce workload during peak hours. For this, aircraft need to be available before peak hours, and enough capacity needs to be available to pre-fuel them. Currently, AS bases the number of pre-fuels on a specific rule set: If an aircraft has a ground time that exceeds the minimum, AS schedules this aircraft for pre-fueling. What happens during operation is completely different, because operators only pre-fuel aircraft when no other higher priority tasks are available during those timeslots.

Scheduling pre-fuel tasks with the current rules does not guarantee an optimal schedule and therefore the best personnel scheduling decision. Since pre-fuel is not obligatory, the planning process should never schedule them with a fixed rule set that generates pre-fuel tasks.

For an optimal schedule, AS would need to consider all possible pre-fuel and final-fuel combinations. As a heuristic, we propose to schedule pre-fuels after the planning process makes a base schedule in which no pre-fuel tasks are included. If the planning process uses this base schedule, it could insert pre-fuel tasks for all eligible aircraft to reduce workload peaks and thus balance the workload. This would be a mere reflection or an insight of pre-fueling possibilities. Scheduling pre-fuels in the rolling planning thus gives an insight in which time slots have capacity available for pre-fuels, not a specific set of aircraft that have to receive pre-fuels. This is our goal here, to match the rolling planning and actual execution, not a mismatch such as Figure 14 shows.

### 4.1.6 Shiftsets

Nowadays, different shifts overlap 30 minutes or more to cover for the time it takes to drive back and forth from the "Jet-plein". This, however, only works when enough equipment is available. Nowadays, dispatchers need to send home employees early to free up equipment for the newly starting shifts (see Figure 40) This is counter-effective, because available capacity is lost. Therefore, AS should consider the effectiveness of its current policy, and should consider its available equipment before deciding how many shifts can overlap in time.

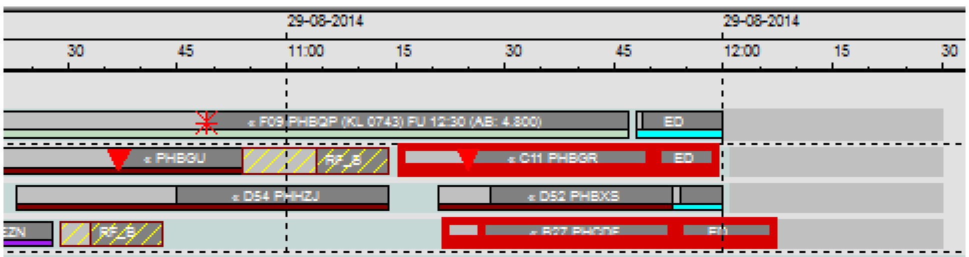


*Figure 40: Screenshot from CHIP. Sending in personnel early to free up equipment. Shifts end 12:30, three operators are finished at 12:00.*

Since the number of available bowsers and dispensers can change over time due to their physical state, we propose that shiftsets should always have the possibility to avoid time overlap. In this way, Refueling can adjust the shiftset according to its available number of dispensers and bowsers.

## 4.2 Other input used during the planning process

In this section, we discuss the use of the flight schedule in the planning process (Section 4.2.1) and the use of input regarding arrival performance (Section 4.2.2). Furthermore, we discuss the use of information regarding contingencies (Section 4.2.3).

### 4.2.1 Flight Schedule

The following factors of the flight schedule are of importance to the planning process:

- The flight links that are used during the planning process and its implications.
- Cancellations of flights and extra flights.
- Parking position assignment.

The current FIFO rule for creating flight links is not necessarily representative for the actual flight links and related ground times during execution. KLM's flight operations is working towards more QTA flights such that with the current aircraft KLM can perform more flights. Reducing ground times also affect available time-windows. The reduction of ground times as part of KLM's commercial strategy reveals the limitation of the current flight linking principle. As ground time becomes more limited and with 40% of the KLM flight links only announced 24 hours before departure, AS does not know which flight links will be QTAs when it makes its rolling planning.

Creating robustness against shorter ground times, therefore, is of importance. Two possibilities contribute to the robustness. First, planning for more buffer between tasks, such that Refueling can handle unexpected shorter ground times. Second, creating insights in what the expected ground times are of the flights related to the scheduled tasks.

For one winter (Figure 41) and one summer day (Figure 42), we recreated the workload profiles containing the rolling planning of pre-fuel and final fuel tasks, and actual workload that AS experienced during that day. We visualized the rolling planning further by splitting out the turnaround times of the aircraft related to the tasks. The current planning process optimized this workload, scheduling tasks such that personnel needs are optimized. Scheduling with another flight link set that has other ground times could have a different result.

Despite that many aircraft have a ground time longer than 3.5 hours, they still make up a large part of the morning peak, where we expected that they would be spread around the morning peak. There are two reasons:

- AS needs to tow the aircraft from buffer positions to the gate before receiving final fuel.
- Refueling does not know the final fuel requirements until the airliner or pilot announces them.

We cannot see the effect of QTAs during the morning and evening peak, because the number of employees is for most days equal to the expected workload. What we do see is that the actual workload is higher than expected during the 11:00 to 12:00 hour interval, in which several QTAs are expected in the rolling planning. These QTAs are daily commuter departures.

QTAs pose stress on Refueling operations, due to the agreement that an operator needs to be present when the aircraft arrives, to avoid a departure delay. In operations this leads to:

- Operators arrive early at the parking position and sit idle until the aircraft arrives.
- QTAs completely block timeslots, and therefore greatly reduce scheduling flexibility during certain periods of the day.

Furthermore, Flight Operations cancels flights as a last resort to repair excessive delays or to cope with broken aircraft. Sometimes Flight Operations schedule extra flights to handle extra passengers. Aircraft that divert to Amsterdam also need service. The planning process should account for the possibility of an extra flight, in the same way it should account for incidental tasks. For cancellations, there is no concern, except for the possibility of defuel tasks. Furthermore, sometimes Flight Operations cancels a large number of flights due to conditions in its flight network. For example, in case of a storm, Flight Operations is forced to cancel flights to keep delays manageable. These cancellations would then reduce the workload.

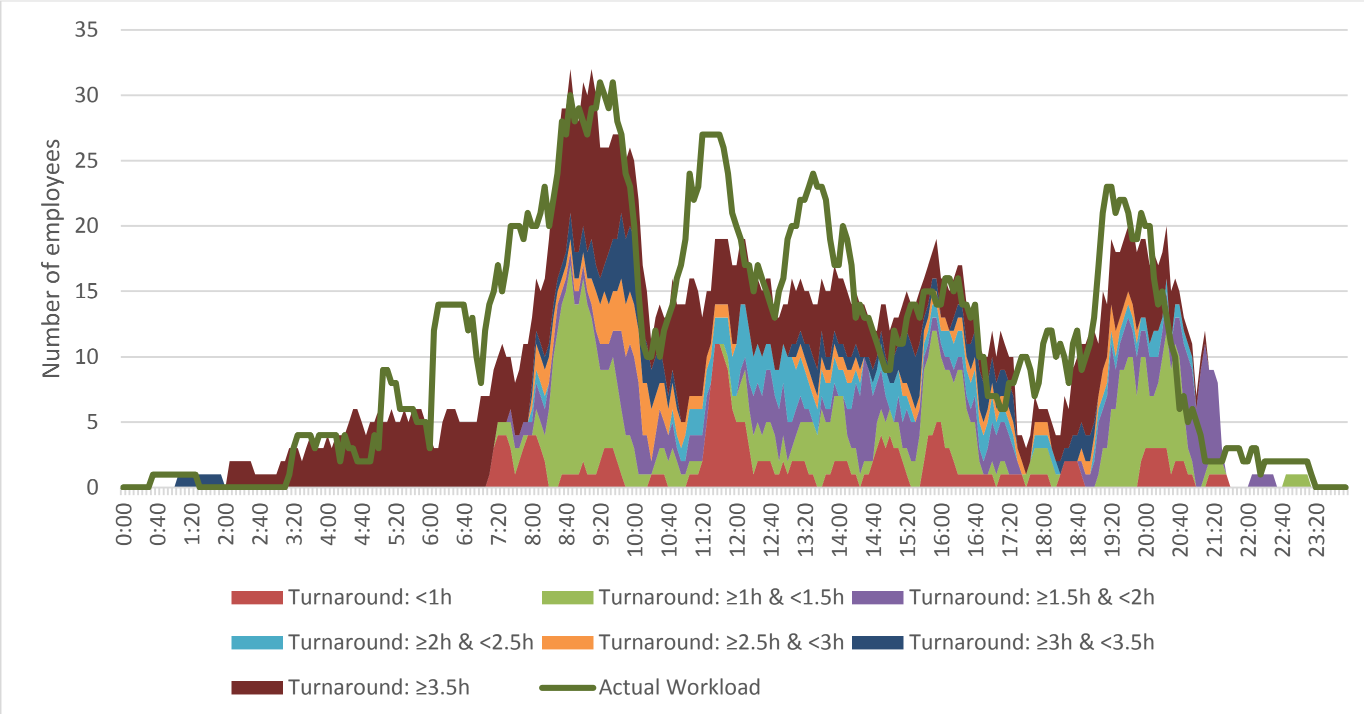


*Figure 41: Insight in scheduled turnaround times and actual, 17th of February 2014, Monday*

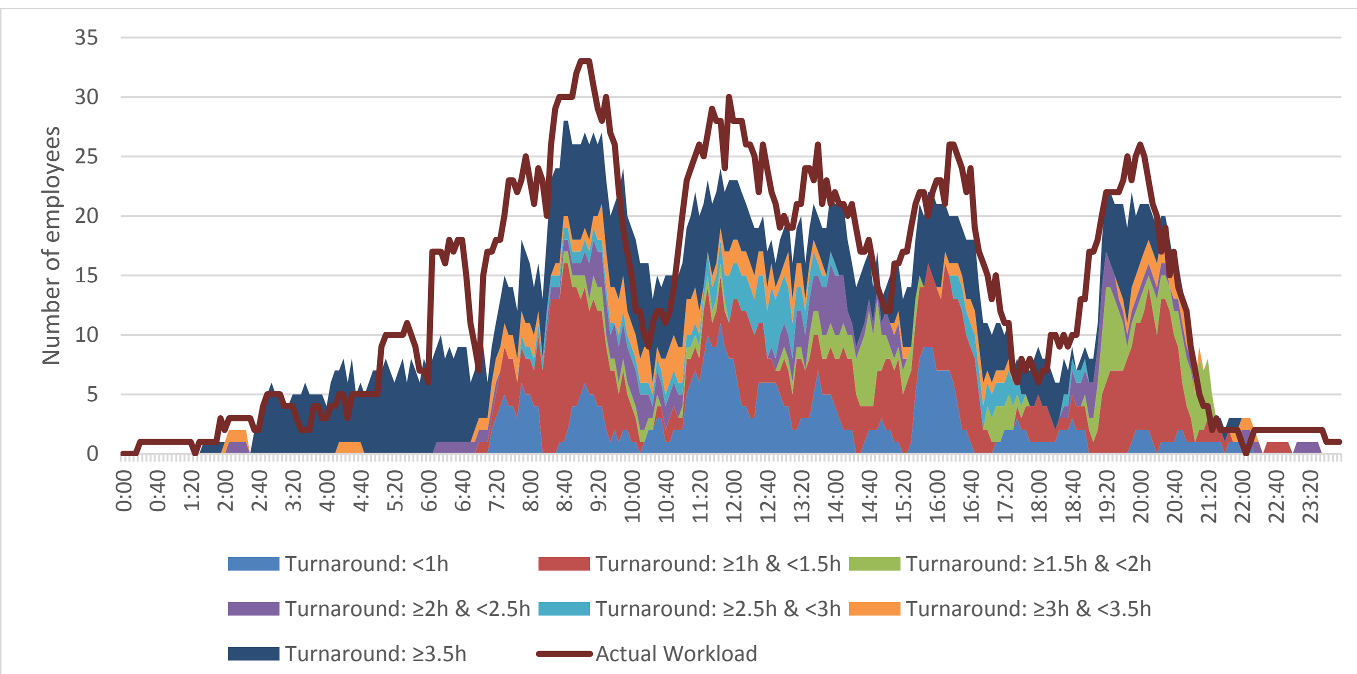


*Figure 42: Insight in scheduled turnaround times and actual workload, 1st of July 2013, Monday*

In addition, since not all parking positions have a hydrant for the dispensers, the parking position assignment of the commuter aircraft is of importance. Flight operations parks commuter aircraft at the B-gate, and the A and B parking positions. The B-gate positions have a hydrant system, the A and B parking positions without a gate do not. The distribution of aircraft across these positions is not of a concern, the distribution of QTAs is. If all QTAs between the 11:00 and 12:00 interval are on the non-gate positions, the effect is that the workload for the bowsers spikes. Therefore, the planning process should also provide insight in both the bowser and the dispenser workload, and the potential effect that interchanging workload between them has. The current rolling planning assigns hydrant and non-hydrant positions correctly for 74% (February 2014) of the cases. There are 6 hydrant positions, and 36 non-hydrant positions for commuter aircraft. The assignment of non-hydrant positions is correct for 79%, while the hydrant assignment is correct for 61% of the cases.

In the best case, Refueling demands that gate-assignment for QTAs is fixed for each time-interval. Otherwise, Refueling needs to account for the possibility of extra QTAs for both dispensers and bowsers. Two examples to describe why this is necessary:

- On February 3, 2014, Flight operations expected seven QTAs on non-hydrant positions between 11:30 and 12:30. During execution, three QTAs were on hydrant positions. This meant that Refueling had three unexpected QTAs for its dispensers.
- On February 17, 2014, the same happened, and the dispensers had four extra QTAs during the time-interval 11:30 – 13:00.

### 4.2.2 Arrival punctuality

The arrival punctuality influences time-windows. We took arrival punctuality as an example in Section 3.4.2 to describe the statistical performance. When delays reduce time-windows, they reduce flexibility to schedule fuel tasks. Therefore, the planning process should consider all statistical information as described in Table 16. All these elements combined should lead to a buffer that accounts for the several statistical effects of arrival punctuality. These elements do not need several buffers, i.e. one buffer can cope with several different effects.

If AS buffers against arrival lateness, we buffer against the loss of scheduling flexibility due to a reduction in time-windows in which aircraft need service. It is not the small delays that cause problems, but the extreme delays, i.e., the aircraft that arrive more than 30 minutes late, or flights that have such delays that a new departure time for the flight-link is set. These aircraft need fuel at a time that Refueling did not expect them. To ensure that severely delayed aircraft do not influence the performance, it is necessary to have buffer capacity at these times for severely delayed aircraft.

### 4.2.3 Contingencies

The last sections discussed improvements for the input that needs to be provided to the planning process. We already discussed that forecasts are always wrong. We also proposed buffers to counter the effects of wrong forecasts, creating scheduling flexibility, and allowing more than one scenario to take place during execution. In some situations, forecasted workload profiles become useless, and either new input must be used in the planning process, or the business manager, shift leader, and/or dispatcher must make experience based decisions. We discussed in Section 3.4.3 that robustness is to handle all situations that were specified, i.e., our proposed improvements are not versatile to extreme operating conditions such as fog, winter conditions, or storm.

| Moment | Negative/small | 0/average | Positive/large |
|---|---|---|---|
| **Mean** | A negative mean leads to larger time-windows. On average time-windows get larger, and buffers against arrival delays can be reduced. | No action | A positive mean leads to smaller time-windows. Refueling needs more buffer to handle smaller time-windows. |
| **Variance** | Little variance means little spread of the arrival performance. Refueling thus needs less buffer to cope with extreme delay. | The more variance, the more spread out arrival performance will be. Apart from more flexibility that Refueling gains to fuel early arrivals, there should also be a buffer to cope with late arrivals, since they could lead to similar problems as scheduled QTAs. | |
| **Skewness** | Negative skewness leads to the positive effect that aircraft that arrive early have a higher chance to arrive very early, than aircraft that arrive late will arrive very late. This means that no further action is required to buffer against delays. | No action | Positive skewness has the negative effect that aircraft that arrive late have a higher chance to arrive very late as opposed to aircraft that arrive early. Refueling should then buffer for arrival delays that lead to tasks on unexpected times. |
| **Kurtosis** | The higher the kurtosis, the more the variance depends on a few extreme values. The lower the kurtosis, the more the following holds: If an outcome is possible, it is just as likely as any other outcome. With a high kurtosis, Refueling should account for some extreme delays. With low kurtosis, Refueling should account for a wider spread of delay. | | |

*Table 16: Arrival lateness statistical information*

The planning process, however, should be flexible. Other input that regards non-normal operational conditions should result in other output. If AS therefore assesses the impact of a possible event, at least the following must be discussed with different departments on the airport:

- Expected arrival performance discussed with Flight Operations and the Airport Authorities.
- Expected number of cancellations and extra flights discussed with Flight Operations.
- Expected extra or less workload and disturbances discussed internally.

We discussed that quantitative risk assessment could have a very wide range of outcomes and therefore might be completely meaningless. Another aspect here is that coping with extreme operating conditions only works if all departments do so. If only Refueling rescheduled its personnel for an expected event, it is not likely that KLM's overall performance will increase.

Therefore, it is not AS's duty to make the risk assessment, but the duty of Flight Operations and the airport authorities. It is however AS's duty to be able to rerun the planning process when Flight Operations and the airport authorities publish new flight schedules, delay expectations, and/or severe weather predictions, but only if the current workload profiles do not cover for these situations.

## 4.3 Output the planning process provides

The planning process should generate more output than is currently the case. The current output is a workload profile, and a list of the tasks that make up this workload profile. Since we provided a lot of extra input that the planning process needs to consider, the planning process should provide output that shows how the input information is processed in the planning process. In addition, since dispenser fueling and bowser fueling have different work-areas and cannot take over each other's tasks, AS should separate their output into two different schedules.

The output consists of two different workload profile sets: one for the dispensers, and one for the bowsers. From these workload profiles, AS can derive the following information for each moment of the day:

- Scheduled pre-fuel and final fuel tasks.
- Scheduled buffers between tasks to cover for longer than expected process duration.
- Scheduled buffer between tasks to handle incidental tasks and process disturbances.
- Scheduled buffer to handle delayed aircraft and flight link changes.
- Scheduled idle-time to underutilize personnel.
- Breaks and end of shift tasks, added to the schedule as currently is happening.
- Scheduled refill tasks for the bowser schedules.

We describe the use of workload profiles that contain the turnaround times of the related tasks and buffers to cover for longer process duration (see Figure 43 and Figure 44). These profiles contain all scheduled pre-fuels and final fuels, and refills for the bowsers. Furthermore, we included a visualization of buffer times between tasks, such that AS knows how much buffer time is scheduled between tasks during the day. These buffers should account for longer process duration, incidental tasks, and arrival punctuality and/or changing flight links. With these profiles, Refueling should be aware of the following factors:

- The possibility that workload scheduled at dispensers during execution is done by bowsers and vice versa. This creates awareness that extra shifts might be needed to cover for this effect.
- The effect of changing time windows and extra QTAs during execution, due to overall arrival punctuality and changing flight links.

Next, the planning process should provide the following output:

- A list of all scheduled tasks, including refill tasks for the bowsers and breaks for personnel.
- A description about the buildup of buffers between tasks for longer process durations, incidental disturbances or tasks, and arrival punctuality.
- A description about the use of any information concerning contingencies, if information about them was provided.

We choose to schedule extra buffers for arrival lateness instead of adding arrival lateness time to the standard arrival times, because when AS would alter the schedule, AS only checks one possible outcome or AS needs to use simulation runs to check different scenarios. If AS uses buffers, it schedules extra capacity to handle delayed aircraft. The basis of this buffer must be the number of scheduled tasks. In the examples of Figure 43 and Figure 44 we scheduled 16% extra capacity. We did so by using Figure 22:

- 13% extra capacity in relation to all scheduled tasks 30 minutes earlier, and
- 3% extra capacity in relation to all scheduled tasks 60 minutes earlier.

Furthermore, these examples hold 10% buffer for incidental tasks and 10% buffer for process duration, both based on the number of tasks at any given moment. These numbers are arbitrary and need to be determined to cover for a percentage of possible situations that matches with AS desired OTP. In addition, we showed buffers as an add-on. To visualize buffers, this is a good manner, but as we earlier proposed, the planning process must schedule buffers between tasks. Also, we scheduled idle-time to match maximum personnel utilization with the scheduling flexibility.

The flight schedule is the basis for the workload profile to create all flight-related tasks. Furthermore, we captured variability in buffers, such that more than one scenario is possible. These buffers are key in the new situation: They express that there is extra capacity, and that it is possible to reschedule tasks, and that we thus created robustness against more than just one scenario. The new output of the planning process provides the following changes:

- There are now two workload profiles, one for dispensers and one for bowsers.
- The workload is built up with tasks related to a flight schedule and buffers between tasks to cover for different scenarios.
- The flight schedule is used as a basis for the workload; buffers between tasks are used to capture all sorts of variability.
- The idle-time buffer makes sure that utilization of personnel does not exceed a critical level and is in relation with the scheduling flexibility.

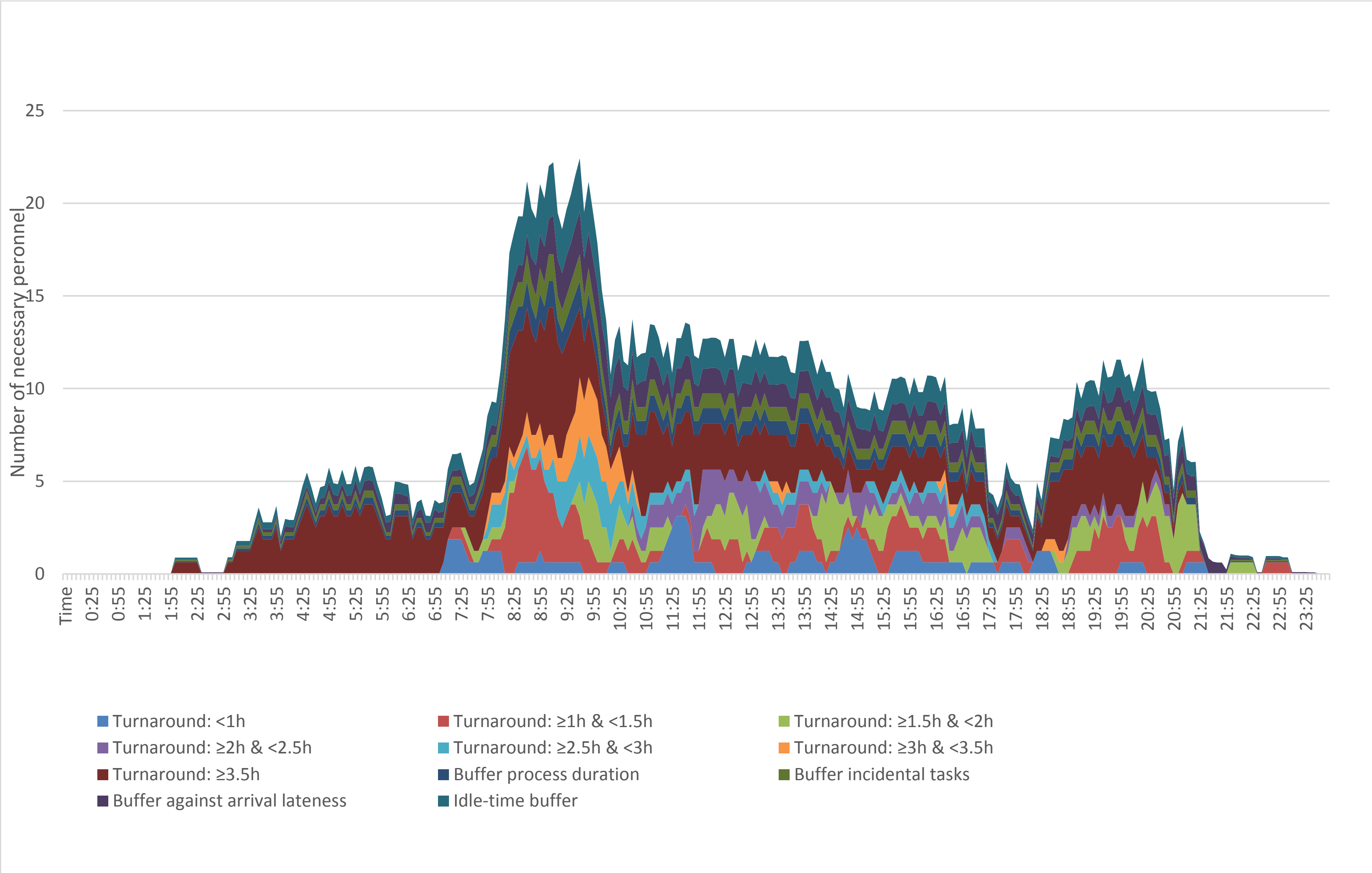


*Figure 43: Workload profile Dispensers, 17th of February 2014, Monday*

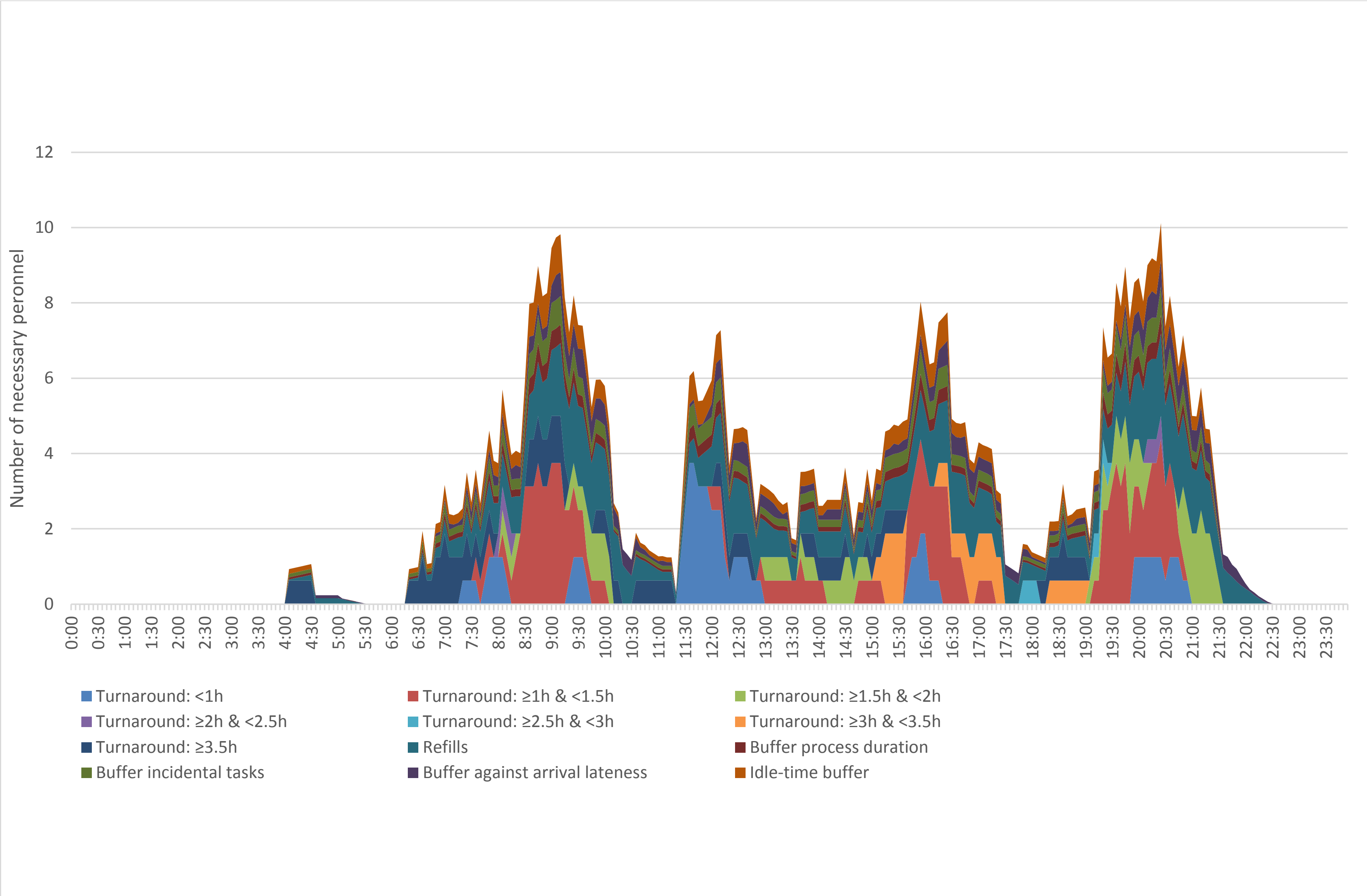


*Figure 44: Workload profile Bowsers, 17th of February 2014, Monday*

## 4.4 Personnel Scheduling

The output that the planning process provides, leads to a personnel decision. If the planning process provides all necessary output, AS schedules according to this. AS currently decides to schedule more personnel than the workload profile recommends, such that AS covers for the adverse effects of variability. In the recommended situation, this should not be the case, because AS covers for most situations by adding several buffers.

Since we propose to make two workload profiles, we schedule personnel for either a dispenser or bowser. Personnel, however, can work with both equipment types and change equipment during execution when necessary. Furthermore, AS needs to be aware of tasks that can change equipment type and that this might result in the need for extra shifts. For example, there is a need for one extra dispenser shift if there are three extra unexpected QTAS between 11:00 and 12:00, but it does not reduce the need for bowser operators due to their workload between 9:00 and 10:00.

## 4.5 Online scheduling and operations

This section discusses improvements for online scheduling and operations. First, Section 4.5.1 discusses the division of personnel between dispensers and bowsers during operations. Second, Section 4.5.2 discusses scheduling for utilization and pre-fuels. Then, Section 4.5.3 discusses schedule changes during operations. Finally, Section 4.5.4 discusses non-performance.

### 4.5.1 Division between dispensers and bowsers

Despite an initial division of workload between the dispensers and bowsers, the predicted parking position assignment a few hours prior to the day of operation is more accurate. Parking position assignments during the day only change if a parking position is not usable due to delays, broken bridges or stairs, etc. AS should therefore divide equipment according to the latest gate assignment. To achieve this, the shift leader needs new workload profiles based on the latest gate assignment during the day of execution, such that he divides his personnel accordingly. If Refueling benefits when an employee switches equipment during the day, this must be done.

### 4.5.2 Scheduling for utilization and pre-fuels

We recommended to schedule buffers between tasks to cope with variability in the refueling process. During operations, we want to keep utilization of personnel such that we can handle variability in the Refueling process equally throughout the day. Currently, CHIP considers that scheduling a task as early as possible in its time-window is preferable. This is true if the schedule prior to this task is unreliable, and the start of the task therefore is likely to be delayed. In case of correct norms and enough buffers between tasks, this is less likely. Therefore, if we schedule a task later in its time-window, this can be beneficial to the rest of the schedule. It provides lower utilization during the beginning of the tasks time-window, and therefore provides more capacity to deal with incidental tasks and longer process durations.

We can best describe this effect using pre-fuels as an example. CHIP now creates pre-fuels for aircraft that are suitable and have a longer than two hour stay. CHIP always considers these pre-fuel tasks, but does not necessarily schedule them. CHIP should not create them with a standard rule, because the dispatcher or CHIP might find the space to schedule the pre-fuel task. The pre-fuel task that CHIP schedules, however, could lead to a high utilization of personnel during the pre-fuel time-window, while during the final fuel time-window there is enough capacity to complete the fuel task, see the example in Figure 45. This example clearly shows that not pre-fueling aircraft could hold a better workload balance, such that we can handle variability in the process with the same possibilities during the whole time line.

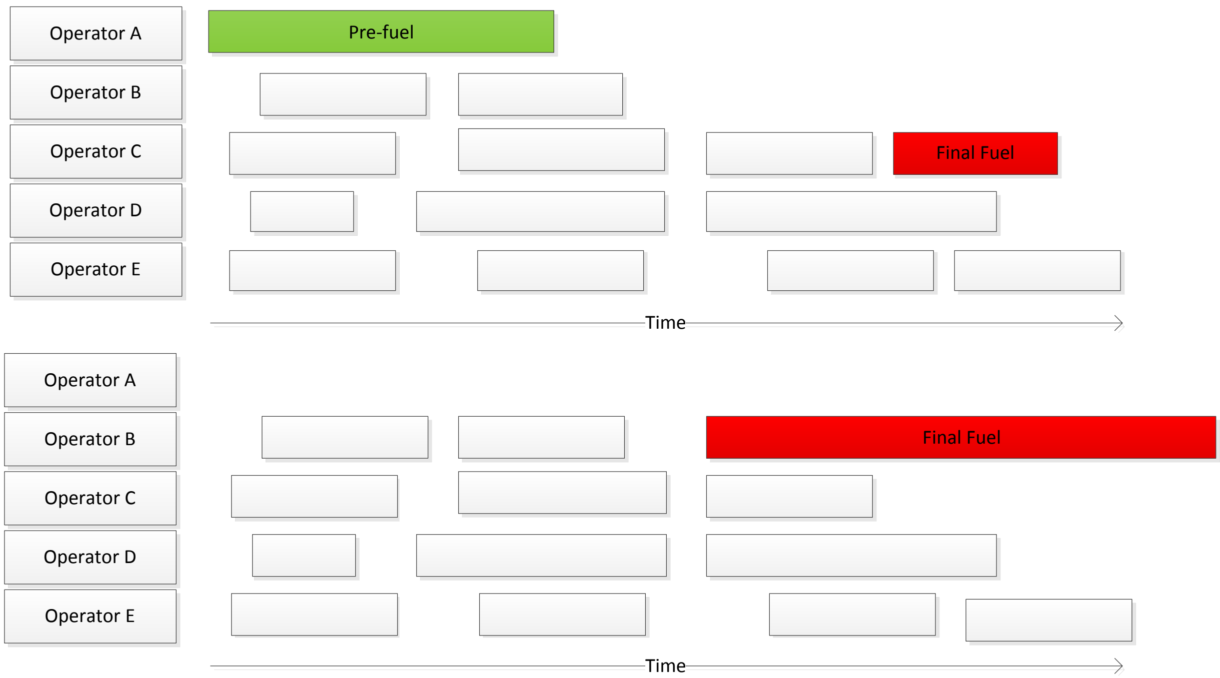


*Figure 45: Pre-fueling versus not pre-fueling with five operators and arbitrary tasks: Despite the capacity to pre-fuel, this might not hold the best workload balance.*

It would therefore be beneficial if CHIP shows the utilization of personnel, such that the dispatcher knows how much free capacity there is. If CHIP shows the expected average utilization for 15-minute time-intervals, the dispatcher knows how critical the schedule is. He also knows how much variability, i.e., incidental tasks and longer process durations, the schedule can handle.

Furthermore, as long as a pre-fuel is scheduled and not completed, the expected time required for final fuels in CHIP is not reduced. This means that the final fuel is scheduled for too long, reducing scheduling flexibility. CHIP should reduce the time needed for a final fuel when a pre-fuel is scheduled.

It is beneficial if CHIP and the dispatcher consider both pre-fuels and final fuels based on utilization and not on available capacity alone. Furthermore, it is beneficial if CHIP is capable of visualizing personnel utilization. Showing the average utilization over 15 minute time-intervals gives insight in how much capacity is available to schedule extra tasks.

### 4.5.3 Schedule changes

In the current CHIP system, high priority tasks affect urgent tasks by removing planned tasks from the schedule. If we express urgency as the deadline of a task, this should never be the case. Using the available settings for task urgency should end these problems, leading to:

- Less human corrections and input from the dispatcher to correct for the errors.
- A less nervous scheduling system.

Furthermore, CHIP now updates the schedule every 30 seconds, constantly updating the schedule. The current optimizer does not consider the value of the current solution, and thus has the option to completely reschedule all tasks. We question whether 30 seconds gives enough computational time to come close to an optimum for the objective function. Furthermore, we question whether it is necessary to update the whole schedule so often, instead of doing nothing or doing small schedule repairs. There are a few reasons for questioning these settings:

- The amount of human interaction with the nervous scheduling system is very high.
- There is always potential to improve the schedule by hand if we visually inspect the schedule.
- The schedule is very unstable and continuously changes, also when there is no apparent cause for these changes.
- Successive solutions are often worse than earlier schedules.
- Operators and managing staff think that performance strongly depends on the skill of the dispatcher.

Therefore, a less frequent update of the schedule should be considered. In addition, CHIP must consider the current schedule and schedule repairs before rescheduling all tasks, such that the schedule gets more stable.

### 4.5.4 Non-performance

CHIP cannot schedule for non-performance, i.e., it is not possible to schedule a task past its deadline, and therefore tasks keep the status unplanned. Non-performance, however, can be beneficial. No matter what happens, Refueling is obliged to finish all final fuel tasks. It is better to finish 10 tasks five minutes late, than it is to finish one task 60 minutes late, e.g., delaying ten 737-300 aircraft 5 minutes costs 700 euros, delaying one 737-300 for 60 minutes costs 3250 euros (see Figure 23, and an example of non-performance in Figure 46).

Therefore, if CHIP has no other option, CHIP should schedule for non-performance in certain situations. CHIP has settings such that tasks can overlap, i.e., instead of scheduling for non-performance, CHIP schedules tasks in their respective time-window while they are in conflict with other tasks. This is to avoid that a task remains unscheduled. A dispatcher is always free to change the assignment of tasks if this is beneficial to the flight network or if this holds better results in conjunction with other ground processes.

That the dispatcher would be better in scheduling for non-performance than CHIP, however, is not true if the duty manager aircraft (DMA) would monitor all ground processes, and would set an EBDE for the specific aircraft Ground Services wants or needs to delay. For example, if an aircraft will be delayed due to cargo problems, it would be better that the DMA sets an EBDE. This avoids that all dispatchers start to schedule the tasks related to this aircraft for non-performance manually. In this way, the DMA accounts for the non-performance, and CHIP can schedule with the new departure time for all ground processes.

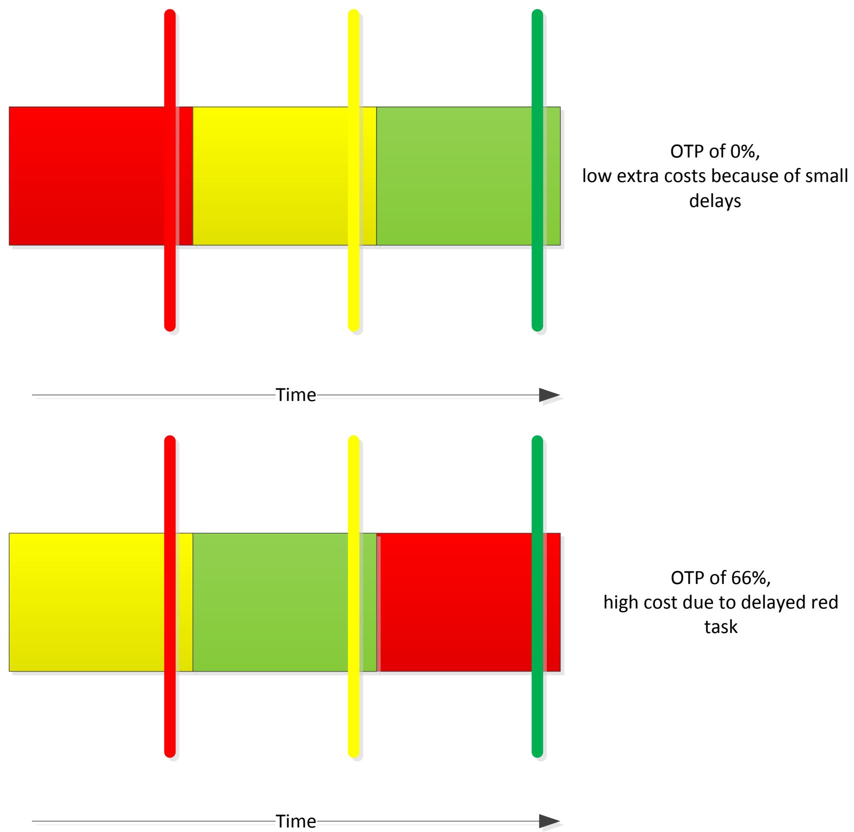


*Figure 46: Two examples of scheduling three tasks with their corresponding deadline and OTP*

## 4.6 Feedback

Feedback should not merely discuss the performance of Refueling expressed in OTP and code 36 delays. After execution, we not only know these figures, but also other factors that influenced the performance (see Figure 47). Not only can AS evaluate the impact of certain factors, but also the difference from the forecasts that were used during the planning phase. The following sections discuss the evaluation of OTP and code 36 (Section 4.6.1), the utilization of personnel and use of scheduled buffers (Section 4.6.2), and the comparison of forecasts and outcomes (Section 4.6.3).

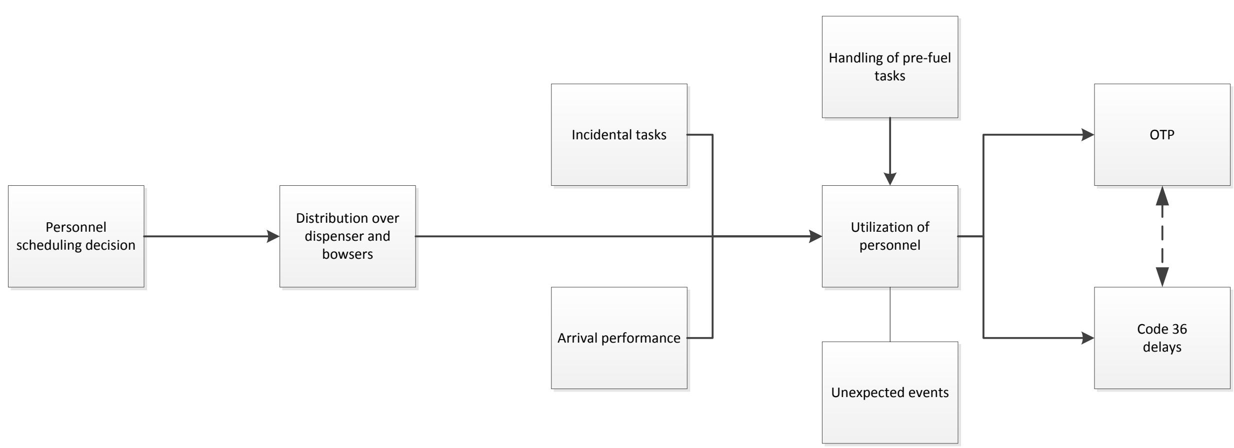


*Figure 47: The influences on OTP and Code 36*

### 4.6.1 Value of OTP and Code 36

If we recall Figure 23, the costs of delayed aircraft for airliners increase in a non-linear fashion with increasing delay. The IATA code for a refueling induced delay is 36, while OTP is defined as whether a task is performed within the agreed upon norms. Code 36 is a subjective appreciation, while OTP is not. Both contradicting statements can be true:

- A task is not finished on time according to OTP, but its related flight is not assigned a code 36.
- A flight is assigned a code 36 delay, while its fuel task was on time.

In terms of cost-accounting, a code 36 delay could directly be accounted to the Refueling department, incurring a penalty for every code 36 set. Performance, therefore, can be measured in two ways:

- Managing OTP and thereby adhering to KLM policies and terms of contract with external airliners.
- Cost-accounting for code 36 induced delays.

When AS evaluates this information, there are three points of attention:

- The personnel costs that AS makes must be in line with the OTP that Refueling has.
- The OTP should be measured for time intervals, not solely for day performances.
- Non-performance is allowed if it avoids long code 36 delays.

### 4.6.2 Personnel utilization and time buffer usage

Since buffer time, or extra scheduled time, plays a key role to counter several effects, AS needs to evaluate the use of time buffers. Buffers are designed to cope with longer process durations and incidental tasks. Therefore, we propose that AS monitors the utilization of its personnel and use of its buffers. If there is a trend in the data that suggests that a time buffer is not covering for its purpose, or is covering for its purpose excessively, the buffer must be reconsidered.

The current situation does not have buffers, except for a scheduled process duration longer than the 50$^{th}$ percentile. So, if AS starts using buffers between tasks, we expect that more variability in the process can be handled. This is only true when personnel utilization is not close to 100%, i.e., AS must not use its remaining idle-time buffer for operations on a regular basis.

Therefore, when providing, feedback AS should know the utilization of its personnel and the use of its buffers. This measure should be part of the weekly performance meeting, next to the OTP and code 36 results. OTP and code 36 expresses the refueling performance, utilization tells the criticality of a schedule during execution, and buffer usage indicates whether enough time for variability in the process was scheduled.

### 4.6.3 Comparing forecasts and outcomes

We discussed earlier that forecasts are always “wrong”. AS, however, needs to make a personnel scheduling decision based on these forecasts. We already proposed several buffers to counter a “wrong” forecast. Therefore, AS needs to determine the unexpected deviations from the forecast, which are either the unknown unknowns, i.e., contingencies that the planner did not expect, or incidents that exceeded the scheduled bandwidth (buffers) that were scheduled for them. Identifying unknown unknowns before execution is not possible, and it is up for debate whether this is possible after execution. Some situations can be identified after execution, like unexpected fog or an unexpected storm for which AS did not schedule personnel. AS, however, will never know if all causes for a bad outcome can be identified in retrospect. If it is a one-off situation, this does not matter. However, if situations that lead to a bad performance happen regularly without AS identifying the cause, this could be troublesome. The least AS should do after every day is the following:

- Consider whether the right amount of tasks and buffer were scheduled.
    - And if not:
        - Consider whether AS could have foreseen this situation.
        - Consider whether this situation will repeat itself in the future and AS needs to schedule for it.
        - Consider how AS must identify this situation in the future.

## 4.7 Conclusion

This chapter discussed a range of potential improvement possibilities in the current planning and scheduling chain. It discussed the input and output that is necessary for the planning process. It discussed personnel scheduling coming forth from it. Furthermore, it discussed online scheduling and operations. In addition, it relates to improvements regarding feedback that the planning process should give. The main improvements for the input that AS provides are:

- Norms consist of three elements: Vehicle check (if necessary), driving time, and fueling task. The fueling task element should account for destination.
- AS must base both plan and online scheduling norms on the 50$^{th}$ percentile for scheduling flexibility.
- For different kinds of incidental tasks and process disturbances AS needs to know the frequency of occurrence and needed time.
- AS must use buffers between tasks that account for:
    - Longer process durations.
    - Delayed aircraft and flight link changes.
    - Incidental tasks and process disturbances.
- AS should plan for specific refill tasks for bowsers, because general extra capacity for refills does not ensure enough capacity for bowsers.
- AS should ensure an idle-time buffer, such that personnel has a maximum utilization level.
- Pre-fuels should not be scheduled according to a fixed rule. Pre-fuels are desirable if it reduces workload peak and needed personnel. AS therefore needs to consider every eligible aircraft for re-fueling to reduce needed personnel.
- Shifts-sets should match available equipment such that personnel is not sent home early to free up equipment.

Potential improvements from other input are:

- The distribution of aircraft between hydrant and non-hydrant positions are of importance in relation to QTAs, since there is a difference between parking positions in the rolling planning's flight schedule and the actual parking positions.
- Accounting for severe arrival lateness of aircraft using buffers.
- AS should account for contingencies in its planning process when Flight Operations or the airport authorities warns for them, and only when all ground processes account for them.

Potential improvements for the output and related personnel scheduling decision are:

- The output that the planning process provides consist of two workload profiles, one for the bowsers, on for the dispensers. These dispensers show the workload during the day, split out for the related turnaround time of aircraft.
- The output should describe the amount of buffers the workload profile holds.
- Personnel scheduling should schedule personnel according to the workload profiles, and AS should not adjust this recommendation at its own discretion.

Potential improvements for online scheduling and operations are:

- A daily update regarding workload division between dispensers and bowers and assigning personnel accordingly.
- Accounting for utilization of personnel during operations, such that incidental tasks, longer process durations, and disturbances can be handled equally throughout the day.
- Make CHIP less nervous (less prone to changes) and make CHIP less dependent on human interaction by:
  - Updating CHIP less frequent and always consider the value of the current schedule.
  - Considering schedule repair before completely rescheduling all tasks.
  - Considering urgency of tasks next to priority of tasks.
- Consider CHIP to schedule for non-performance, since this holds better results than not scheduling some tasks at all.

Potential improvements for feedback are:

- Use OTP as a measure for compliance to KLM policy and to terms of contract of other airlines.
- Relate the costs of delay to Refueling in case of code 36 delays.
- Monitor the use of buffers and personnel utilization.
- Compare forecasts and outcome to identify causes that influence the Refueling process, and to ensure that plan norms and buffers correctly reflect reality.

# 5 Implementation

It is not necessary to change the planning and scheduling chain. In this report we show that there is a lot of potential for improvement, but also that there is a system that functions. We never identified Refueling as the department that accounts for a significant amount of ground delays, we only identified discrepancies between the offline planning processes and online execution. Discrepancies do not have to lead to the implementation of any of our potential improvements. The main concern with this argumentation, however, is that most of the insights in this report include elements that affect AS. The current system functions, but misses many of these elements. Changes in KLM policy will not be noticed within the current planning and scheduling chain; it is reactive to its environment. The whole setup of thinking about QTAs, buffering for variability, delay costs, etc. is to create a proactive planning and scheduling chain that notices changes across the KLM operation.

Section 5.1 describes what AS can do on the short-term without the need of other departments and the change of software systems. Section 5.2 describes the implementation of improvements that need cooperation from other departments, software changes, and/or organizational changes. Section 5.3 discusses continuous monitoring of the planning and scheduling chain, such that it remains a proactive chain that adapts to changes within KLM. Finally, Section 5.4 discusses the implementation of our findings at other aircraft services.

## 5.1 Changes on the short-term

On the short-term there are various possible changes. Apart from changing the input that AS delivers to the planning process, the planning process needs to be able to process this input. Therefore, this section discusses what is possible with the current output from the planning process. First, the section discusses what AS should do with the workload profiles and how AS must schedule personnel. Then the section discusses possible short-term changes in CHIP, before it finishes with implementing improvements in the feedback that AS provides about the planning and scheduling chain.

Facing the current planning chain, some improvements are easy to implement. AS can divide the workload profiles in a profile for dispensers and a profile for bowsers. Since the used flight schedule is available, we know the ground-times of the aircraft related to the task. Instead of showing pre-fuel and final fuel tasks, we propose to show the related ground times.

As long as the planning process does not provide buffers between tasks, and the current plan norms are in use, AS should know that the plan norms do not schedule sufficient time and that there is not enough capacity for delayed aircraft and incidental tasks. This means that AS needs to make adjustments to cover for variability in the refueling processes, which means that it is justified to schedule more personnel than the workload profile advises.

Despite the current experience-based practice of adjusting the personnel schedules, there is no connection to the overcapacity or capacity shortage of personnel. We introduced personnel utilization both for online scheduling and as a number that can be used as feedback on the planning and scheduling chain. AS must not directly see low utilization as over-capacity. In this variable environment, there will be days that have such an arrival lateness and little disturbances or incidental tasks that utilization is low. This only means that Refueling was prepared for a worse scenario, not that there is too much personnel present.

AS could implement some changes in CHIP on the short-term. Since 2012, there is a change ready for implementation in which urgency of tasks is part of the optimizer. AS needs to implement this change. Furthermore, CHIP is already suitable for non-performance in which tasks are scheduled outside their time-window if no other possibility exists. This must only be done when it is in accordance with other services. The role of the hub control center, therefore, must be to coordinate delays with the dispatchers and set EBDE times accordingly. In this way, AS avoids that all departments have different non-performances for different flights.

It is not possible to show the (expected) personnel utilization for personnel across the working day. However, AS can inform and train dispatchers to look at personnel utilization, especially when they schedule pre-fuel tasks. In addition, during the weekly performance meeting, AS can introduce personnel utilization next to OTP and code 36 figures.

For these figures during performance meetings, daily averages do not have much meaning. Information that can be provided on the short-term is:

- The number of 30-minute time intervals that the OTP dropped below the target during the day.
- The number of 30-minute time intervals in which the utilization was higher than the target during the day.
- The spread of code 36 delays, OTP performance below target, and utilization above target across the working day.

Buffering against variability costs money. Despite this fact, the software that is currently in use does not provide buffers. AS, however, should think about how much costs it wants to make for buffers. The more that AS uses buffers, the more OTP will increase, and the more code 36 delays and personnel utilization will decrease. For this, AS needs to decide what the OTP target is. It could be either a minimum requirement that must be met 99% percent of the time, or it could be an ambitious target that AS must meet 50% of the time. The amount of scheduled buffer can change according to the KLM's goals, Ground Services goals, Aircraft Services goals, and/or Refueling goals.

## 5.2 Changes on the long-term

On the long-term a lot of input for the planning process must be collected and/or altered. This section discusses which changes need to be initiated and what is needed for them. Many of the potential improvements need system changes. With the current planning process that provides workload profiles, it is not guaranteed that all this information can be processed. The software that the planning process uses is the responsibility of ST. The situation in which AS shows potential improvements and identifies its needs, but cannot change the planning and scheduling itself, is far from ideal, because AS is responsible for its own performance.

This does not change the fact that AS should improve its input and can ask for better output of the planning process. In the remainder of this section, we discuss the introduction of the improvements discussed in Chapter 4.

Most improvements need data analysis before AS can propose them. This concerns the identification of new plan norms and needed buffer times for longer process durations, arrival lateness, and incidental tasks. AS and ST collect norms via manmade observations, which limits the statistical validity of norms. We recommend that AS creates enough support for data analysis based on database data. Furthermore, we recommend that AS constructs a driving time matrix based on historical driving data, instead of a distance based matrix that likely underestimates needed driving time. In addition, we recommend that AS implements a vehicle inspection norm to all relevant tasks, i.e., the first task an operator performs on his bowser or dispenser. Furthermore, AS should base its planning norms on the 50$^{th}$ percentile.

Then, AS needs to develop buffer times. Buffers for longer process duration are available. AS could derive these from the current data and plan norms. The other buffers are to provide extra capacity for handling incidental tasks and aircraft that are delayed, and an idle-time buffer that ensures maximum utilization of personnel. These buffers between tasks must be such that AS has enough capacity to reschedule regular tasks, and schedule incidental and delayed tasks. Therefore, the buffers must be such that:

- There is enough planned buffer capacity to ensure a minimum OTP target.
- Shorter ground times should go hand in hand with larger idle-time buffers such that if AS has less scheduling flexibility, maximum personnel utilization gets lower.

AS does not know what level of maximum personnel utilization satisfies the current time-window constraints of the flight-schedule. Neither does AS know whether maximum personnel utilization must be similar across the working day. Next to determining the capacity need for extra tasks and longer process duration, AS thus needs to determine an idle-time buffer. This idle-time buffer must be coherent with the OTP target.

Other improvements discuss both online and offline planning and scheduling decisions, such as rules for pre-fuels, and scheduling decisions regarding personnel utilization. AS must not bind the pre-fuels to strict rules. Strict rules limit pre-fuel potential, but also obliges the planning process to plan for them. A system in which all wide-body aircraft may be pre-fueled gives the planning process more freedom in deciding which aircraft to pre-fuel and reflects the online situation for pre-fuels better.

AS must schedule tasks during operations not only based on available time, but also based on personnel utilization. For this, we propose to introduce a graph in CHIP that shows personnel utilization across the working day. Currently, CHIP already has a graph tool. This graph tool must be programmed such that it shows personnel utilization for 15-minute to 30-minute time intervals.

## 5.3 Continuous monitoring of the planning and scheduling chain

This section discusses the monitoring of improvements. The regular feedback that the planning and scheduling chain receives comes forward from the weekly performance meeting. This is a result-oriented meeting: It does not discuss whether the input of the the planning process (workload profiles) have been valid; neither does it discuss personnel utilization and buffer usage. It is not solely OTP that matters, but also the factors that caused it. If AS develops a system that provides feedback regarding buffers and utilization, we already know that:

- Too much/ not enough ‘longer task duration’ buffer usage indicates wrong norm times.
- Too much/ not enough ‘arrival lateness’ buffer usage indicates the arrival lateness buffer does not reflect reality. This is either due to a contingency not considered during planning or due to a change in conditions at the airport or at the KLM.
- If the performance is still lower than the target, despite enough scheduled capacity and scheduled buffers, there is not enough idle-time in relation to the scheduling flexibility. If performance is high, the idle-time buffer is large, which probably leads to higher personnel costs.

To keep the planning and scheduling chain up to date, AS should monitor and change its norm times and buffers to match the performance target. It relates the planning phase to the online execution. The explicit scheduling of idle-time creates extra scheduling flexibility.

We do not know if we found all the causes that influence the performance of Refueling. We identified discrepancies between planned and actual workload, and proposed improvements to deal with these discrepancies. It is possible that new causes affect the performance of Refueling, and these effects may need a buffer if they become permanent. To monitor the planning and scheduling chain continuously, we developed a flowchart (see Figure 48) that assesses OTP, code 36 delays, plan norms, and all proposed buffers. Furthermore, it assesses whether new causes influences the performance. This flowchart is for identification of trends, not for one day situations that AS did not cover.

To demonstrate the use of this flowchart, we give an example:

- Due to new airliners landing at Amsterdam, there are traffic jams on the airport roads between 10:00 and 11:00.
- Due to a new European flight traffic system, extreme late arrival of aircraft is reduced by 50%.

Going through the flowchart, we see that OTP has dropped between 10:00 and 11:00, but that in general OTP has improved and the number of code 36 delays is reduced. The problems we face with the traffic jams between 10:00 and 11:00 cannot be solved with the current buffers that are in place. There are two possible solutions:

- Using a different driving time matrix between 10:00 and 11:00.
- Buffer for longer driving times within the 10:00 and 11:00 time interval.

If we go further, we see that our arrival lateness buffer is hardly necessary due to the new flight traffic system. This buffer must be adjusted to cover for the new situation. The other buffers are not affected, and thus do not need adjustments.

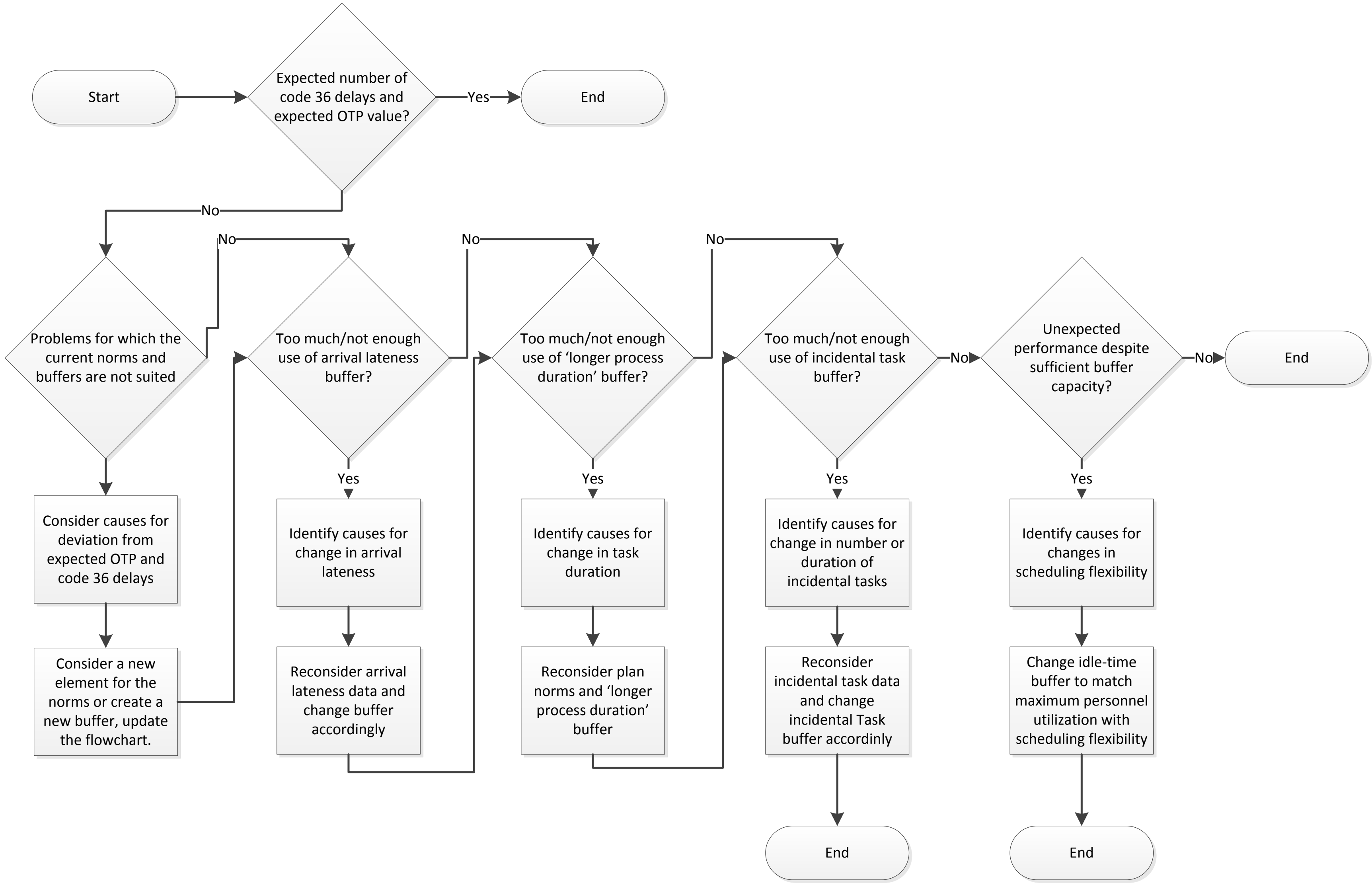


*Figure 48: Flowchart for monitoring trends in performance, norms, and used buffers.*

## 5.4 Implementation of findings at other services

The findings of this research relate to the Refueling department. The reason for selecting Refueling are its relative long process duration and its variable capacity need across the working day. Due to these reasons, Refueling is often critical to the aircraft departure time. This research discussed input and output of the planning process. Furthermore, this research addressed improvements of the scheduling system during execution, and the feedback that AS needs to provide.

For the input that AS needs to provide to the planning process, AS can generalize most findings. Plan norms can be based on the $50^{th}$ percentile from database data, and consist of different building blocks for a vehicle check, driving time, and task execution. In addition, AS can generalize the findings on buffers for incidental tasks and personnel utilization findings. Pre-fuels, or splitting a final task in two separate tasks, only happens at Refueling. Statistical information regarding the arrival punctuality of aircraft can be used at all services. Furthermore, dealing with contingencies is of importance to every department, and especially de-icing, which is a weather forecast dependent planning process.

Then AS can generalize the output of the planning process as well. Creating insight in turnaround times of the aircraft related to the tasks, and creating insight in scheduled buffer give better insight in what is scheduled and where AS can expect most difficulties during execution.

In addition, AS should use the improvements for CHIP at every service that uses it. AS can make utilization of personnel visible, and start scheduling for utilization at each preparation service. Support service, i.e. all services part of the flight process (Pushback, Airside Handling Support, and De-icing), cannot make use of scheduling for personnel utilization, since they do not have any scheduling flexibility. Improvements regarding schedule changes that CHIP makes, and the possibility of scheduling for non-performance can be used at all services.

During feedback sessions, most findings are applicable. Cost accounting for service induced delay and OTP feedback for smaller than one-day intervals can be used by all services. Furthermore, feedback considering personnel utilization and buffer usage are relevant to all services when the right buffers are in place.

Two points of attention remain:

- This research focuses on a service with planning flexibility. Planning for support services that do not have this flexibility are more prone to flight-delays, and therefore especially need idle-time buffer.
- This research touched upon contingency planning and risk management. De-Icing needs more research on these areas before it can benefit from this research.

## 5.5 Conclusion

This chapter discussed the implementation of improvements in the planning and scheduling chain.

On the short-term, there are several possibilities for improvement. Despite that norm times are too short, and the current planning process cannot plan buffers between tasks, AS can start splitting the workload profile in one for dispensers and one for bowsers. Furthermore, AS can start to provide insight in turnaround times in these workload profiles. In addition, AS could start to rethink its OTP and code 36 policy and the costs they want to make for buffers. Finally, AS should directly implement urgency settings and non-performance settings in CHIP.

On the long-term, AS needs to consider its position regarding the planning software. That ST is in control of the planning software, while AS is responsible for the performance of its services is far from ideal. Most other changes concern data analysis: Making new plan norms, identifying needed buffer capacity for incidental, delayed, and longer process duration, and identifying the need for idle-time buffer to match the scheduling flexibility with the performance target.

To monitor the planning and scheduling chain, we developed a flowchart to identify trends that AS should account for. With this flowchart, AS must:

- Identify potential causes for which the current buffers do not account and that might need a new buffer.
- Check whether the current buffer capacity and norm times reflect reality.
- Check whether the idle-time buffer is such that rescheduling flexibility is sufficient to match the performance target.

For other aircraft services, AS can generalize most findings. Since De-Icing is a fully weather dependent service, AS needs more research in the areas of risk management and contingency planning before it can benefit from this research. Support services do not hold scheduling flexibility and therefore benefit more from idle-time buffer solutions.

# 6 Conclusion

This chapter presents the main conclusions of this research (Section 6.1), addresses the limitations of this research (Section 6.2), gives recommendations (Section 6.3), and discusses topics for future research (Section 6.4).

## 6.1 Conclusions

Before this research, the discrepancies between the planned and actual workload could not be explained. Despite earlier research into the design of a planning and scheduling chain and robust planning techniques, there was still a need to identify these discrepancies. Furthermore, there is a need for improvements that reduce or deal with these discrepancies. This led to the following main research question:

What are the current discrepancies between planned and actual workload, and what are potential improvements to deal with these discrepancies?

We selected the Refueling department for further research. We found that the current planning process provides workload predictions that do not match the actual workload. The workload predictions are made with a deterministic and static planning method. This system accounts for tasks related to the flight schedule using plan norms, and accounts for tasks unrelated to the flight schedule using historical averages.

During execution, the planning system CHIP accounts for a dynamic changing environment in which aircraft arrive late, incidental tasks arise and must be executed, flight links change, tasks get disturbed, and available personnel is different in number from the rolling planning personnel recommendation. CHIP makes a new schedule every 30 seconds for the upcoming four hours.

We found that AS faces a scheduling problem that can be characterized as a dynamic vehicle routing problem with stochastic demands and variable time-windows. We furthermore found that Refueling depends on arrival delay of aircraft, and that the cost of aircraft delay rises exponentially with an increase in delay time. In addition, the value of information about future events is of importance. AS needs to know whether it deals with information that is deterministic, a forecast, or probabilistic. AS should also know how this information develops and how they should act upon this information. With robust planning AS could find a balance between feasibility (more possibilities during execution) and optimality (less costs). AS needs to do more than buffer for longer task duration. They should account for incidental tasks, arrival delay, and contingencies.

Therefore, if AS improves its planning and scheduling chain, they should reconsider the norms that they use for planning and scheduling tasks. These norms should be based on the 50$^{th}$ percentile of historical data accounting for vehicle inspection, driving time, and actual task duration for the aircrafts destination and type. In addition, we need time buffers for tasks that take longer than the 50$^{th}$ percentile norms, time buffers for incidental tasks, and time buffers for severely delayed aircraft. Besides, we propose that AS schedules an idle-time buffer that matches scheduling flexibility with personnel utilization. Furthermore, Refueling should have two workload profiles, one for dispensers, and one for bowsers, and should visualize the turnaround times of the aircraft related to the tasks. These workload profiles should be the basis of the personnel scheduling decision, and AS should be aware of the possibility that workload (especially QTAs) moves between the dispensers and bowsers due to a change in parking position assignment.

During online operations, CHIP must be less nervous and not update the system every 30 seconds. For this, CHIP must always consider the current solution and schedule repair before rescheduling all tasks. CHIP should also be capable of scheduling for non-performance. We also recommend that CHIP gets a functionality that shows personnel utilization across the day, and that CHIP should not only schedule for earliest possible completion of tasks, but also for personnel utilization balance across the working day. When evaluating the execution, AS must consider cost-accounting for code 36 delays. Next to reviewing the OTP, AS must also consider buffer usage and differences between forecast and outcome.

It is not necessary to change the planning and scheduling chain. It functions with some limitations and is very reactive to KLM changes, so we do recommend that AS starts improving its planning and scheduling chain, such that it becomes proactive in noticing changes in KLM policy and operations. On the short-term, Refueling must start using two workload profiles instead of one. In addition, they should start considering buffers for incidental tasks, arrival lateness and longer process duration. Furthermore, AS must reevaluate the use of targets and decide whether OTP is an ambitious target or minimum target that AS need to make.

On the long-term AS must consider its position regarding the planning process. The situation in which AS is responsible for the performance it achieved, but cannot change the planning process, is far from ideal. Furthermore, AS must make new norms that includes driving time matrix based on historic data and the possibility to schedule vehicle inspections. Moreover, when possible, AS must base these on historical data, not on manmade observations. Then, AS must develop buffer times, such that enough buffer is scheduled to cope with incidental tasks, longer process duration, and arrival lateness. In addition, AS must develop the idle-time buffer to ensure maximum personnel utilization in relation to the scheduling flexibility.

To monitor the planning and scheduling chain, AS must evaluate trends in the data to see whether new buffers or changes to the norm times are necessary, whether the current buffers are good reflection of reality, or whether there are reasons to change the buffer.

The result of this research is an identification of reasons that result in discrepancies between planned and actual workload, and potential improvements within the current planning and scheduling chain that either reduce or deal with these discrepancies.

## 6.2 Limitations

This research has several limitations:

- We were bound to the current planning and scheduling software that provides the workload profiles. This software is not the responsibility of AS, but does provide the information on which AS needs to base its personnel scheduling decision. This leads to a division of responsibility between planning and performance. This might result in organizational constraints that limit improvement possibilities.
- We did not deliver technical descriptions for how the planning and scheduling chain should work.
- We did not provide ground service wide analysis that focuses on the turnaround of aircraft and overall performance of the KLM. Neither did we prove that an improvement in Refueling

performance results in an improvement of KLM performance. The improvement of the planning and scheduling chain for one AS department does not automatically lead to a better departure performance at KLM.

- We did not discuss the individual performance and motivation of refueling employees. Performance loss due to changing labor conditions and the use of temporary labor are not discussed. The current agreement is that it is forbidden to measure individual performance with database data; it is impossible to monitor the performance of individuals. Therefore, we do not know what the impact of individual performance is on the Refueling performance.

## 6.3 Recommendations

This section provides recommendations that do not require further research. Our main recommendation is to start buffering for variability of different processes during execution, and relating personnel utilization to planning and scheduling flexibility, no matter how the planning and scheduling chain develops and/or changes.

Second, we advise to relate this research to other KLM operations. We showed that AS connects the current planning chain to other KLM operations once a season during the OPC. AS does not explicitly link her other planning phases (offline operational, online operational) in the planning and scheduling chain to other aircraft services and/or KLM operations, while this could be very beneficial.

Third, we recommend visualizing the planning process and CHIP process more, such that each AS employee can understand by visualization how the planning process makes workload profiles, and how CHIP makes schedules. In this manner, AS knows how its current systems work, next to starting the implementation of improvements.

Fourth, we suggest that AS does not only improve planning and scheduling operations at Refueling, but also at other aircraft services. Furthermore, we recommend that the results are shared with all planning and scheduling operations at KLM, such that other KLM divisions can benefit.

Fifth, we advise that AS checks whether the current planning and scheduling software that currently is in use, is suitable for the current airline operations and the findings in this report. Despite the costs that are made for systems currently in use, there could be software packages that outperform the software that is currently in use.

Finally, we recommend that AS creates awareness regarding the current discrepancies between planning and execution of the Refueling process. Despite that AS could introduce buffers, change OTP targets, and could link its cost accounting to flight delays, these improvements and changes will not be available tomorrow. Everybody that makes or relies on workload profiles must be aware of the discrepancies that this research found.

## 6.4 Future Research

In this research, we proposed improvements across the planning and scheduling chain. We did not discuss the organizational structure that deals with the planning, scheduling, and execution. We neither discussed nor proposed the technical design of several planning tools that the planning and scheduling chain uses. Furthermore, we did not touch upon the effect that labor agreements and conditions have on AS departments.

First, we recommend researching the effects that the current organizational structure and division of responsibilities have on AS performance.

Second, we recommend that AS researches the labor agreements and working conditions of employees. It has come to our attention that KLM does not hire refueling employees anymore and hires new employees with flex worker contracts. KLM personnel has a regular working roster, monthly payouts and a fixed salary. Flex workers get paid for the hours they work and do not have a guaranteed number of working hours per week. This leads to tension between employees and motivational problems.

Third, based on this research, we recommend that AS makes a technical design for both the system that creates workload profiles and the CHIP system. Furthermore, AS needs to analyzes whether the current systems can handle those requirements.

Fourth, we recommend that AS looks at integral planning and scheduling solutions such as network planning and/or critical path planning. Aircraft depend on all ground services to be finished before departure.

Finally, we recommend that AS researches the possibilities for connecting its cost accounting to Flight Operations, such that AS is not only responsible for its own budget and OTP, but also for the delay costs that it induces.

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# Appendices

## A. Glossary

Actual In Block Time (AIBT) or Actual Time of Arrival (ATA) – The time the aircraft arrives at the parking position and has shut down its engines.

Actual Off Block Time (AOBT) or Actual Time of Departure (ATD) – The time the aircraft starts pushback or taxi from its parking position.

Arrival performance – The deviation of an aircraft's actual arrival time in comparison with the scheduled arrival time.

Duty Manager Aircraft (DMA) – The responsible manager at the Hub Control Center for the online monitoring and scheduling of all ground processes.

EBDE – Set departure time, different and later from STD.

Flight Link – The link of scheduled flights to a specific aircraft (or registration).

Flight Network – The state of all aircraft and related operations of an airliner.

Hub Control Center (HCC) – The center responsible for online monitoring, scheduling, and control of ground processes.

Plan norm -Time measurements used to schedule fueling tasks in advance of operations.

Planning Principles (in Dutch: plannings uitgangspunten, or PUG) -All information and agreemets that needs to be considered in the workload profile

Quick turnaround -Aircraft that are scheduled to be on the ground as short as possible.

Reactionary delay - Delay caused by late arrival of aircraft or crew from previous journeys.

Registration -Registration code of a specific aircraft, also used to denote the aircraft itself.

Scheduling norm -Time measurement used to schedule tasks during operations.

Standard time of Departure (STD) - Scheduled time an aircraft leaves

Turnaround time-Available time to make an aircraft ready for departure after arrival.

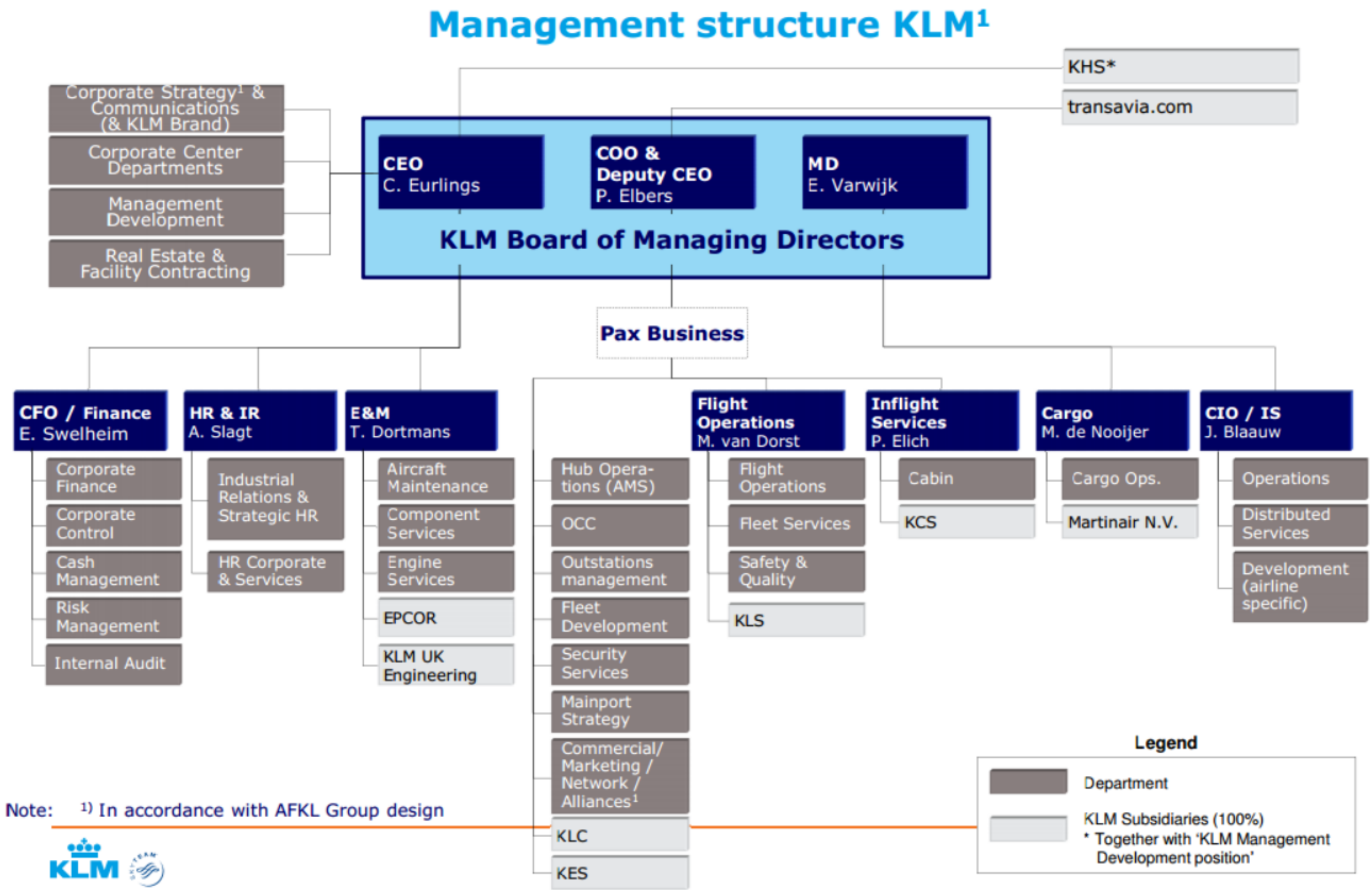
Wide body aircraft -Aircraft with two walking isles and capable of intercontinental flights.

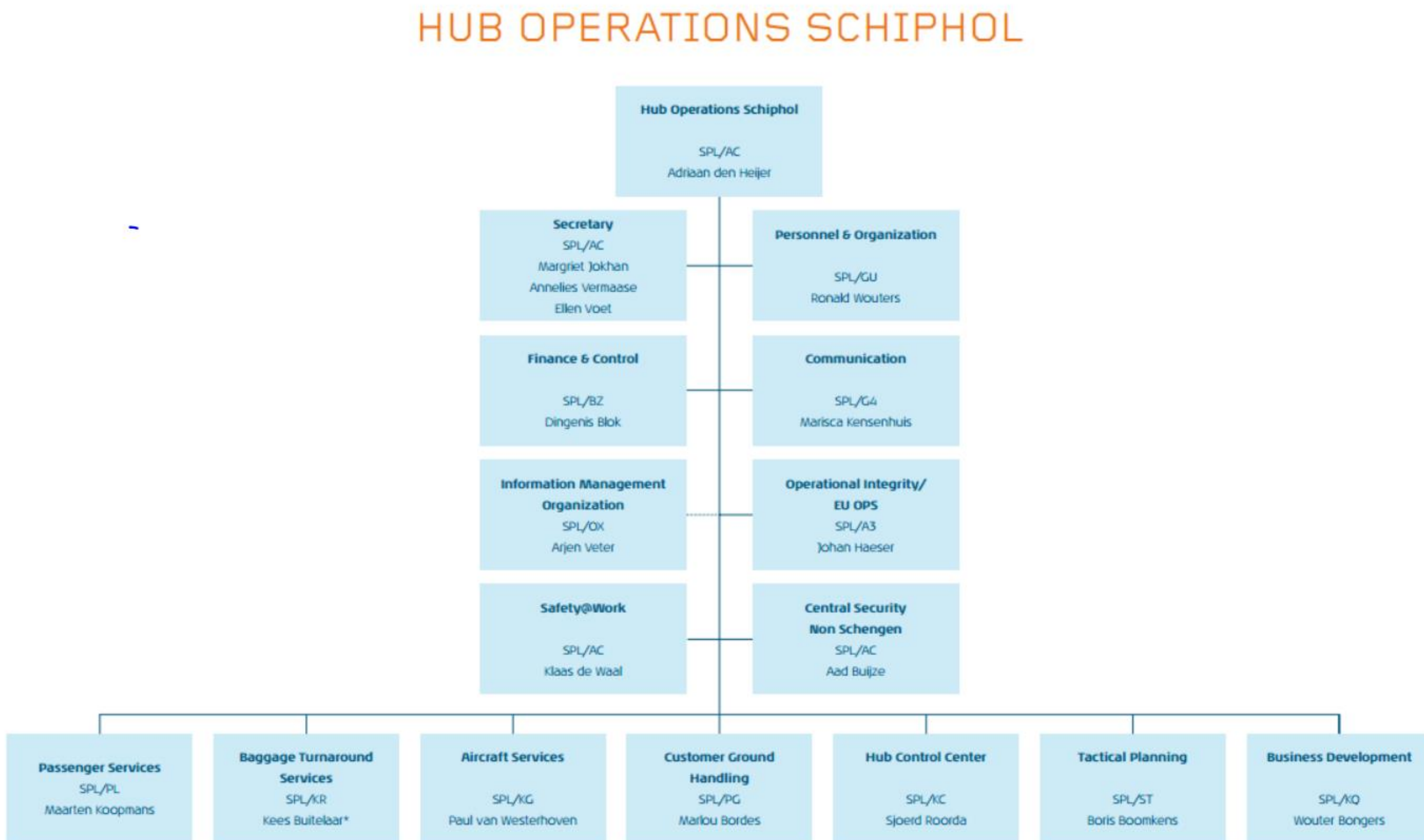
Workload - The total number of tasks that AS performs at a certain moment in time.

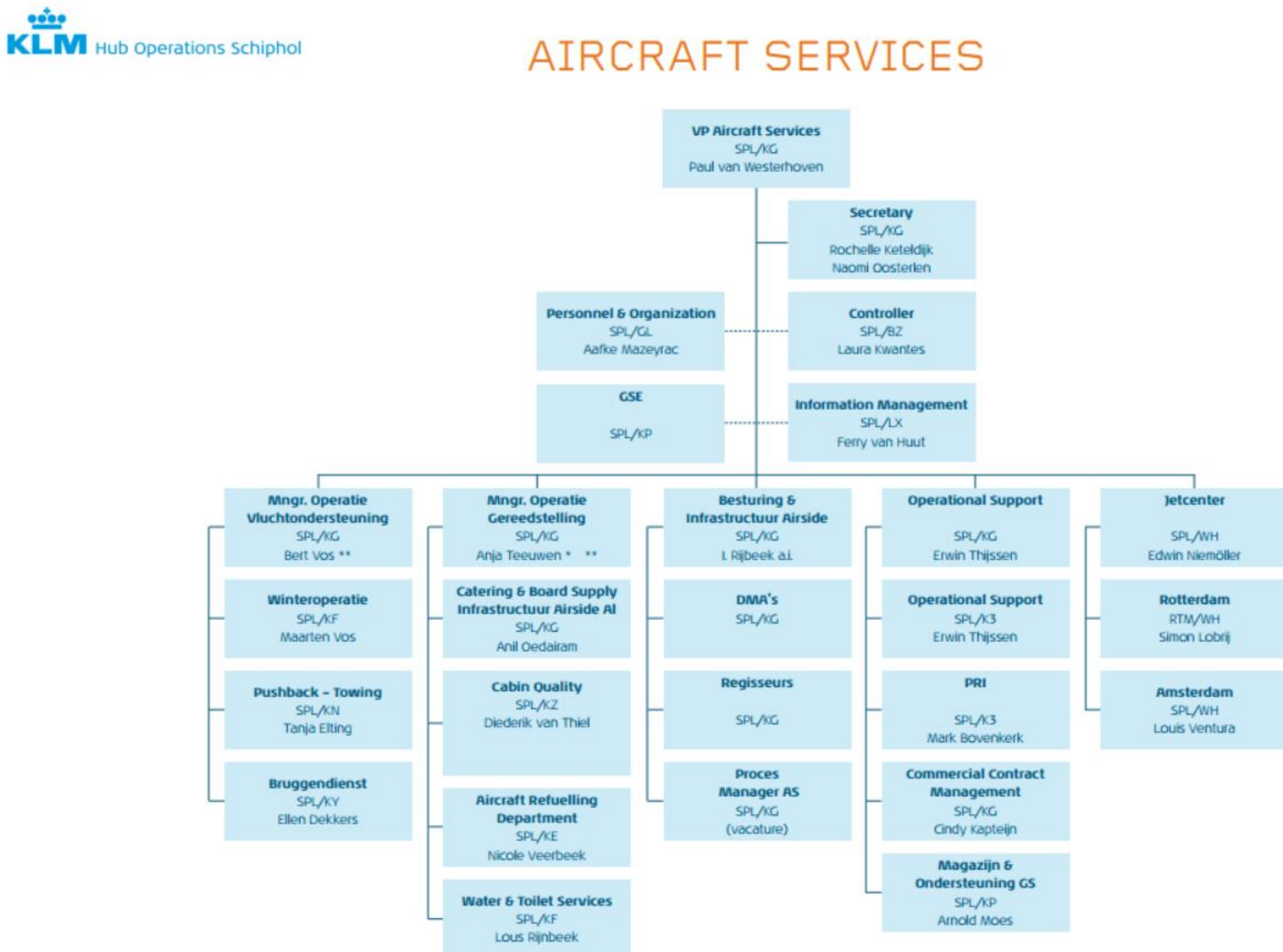
Workload peak - More workload during a certain time interval than before and after this interval.

Workload Profile -A representation of workload over time, representing the workload across a 24-hour day for 5 minute time intervals.

## B. Organograms KLM




HUB OPERATIONS SCHIPHOL
Hub Operations Schiphol
SPL/AC
Adriaan den Heijer
Secretary
SPL/AC
Margriet Jokhan
Annelies Vermaase
Ellen Voet
Personnel & Organization
SPL/GU
Ronald Wouters
Finance & Control
SPL/BZ
Dingenis Blok
Communication
SPL/G4
Marisca Kensenhuis
Information Management Organization
SPL/OX
Arjen Veter
Operational Integrity/ EU OPS
SPL/A3
Johan Haeser
Safety@Work
SPL/AC
Klaas de Waal
Central Security Non Schengen
SPL/AC
Aad Buijze
Passenger Services
SPL/PL
Maarten Koopmans
Baggage Turnaround Services
SPL/KR
Kees Buitelaar*
Aircraft Services
SPL/KG
Paul van Westerhoven
Customer Ground Handling
SPL/PG
Marlou Bordes
Hub Control Center
SPL/KC
Sjoerd Roorda
Tactical Planning
SPL/ST
Boris Boomkens
Business Development
SPL/KQ
Wouter Bongers


KLM Hub Operations Schiphol
AIRCRAFT SERVICES
VP Aircraft Services SPL/KG Paul van Westerhoven
Secretary SPL/KG Rochelle Keteldijk Naomi Oosterlen
Personnel & Organization SPL/GL Aafke Mazeyrac
Controller SPL/BZ Laura Kwantes
GSE SPL/KP
Information Management SPL/LX Ferry van Huut
Mngr. Operatie Vluchtondersteuning SPL/KG Bert Vos **
Winteroperatie SPL/KF Maarten Vos
Pushback - Towing SPL/KN Tanja Elting
Bruggendienst SPL/KY Ellen Dekkers
Mngr. Operatie Gereedstelling SPL/KG Anja Teeuwen * **
Catering & Board Supply Infrastructuur Airside AI SPL/KG Anil Oedairam
Cabin Quality SPL/KZ Diederik van Thiel
Aircraft Refuelling Department SPL/KE Nicole Veerbeek
Water & Toilet Services SPL/KF Lous Rijnbeek
Besturing & Infrastructuur Airside SPL/KG L Rijbeek a.i.
DMA's SPL/KG
Regisseurs SPL/KG
Proces Manager AS SPL/KG (vacature)
Operational Support SPL/KG Erwin Thijssen
Operational Support SPL/K3 Erwin Thijssen
PRI SPL/K3 Mark Bovenkerk
Commercial Contract Management SPL/KG Cindy Kapteijn
Magazijn & Ondersteuning GS SPL/KP Arnold Moes
Jetcenter SPL/WH Edwin Niemöller
Rotterdam RTM/WH Simon Lobrij
Amsterdam SPL/WH Louis Ventura

## C. Aircraft Services

**Aviobridge services (AHS)**

Airside handling support performs the connection and disconnection of the aviobridge at the gate. Furthermore, AHS facilitates crew briefings. They also drive the crew to the aircraft if it is at a remote location.

**Board Supply**

Board supply is the distribution of non-food in the aircraft. The cleaning companies perform this service after they are finished cleaning the aircraft. The supplies get on board with the catering supplies provided by KLM catering services (KCS), so this process is completely outsourced.

**Catering distribution**

KLM catering services (KCS) is a fully owned daughter company of KLM, providing the supply, preparation, and distribution of catering and non-food supply for all associated airlines at Schiphol.

**Cleaning**

KLUH and ASITO perform the cleaning of the aircraft, supervised by KLM. In addition they distribute the board supply and do security checks.

**De-icing**

The de-icing service removes ice (de-icing) from aircraft and prevents new freezing (anti-icing) before departure. De-icing does this at the gate or at a remote location just for departure. This service is on standby during the winter season, performing the service for departing aircraft when the climate conditions for de-icing are met.

**Flex tasks**

The flex tasks are services AS performs when there is a need for it; this includes cooling (summer) and heating (winter) of aircraft, providing jet starts to engines that cannot start on their own, connecting ground power units, and connecting stairs if there is no aviobridge available. Most of these services are the responsibility of Aqua Services.

**Pushback**

Towing performs the pushback for departing aircraft. This happens on all locations where it is not possible to depart without reversing. After a tug reverses the aircraft on to the taxiway, the aircraft continues to taxi on its own power.

**Refueling**

The Refueling service (KE) provides fuel to all airliners that are under KLM or Shell contracts at Schiphol. The Refueling process could be either pre-fuel or final-fuel.

KE mostly does pre-fuelling for intercontinental destination flights, fuelling aircraft when the workload is not at peak times. A pre-fuel takes in the minimum required amount of fuel the aircraft needs for its next flight.

Shortly before departure, KE performs a final-fuel such that each aircraft, pre-fuelled or not, has the exact requirement needed based on the in-flight weather and destination.

For the larger part, Schiphol uses a dispenser system, an underground system of piping that provides fuel at most of the gates. For the system dispenser trucks are used that hook up the aircraft to the piping. Locations that are not connected are serviced by bowser trucks, which need to be refueled themselves after refueling one or several aircraft.

**Security Check**

Schiphol, KLM, or one of the cleaning companies performs the security check. They check the aircraft on hazardous items and situations.

**Toilet service**

Aqua services empties and flushes the toilet tank of an aircraft. This service is separated from the water service for hygiene reasons.

**Towing**

Apart from pushback, towing is responsible for moving aircraft between gates, buffers, and hangars. Towing uses the same tugs as for pushback to tow the aircraft. This is done for different reasons:

- The arrival gate is different from the departure gate (gate-gate).
- For longer ground-times towing tows the aircraft to a buffer position (gate-buffer-gate).
- Maintenance is scheduled at Schiphol Oost (gate-hangar-gate).

**Water service**

Water service is the part of aqua services that refills and refreshes the water supply aboard the aircraft. Aqua Services separates this from the toilet service and never performs these services at the same time.

## D. Norm schedule/times for the turnaround of a 737-800

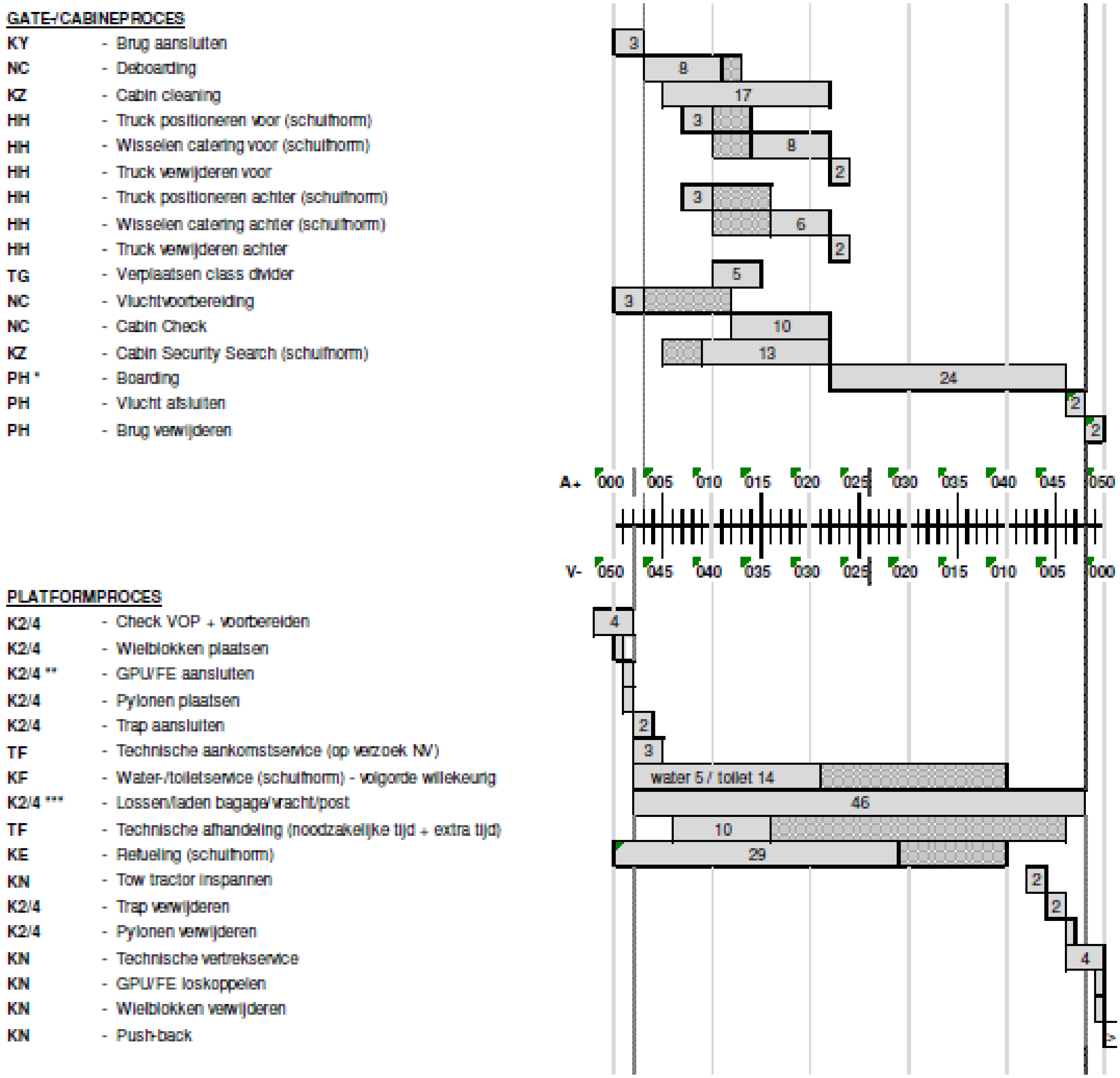



*Figure 49: Turnaround of a Boeing 737-800 (derived from Ground Operations Manual Schiphol)*

**A+ tijden V- tijden Afdeling Beschrijving activiteit**
A-02 V-52 K2/4 TLO / teamleden / materieel bij vliegtuig
A+00 V-50 K2/4 Wielblokken plaatsen
A+00 V-50 KY Aanvang brug aansluiten
A+01 V-49 K2/4 GPU/FE aangesloten
A+01 V-49 K2/4 Pylonen geplaatst
A+02 V-48 K2/4 Openen eerste vrachtdeur / aanvang lossen ruimen
A+02 V-48 K2/4 Aanvang trap aansluiten
A+02 V-48 TF Aanvang technische aankomstservice (op verzoek NV)
A+02 V-48 KF Aanvang water-/toiletservice
A+03 V-47 KY Brug aangesloten
A+03 V-47 NC Aanvang deboarding
A+04 V-46 K2/4 Trap aangesloten
A+05 V-45 KZ Aanvang cabin cleaning
A+05 V-45 KZ Aanvang Cabin Security Search
A+06 V-44 KL Afvoer hete transfer bagage
A+07 V-43 HH Aanvang positioneren catering truck voor
A+07 V-43 HH Aanvang positioneren catering truck achter
A+07 V-43 TF Aanvang technische afhandeling
A+10 V-40 TG Aanvang verplaatsen Class Divider (indien van toepassing)
A+10 V-40 HH Aanvang wisselen catering voor
A+10 V-40 HH Aanvang wisselen catering achter
A+13 V-37 NC Einde deboarding
A+16 V-34 KL Afvoer AMS bagage
A+16 V-34 KL Afvoer koude transfer bagage
A-10/0/5/15 V-60/50/45/35 * PH GA in gate (10 min vroeger indien geen SA 2)
A-10/+10/15/20/25V-60/40/35/30/25 * PH SA 1 in gate (10 min vroeger indien geen SA 2)
A-10/+20 V-60/30 PH SA 2 in gate (optioneel)
A+05 V-45 NC Cabincrew in gate
A+05/20 V-45/30 NC/Cockpit Uitsluitsel uitgifte cockpit-/crewseats
A+12 V-38 NC Aanvang Cabin Check
A+15 V-35 TG Einde verplaatsen Class Divider (indien van toepassing)
A+40 V-10 KF Einde water-/toiletservice
A+00 V-50 KE Aanvang refueling
A+22 V-28 KZ Einde cabin cleaning
A+22 V-28 Cockpit Cockpitcrew in vliegtuig
A+22 V-28 NC Einde Cabin Check
A+22 V-28 KZ Einde Cabin Security Search
A+22 V-28 PH Aanvang boarding
A+22/24 V-28/26 HH Einde wisselen catering voor / truck verwijderd
A+22/24 V-28/26 HH Einde wisselen catering achter / truck verwijderd
A+20/30 V-30/20 K2/4 Fysieke informatie-overdracht aan Captain en (Senior) Purser
A+35 V-15 PH Start inventarisatie ontbrekende pax / start gate is closing
A+35/42 V-15/08 PH Voltooien on-/offloaden pax / informeer TLO over ontbrekende pax
A+35 V-15 PH Start vluchtafsluiting
A+36 V-14 KL Afmelden laatste bagage aan K2/4
A+40 V-10 KL Laatste bagage bij vliegtuig
A+40 V-10 K2/4 Afmelden actuele belading aan KK (indien van toepassing)
A+40 V-10 KE Einde refueling
A+40 V-10 PH Einde ABC boarding
A+40 V-10 K2/4 Contact Captain bij vertraging
A+42 V-08 PH Codeco updated
A+44 V-06 KK-K2/4 Loadsheet in cockpit
A+44 V-06 KN Tow tractor ingespannen
A+44 V-06 K2/4 Aanvang verwijderen trap
A+46 V-04 PH Einde boardingproces
A+46 V-04 K2/4 Trap verwijderd
A+46 V-04 TF Einde technische afhandeling
A+46 V-04 KN Aanvang technische vertrekservice
A+47 V-03 K2/4 Pylonen verwijderd
A+48 V-02 K2/4 Einde laden ruimen / laatste vrachtdeur gesloten
A+48 V-02 PH (Laatste) passagiersdeur gesloten
A+48 V-02 PH Aanvang verwijderen brug
A+50 V-00 PH Brug geparkeerd
A+50 V-00 KN Einde technische vertrekservice
A+50 V-00 KN GPU/FE losgekoppeld
A+50 V-00 KN Wielblokken verwijderd
A+50 V-00 KN Aanvang push-back

# E. Comparison matrix Aircraft Services

| | **Airside Handling Support** | **Board Supply** | **Catering** | **Cleaning** | **De-Icing** | **Flex-tasks** | **Pushback** | **Refueling** | **Security Check** | **Toilet Service** | **Towing** | **Water Service** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Arrival/Departure Oriented/Strict process* | Strict | Oriented | Oriented | Oriented | Strict | Oriented | Strict | Oriented | Oriented | Oriented | Oriented | Oriented |
| *Dependent on aircraft type* | x | | | | x | | x | x | x | x | x | x |
| *Dependent on destination* | | x | x | | | | | x | | | | |
| *Gate allocation dependent* | x | | | | x | x | x | x | | | x | |
| *Dependent on # passengers* | | x | x | | | | | | | | | |
| *Dependent on weather* | | | | | x | x | | x | | | | |
| *Norm time (737-800)* | 3 | | 13 (front side)/ 11 (back side) | 17 | | | | 29 | 13 | 14 | | 5 |
| *Process duration / norm ground time (oriented processes, aggregate all aircraft)* | 0.045 | 0.483 | 0.483 | 0.439 | Unknown | 0.022 | | 0.565 | 0.184 | 0.229 | | 0.257 |
| *Process time standard deviation (aggregate all aircraft)* | 1.37 | Unknown | Unknown | 14.79 | Unknown | 4.61 | | 13.58 | 3.56 | 2.75 | | 5.51 |
| *Coefficient of Variation* | 0.28 | Unknown | Unknown | 0.46 | | 0.73 | | 0.34 | 0.26 | 0.34 | | 0.39 |
| *Makes use of planning* | | Outsourced | Outsourced | Outsourced | No long-term planning, no GOMS norm | No long-term planning, no GOMS norm | Not reliable/in use | X | | X | Not reliable/in use | X |
| *Flexible time windows* | | | x | | | | | x | x | x | | x |
| *Sequence dependent* | x | x | x | x | x | x | x | | x | | x | |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Other processes* | | | Brings board supply aboard aircraft | Performs distribution of board supply | | | No other services can be performed | | | Performed by Aqua Services | No other services can be performed | Performed by Aqua services |
| *Outsourced* | | x | x | x | | | | | | | | |

*Table 17: Comparison of aircraft services, based on current information and Harmsen(2012)*

## F. Screenshot CHIP

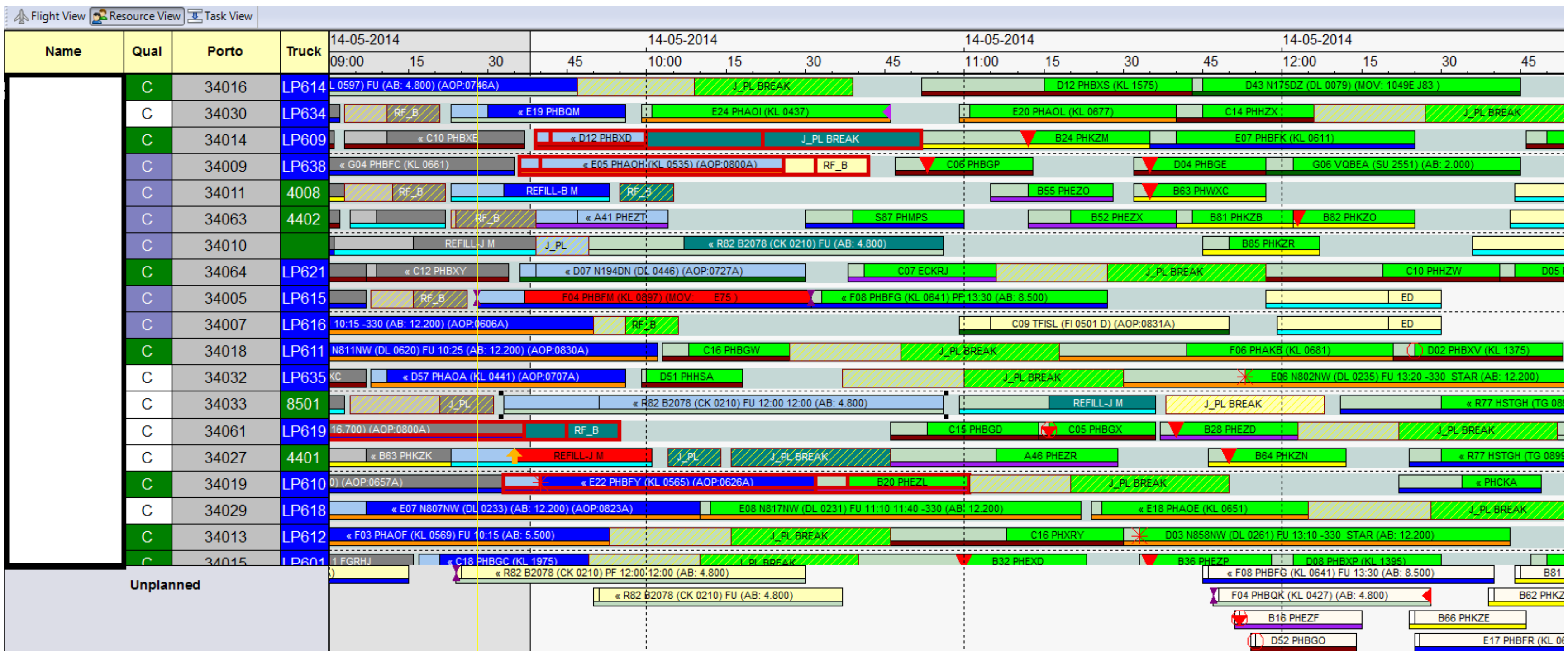



*Figure 50: All operators on shift, and their planned tasks plus all unplanned tasks as seen in CHIP.*

## G. Comparison CHIP with shifting time windows

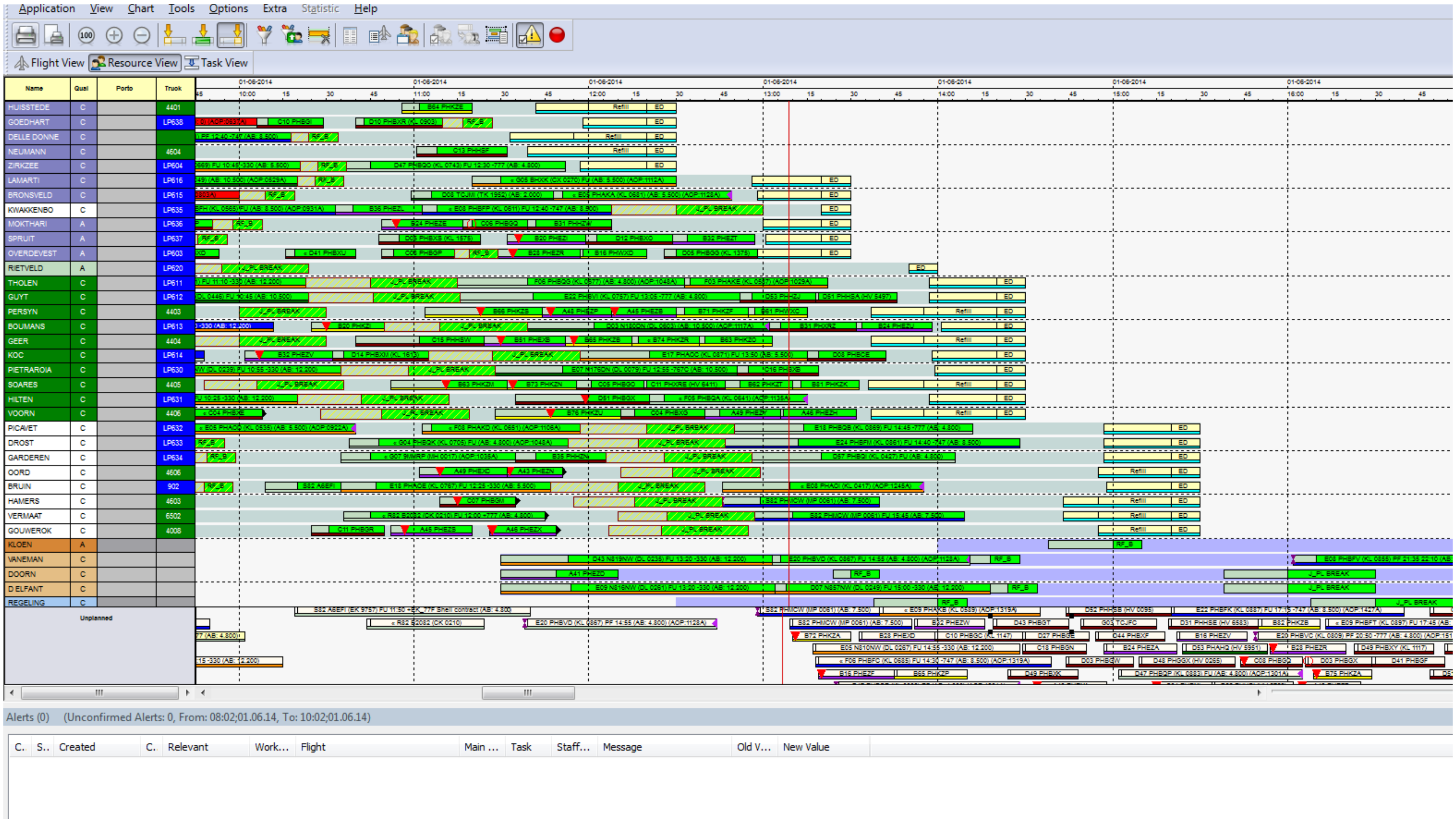



*Figure 51: Around 10:00 to 12:00 almost all tasks are scheduled. The red line indicates the end of the optimization window.*

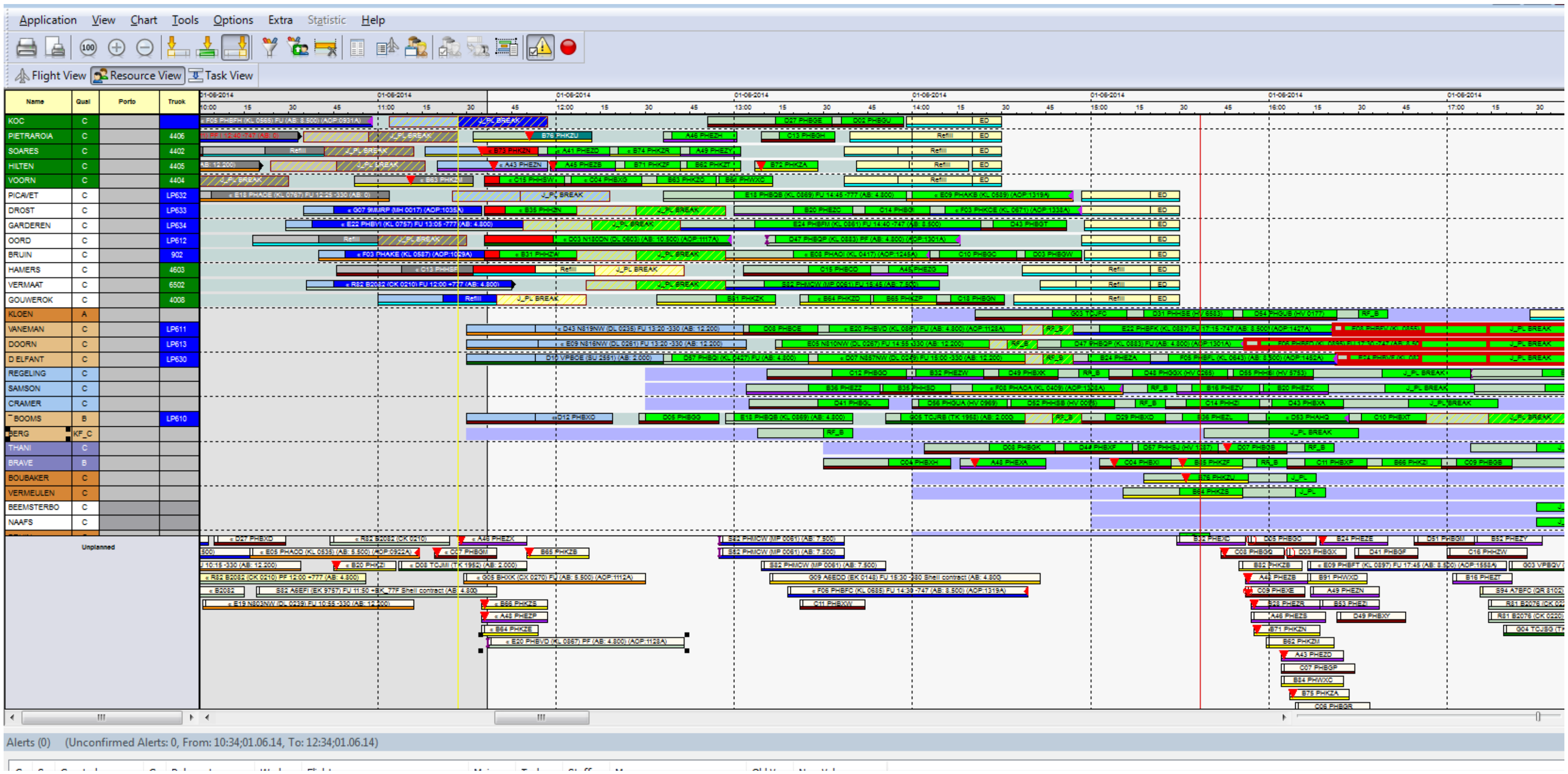



*Figure 52: A few hours later tasks are not executed and unplanned between 10:00 and 12:00. The red line indicates the end of the optimization window.*

## H. Screenshot flight schedule

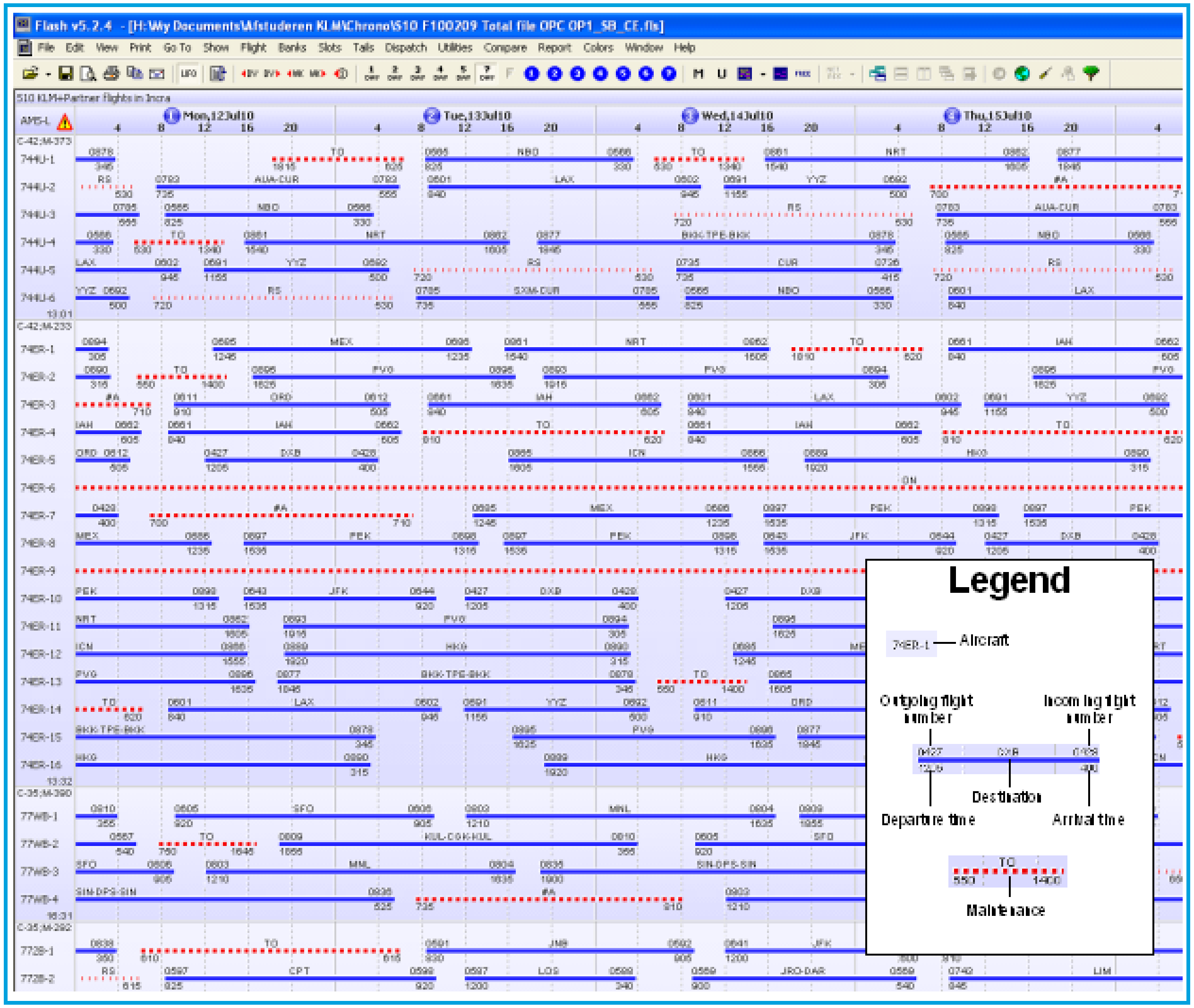



*Figure 53: Screenshot of KLM flight schedule*

# I. Airport Layout

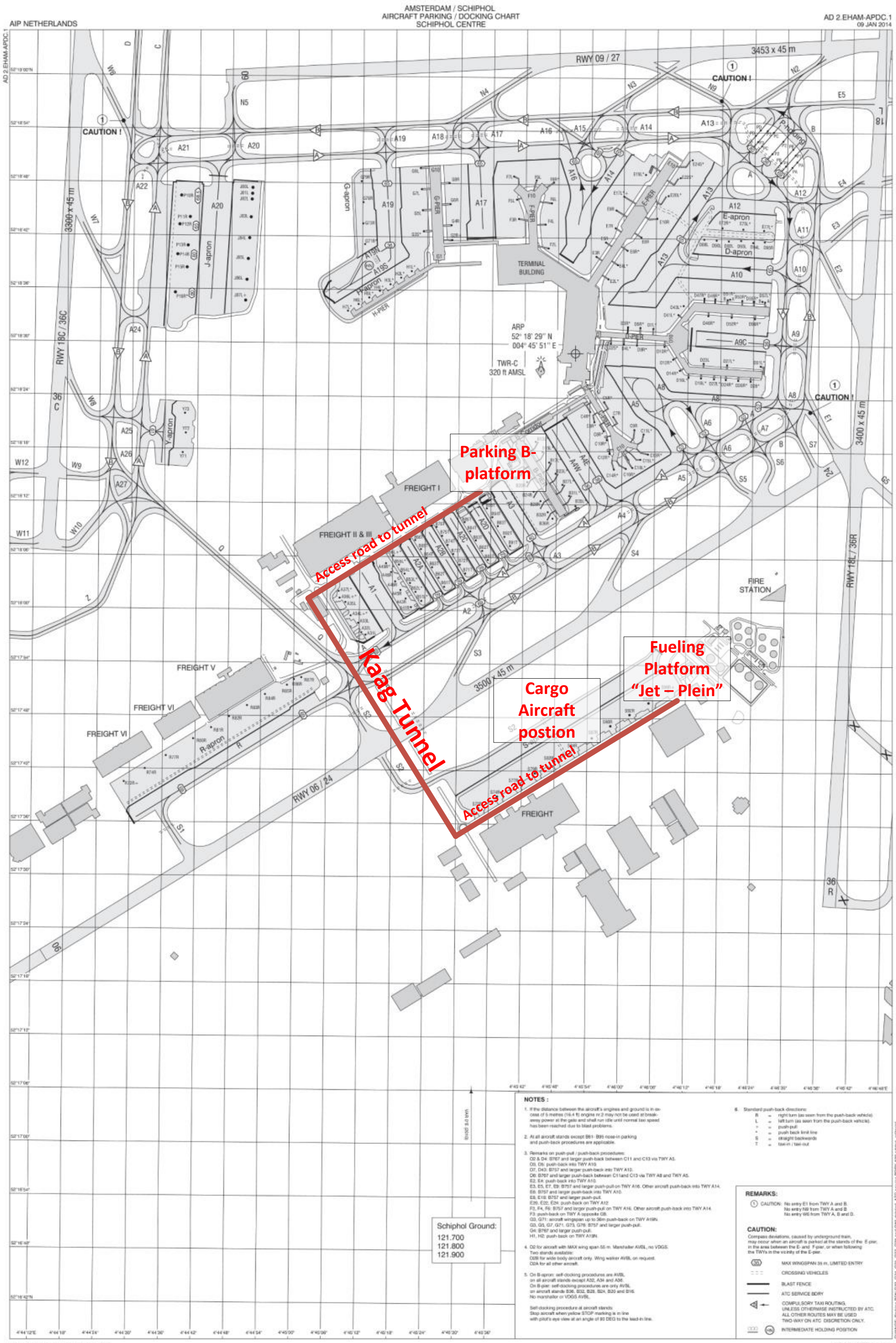



*Figure 54: Airport map, tunnel connecting the Fueling platform to the terminal*