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Slack in production plans

Illustrations from slack in transportation

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Submission date: June 2015
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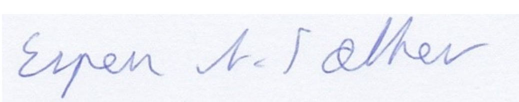
i. Preface

This thesis, TPK4920, represents my final work of the five-year Master of Science program in mechanical engineering at the Norwegian University of Science and Technology (NTNU). The thesis is weighted at 30 credits. In addition to giving me experience in, and knowledge about, writing academic reports, the purpose of the thesis has been to review the concept of slack.

An attempt has been made to define the concept of slack in the context of production planning. After reviewing slack in general production planning the focus was narrowed down to production planning in transportation. The topic was chosen due to both a professional interest in production planning and a personal interest in transportation planning.

A big thank you goes to my supervisor Professor Nils Olsson. He has contributed largely to this thesis through essential feedback throughout the writing process, and by being available to provide input and answering questions during the whole period. His knowledge and experience has proved invaluable.

Thanks also goes to Andreas Hægstad from NSB, Helge Holtebekk, Helena Volen and Iver Wien from Ruter, Avinor at Værnes airport and Panagiota Kostara from Kolumbus. All of the mentioned has contributed data to the thesis work in addition to being available for questioning. This thesis would not be possible in its current shape without their help. Finally, thanks go to Thor Sæther for reading through the final discussion and conclusion before delivery.



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10.06.2015

ii. Summary

The purpose of this thesis has been to define the meaning of slack in organizational context before reviewing how slack is viewed in manufacturing and logistics theory. Finally, an attempt has been made at reviewing literature and analyzing data in terms of slack in transportation industries. In manufacturing and logistics literature, the scope has been narrowed to briefly include ideologies and line of thought with a focus on relevance to slack. The same method is used for transportation production planning. In this case, the scope includes timetable planning and fleet/vehicle planning only.

Both qualitative and quantitative methods have been utilized to write this thesis. Literature used was found through searches in Google Scholar and BIBSYS Ask, in addition to webpages relating mostly to the actors involved in the data analyses section. These sources are considered to be of good quality, and should therefore provide reliable information. NSB granted access to their punctuality and utilization database, and NSB, Ruter, Avinor and Kolumbus provided data through Microsoft Excel spreadsheets. Data was also gathered from MiT, Norwegian.com and Flightradar24.com. The data used is considered accurate and reliable. Microsoft Excel was used to analyze and compile data.

The thesis has revealed that there are mainly two aspects related to slack in production planning. Slack that are present due to poor processes are considered waste and should be removed. If slack on the other hand is used as a tool to cope with uncertainty, it can be an enabler for quality. In transportation, slack is mostly mentioned related to buffer times that allow acceptable punctuality. The use of back-up vehicles/rolling stock/aircraft is also frequently mentioned.

Data analysis, together with the literature review, showed that there are differences in the use of slack among transportation industries and segments within industries. It was also clear, however, that in order to compare the use of slack in different industries it is necessary to account for the different characteristics of modes and business models. This includes the difference in uncertainty and consequence of poor performance. In relation to this, it has been shown that there are indications of a relationship between the amounts of slack and uncertainty. Further research could be directed towards quantifying the amounts of slack and the uncertainty in a more precise manner. Quantifying the relationship indicated in this thesis more accurately would allow a better and more direct comparison between the different industries and segments.

iii. Oppsummering

Målet med denne masteroppgaven har vært å definere betydning av slakk i organisasjoner, før det så er foretatt en gjennomgang av hvordan man ser på slakk innen produksjons- og logistikkteori. Til slutt har det blitt gjort et forsøk på å gjennomgå litteratur og å analysere data innen ulike transportindustrier med bakgrunn i slakk. Innen produksjon og logistikk er omfanget begrenset til å inkludere ideologier og tankesett med fokus på det som er relevant for slakk. Samme metode er brukt for å gjennomgå produksjonsplanlegging innen transport. I dette tilfellet er omfanget begrenset til å kun inkludere ruteplanlegging og flåte-/kjøretøysplanlegging.

I denne oppgaven er det brukt både kvalitative og kvantitative metoder. Literaturen som er brukt for å skrive oppgaven er funnet gjennom søk i Google Scholar og BIBSYS ASK, i tillegg til internettsider som for det meste inkluderer hjemmesidene til noen av aktørene i dataanalysen. Disse kildene er ansett for å være av god kvalitet, og informasjonen er dermed til å stole på. NSB ga tilgang til deres punklighets- og utnyttelsesdatabase, mens NSB, Ruter, Avinor og Kolumbus bidro med data gjennom Microsoft Excel regneark. Data ble også samlet fra MiT, norwegian.com og flightradar24.com. Dataene er ansett for å være presise og pålitelige. Microsoft Excel ble brukt til å analysere og sette sammen data.

Oppgaven har vist at det i hovedsak er to aspekter relatert til slakk i produksjonsplanlegging. Slakk som finnes på grunn av dårlige prosesser er ansett for å være uønsket og bør bli fjernet. Dersom slakk på den andre siden er brukt som et verktøy for å takle usikkerhet kan det være en tilrettelegger for kvalitet. Innen transport er buffertider som muliggjør akseptabel punktlighet det som er nevnt oftest i forbindelse med slakk. Bruk av reservekjøretøyer er også hyppig nevnt.

Dataanalysene, sammen med litteraturgjennomgangen, viser at det er forskjeller mellom transportindustrier og innen den enkelte industri når det gjelder bruken av slakk. Det kom fram at for å kunne sammenligne bruken av slakk på tvers av industrier og segmenter er det nødvendig å ta høyde for de ulike karakteristikkene i moduser og forretningsmodeller. Dette inkluderer forskjeller i både usikkerhet og konsekvensene av dårlig ytelse. I sammenheng med dette er det vist at det er indikasjoner på at det finnes en sammenheng mellom mengden slakk og usikkerhet. Videre forskning kan rettes mot å kvantifisere mengdene av slakk og usikkerhet på en mer presis måte. Gjennom å kvantifisere sammenhengen indikert i denne masteroppgaven nøyere vil man kunne gjøre en bedre og mer nøyaktig sammenligning mellom ulike industrier og segmenter.

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1. Introduction

1.1 Background

In disciplines like supply chain management and manufacturing planning and control, there are a large variety of different strategies that are applicable to different scenarios and market conditions. It is common to place these strategies in between two extremes. The basic ideas is that one of these extremes is to fully optimize processes in terms of costs, while the other one attempts to handle and cope with larger uncertainties and will therefore require more flexibility and freedom to maneuver. The term "slack" is thus more related to the latter, and this includes factors like buffers, back-up resources and degree of utilization among others.

The supervisor, professor Olsson, suggested the topic of the thesis after a meeting in a research group called "Presis" (Precise). This research group is focusing on railways and during this meeting it was suggested that it could be interesting to do a master thesis focusing on slack in railway production planning. It was also mentioned that the topic could potentially have a link to punctuality in railways, which was the topic of the author's specialization project.

After being presented with the potential topic, there was several discussions between the author and professor Olsson about how to proceed from there. The discussion included potential angles that the thesis could take and also potential changes and extensions. It was decided early on that the theoretical part would consist of well-established strategies within production management, including lean, and logistics management, with a particular focus on the concept slack and how this concept is normally used and implemented.

A prerequisite for the topic was also that it would link the theoretical part to the railway, and railway production planning in particular. During the discussions, however, it was mentioned that a possible angle for the thesis could be to compare the use of slack in production planning between different transportation modes. This would include the railway, and could potentially also include bus companies, airlines and others. The goal of such a thesis would be to gather the experiences from the use of slack in production planning amongst different transportation modes, and to uncover differences in the use and implementation of slack. After some final discussions about potential data and partners, it was decided to continue the thesis process with this topic.

1.2 Problem definition

The main topic of this thesis is thus the concept of slack. More specifically the thesis will review the concept of slack in logistics and production planning in order to gain a solid theoretical basis, before analyzing the use of slack in transportation production planning based on both literature and data provided from partners. Based on this the thesis problem definition is the following:

1. The concept of slack
    1.1. What is the definition of slack?
    1.2. Which different aspects of slack in general can be identified?
2. Slack in transportation production plans
    2.1. Which types of slack are applicable in transport?
    2.2. What levels of slack do the selected modes of transport have on the selected types of slack?
    2.3. What are challenges when comparing slack levels between different modes of transportation?

The problem definition is derived from the official thesis description, which is:
"The thesis will study the use of slack in production plans in transport companies. The theoretical part addresses the concept of slack in logistics and production planning, while the empirical part will include analysis of data from railway production."

1.3 Scope and limitations

The thesis will be based around the topic “slack in production planning”, and slack related to transportation industries in particular. An attempt will be made to introduce the concept of slack and to give an overview of the use of slack in manufacturing and logistics theory, before reviewing how slack is used in different transportation industries.

The concept of slack will be the used as the common thread of the thesis, and the concept and its use in the thesis is defined properly in an early chapter. This chapter will try to define the word itself, the concept in the context of this thesis and review similar terms and expressions that are interchangeable with “slack”.

Since the fields of manufacturing and logistics strategies are immense, these will only be reviewed briefly, with a focus on how slack is viewed and used. This means that common concepts like Lean manufacturing, Total Quality Management and the lean and agile supply chains, which on their own could easily provide a basis for thesis work, will be barely touched upon through an attempt to show their take on slack.

After the defining of slack and the review in terms of manufacturing and logistics strategies the focus will change to transport. A general introduction to transportation and to the respective transportation industries will be given, with a focus on production planning. Production planning in this thesis will be limited to timetable planning and materials planning, and will thus exclude personnel planning, maintenance planning and other similar activities. This part will also include the take on slack in each industry.

Finally, the thesis will contain some data analyses that will attempt to show and reveal the use of slack in the different transportation industries in a mostly quantitative manner. The goal is to try to compare the use of slack in the mentioned industries to find similarities and differences. Four parameters will be used for this comparison, divided on two categories. The first category is route planning, which contains the parameters recovery time and turnaround ratio**.** The second is fleet planning and contains fleet utilization and materials utilization. These are defined in chapter 10. Data made available from several actors is used in the analyses.

1.4 Structure of the thesis

The thesis starts with a thorough review of the methods used to write the thesis in chapter 2. This is done to give the reader a better understanding of how the literature review and data analysis has been performed, and to fully appreciate the thesis. It also gives others an opportunity to continue or criticize the work.

After presenting the method, chapter 3 will start by introducing and defining the concept of slack. Since the concept of slack will be the common thread throughout the thesis this is an important chapter. After the defining of the concept there will be a review of similar terms and concepts that in practice can be interchangeable with the term slack, and finally there will be a summary that describes how the concept is used and interpreted through the rest of the thesis.

Chapter 4 represents a very small part of the thesis, but still plays an important role. Some definitions and clarifications when it comes to strategy and the use of strategy will be made, as well as an attempt to explain if and how operations management differ from supply chain management. This is done to provide a backdrop before discussing different strategies within these fields in chapter 5.

When the terms mentioned din the previous paragraph have been clarified, the thesis will move on to describe and discuss important manufacturing and supply chain strategies and ideologies in chapter 5. This chapter is meant to be a reference on the use of slack, and is thus meant as a baseline for comparison when discussing slack in transportation industries. The chapter will provide an overview of the strategies and ideologies, and briefly describe those that are deemed to be most relevant with a focus on slack.

Following this introduction to strategies and ideologies is the chapters about transportation. Chapter 6 will be used to give general information about transportation, critical success factors within transportation and also an overview of planning processes that are relevant to all of the transportation industries included in this thesis.

Chapters 7, 8 and 9 will introduce the railway, urban transportation and the airline industry respectively. These chapters will describe the characteristics of each industry and review how timetable planning and materials planning are done with an emphasis of how slack is and can be implemented. The reasoning behind these chapters is to be able to compare the use of slack between industries, and to compare the use of slack to the manufacturing strategies.

When the description of the characteristics, planning methodologies and take on slack is done, chapter 10 contains the data analysis part of the thesis. Chapter 10 contains analyses from all of the different industries, separated in to different sub-chapters. Data from different sources will be analyzed and presented based on the parameters mentioned in chapter 1.3 for each industry. Each sub-chapter will have a summary in the end, presenting the findings in a way that allows for comparison between industries.

Finally, chapter 11 will provide a discussion about the concept of slack. This discussion will aim to reveal the different aspects of slack and to connect the concept of slack to the results of the data analyzes. Chapter 12 will contain the conclusion, answering the problem definitions given in chapter 1.2. References are presented in chapter 13.

2. Methodology

As was mentioned in the pre-study report (See appendix 1), Olsson (2011) says that it is common to separate between quantitative and qualitative methods. The two can also be combined. Quantitative methods are methods that makes of use of measureable and quantifiable data, and can thus provide exact results. These methods focus on precision and are recognized by a high degree of verifiability. Qualitative methods on the other hand are based on textual or spoken information. The main focus in these methods are often to achieve an overall understanding of the issue at hand.

This thesis applies a combination of qualitative and quantitative methods in order to answer the problem definitions shown in chapter 1.2. Chapters 3 through 9 are done as literature reviews and are thus done qualitatively, while chapter 10 mostly uses quantitative methods in order to quantify several parameters related to the problem definitions of this thesis. The final discussion and conclusion will be of a mostly qualitative manner.

To establish a theoretical background for the concept of slack it was necessary to do some literature searches for both definitions of the term slack and how it is used, before doing the same for similar expressions that are used interchangeably with slack. The content of chapter 3 was therefore found in different sources. Definitions of the word itself was found in online dictionaries and they were also used to find synonyms for the word slack in order to establish a base of similar expressions that could potentially be used in scientific literature. The part about how slack is used and described in the different fields of study was found in the same literature that was used to write chapters 4 through 9, and this part was thus written after or at the same time as these chapters for natural reasons.

Chapters 4 and 5 regarding manufacturing and logistics strategies were completed by doing a literature searches. The chapters were written using textbooks about strategy, manufacturing and logistics as the main baseline, while adding information from research papers and the likes to provide more details and empirical results to increase the quality of the work. Original sources have been traced down where possible. Some information from relevant lectures was also used where fitting for the same reason. Literature searches were mostly performed using Google Scholar and the database BIBSYS ask. These search tools are considered to be reliable, and there is thus no reason to doubt the credibility and precision of this information. Some websites of consultancy firms and similar were also used to help with superficial definitions and descriptions. These were reviewed more critically than other sources, and cross-checked against textbooks whenever there was any doubt.

A similar method was used for the subsequent chapters 6 through 9 about transportation in general and the specific transportation industries. The goals of these chapters are to present the characteristics of transportation and each industry in such a way that both a comparison of the use slack between the respective industries and between the transportation industries and the established manufacturing and logistics norm is possible. It is also the purpose of these chapters to provide a theoretical background for the data analyses. Textbooks about the respective industries where again used as a general baseline, while information from research papers and industry journals provides details to improve the quality and depth. The search tools Google Scholar and BIBSYS ask was used once again, and should ensure the quality of the information.

Chapter 10 separates itself from the other chapters. This chapter contains the data analyses section, and is thus of a more quantitative nature than the other chapters. Most of the sub-chapters contains data analyses aiming to provide solid quantitative results, while a few uses a combination of quantitative and qualitative methods due to the nature of the available data. The data in the different sub-chapters come from several different sources, and each of them will therefore be described separately in the next paragraphs. Microsoft Excel was used to perform all data analyzing and compiling.

The Norwegian railway company NSB, through Andreas Hægstad, provided data related to the railway. Data about runtime calculation for the case stretches and data regarding the Iceberg benchmarking project where provided directly in the form of excel spreadsheets. In addition to this access was granted to NSB's traffic database. This database was later used to find the data regarding fleet utilization. The quality of this data is thus deemed to be good. All of this data were later gathered in Microsoft Excel were it was compiled in a suitable way for presentation in the thesis.

Different departments of Ruter has provided the bus and subway data for the data analysis. Both sent the data in the form of Microsoft Excel spreadsheets. Bus data was given by Helena Volen as punctuality data for a given period in order to compare this to the scheduled run time. Helge Holtebekk provided subway data, and this included fleet and materials utilization data for the thesis case period. Data is thus gained straight from the source and the quality and reliability is considered adequate.

Data about Norwegian Long Haul is gathered based on the author's creation of the airline's timetable and fleet planning for the period of 09.03.15 to 22.03.15 in Microsoft Excel. The timetable was created using a combination of Norwegian.com (2015) and flightradar24.com (2015), and was made possible due to the limited fleet size of the airline. The first provided departure and arrival times while the second showed which aircraft flew where.

Using this method should provide a correct timetable as the information from these websites are considered accurate, but will of course be subject to human error since it is done manually. An example of this occurred when on the 18th of march an aircraft is supposed to have taken off and landed at the same time, which is of course not possible. Data on flightradar24.com is only stored for 2 weeks, and there is thus no way to correct the error. The error shot not have a crucial impact on the final numbers, in the best case scenario it is evened out during the next day. Thorough review of the data has not revealed any similar problems. The created timetable and other data not included in the main part of the thesis can be found in appendix 2.

MiT (2015a) provides detailed data about aircraft utilization among larger American airlines spanning over a decade as a result from an airline data project. Data from the last two years of the project for several of these airlines was compiled in Microsoft Excel in order to provide results comparable to the other data in the thesis and to divide the data on the desired categories. With the reputation of MiT as an institution in mind it is assumed that the data provided are accurate, and they also disclose data that are considered to be questionable.

Avinor, the Norwegian airline authority, at Værnes Airport in Trondheim provided raw punctuality data for the period 01.01.15 to 30.04.15 in a Microsoft Excel spreadsheet. This data was sorted by airlines using the filter function in excel, and the sorted spreadsheet was later used to find the scheduled turnaround times for the airlines operating at Værnes without based aircraft. Finding the scheduled turnaround times were done using the scheduled arrival and departures times, and there is no reason to doubt that the times given are incorrect. Information about the turnaround times for each aircraft type was gathered from the respective manufacturers. While it should be remembered that these presentations are made to sell aircraft, and thereby considered optimal times, they give a good starting point for discussions about slack.

3. The concept of slack defined

One of the goals of this thesis is to do a review of the term slack and identify different aspects of slack in the context of manufacturing and logistics. It is therefore necessary to define and point out what the term implies in this case. Most have some idea of what introducing slack processes would mean. Since there are many similar terms and expressions that in many cases are used interchangeably, it is still necessary to define and discuss what the meaning is in this thesis.

Firstly, an attempt will be made to define the word slack and what it can mean in different circumstances and context. After this section there will be a section reviewing the meaning of slack in organizational context. This includes different expressions and terms used in manufacturing and logistics lingo that in practice will be synonyms to slack. Finally, a short summary will define how the term is used in this thesis, in order to give the reader the opportunity to follow the authors line of thinking and to judge the work based on this prerequisite.

3.1 Definition of the word slack

The Oxford Online Dictionaries (2015a) gives several definitions of slack. The first is that slack means "not taut or held tightly in position; loose". This definition mostly gives a reference to physical objects like screws or handles, but still gives a good starting point for the desired definition for this thesis. Their second definition says that slack is "decrease or reduce in intensity, quantity or speed", which gives a turn towards a definition that is significantly more relevant to this thesis. The final definition given by the Oxford Online Dictionaries (2015a) is directly related to business or trade and says that slack in this context is "characterized by a lack of work or activity; quiet."

Thesaurus.com (2015) defines slack as "loose, baggy; inactive", which overall is very similar to the definitions given in the previous paragraph by The Oxford Online Dictionaries (2015a). They also provide commonly used synonyms to slack, and these include quiet, slow, flexible and relaxed. Finally, they also give examples of antonyms of slack. These include active, quick, rigid and tight. Together these definitions, synonyms and antonyms give a clear insight in what the word slack means. After establishing this basis, it is possible to show and define how the concept is used in manufacturing and logistics.

3.2 The concept of slack in organizational context

Galbraith (1984) mentions slack as a design strategy when it comes to organizational design. He says that when task uncertainty increases organizations must take action. He describes two possible general ways to proceed, where the first is to reduce the amount of information that is processed and the other is to increase information handling capacity. One of the methods that can be implemented to reduce the need for information he says is the creation of slack resources. The meaning of the creation of slack resources in Galbraiths (1984) context is increasing planning targets so that fewer exceptions occur. This could be extending completion dates, raising budget targets, having buffer inventory and the likes. The greater the uncertainty, the greater the magnitude of the inventory lead time or budget needed to reduce an overload. The goal of this is to reduce the interdependence between subunits. We see that the description of slack resources fits the definitions from chapter 3.1.

Finally, he mentions that this kind of strategy has its natural costs. Relaxing budgets requires more budget, and increasing the time to completion delays the product to the customer. Increasing buffer inventories binds up capital funds that could have otherwise been used elsewhere. This means that if slack resources is to be used it is of crucial importance to make qualified choices about which resources to make use of and how much of the respective resource should be used.

Pinto (2013) mentions slack in project management, and says that slack (or float) is related to each of the identified activities, and shows which activities in the project that can be delayed and the ones that cannot. This fits the before mentioned definitions of slack, as it is the activities that can be moved are loose, while the activities that cannot be delayed are rigidly “held in place”.

Olsson (2006) mentions slack when discussing flexibility strategies in relation to redundancy and change management. The term slack is in this case more or less used as a synonym for high redundancy. In the case where you choose to manage changes, the high redundancy is related to over-specification so that there is a certain flexibility in the product or decision process. If the choice is to manage the changes on the other hand, high redundancy is meant as the capacity to manage a wide range of changes. This is done through budget reserves, time slacks and organization capacities to handle change among other possible measures. In this context high redundancy is very similar to Galbraiths (1984) description of slack resources.

As can be seen in the previous paragraphs there are several other terms than slack that can be used to describe similar measures or consequences. These are synonyms in practice, which means that it is important to recognize and know about these terms before reviewing the literature on strategy.

Redundancy was mentioned as a potential synonym to slack as mentioned by Olsson (2006). The Oxford Online Dictionaries (2015c) defines the word redundancy as “the state of being not or no longer needed or useful.” Drawing the line from this definition to the definitions of slack is not hard, and this shows that they in an organizational and strategy context very well could be used for the same measures.

Olsson (2006) mentioned “budget reserves” as a slack measure. Reserves, or back-up, is a term that are often used in such a context and can for example also be related to reserve personnel or materials. The Oxford Online Dictionaries (2015d) defines a reserve as “retain for future use”. Again, this is similar to the meaning of slack when it is considered to mean inactive or not in use.

Another term mentioned by Galbraith (1984) in the context of slack resources is the term buffer. The Oxford Online Dictionaries (2015e) defines a buffer as “A person or thing that reduces a shock or that forms a barrier between incompatible or antagonistic people or things”. This definition does not have the obvious link to slack that the previously mentioned terms had. It can however be said that having a buffer is a form of slack in the sense that the buffer resources are inactive and does indeed reduce the tempo of the organization.

A final concept that can be mentioned related to slack is the term contingency. One of the definitions of contingency made by The Oxford Online Dictionaries (2015f) is that it is “a provision for a possible event or circumstance”. It is clear that in practical terms this means that by implementing contingency measures one hopes to achieve the same as if one is introducing buffers or reserves, and thus there is a link to slack also in this case.

3.3 Use of slack in this thesis

As shown in the previous sections, many terms and concepts are used when processes and activities are performed in a way that is not optimized in terms of cost or time. This means that the term slack in itself could be considered an umbrella term for all of these, particularly when discussing slack as a concept in broad terms.

This thesis will therefore make a broad use of the concept slack, and also make use of the more specific terms like the ones mentioned earlier. It will be assumed that from this point in the thesis it is understood that these terms implies the use of what in this context is referred to as slack. The explicit word slack will be used for all summaries, discussions and data analyses made by the author.

Not everyone will agree that all introductions of buffers and similar methods should be considered slack. This might be the case if for example the buffers are necessary to deal with unavoidable uncertainty. In this thesis such implementations will be referred to as slack, but using the literature review and data analyses results it will be discussed if slack is indeed a necessity in the individual cases. In other words, slack will not be regarded as something “bad”, but a tool that might be appropriate under certain circumstances.

It is also important to be aware of the fact that the listed concepts related to slack is by no means a complete list, and there could thus be other examples of similar nature.

4. Introductions and definitions

The purpose of this chapter is to define and to give a very short introduction some important terms and concepts that are very relevant as a backdrop to the working questions in this thesis. It aims to give an idea of why it is important to be conscious of the choice of strategy, and to define the functions and activities relevant for the strategies and ideologies mentioned later on.

4.1 Strategy

In this thesis, introducing the term strategy and providing some insight in to generic ways to think about strategy is only meant to underline how important it is to have a conscious relation to strategy and strategic decisions in organizations. The reasoning behind this is that the choice of implementing slack in production planning has to be made on the grounds that it fits the strategy, helps the organization reach its goals and most importantly create value for the end customer. This chapter will thus only touch the surface of strategic literature in order provide some background for the ideologies and strategies presented in chapter 5.

The Oxford Online Dictionary (2015b) defines a strategy as “a plan of action designed to achieve a long-term or overall aim”. While this definition gives a clear idea of what a strategy is and what it hopes to achieve, it is still very general and to diffuse for being of any practical use.

Rangone (2014) uses a similar definition of a strategy, but gives a more specific description of what a strategy is in business terms. He says that a strategy is an “integrated comprehensive plan which identifies the scope and direction of the organization, is aimed at obtaining long term performance superior to competitors and integrates a coherent set of strategic decisions”. The definition includes the term “strategic decisions”. He defines this as a “decisions that has long term, significant and non-reversible effects on the final goal of the organization, and that usually requires large amounts of resources”.

Slack, Chambers and Johnston (2010) does not define strategy per se, but say that a strategy is recognized by several describing remarks. They start by saying that a strategy should set broad objectives that drive the organization towards its goals and contain a general plan of how to achieve these goals. So far, this is very similar to the definition made by Rangone (2014). In addition they expand the definition and say that a strategy also stresses long-term objectives, deals with the total picture and that it is detached from the day-to-day activities.

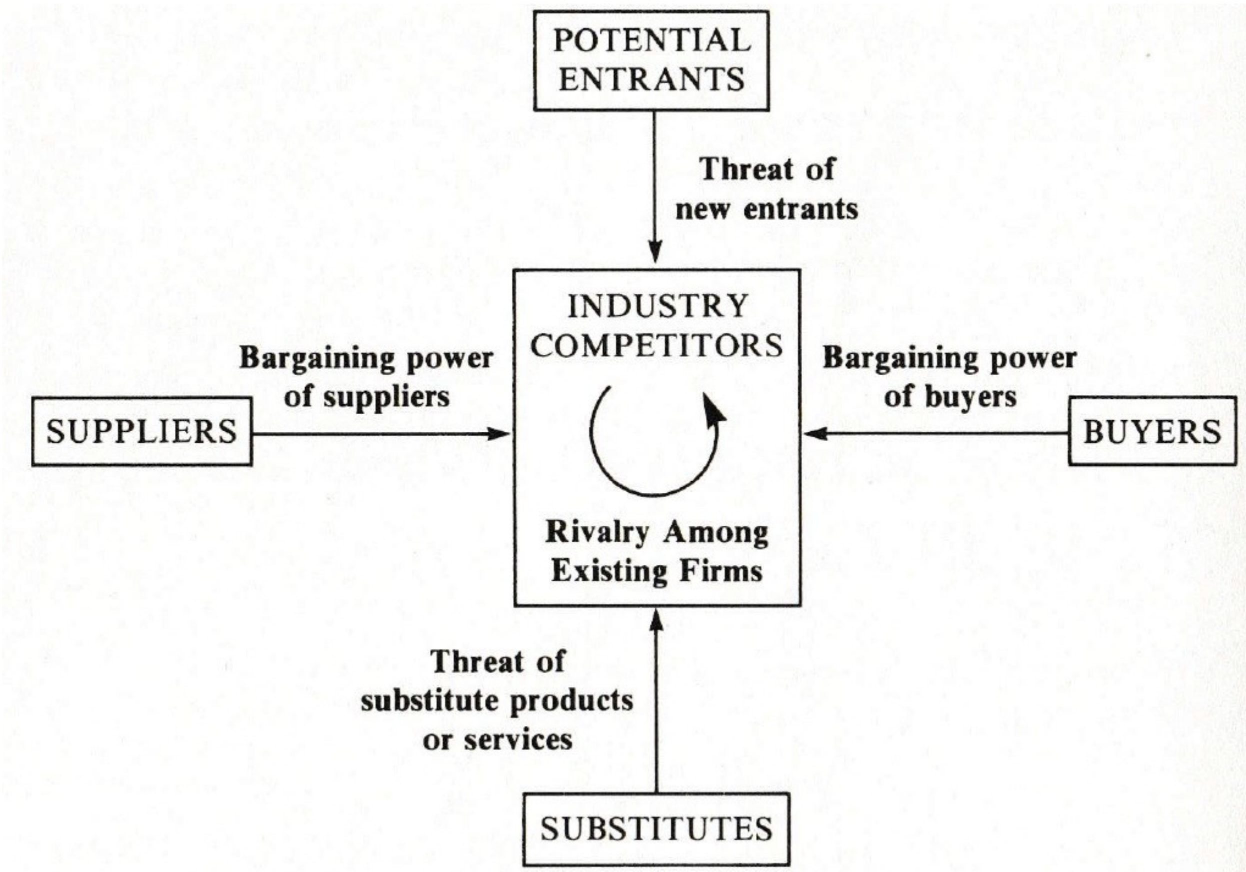

Figure 1. Forces Driving Industry Competition (Porter, 1998, p.4)

Porter (1998) mentions what he calls the five competitive forces. These can be seen in figure 1. Based on these competitive forces he says that on the broadest level it is possible to identify three internally consistent generic strategies that can be used alone or in combination to allow the company to create a defendable position in the long run, and to outperform competitors. These are:

1. Overall cost leadership: Achieve overall cost leadership in an industry through a set of functional policies aimed at this objective.
2. Differentiation: Differentiating the product or service, creating something that is perceived industrywide as being unique.
3. Focus: Focusing on a particular buying group, segment line or geographic market.

Whittington (2001) summarizes strategies in to four different generic strategy categories or perspectives. These are shown in figure 2, and as can be seen from the figure they differ substantially along two axes, namely when in terms of outcomes of the strategy and the processes by which it is made.

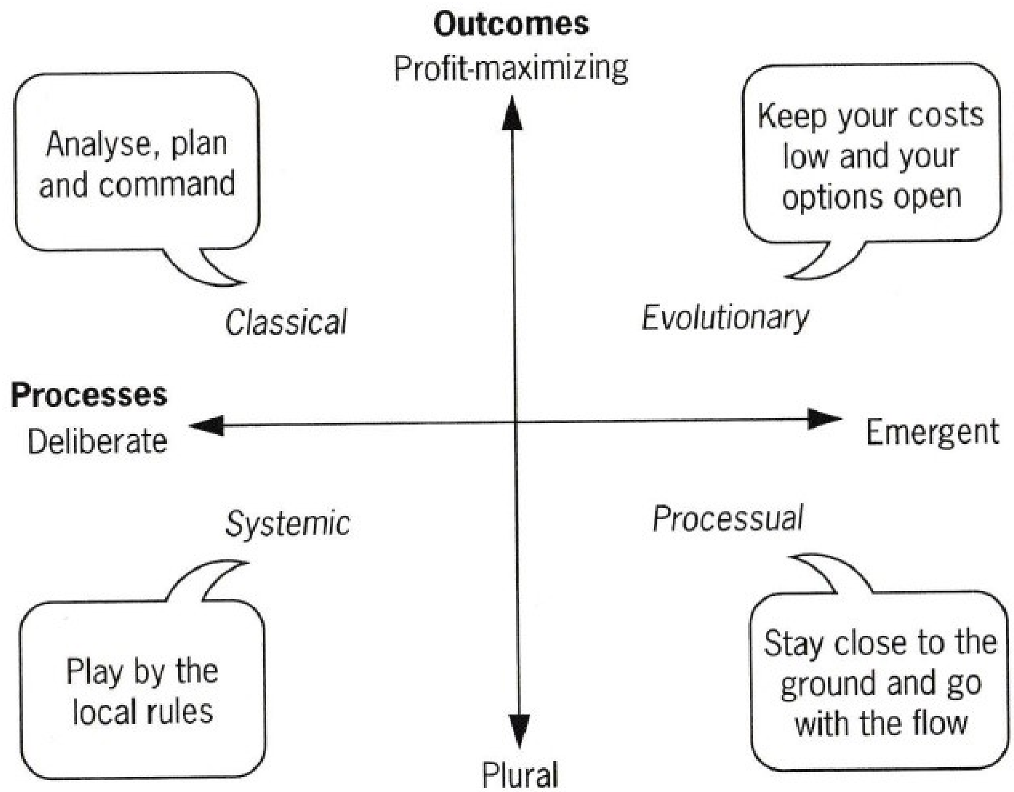

Figure 2. Summary implications of the four perspectives on strategy. (Whittington, 2001, p.10)

Harrison, van Hoek and Skipworth (2014) describes the strategies in figure 2 as follows:

- Classical: A formal strategy in order to achieve financial goals
- Evolve: Operating decisions are made on a day-to-day basis without a formal strategy, with financial goals as the only guideline
- Systemic: Goal setting takes place across all major parts of the business, and these are linked to the means by which they will be achieved in practice.
- Accommodate/Processual: Operating decisions are made on a day-to-day basis without a formal strategy, but financial goals are no longer the main concern

A more comprehensive summary of the strategies in figure 2 given by Whittington (2001) are given in table 1.

	Classic	Processual	Evolutionary	Systemic
Strategy	Formal	Crafted	Efficient	Embedded
Rationale	Profit Maximization	Vague	Survival	Local
Focus	Internal (plans)	Internal (Politics/cognitions)	External (markets)	External (societies)
Processes	Analytical	Bargaining/learning	Darwinian	Social
Key influences	Economics/military	Psychology	Economics/biology	Sociology
Key authors	Chandler; Ansoff; Porter	Cyert & March; Mintzberg; Pettigrew	Hannan & Freeman; Williamson	Granovetter; Whitley
Emergence	1960s	1970s	1980s	1990s

Table 1. The four perspectives on strategies. (Whittington, 2001, p.39)

Based on table 1 it is easy to see that there are large differences between the generic strategies, and this includes their influences and the rationale behind the goals.

From the five competitive forces and the generic strategies made by Porter (1998) and Whittington (2001) it is possible to say that there are many categories of generic categories, and that a conscious relationship to what one wants to achieve by using different strategic measures is a necessity.

That said, both Hill (1993) and Porter (1998) says that it is wrong to use these stereotypes as-is. While it can ease the process, it will confuse the outcome. Because of this, they continue by emphasizing that a strategy has to be time- and market specific in order to satisfy customers, in other words it has to reflect the particular circumstances in the particular case.

4.2 Operations management vs. supply chain management

Since this thesis will review several logistics and manufacturing strategies, it is good to have some knowledge about how these functions fit in an organization and in the supply chain. This also means defining operations management and supply chain management. Chapter 4.2 will only aim to define these terms and functions in order for the reader to get a basic impression of them. An overall and comprehensive review of the different possibilities and opinions are thus not the intention.

Slack, Chambers and Johnston (2010) says that the operations management (OM) function is one of three core functions that are parts of any organization, with the other two being marketing/sales function and the product/service development function. The operations function they say is “responsible for fulfilling customer requests for service through the production and delivery of products and services” (Slack, Chambers and Johnston, 2010, p.5). As a natural derivation of this, operations management is “the activity of managing the resources which produce and deliver products and services” (Slack, Chambers and Johnston, 2010, p.4). From these descriptions, it is clear that both the supply chain and manufacturing activities are a part of the operations function.

The Council of Supply Chain Management Professionals (CSCMP) (2015, p.187) says that:

> "Supply Chain Management encompasses the planning and management of all activities involved in sourcing and procurement, conversion, and all logistics management activities. Importantly, it also includes coordination and collaboration with channel partners, which can be suppliers, intermediaries, third-party service providers, and customers. In essence, supply chain management integrates supply and demand management within and across companies. Supply Chain Management is an integrating function with primary responsibility for linking major business functions and business processes within and across companies into a cohesive and high-performing business model. It includes all of the logistics management activities noted above, as well as manufacturing operations, and it drives coordination of processes and activities with and across marketing, sales, product design, finance and information technology."

Notice that this definition includes the activities and responsibilities that was previously included in operations management.

The evolution of the organizational functions are moving them towards being more and more integrated. The term Operations and Supply Chain Management (OSCM) given by Jacobs, F.R. and Chase, R.B. (2013, p.3) is therefore fitting:

> "Operations and supply chain management (OSCM) is defined as the design, operation and improvement of the systems that create and deliver the firms primary products and services. OSCM is concerned with the management of the entire system that produces a product or delivers a service."

Manufacturing is described by Hill (1993) as a process where the main function is to take inputs (i.e. materials, labor, energy) and transform these into products. This is very similar to the definitions of operations management made in the previous, and thus underline manufacturing as one of the main activities under the responsibility of the operations and supply chain manager. In order to complete these the company usually have several choices between modes of manufacturing, and normally companies make use of more than one. The important thing when making this decision is to make sure that the chosen process allows the company to compete in the market place.

Logistics on the other hand is defined by Harrison, van Hoek and Skipworth (2014, p.9) as

> "The task of coordinating material flow and information flow across the supply chain to meet end-customer needs", and underline the fact that logistics both have long-term (strategic) and short-to-medium-term (planning and control) aspects.

5. Operations and supply chain strategies

One of the main theoretical topics of this thesis is the use of slack in production and logistics strategy and planning. These fields are however very large and comprehensive, and it is thus not possible to completely review all alternatives and possible angles. The goal will therefore be to mention the most commonly used and mentioned strategic options and process methodologies, briefly describe them, and give an impression of how they view the use of slack. This should provide a background for the appropriate use of slack and show how it fits in the bigger picture.

5.1 Overview

Jacobs and Chase (2013, p.11-14) gives an overview of the historical development of operations and supply chain management. There are several major concepts related operations and these include:

The manufacturing strategy paradigm meant that factory and company owners started to consider the possibility of using their factories capabilities as strategic competitive weapons. This meant that the notion of trade-offs suddenly became of great importance. It also meant that it was necessary to define several performance objectives in order to find areas where the company could differentiate from competitors and excel in order to gain customers.

Just-in-time (JIT) designates a principle that implies an integrated set of activities designed to achieve high volume production using minimal inventories of parts that arrive at the workstation exactly when they are needed. The philosophy, coupled with *total quality control (TQC)* which aggressively seeks to eliminate causes of production defects, is now a cornerstone in many manufacturers' production practices, and the term *Lean manufacturing* is used to refer to the set of concepts. This set of concepts have later evolved in to also being applicable to service industries with regards to quality and productivity.

Total Quality Management (TQM) and *Quality certification* was developed in the 1980s and 1990s by the quality gurus W. Edward Deming, Joseph M. Juran and Philip Crosby. Inc.com (2015) says that TQM refers to management methods used to enhance quality and productivity, and that it is a comprehensive approach that works horizontally across an organization, thus involving all departments and employees and extending to suppliers and customers.

Business process reengineering seeks to make revolutionary changes. This is done by taking a fresh look at what the organization is trying to do in all its business processes, eliminating non-value-added steps and computerizing the remaining ones to achieve the desired outcome.

Six Sigma Quality was originally a part of TQM, but saw a dramatic expansion during the 1990s as a number of new diagnostic tools were developed. iSixSigma.com (2015a) says that Six Sigma quality simply means a measure of quality that strives near perfection. It is a disciplined, data-driven approach and methodology for eliminating defects in any process. As the name implies, the goal is a process where there are six standard deviations between the mean and the nearest specification limit.

Supply chain management was mentioned in a previous chapter. The central idea of supply chain management is to apply a total system approach to managing the flow of information, materials and services from raw material suppliers through factories and warehouses to the end customer. Trends such as outsourcing and mass customization are forcing companies to find flexible ways to meet customer demand. The focus is on optimizing core activities to maximize the speed of response to changes in customer expectations.

Electronic commerce or *eCommerce* refers to the use of internet as an essential element of business activity. Mangiaracina (2014) defines Business-to-consumer (B2c) eCommerce as sales of products and services via the internet, through order by shopping cart or web form to end customers.

The service science management and engineering (SSME) university and industry programs aims to apply the latest concepts in information technology to continue to improve service productivity of technology-based organizations

Business analytics describes the use of current business data to solve business problems using mathematical analysis. The new part is that so much more data is captured and available for decision-making analysis than what was available in the past, and in addition, mathematical tools are now readily available to be used to support the decision-making process.

Going in depth on all of these concepts would be counter-productive and would also exceed the scope of this thesis both when it comes to the sheer volume and when it comes to content. Because of this, a more thorough presentation will only be given of a few of the above-mentioned concepts. These are performance objectives, Lean manufacturing, TQM and some supply chain management strategies. They are chosen on the account of being most used and also because they are deemed to be most relevant to shed light on the concept of slack. Due to this the focus will also be put on the ideologies and ways of thinking rather than practical solutions and implementations.

5.2 Performance objectives (Manufacturing strategy paradigm)

In order to choose the right strategy and to make the decisions that aim the company in the desired direction, it is important to have a conscious relationship to the general operations performance objectives. These objectives apply to all kinds of operations from hospitals to supercar manufacturers.

The reasoning behind using the objectives is that in order to satisfy ones customers and to be able to be competitive, one must be aware of them in order to make the right choices and to give the most weight to the most important objectives in the organizations business area. This means that in relation to slack, the implementation of slack measures would have to be anchored in the demands of the customers and their weighting of the different objectives.

Slack, Chambers and Johnston (2010, p.39) describes the "five basic performance objectives" These are quality, speed, dependability, flexibility and cost. Note that in addition to being important to the customers, the objectives will also have an impact internally in the organization. Table 2 lists the potential impacts of the different objectives on both the operations and the relation to the organizations customers.

The cost objective is a bit different from the other objectives, since it is largely affected by how the other objectives are handled. Lower costs means larger profit margins and/or lower prices for the customers. It will therefore be the goal of any organization to keep costs as low as possible while still being inside the acceptable framework of the other performance objectives deemed acceptable by customers.

Objectives	Inside the operation	Customers
Quality	- Reduces cost - Increases dependability	- Satisfaction or dissatisfaction
Speed	- Reduces inventories - Reduces risks	- Increases value for some customers
Dependability	- Saves time - Saves money	- Judged over time
Flexibility	- Speeds up response - Saves time - Maintains dependability	- Product/service flexibility, mix flexibility, volume flexibility and/or delivery flexibility
Cost	- Universally attractive - Increases potential revenue/sales	- Lower price

Table 2. Performance objectives and their impacts on the organization and customers. A summary of Slack, Chambers and Johnston (2010, p.39-52)

Jacobs and Chase (2014) also mentions the performance objectives, but describes them as competitive dimensions. The competitive dimensions are very similar to that of table 2, with some small differences. They mention cost, quality, speed and reliability (dependability), but split flexibility in to two separate dimensions. What was previously called the flexibility objective is here named “coping with changes in demand” and “flexibility and new-product introduction speed”. Given the categories names it is easy to see that these are put together in the performance objectives. In addition to these main dimensions, they also mention other dimensions that are less general, including technical liaison and support, after-sale support and environmental impact. These are considered to be of a supportive nature.

This report will from here on out make use of the term performance objectives as a common phrase for both the objectives in table 2 and the competitive dimensions mentioned in this paragraph. As an extra underlining of which performance objectives that correspond to different customer demands, table 3 shows a basic overview of competitive factors linked to the related performance objective.

Performance objectives	Competitive factor
- Cost - Quality - Speed - Dependability - Flexibility (product/service) - Flexibility (mix) - Flexibility (volume and/or delivery)	- Low price - High quality - Fast delivery - Reliable delivery - Innovative products and services - Wide range of products and services - The ability to change the timing or quantity of products and services

Table 3. Performance objectives and corresponding competitive factor. (Slack, Chambers and Johnston, 2010, p.69)

Both Jacobs and Chase (2014) and Slack, Chambers and Johnston (2010) stress that it in most cases is important to regard the performance objectives as trade-offs rather than trying to exceeding in all the mentioned areas. This means that companies should focus on deciding which parameters are the most important to succeed towards the market using their current business model, and then channel their resources towards these characteristics.

In the previous paragraph it was mentioned that companies have to choose which performance objectives to put focus on, depending on market demand and the current business model. This does however not mean that companies can choose to focus only on one or some of the objectives. This is where the notion of order winning and qualifying criteria mentioned by Hill (1993) comes in to play.

Qualifiers are criteria that are necessary to fulfill to even be considered as a supplier for customers. This means that companies only have to focus on these criteria just enough to meet the requirements, as they do not win orders. Order winning criteria are the criteria that win orders. These criteria are where the company needs to excel compared to the competition, in order to impress and stand out.

Another notion it is important to be aware of is the distinction between effectiveness and efficiency. Olsson (2006) says that in general terms, efficiency is related to producing direct outputs, while effectiveness is related to added value for owners and users. Efficiency is thus related to saving costs and doing things the right way, while effectiveness is linked to fulfilling customer wishes and thereby doing the right things.

5.3 Lean manufacturing (Just-In-time/Toyota production system)

As previously mentioned, lean manufacturing is used to describe a set of concepts that are integrated in order to achieve high volume production with minimal inventories, aggressively seek to eliminate causes of production defects and eliminating what is referred to as waste. The term Lean manufacturing is derived from the Toyota production system (TPS).

Related to slack one could see that in its most extreme form the Lean manufacturing ideology aims to remove most buffers and other forms of slack in order to create a more streamlined production system. It will however become clear that the aim of these removals are related to the creation of value, and thus the discussion is not black and white.

> "The basic concept of the Toyota production system is "Thorough elimination of wasteful practices" " (Ohno, 1982)

The Japanese word for waste is "muda", and is used to describe any human activity that absorbs resources but creates no value. According to Womack and Jones (2003), the antidote to muda is lean thinking. It is referred to as "lean" because it provides a way to do more with less human effort, less equipment, less time and less space, while at the same time coming closer to giving the customers what they want. Slack, Chambers and Johnston (2010) says that the lean philosophy is defined by the three key issues involvement of staff in the operation, continuous improvement and elimination of waste.

The first step of lean thinking is value, which can only be identified by the final customer and only has meaning in terms of a specific product. After defining the value, the next step is to identify the entire value stream for each product. This analysis will reveal three types of actions, the first creates value, the second does not create value but is unavoidable (type one muda) and the third does not create value and can be removed. (Womack and Jones, 2003)

After eliminating the non-value creating activities the next step is flow. Flow implies a change from batch-production, functions and departments to a system of continuous flow. This was already known to be possible for large volume production, but Toyota managed to implement continuous flow for small-lot production. The fourth principle introduced was that of pull production. Instead of "pushing" products on the customers one lets them "pull" it from you (Womack and Jones, 2003).

The final principle in lean thinking is perfection. Through a self-reinforcing circle, the four previously mentioned principles allow for a more and more precise definition of value and removal of waste. Transparency is perhaps the most important catalyst for perfection, seeing as all actors – be it customers, suppliers, employees etc. – can see everything in a lean system (Womack and Jones, 2003).

Monden (1998) describes the Toyota production system (TPS) as a revolutionary system inspired by Taylor's scientific management and Ford's masse-assembly line. He says that the main purpose of the TPS is profit through cost reduction. The TPS achieves cost reduction (which has a very broad meaning in this context), or productivity improvement, through the elimination of different kinds of waste.

The Toyota executive Taiichi Ohno identified the first seven types of waste. Womack and Jones (2003) lists these seven types of waste, while adding one of their own. They also emphasize that there might be more types of waste. The following is the original seven types of muda, also described by MLG (2015):

1. Defects: Components or products that do not meet specification, i.e. poor quality.
2. Over-production: Making components and/or products that are not required. Considered the worst kind of waste because it in essence contains all others (Monden, 1998; iSixSigma.com, 2015b; Slack, Chambers and Johnston, 2010).
3. Waiting: Time not being used effectively when waiting for a delivery from an upstream activity. Applies to people, machines and perhaps less obvious, items.
4. Transportation: Moving goods and employees from one place to another in the operation does not add value.
5. Movement: People spending time moving around a factory because of things like a poor layout or work process.
6. Over-processing: Processing steps that are not adding any value for the customer.
7. Inventory: Holding unnecessary inventories.

The eighth waste added by Womack and Jones (2003) is creating goods and services that do not meet the needs of the customers.

The goal of TPS is to control overproduction through ensuring all processes make products according to the sales velocity of the market. For the TPS to reach its goals it must first meet three other subgoals. The first is quantity control that allows the system to adapt to fluctuations in demand of quantity and variety. Second is quality assurance that assures that each process will only supply subsequent processes with good units. Finally, the last is respect for humanity (Monden, 1998).

The TPS is supported by two fundamental principles, where the first is "Right on time" and the second is "Automation". (Ohno, 1982) Monden (1998) refers to the same concepts as Just-in-Time (JiT) and Autonomation. These designations will be used from here on out. While JiT basically means to produce the necessary units in the necessary quantities at the necessary time, Autonomation can be loosely interpreted as autonomous defects control. Ohno (1982) describes this as the system "working of itself" as opposed to "moving of itself". It supports JiT by never allowing defective units from a preceding process to flow into and disrupt a subsequent process. Through these concepts one can achieve a continuous flow of production or adaption to demand changes.

Ohno (1982) compares a factory where JiT has been thrououghly understood to a baseball team with good teamwork. Autonomation on the other hand eliminates overproduction and prevents the production of defective goods through enhancement of each individual worker's skill.

5.3.1 Inventories

Inventories is considered one of the seven wastes of the lean philosophy. The reasoning behind this mainly consists of two parts, namely wanting to reduce costs and also to achieve continuous flow. Inventory costs consists of holding costs, setup costs, ordering costs and shortage costs, and there are several purposes for holding inventory. Reasons for maintaining inventories include maintaining independence from operations, meeting variations in product demand, and allowing for flexibility in the production scheduling. It also provides a safeguard for variation in raw material delivery time and allows the company to take advantage of the economic purchase order size (EOQ). Finally, other domain-specific reasons may be applicable. (Jacobs, F.R. and Chase, R.B (2013)) While lean manufacturing attempts to completely eliminate inventories, this will in most cases be impossible due to uncertainty.

Womack and Jones (2003) mentioned flow as one of the key principles of Lean thinking. Figure 3 shows the difference between the traditional approach and the lean approach to flow in an operation. As the figure shows, buffer inventory between stages are eliminated in the lean approach, and a pull methodology has replaced the traditional push methods. Lean philosophy also views inventories as something that prevents the discovery of problems in the production system. (Slack, Chambers and Johnston, 2010) This is can be visualized by the river and rocks analogy seen in figure 4.

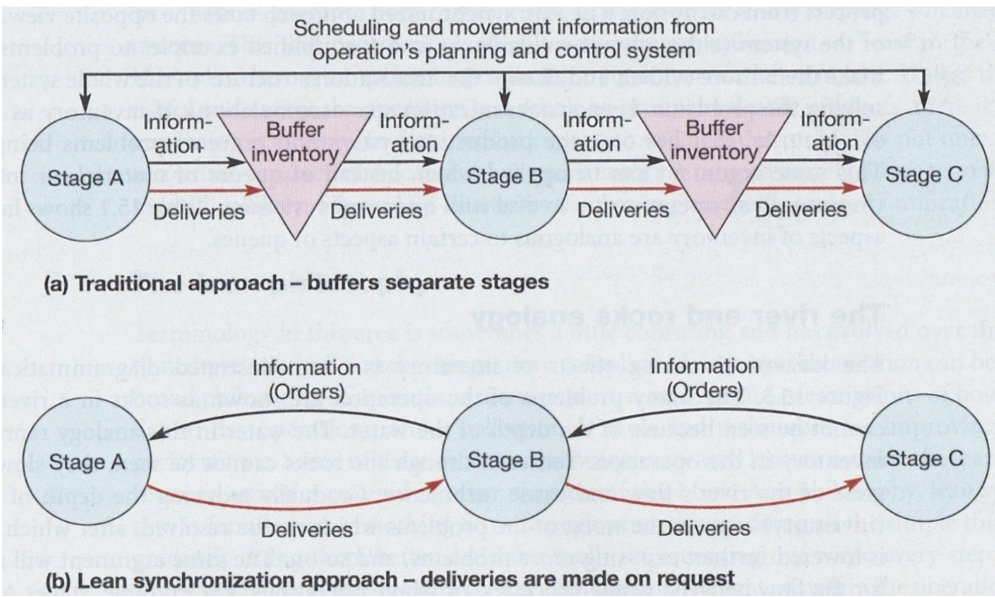

Figure 3. Traditional and lean synchronized flow between stages. (Slack, Chambers and Johnston, 2010, p.431)

In figure 4 the water symbolize inventories, that hides the problems which in this cases are shown as rocks. Removing inventories will thus make the problems surface so that they can be dealt with. This exposure is in line with the Lean philosophy, and the exposure allows the problems to be solved in line with the key issue of continuous improvement.

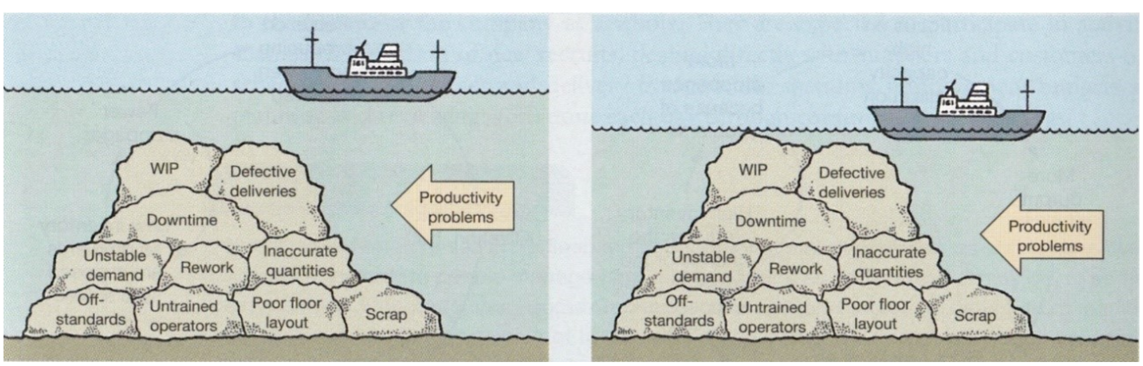

Figure 4. River and rocks analogy. (Slack, Chambers and Johnston, 2010, p. 433)

5.4 Total Quality Management (TQM)

Evans and Lindsay (2010) provide a definition of TQM, or TQ, given in 1992 by a cooperation of CEO's, academics and recognized consultants. This definition is:

> "Total Quality (TQ) is a people-focused management system that aims at continual increase in customer satisfaction at a continual increase in customer satisfaction at continually lower real cost. TQ is a total system approach (not a separate area or program) and an integral part of high-level strategy; it works horizontally across functions and departments, involves all employees, top to bottom, and extends backward and forward to include the supply chain and customer chain. TQ stresses learning and adaption to continual change as keys to organizational success.
>
> The foundation of Total Quality is philosophical: the scientific method.TQ includes systems, methods, and tools. The systems permit change; the philosophy stays the same. TQ is anchored in values that stress the dignity of the individual and the power of community action. "

Based on the definition of TQM it is clear that going in to depth about the philosophy and all the systems, methods and tools is outside the scope of this thesis. Focus will therefore be put on the philosophy behind TQM and the quality gurus responsible for the same philosophy. The content will be aimed at being useful when discussing the use of slack.

The term "quality" is by no means self-explanatory, but going into detail about this would possibly deserve a thesis of its own. Quality can take on different meanings depending on the perspective, and will be used in wide terms in the following. Note also that the "Quality" performance objective mentioned in chapter 5.2 has a much narrower interpretation than in TQM.

Often regarded as the ancestors of the quality management movement, several quality philosophers are important to the development of TQM and the surrounding mindset. W. Edwards Deming, Joseph Juran and Philip B. Crosby are considered the most influential, with A.V. Feigenbaum, K. Ishikawa and G. Taguchi also frequently mentioned among the "quality-gurus". (Brun, 2013; Evans and Lindsay, 2011; Dale, 2003)

Deming's early works consisted of 14 points for achieving quality excellence. This was in a time where organizations were highly autocratic and short-term profits was focus. During his career, his philosophy underwent many changes and the 14 principles were shortened to a "system of profound knowledge", consisting of four interrelated parts (Deming, 2000):

1. Appreciation for a system: The whole system must work together towards a common purpose, without sub-optimizing single parts. The greater the interdependence, the greater will be the need for communication and cooperation between them.
2. Understanding variation: First understand, and then work to reduce. Two mistakes are frequently made regarding variability. The first is to react to an outcome as it if came from a special cause when it came from common causes of variability. Second is to treat an outcome as if it was special when it came from a common cause.
3. Theory of knowledge: Management is prediction. Rational decision making thus require a need to understand how things work and how decisions affect the future.
4. Psychology: Understand human behavior and treat people fairly. People are different and it is necessary as a manager to be aware of this.

Deming believed that variation is the paramount cause of poor quality, but he never gave a precise definition of quality. (Brun, 2013; Evans and Lindsay, 2011; Dale, 2003)

> "Excessive variation results in products that fail or perform erratically and inconsistent service that does not meet customers' expectations." (Evans and Lindsay, 2011, p.96)

Joseph Juran provides a two-sided definition of quality. The external view says that quality means that product features meet customer needs and thereby results in customer satisfaction, while the internal view is that quality means freedom from product deficiencies, which avoids customer dissatisfaction. The first is related to income while the second is related to costs, which means that they are related to the previously defined effectiveness and efficiency respectively. In other words, quality means "fitness for use". Juran also presents what he calls the "Quality Trilogy", which consists of quality planning, quality control and quality improvement. Figure 5 shows the quality trilogy. Quality control can be seen as a parallel to Deming's desire to reduce variability. (Juran and Godfrey, 1999)

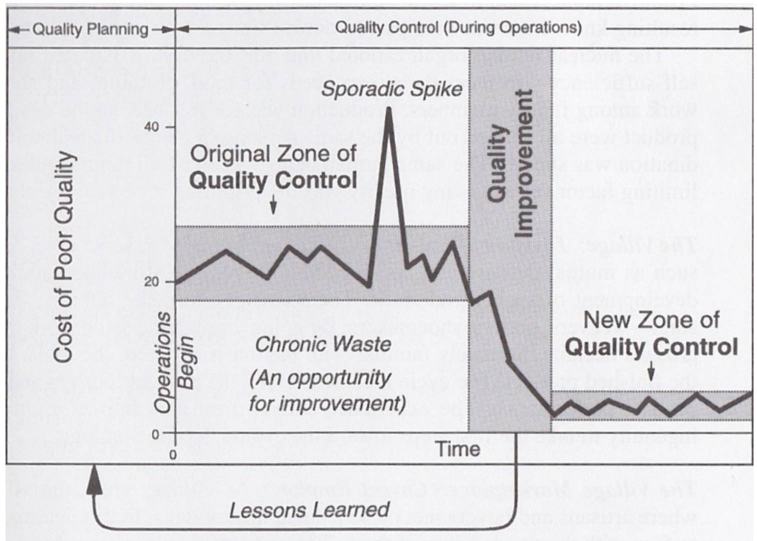

Figure 5. The Juran Trilogy diagram. (Juran and Godfrey, 1999, p.2.7)

Philip Crosby claims that quality is "not only free, it is an honest-to-everything profit maker" (Crosby, 1979, p.1) This is argued that through doing things right the first time one saves costs, which in turn will show in the bottom line. He also wrote "the absolutes of quality management" (Crosby, 1979, p. 131):

- Quality means conformance to requirements, not elegance.
- There is no such thing as a quality problem: Problems must be identified by individuals or departments causing them.
- There is no such thing as the economics of quality: Doing the job right the first time is always cheaper. Quality is always free!
- The only performance measurement is the cost of quality.
- The only performance standard is "Zero Defects"

Based on the work of the quality gurus and others, Dean and Bowen (1994) describe TQM as an approach to management that is characterized by its principles, practices and techniques. Each principle is implemented through a set of practices, which in turn are supported by a number of techniques. The three fundamental principles include customer and stakeholder focus, continuous improvement through process analysis and teamwork that includes everyone in the organization. These three principles are mutually reinforcing, and they ultimately focus on fulfilling customers' needs.

To successfully implement TQM in the organization, Dale (2003) lists what he calls the key elements of TQM. These include commitment and leadership of top management, planning and organization, using the appropriate tools and techniques, proper education and training, involvement, teamwork, measurement and feedback, and finally ensuring that the corporate culture is conducive to continuous improvement activity.

5.5 Supply chain management strategies

The goal of chapter 5.4 is to introduce several types of supply chain strategies. Since this is a large field of study, focus will be put on the extremities of strategies, and their relation to slack, in order to narrow the focus down to a manageable and useful scope.

Lee (2002) says that the right supply chain strategy depends on several factors like the specific needs of the customers and the uncertainty surrounding both the demand of the product and the supply sources. The use of IT solutions can support or enable different strategies. He also says that strategies based on "one-size-fits-all" are doomed to fail.

Harrison, van Hoek and Skipworth (2014) says that the main trade-off in supply chains are the one between cost and time. A focus on cost means to have a supply chain tailored for high volume products where demand is stable and high throughout a year, while a focus on time means to tailor the supply chain to fit products where demand fluctuates highly throughout a year and often on short notice. In practice, this means that a focus on cost and time is for the most part mutually excluding.

Perego (2014a) says that there are numerous ways to classify and identify the main logistics strategies. One is to separate between time-Based, productivity-based, technology-based and relationship-based strategies. Another, that is deemed more relevant for this thesis, is the Lean and Agile supply chains.

5.4.1 Lean and agile supply chains

This method for classifying supply chain strategies is presented by Lee (2002). He says that using an "uncertainty framework", you can easily match the supply chain strategies to fit the uncertainty surrounding the product. This uncertainty framework includes both supply side and demand side uncertainty.

Lee (2002) says that the demand uncertainty is related to the products, and if they are functional or innovative. Functional products are said to have long life cycles and relatively stable demand while the opposite is said to be true for innovative products. The supply side uncertainty is related to the process, and if the process is stable or evolving. A stable process is recognized by a mature process and mature technology, with a solid supply base. An evolving process is constantly and rapidly changing, due to the development of process and technology. This may cause the supply base to be limited in size and experience. Table 4 gives and overview of the characteristics that applies to the different cases.

Demand characteristics		**Supply characteristics**	
Functional	Innovative	Stable	Evolving
- Low demand uncertainties - More predictable demand - Stable demand - Long product life - Low inventory cost - Low profit margins - Low product variety - Higher volume per SKU - Low stockout costs - Low obsolescence	- High demand uncertainties - Difficult to forecast - Variable demand - Short selling season - High inventory cost - High profit margins - High product variety - Low volumes per SKU - High stockout costs - High obsolescence	- Less breakdowns - Stable and higher yields - Less quality problems - More supply sources - Reliable suppliers - Less process changes - Less capacity constraint - Easier to changeover - Flexible - Dependable lead time	- Vulnerable to breakdowns - Variable and lower yields - Potential quality problems - Limited supply sources - Unreliable suppliers - More process changes - Potential capacity constrained - Difficult to changeover - Inflexible - Variable lead time

Table 4. Demand and supply characteristics. (Lee, 2002, figure 1 and 2 p.106-107)

Based on the characteristics in table 4, Lee (2002) devices 4 types of strategies aimed at coping with the different levels of uncertainty in both the demand side and the supply side. These strategies are found in table 5.

	Demand side uncertainty		
Supply side uncertainty		**Low**	**High**
	Low	Lean Supply Chain (Efficient supply chain)	Responsive Supply Chain
	High	Risk-Hedging Supply Chain	Agile Supply Chain

Table 5. Supply chain strategies. (Perego, A., 2014a)

The two main archetypes are the lean (or efficient) supply chain and the agile supply chain. These two types are widely mentioned in supply chain literature. They will therefore receive the most attention in the following parts, and will be reviewed after a quick introduction to the two types in between the two extremes.

The risk-hedging supply chain strategies focuses on minimizing the risks related to the high uncertainty in the supply side. These kind of strategies aims for pooling and sharing resources between the actors in the supply chain so that the risks of supply disruptions are minimized (Lee, 2002). Through this cooperation, the companies involved can save costs related to keeping safety stocks, and the shared inventory information can also give other benefits like efficient shipment between the sites that needs it the most. This fits functional products with evolving supply processes.

As a response to high uncertainty in the demand side of the supply chain, responsive supply chains aim at being responsive and flexible to diverse and changing customer needs (Lee, 2002). This can be achieved by using build-to-order and mass customization processes to meet the specific demands of each customer. Order accuracy is regarded as the key to success of mass customization. The responsive supply chain is suited for innovative products with stable supply processes.

When there are low uncertainty both in the supply side and demand side of the supply chain, the appropriate choice of supply chain strategy will be an efficient strategy, which in most cases are called a lean supply chain strategy. The goal in a lean supply chain is to obtain the highest cost efficiencies. This is obtained by for example eliminating non-value adding activities, make use of scale economies, optimize capacity utilization both in production and distribution and effective transmission of information through the supply chain. (Lee, 2002) Based on this the lean supply chain is suited for functional products with stable supply processes.

The final strategy is the agile supply chain. It combines the strengths and characteristics of the risk-hedging and responsive supply chains, meaning that it pools inventories and/or resources to counter supply shortages while also being flexible and responsive towards customer demands and wishes. These types of strategies are thus called agile because they can counter high risks in both the demand and the supply side of the supply chain. It is obvious this should be used when dealing with innovative products in evolving supply processes. (Lee, 2002)

5.6 Summary in the context of slack

This chapter has aimed at giving an introduction to the most used and well known concepts and ideologies within manufacturing and logistics strategies. Performance objectives, lean manufacturing, total quality management and some supply chain strategies have been briefly presented. The goal of these presentations has been to provide enough background to give an understanding of the ideologies line of thought and reasoning, but are not to be regarded as complete reviews. Focus has been put aspects relevant to slack as it has been defined earlier in the thesis.

Lean manufacturing emphasizes the removal of waste, which is described as every activity that do not add any value for the final customer. This includes the removal of traditional manufacturing functions such as inventories, through the implementation of what is called just-in-time manufacturing. In such a system there is thus a very limited amount of slack, as waiting times, inventory and other forms of what is referred to as waste is attempted removed. An important point in this matter is however that these are only removed if they *do not create value*. It is also important to realize that the original Toyota production system (TPS) was designed for a closed factory where Toyota could control most aspects of the manufacturing process.

Lean thinking and methodologies have also been applied largely to supply chains. As seen however, determining the appropriate supply chain strategies depend on the level of uncertainty both in the demand and the supply side of the chain. Table 5 shows that lean (or efficient) strategies are only applicable when uncertainties are low in both sides of the supply chain. In the opposite case, we find the agile supply chain that are designed to be flexible and to adjust to these uncertainties. In this case buffer inventories, among other factors, are considered necessities. Based on this it is possible to create figure 6.

Figure 6 illustrates the points that have been made during the last few paragraph. Based on the descriptions of the different ideologies and strategies there seems to be a relationship between the uncertainty of the processes involved (could also be referred to as the degree of control) and both the affinity for implementing slack and how extensive the implementation is.

This thesis will not attempt to accurately place different types of manufacturers and supply chains into figure 6. To illustrate the point however, one could say that a single manufacturing plant in a business with stable demand and reliable suppliers would aim to be placed at point 1 in the figure. Long supply chains consisting of a large amount of actors operating without any particular integration would on the other hand likely be placed around point 2, seeing as the uncertainty in such chains are inherently high.

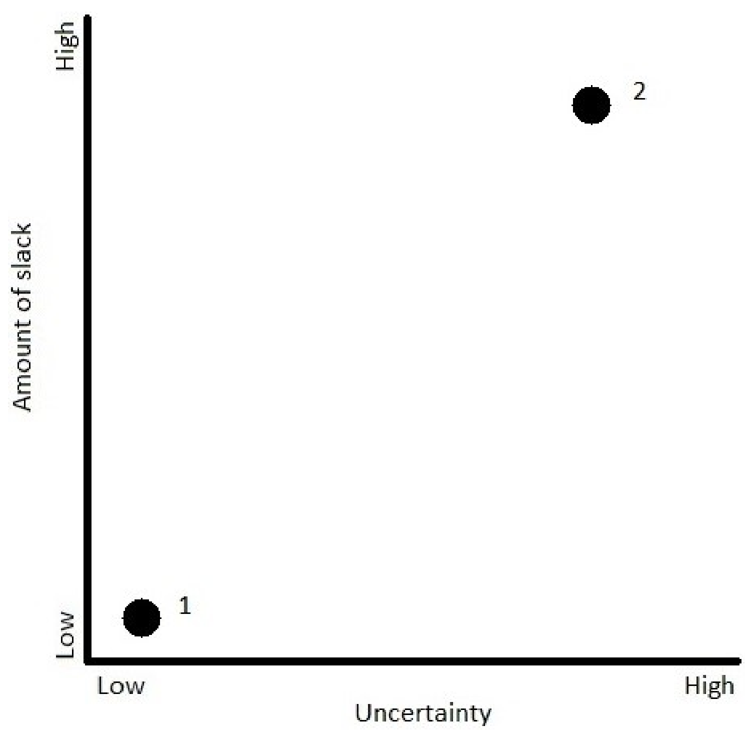

Figure 6. The amount of slack vs. uncertainty.

Total quality management (TQM) emphasizes the importance of customer focus, continuous improvement and teamwork. The goal is ultimately to produce products or services that fulfill the customers' wishes while at the same time improving processes so that variation is lowered. Excessive variation is frequently mentioned as the paramount cause of poor quality, and reducing variation will thus lead to increased income while also reducing costs. This implies that in environments with high uncertainty, it is necessary to implement measures that, in wide terms, allow for low variation in products and services. These measures could include slack.

Due to the importance of customer satisfaction, other influencing factors when it comes to the implementation and size of slack are the before mentioned performance objectives. If the customer's most important performance objective is reliability, slack could be one way to increase performance in this area. Another example could be if the customer values speed. In this case, two of the alternatives could be to either implement as little slack as possible, or to implement inventories, i.e. slack, in order to always respond to customer request depending on the type of product. Examples such as these could be made for all of the performance objectives, showing that customer requirements and wishes will have an impact on the decisions around the implementation of slack.

Based on the previous paragraphs it is clear that the concept of slack is two-sided. Slack in processes where it is not needed is indeed waste, but on the other hand implementing slack can be an enabler for quality. It allows companies to cope with the inherent uncertainty of different process, making reliable services to the end customer possible. That said, in line with both Lean and TQM, businesses should strive to improve processes in a way that reduces variability. In this way the amount of slack needed to maintain an acceptable quality could potentially gradually be lowered.

6. Transportation

This chapter is aimed at introducing transportation in general, characteristics, and factors that are important to customers. This is meant to be a short precursor to the next chapters that will introduce each of the respective industries in detail. Chapters 7 through 9 will include the current take on the use of slack in transportation production planning.

Through this short introduction of each industry, their characteristics, and their views on slack, the hope is that the reader will get a deeper appreciation of the data analyses that are to follow later in the thesis. It will also be possible to draw conclusions that are more comprehensive from the thesis as a whole. This chapter is however meant to contain information that apply to all of the industries.

6.1 General introduction

All different modes of transportation have their areas of strengths, while being less suited for other types of activities. Table 6 shows a comparison between the different modes of transportation in relative terms.

Mode	Cost [$/(ton*km)]	Line haul transit time	Delivery time variability		Accessibility
			Absolute	%	
Road	3	2	2	1	1
Rail	2	3	3	2	2
Water	1	4	4	3	4
Air	4	1	1	4	3

Table 6. Transport modes performance comparison.1 = Best, 4 = Worst. (Perego, A., 2014c)

The information shown in table 6 shows that most of the transportation modes have an area where they excel over others. Transportation by water is the cheapest in terms of volume, air transport is the quickest and road transport have the advantage of being the most accessible. The railway does not stand out in any of the categories, but performs consistently well in several of the categories, making it a good all-rounder.

6.2 Factors affecting passenger satisfaction

Factors affecting passenger satisfaction are very important to be aware of for companies within the sector. Profillidis (2014) presents different factors and their importance to different client segments of railway travel in table 7. It is easy to notice the difference between business and leisure travelers, and the fact that for commuters most factors have a similar weighting. The reason for the difference between business and leisure travelers is mainly because business travelers do not pay for their own travels and it is more urgent for them to be on time for obvious reasons.

Parameters affecting rail passenger demand	Category of rail passenger demand		
	Intercity		Commuting
	Business	Leisure	
Travel time	+++	+	++
Cost of travel	++	+++	++
Frequency of services	++	+	++
Quality of services	++	++	+
Punctuality	+++	+	++

Table 7. Parameters of rail transport and their degree of influence for business, leisure and commuting demand. Legend: +++ high influence, ++ medium influence, + low influence. (Profillidis, 2014, p.70)

Seco and Goncalves (2007) performed a revision of performance indicators that were used world-wide to evaluate service quality in public transport services in urban areas. They also compared and showed some findings in which indicators that meant most for the users. The most important factor for the public users were Punctuality/Reliability, which was referred to in all the studies they looked at. In second place were regularity/frequency that showed up in 80 percent of the studies reviewed. Other important factors included travel time and also cost.

Ruud, Ellis and Norheim (2010) conducted a study in Oslo and the county Akershus in order to show how much weight the customers put on different factors when it comes to travel. In both Oslo and Akershus punctuality was the factor given the most weight, with 59% and 63% respectively marking it as a factor of great importance. In Oslo the number of departures (frequency) was the second most important with price coming in third, while this was opposite in Akershus.

Holloway (2008) describes on-time performance as a key metric in airline business, and one side of this is that it is an important product attribute for customers. Good punctuality is also a potential driver for loyalty, especially for business travelers.

Thus, it is possible to remark that punctuality is a key satisfaction parameter for customers in all of the transportation modes included in this thesis. This will of course affect how the companies within each of the individual sectors approach scheduling and materials planning, and assumingly this will have direct implications for the use of slack in these processes.

6.3 Transportation scheduling

Ceder (2001) says that public transport scheduling in essence includes four modes of transportation, and these airlines, railways, buses and passenger ferries. It is natural to assume that subways and metros are included in the railway mode in this context. He goes on to say that airline scheduling has some special features compared to the other three, which is highlighted in figure 7.

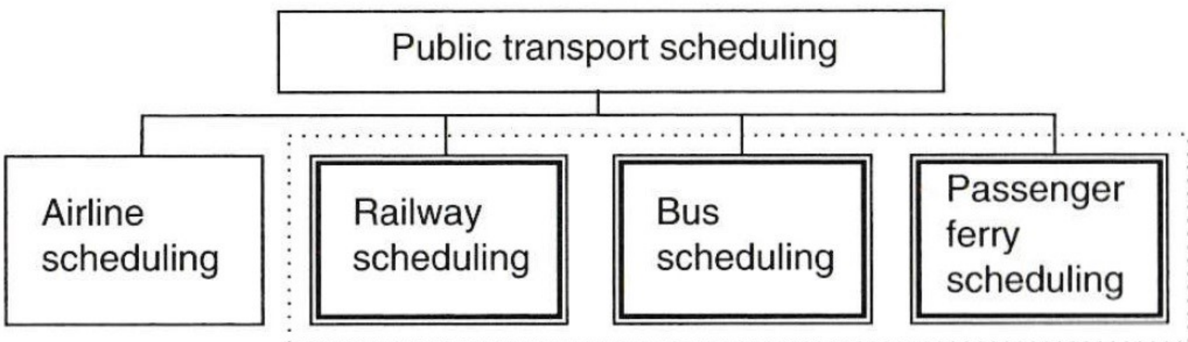

Figure 7. Four major modes of public transport with emphasis on the similarities between bus, railway and passenger ferry. (Ceder, A., 2001, p.540)

According to Ceder (2001), the scheduling process consists of four basic components. These are:

1. Network route design
2. Setting timetables
3. Scheduling vehicles to trips
4. Assignment of crew

These four components are present in the scheduling of all the mentioned modes of transportation. What separates airline scheduling from the other modes is that the timetable is developed first and the routing afterwards. The components are usually performed in sequence. While it would be preferred that these where performed simultaneously, the complexity of the planning process makes this unfeasible. Because of this each component is done treated separately, with the outcome of one being the input of the next component in the process. The whole process is shown in figure 8.

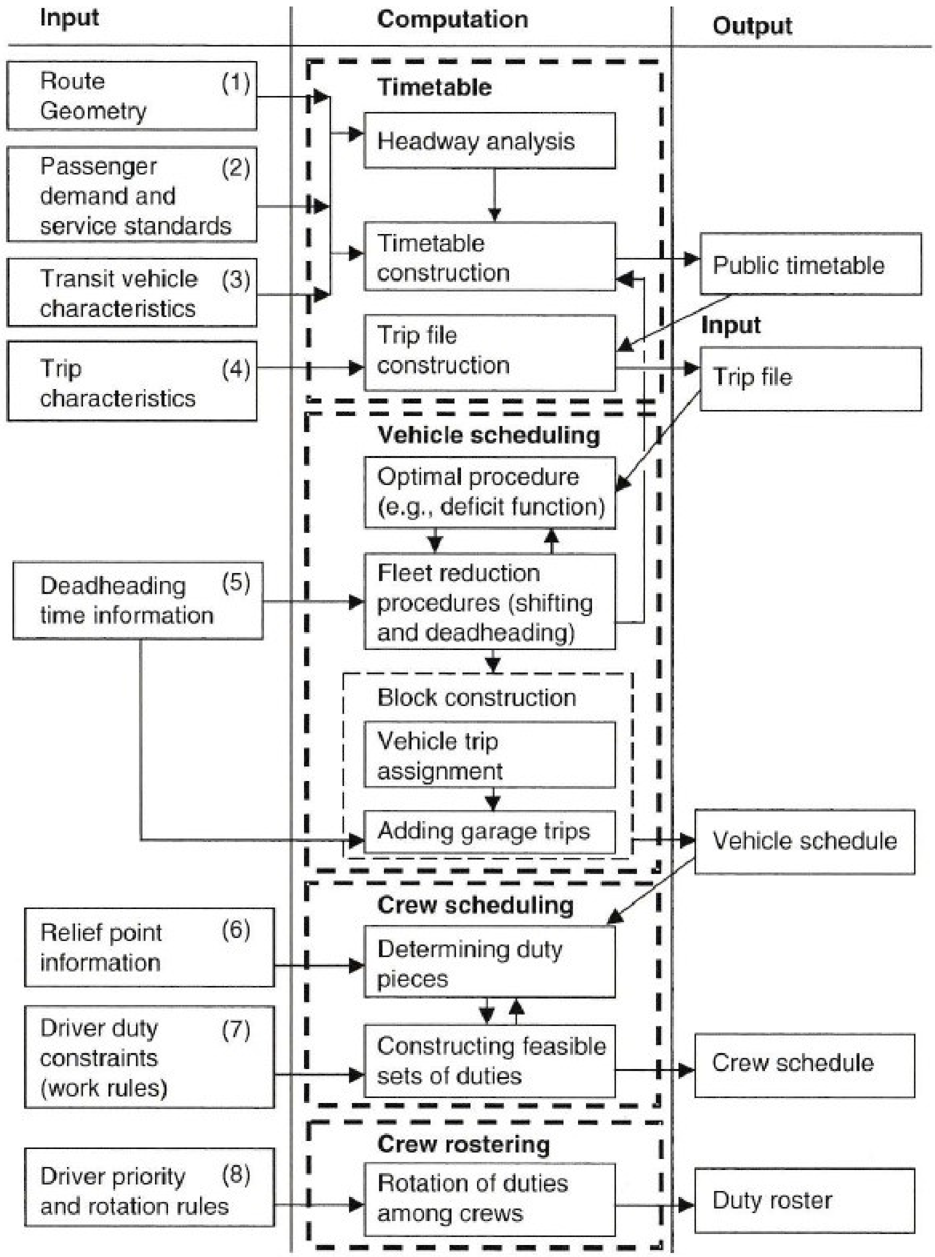

Figure 8. Functional diagram of a public transport scheduling system. (Ceder, A., 2001, p. 541)

Figure 8 shows the entire scheduling process for public transport scheduling, in the sequence of railway, bus and passenger ferry scheduling. It underlines the inherent complexity of scheduling, and shows why it is so important to take this seriously. The planning processes for each transportation mode relevant to this thesis will be elaborated further in their respective chapters. Note that in the rest of this thesis timetable planning and materials/vehicle planning will be mentioned as separate entities, while crew scheduling is considered to be outside the scope.

7. Railway

7.1 Railway characteristics

Profillidis (2014) says that the main characteristic of the railway is its capability to join several units into trains. Another characteristic is the guided movement of wheels on tracks with metal-to-metal contact. A final characteristic of railway transport is that it has one degree of freedom compared to two degrees for road and water transportation and three for transportation by air. Olsson and Veiseth (2011) also mention these characteristics. Table 6 shows the strengths of the railway relative to other modes of transportation.

Olsson and Veiseth (2011) describes three areas where the railway traditionally has been regarded as the strongest mode of transportation. The first is commuting to work in the bigger cities, second is the transportation of people between larger population centers and the last area mentioned is freight transport of large quantities of goods over large distances. According to Perego (2014c), freight transportation by rail, or by a combination of rail and road (intermodal transportation), becomes a better option when the distances exceed 500-600 kilometers.

Profillidis (2014) mentions three other factors where the railway shows strength compared to other transportation modes. The first is the energy consumption, which is about a third of that of road transportation for the same load. Second, he mentions that the railway has a much better safety record than that of cars, while the last impressive feat of the railway is the modest pollution levels.

As previously mentioned, one of the defining characteristics of the railway is that it only has one degree of freedom. This means that there are several constraints related to railway operations that in most cases do not apply to transportation by sea, road and air. The biggest consequence of only having one degree of freedom is that the railway networks are interdependent. Since the trains cannot move where there are no tracks, this means that the operators depend on the infrastructure managers and wise versa. In practice, this means that the railway function as a much more cooperative and integrated environment. Operators have to apply to the infrastructure managers in order to be allowed to start the operations they want due to the restricted amount of available tracks. Glover (1999) describes track capacity as a scarce resource, and this fits well with the previous description.

Due to trains being dependent on tracks in order to go places, this also means that the railway is dependent on points where people and freight can be loaded on and off. For passengers these are the train stations, which are normally located in the most densely populated areas. The designated points for freight trains are freight terminals. These terminals are normally relatively large and they are thus located outside cities. They are also more dependent on available logistics networks (intermodal transport) than access to people. Together this means that in many cases you need another mode of transportation to get to and from the stations or terminals, since the railway does not offer door-to-door transport. The lack of this opportunity and the lack of flexibility is mentioned by Profillidis (2014) as weaknesses of the railway compared to road transport.

Glover (1999) describes the consequence of the before mentioned constraints as the railway not existing in a vacuum. The railway networks work as a single organism, and competition and possibilities are thus much more limited than in other transport industries.

7.2 Railway scheduling

Watson (2001, p.527) gives a very wide definition of railway scheduling and says that

> "Railway scheduling is the process by which "demand" for railway transport (passenger and freight) is brought together with the "supply side" constraints (such as favorable infrastructure capacity, rolling stock and staff) to produce timetables and resource plans that meet the demand at an appropriate level of cost."

As can be seen from the definition, Watson (2001) views railway scheduling as being the "complete picture". Pachl (2002) on the other hand, says "the task of scheduling is to determine on which days each train should run, the route each train should follow through the network, arrival and departure times and the maximum speeds" (Pachl, 2002, p.174). We see that compared to Watson (2001), this definition is mostly limited to the timetable planning.

7.3 Railway timetable planning

It was mentioned in chapter 7.2.1 that the railway system is characterized by being highly interdependent and integrated due to the one degree of freedom. Because of this, railway traffic is very dependent on planning with a very high level of detail. This is reflected in what Hansen and Pachl (2008) says is the purpose of railway scheduling. They say that the purpose is to "coordinate the train paths for optimum use of the infrastructure and to ensure predictability of train traffic. It produces timetable data for passenger information and is due to all this essential for traffic control, locomotive and rolling stock usage and crew scheduling" (Hansen and Pachl, 2008, p.9). We see that this purpose fits the order of action seen in figure 8, where the timetable planning precedes the rolling stock scheduling.

Olsson and Veiseth (2011) says that "the minimum requirements for a railway timetable is that it should fulfill safety regulations, be theoretically and practically drivable and it should have reset capabilities when irregularities" (Olsson and Veiseth, 2011, p.33). The term reset capability can also be described as the robustness of a timetable, and this is closely related to the use of slack in railway scheduling. This will be described further later on.

According to Olsson and Veiseth (2011), the railway schedule for passenger trains usually repeats itself on a weekly basis, but it has variations between the different days of the week during each day. Normally the variations are there to fit reduced or increased demand.

7.3.1 Scheduled run times

In order to make the timetables you need to estimate the scheduled run times. According to Hansen and Pachl (2008), you first need to estimate the pure running time between scheduled stops. In order to do this you need route details like distance, traction unit characteristics, rolling stock characteristics and data about the operating cycle such as starting points, stops and timetable restrictions where this is applicable (Hansen and Pachl, 2008, p.58).

In addition to the pure running time, the scheduled time consists of the scheduled duration of stay at stations, recovery time and scheduled waiting time (Hansen and Pachl, 2008, p.16). The recovery time can be split in regular and special recovery time, where the regular is usually added as a percentage of the pure running time, while the special run time is added where found appropriate. This recovery time (or buffer time) can be used to increase the reset capabilities of the schedule. The different time components of the scheduled run times and their connection to each other are shown in figure 9.

Schrader (2014) says that there are several strategies when choosing recovery time and that different countries utilize different strategies. In Switzerland, they add 10-12% and in Germany there is a 3% basic addition and additional time added for works and slow driving that in total becomes around 10%. The Norwegian railway authority Jernbaneverket uses a basic addition of 4% and normally uses several other additions that does not follow specific rules. He also says that a recovery time of around 10% is necessary to have a robust schedule.

While the size of the recovery time is important, its placement in the timetable is also important. Palmquist (2014) mentions that there are three possible approaches to this problem. The first is to place the recovery time at critical points, as defined by Andersson (2014). The second is to place them at specific stretches, while the third is to distribute it evenly across the line.

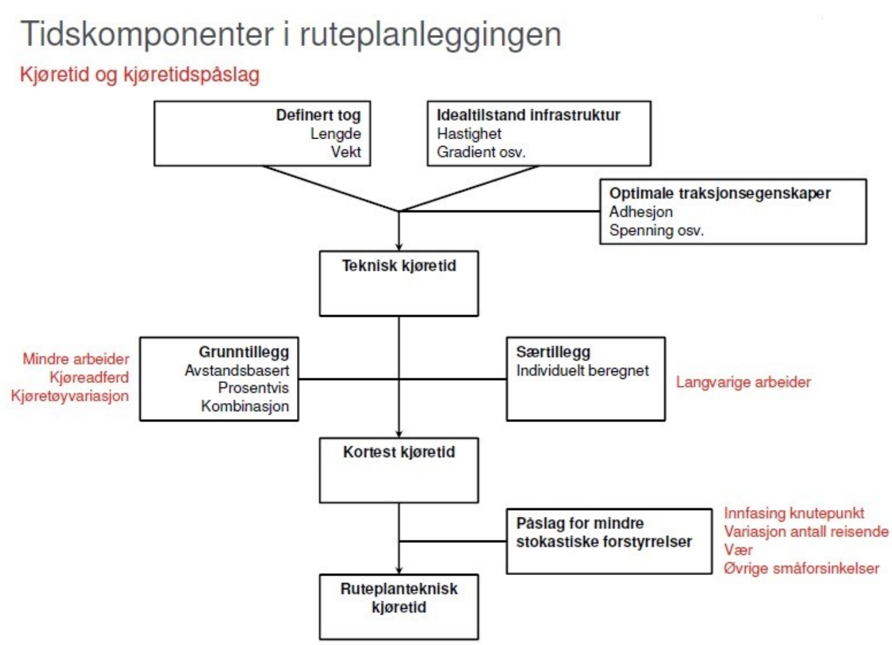

Figure 9. Time components in railway scheduling. (Weidmann, as referenced by Schrader (2014), 2011)

Palmquist (2014) goes on to conclude that if the assumption that errors might occur at any point on the line holds, and that there are no evidence of specific stretches being more exposed to delay, the best solution is to spread the recovery time across the line.

7.3.2 Robustness

Salido, Barber and Ingolotti (2008) gives two definitions of robustness in a railway scheduling context. The first is that robustness is the number of smaller disruptions the timetable is able to handle without modifications. Second, they say that a timetable is robust if it after a disruption is able to return to its original form in a given time. They also describe several ways to increase the robustness of a timetable, which includes decreasing optimality/increase buffer times, decrease capacity and decrease heterogeneity of the railway traffic.

Hansen and Pachl (2008) say that robustness may lead to high punctuality in real time operations. They also point out that “the robustness of timetables has one or more of the following effects:

1. Initial disturbances can be absorbed to some extent so that they do not lead to delays
2. There are few knock-on delays from one train to another
3. Delays disappear quickly, possibly with light dispatching measures.”

(Hansen and Pachl, 2008, p.142)

Andersson (2014) defines a robust as “a timetable in which trains should be able to keep their originally planned train slot despite small delays and without causing unrecoverable delays to other trains” (Andersson, 2014, p.11). She goes on to say that robustness measures need to capture interdependencies and point out specific weaknesses in timetables. According to her, it is particularly important to identify time-critical interdependencies in networks with heterogeneous traffic, little symmetry and that are highly utilized.

7.4 Rolling stock circulation planning

Rolling stock circulation planning is made based on a timetable. A rolling stock plan describes the movements of trains during a given period, and shows where the trains are placed during the night, stretch covered etc. Such a plan should secure that the available rolling stock covers all planned departures with an acceptable capacity based on demand. It is also important that the plan allocate time for the activities needed to keep the trains running, like turnaround times, cleaning and maintenance. The goal of the planers is to find feasible plans that do not drive cost, while at the same time maintaining robustness. (Olsson and Veiseth, 2011)

The efficient use of rolling stock is one of the main objectives in railway operations due to its cost, (Abbink et al., 2004; Alfieri et al., 2006) and the effectiveness of the rolling capacity is mainly determined by the allocation of the train types and subtypes to the different lines. (Abbink et al., 2004)

To utilize the train units on a single line in an efficient way they are coupled to, or uncoupled from, the trains at certain stations to meet the demand during peak hours and non-peak hours. Because coupling and decoupling train units must respect specific rules related to the shunting possibilities at each respective station, the order of the train units must be taken into account. This increases the rolling stock circulation problem significantly. (Alfieri et al., 2006)

An important aspect of the rolling stock circulation plan is to allow maintenance to be completed in the right way, at the right times, according to specifications and in line with how the trains are run. The plan must also allow for depositing of trains during non-peak hours or nights in a way that makes sure that tracks are available and that the depositing happen at favorable places in terms of both space and distance to the station where the train is to resume service. (Olsson and Veiseth, 2011)

8. Urban transport

Urban transportation is often referred to as public transport, or in the case of Vuchic (2005), urban transit:

> "A transit line is the infrastructure and service provided on a fixed alignment by vehicles or trains operating on a predetermined schedule. The infrastructure may vary from simple stop designations along a street to a grade-separated, fully controlled right-of-way with stations. A transit network is a set of transit lines that connect with or cross each other and that are coordinated for efficient operation and provision of integrated services in an area for the convenience of passengers and efficiency of operation" (Vuchic, 2005, p.4)

Based on this definition it is obvious that urban transport include several modes of transportation, such as buses and subways to mention two of the most common. This chapter will treat all of these, and because of this not go into depth about any of them, but rather give an overview that aim for relevance towards the problem definition and also for comparison with the other modes of transportation mentioned in the thesis.

8.1 Urban transport characteristics

Transit demand can be used in two ways. One is defined as the number of passengers wanting to use a given service and pay its price, while the other is the volume of travel that would take place if service is very good and the price is low or moderate. This last definition could also be called potential demand (Vuchic, 2005).

In general, the volume of passengers in a network depends on the total volume of passengers in a city and the level of service delivered in relation to the price, compared to other competing modes of transportation like bikes, cars and taxis. Well-planned urban transit networks are considered superior in city center areas and similar with high traffic density. This is due to the inherent capability of urban transit to handle large passenger volumes. Average trip lengths vary from city to city, and between urban transit modes. Street transit, rapid transit and local trains have an increasing average travel length respectively (Vuchic, 2005).

When it comes to buses, White (2005) says that in broad terms, all measures that benefit rad users benefit buses. Improvements like traffic lights at intersections, new roads and traffic-management measure allows higher flows and/or higher speeds. In some cases the opposite may be true, which the case for one-way schemes and traffic lights. These may increase route length and increase variability in delays respectively. Up to one third of a bus journey may be spent stationary, with roughly half at passenger stops and the other half at intersections. Reduction of time at stops may be attained by making use of appropriate ticketing and boarding systems.

8.2 Urban transport scheduling

> "Transit Scheduling is the process of computing the frequency of service, the number of vehicles required, the timing of their travel and other related operating elements" (Vuchic, 2005)

The scheduling process consist of three components. The data input, scheduling work and output. Line characteristics, passenger flow, service standards, vehicles, operating factors and work rules are the required data input for the scheduling process. These data are then used in the scheduling work to complete the timetables, determine vehicle planning and finally make crew plans, which is consistent with the figure in chapter 6.3. The output thus include the final timetables and schedules, but also performance data and analyses of these data (Vuchic, 2005).

Virtually all well-run urban transit systems use uniform clock headways for each scheduling period of the day. Headway is the average interval of time between vehicles on the same route. For regular transit lines, uniform headways during each schedule period represent the optimum operation for several reasons. There are several reason that this is the optimum. For random passenger arrivals, they minimize waiting times, while also minimizing probability of delay propagation that in turn results in higher capacity and reliability. They also make travelling easier for customers. On long distance or suburban routes with lower frequencies and demand however, the headways may vary (Vuchic, 2005).

When a timetable does not meet the level of demand, it leads to public transport vehicles slowing down, traveling behind schedule and finally entering the process of slowing even further down. This situation cause the "bunching" phenomenon with the vehicles that follow. In the opposite case, overestimating demand could lead to vehicles running ahead of time (Hassold and Ceder, 2014).

Transfers are an important part of public transportation networks. They are used to reduce the need for direct routings between all origin-destination pairs, and to concentrate passengers on major routes with high speed and high cost equipment (Lee and Schonfeld, 1991). An important point when it comes to urban transportation transfers is also that transfers are not only intramodal, but also intermodal.

In order to reduce passenger waiting times at transfer zones, transfers can be coordinated. This is used especially when headways are large, which is often the case in rural areas. In large cities, frequencies are often high and in these cases missing a connection only extends waiting time by a few minutes. Due to congestion, coordinating transfers in these cases may actually lead to more insecure transfers. Coordinating transfers are however of great importance in low density areas, seeing as a missed connection might lead to a long delay. Poor synchronization may in these cases cause people to not use public transportation (Guihaire and Hao, 2008).

At terminals where two routes interchange passengers, total system costs may be reduced by allowing some “slack” time in the vehicle schedules to decrease the probability of missed connections. Slack times do however impose additional waiting times for vehicles, drivers and some non-transferring and thus the slack times should be optimized. Results provided by Lee and Schonfeld (1991) show that schedule coordination between two routes is not worth attempting when standard deviations of arrivals exceed a certain level.

Good transfer opportunities allow passengers to choose from a larger amount of travel paths, with minimal inconvenience if done correctly, while at the same time increasing network efficiency. The optimal transfer times between lines depend on the headway of the line that is connected to. A short headway allows for shorter transfer times, while a long headway complicates the matter due to variation (Vuchich, 2005).

Wu et al. (2015) says that the randomness in bus travel times may cause passengers to lose their planned transfers. This means that passengers are forced to wait longer for the following bus, which in turn might discourage passengers from choosing bus transit service. They also showed that adding slack time into timetables greatly benefit transferring passengers y reducing the rate of transferring failure.

8.3 Urban transport vehicle planning

Rolling stock circulation planning in rapid transit systems depends on two different problems. The first is the rolling stock assignment, which consists of determining the type and number of train units to be assigned to a service in order to satisfy the given timetable and demand while optimizing shunting. Train routing is the second problem, and this involves assigning individual train units to the rolling stock assignment in a sequence of operations in such a way that each operation is included in only one sequence (Cadarso and Marin, 2014).

The vehicle (bus) scheduling problem is recognized by the need for sequencing of vehicles in both space and time. The feasibility of an activity is thus influence by both time and space in the way that a single vehicle cannot serve two locations at the same time. Three real world constraints commonly determine the complexity of the vehicle scheduling problem. These include how long a vehicle can be in service before returning to a depot, that only certain vehicles may perform some activities, and finally the location of depots where the vehicles may be stored (Raff, 1983).

> "The robustness of a public transport system is the ability to withstand or quickly recover from disturbances such as infrastructural and vehicular malfunctions and planned maintenance closures without significant reduction in the performance of the system. (In terms of travel times etc.)" (Cats and Jenelius, 2015, p.1)

Cats and Jenelius (2015) found that introducing reserve capacity in public transport networks could lead to a significant improvement in network robustness. Reserve capacity was used to make the proper capacity enhancements in the case of a disruption. Capacity enhancement could in this case mean both capacity to increase frequency and the capacity to increase the available number of seats, both on alternative lines.

9. Airline industry

9.1 Airline industry characteristics

Cento (2009) and Wu 2010) says that the effects of deregulations in the aviation industry resulted in two main effects. The first was the reorganization of the legacy carriers' networks from point-to-point (pp) to hub-and-spoke (HS) systems. The second was the adoption of PP systems by low cost carriers (LCC). Airline business models will be further elaborated in a later chapter.

According to Wu (2010) the term "airline network" has two meanings. The first focuses on the spatial coverage of the network, in other words the network formed by those airports that are served directly or indirectly by an airline. Point-to-point networks, shown in figure 10, are examples of these types of market focused networks. They focus on individual city pair markets large enough to sustain direct flights.

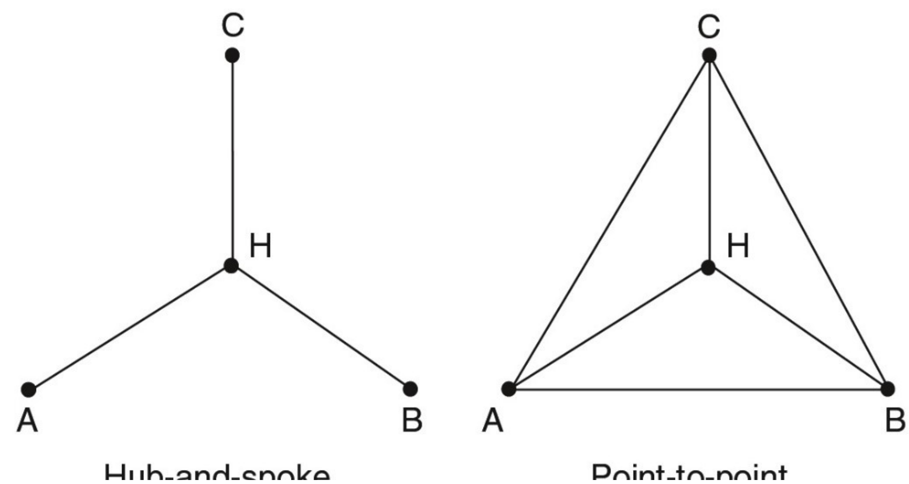

Figure 10. A scheme of hub-and-spoke and point-to-point configurations (Cento, 2009, p.32)

The second meaning mentioned by Wu (2010) is focused on the temporal attributes of the network. The temporal attributes are characterized by the frequency of service between two airports and the extent an airport is connected with other airports via various service types and service frequencies. Hub-and-spoke networks, shown in figure 10, focus more temporal attributes. These networks has at least one "hub airport" that collects and distributes passengers through the network. To efficiently exchange the passengers, inbound flights come in "waves" followed by "waves" of outbound flights. The hubs therefore need to facilitate intensive and often dense ground operations.

Figure 11 shows an illustration of an outbound "wave". The five aircraft flying almost in a straight line marked with the TK prefix are all Turkish Airlines flights that departed from the airline's hub in Istanbul within 15 minutes of each other heading for several destinations in the United States.

The growth of airline alliances changed the definitions of an airline network. Through code-sharing agreements among alliance partners airlines are able to expand their networks considerably without operating the flight themselves. This saves cost, while at the same time providing passengers with better network coverage (Wu, 2010).

Figure 11. Illustrative picture showing a "wave" of Turkish Airlines (TK) aircraft heading for the US. (Flightradar24.com, 2015)

9.1.1 Business models

Cento (2009) describes three main business models used in aviation. These include full-service carriers, low-cost carriers and charter operators. The two first are presented in the following.

A full-service carrier (FSC), commonly referred to as a legacy carrier or network airline, is defined as a former state-owned flag carrier using the following elements in its business model;

- Core business: Passenger, Cargo, Maintenance
- Hub-and-spoke network
- Global player
- Alliances development
- Vertical product differentiation
- Customer relationship management: Loyalty programs
- Yield management and pricing
- Multi-channel sales
- Distribution systems

The FSC mode is cost-penalized by the synchronized hub operations, due to long aircraft turns and slack built into schedules to increase connectivity among other factors.

Low-cost carriers (LCC) originates from Southwest Airlines that started in the United States in the 1970s. Other terms used to describe LCCs are low fare or no-frills airlines. They are defined as airline companies designed to have a cost advantage over an FSC. Some or all of the following key elements characterize their business models:

- Core business: passenger air service
- Point-to-point network
- Secondary airports
- Single aircraft fleet
- High aircraft utilization
- No frills service
- Minimized sales/reservation costs
- Ancillary services

The LCC success is thus related to the design of a simple, focused operation model around non-stop air travel to and from high-density markets.

9.2 Airline scheduling

> "The structure of an airline network is the result of airline route planning, which is aimed at maximizing network revenues by changing the structure, i.e. by adding and/or dropping airports or by changing service frequency between airports in a network" (Wu, 2010, p.3)

Bazargan (2010) quotes several authors and says that the starting point of all other airline planning and operations is flight scheduling. This confirms the claim made by Ceder (2001) which was mentioned in chapter 6. He goes on to say that "a flight schedule is a timetable consisting of what cities to fly to and at what times", and that where airlines will fly depends on market forecasts, available aircraft, regulations and competing airlines among other things. Lohatepanont and Barnhart (2004) says that airline scheduling is to decide when and where to offer flights such that profits are maximized.

Grandeau et al. (1998), as referenced by Bazargan (2010), says that the level of detail in constructing the flight schedule varies among the airlines, but it will be a complete schedule for a full cycle. Within a schedule, there is normally a repeating pattern of flights, with the pattern covering one or several days, usually a week (Abara, 1989; Bazargan, 2010).

Most airlines make use of some variation of the hub-and-spoke model shown in figure 10 (Bazargan, 2010). Some of the advantages of the hub-and-spoke model include higher revenues, higher efficiency and less aircraft needed compared to the point-to-point model. Disadvantages of these operations include discomfort to the passengers due to having to connect through a hub, congestion and delays at the hubs and a higher personnel and operational cost for the airlines (Radnoti, 2002). The increased travel time due to having to connect through a hub is also mentioned by Wu (2010).

Time	60+ months	36-12 months	12-3 months	4-1 months
Activity	Long range planning	Market evaluations	Schedule optimization	Schedule issues

Table 8. Phases of flight schedule development. (Bazargan, 2010, p.33)

Bargarzan (2010) separates between two types of route development activities, strategic and tactical. Strategic development focus on future, between a few months and several years ahead, schedules and respond to major changes in business and operational environments. Tactical activities on the other hand focus on short-term changes to the schedule, sometimes on a daily basis.

Table 8 shows the activities performed in different timelines. Long range planning include fleet diversity, manpower planning, hub planning and adequate facilities at airports while market evaluations include frequencies, choice of markets to serve, pricing policies and agreements and alliances among other activities. Schedule optimization is the activity of developing an initial schedule, assigning aircraft to flights and evaluating facilities and manpower capabilities. Finally, schedule issues includes crew issues, arrival and departure times and maintenance issues (Bazargan, 2010).

Bargarzan (2010) underlines the inherent complexity of aircraft planning. In order to counter this the problem is divided in to sub-problems and the whole process is performed as a feedback system. In this way, if a solution provides unwanted results in a sub-process the schedules can be changed to achieve a more desired result.

Wu (2010) points out that although airlines focus on revenue maximization and asset utilization, operational issues from running a complex network may offset some of these financial gains. When examining airline operations and scheduling one must balance potential financial gains and uncertainties in real world operations. AhmadBeygi, Cohn and Lapp (2010) call this a fundamental conflict. Slack in the planned schedule is considered undesirable since it diminishes the utilization potential, while slack is critical for operations as a means to absorb disruption.

In general, most airline planning optimization tools assume deterministic flight times and other parameters while aiming to generate schedules with as little slack as possible to achieve high utilization rates. In practice however, flight times are not deterministic. Departures and arrival delays occur due to mechanical problems, bad weather and other sources. On their own, these delays are costly, but in a network structure they can have an even greater impact. Without adequate slack to absorb an initial root delay, subsequent flights may be delayed as well. This is referred to as delay propagation (AhmadBeygi et al., 2008).

Lan, Clarke and Barnhart (2006) touch upon the same subject as in the previous paragraph when they claim that airlines typically construct their schedules assuming that every flight leg will depart and arrive as planned. Because this rarely occurs, the schedules are frequently disrupted and this leads to a significant cost in addition to those already planned while also causing passenger delays. A more robust plan can reduce the occurrence and impact of these delays.

Cadarso and Marin (2012) says that robustness is introduced through passengers' itineraries by providing them with enough connection time. There is however a trade-off, seeing as longer transit times carry consequences for both passengers and airlines. For the passenger it means longer waiting times at airports (i.e. a longer journey), while for airlines it means a lower aircraft utilization. There is thus a motivation for optimizing the process.

Holloway (2008, p.430) describes the key characteristics of a robust schedule that allows for reliable service as:

- Meets the business rules and constraints imposed for regular operations
- Permits disruptions to be dealt with locally as far as possible
- Minimizes the time taken, cost expended, or profit forgone to recover from irregular to regular operations
- Delivers operating performance metrics to the required standard

Two considerations driving the robustness of a schedule are block-hours and turnaround times. MiT (2015b) defines a block hours as:

> "Time from the moment the aircraft door closes at departure of a revenue flight until the moment the aircraft door opens at the arrival gate following its landing."

Holloway (2008) says that scheduled block-hours and vary seasonally on long haul routes and by time of day for short haul flights. One approach to establishing block-hours is to develop a histogram of actual times, and then schedule for somewhat longer than the achieved mean. While this, on average, builds in a small buffer, some airlines schedule with even larger buffers. To large buffers are not without issue, and along with other issues it increases costs and can actually create ground delays due to gates not being available when arriving before schedule.

Scheduled turnaround times are determined first and foremost of the actual time it takes to turn around an aircraft of the type intended to be used for a certain stretch. This time will be modified to allow for both onward connections and specific high volume inbound connections before departure. (I.e. related to the previously described "waves" of inbound and outbound flights.) Ground times could also include a contingency buffer for specific airports. By aggressively scheduling turnaround times it is possible to increase aircraft utilization, but this removes a ground-buffer capable of absorbing delays (Holloway, 2008).

AhmadBeygi et al. (2008) did a study of the potential for delays to propagate in passenger airline networks. It was shown that the keeping aircraft and crew together appears to have a large effect in reducing delay propagation. They conclude that all other characteristics being equal, the optimal location for added buffer time (slack) is the middle of the chain.

As an intermediate measure to partially decrease the propagation of delays while researchers and the industry come up with more complete solutions to this problem, AhmadBeygi, Cohn and Lapp (2010) suggests re-allocating slack within the existing framework. By re-allocating the slack to flights most prone to delay propagation, they say that it is possible to reduce downstream impact without changing crew plans, fleeting costs or revenue projections.

Holloway (2008) concludes that while aggressively timetabled block-times and tight turnarounds do increase aircraft utilization, they can compromise both punctuality and schedule integrity if not managed carefully. There is thus a trade-off between reliability, revenue and cost.

9.3 Airline fleet planning

Clark (2007, p.1) says that the definition of fleet planning from the viewpoint of an airline is:

> "Fleet planning is the process by which an airline acquires and manages appropriate aircraft capacity in order to serve anticipated markets over a variety of defined periods of time with a view to maximizing corporate wealth."

The goal of this process, according to Abara (1989, p.20) is:

> "The goal of the fleet planning process is to assign as many flight segments as possible in a schedule pattern to one or more aircraft types while optimizing some objective and meeting various operational constraints"

Fleet assignment involves assigning aircraft types to flight legs to maximize revenue and minimize operating costs (Lohatepanont and Barnhart, 2004). It is however pointed out by Clark (2007) that operating economics will deteriorate due to difficulties in optimizing aircraft utilization when using the hub-and-spoke model.

MiT (2015b) defines aircraft utilization as:

> "Measure of aircraft productivity, calculated by dividing aircraft block hours by the number of aircraft days assigned to service on air carrier routes. Typically presented in block hours per day".

Aircraft utilization is an important measure of operational efficiencies, and increased utilization will lower unit costs due to lower fixed costs per unit because the costs are spread on more trips and passengers. Factors that affect utilization rates include airplane availability (Total number of days minus the downtime), the average elapsed time per trip (Average block time per trip plus the average turnaround time) and the maximum number of trips (Availability divided by averaged elapsed time per trip) (Cederholm, 2014).

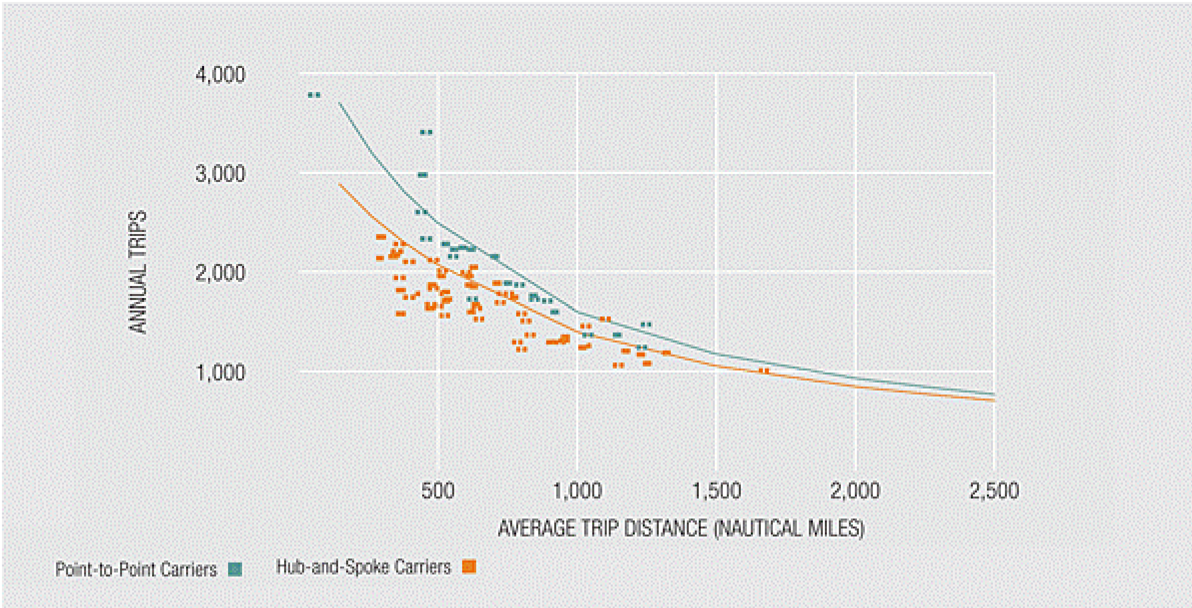

Figure 12. Aircraft utilization: Point-to-Point vs. Hub-and-Spoke (Boeing, 2008)

While legacy carriers have traditionally organized their schedules, and thus their fleet planning, to best meet the customer demands, low-cost carriers take advantage of the their more price-sensitive market. Their market is less opposed to inconvenient scheduling due to the low prices and these airlines can therefore force the customers to move towards their schedules while at the same time achieving higher aircraft utilization (Clark, 2008).

Boeing (2008) compares the utilization rates of Point-to-Point carriers and Hub-and-spoke carriers, as shown in figure 12. The shorter turnaround times of the Point-to-Point carriers allows them to achieve higher utilization rates. While the advantage is significant on shorter trip distances, it diminishes gradually as the average trip distance increases.

10. Data Analyses

The data analyses will try to unveil the use of slack in transportation production planning. This will be done by using data from several partners within the respective industries. Some of the data is contributed from the companies themselves, while some has been gathered from various sources and databases. How the data was found will be pointed out in each case in order to give a full disclosure of the quality and reliability of the data.

In order to be able to compare the data across industries, it is necessary to define some parameters that are applicable for all of them in spite of their different characteristics. In co-operation with the supervisor professor Olsson, four parameters have been defined. These are shown in table 9.

1. Route planning parameters		**2. Fleet planning parameters**	
Recovery time	**Turnaround ratio**	**Fleet utilization rate**	**Materials utilization rate**
Scheduled run time divided by the theoretical run time.	The scheduled turnaround time divided by the technical (possible) turnaround time.	Vehicles in use (per day) divided by the total number of vehicles.	The total time the fleet is in use divided by the total available time.

Table 9. The four parameters used for comparison.

These parameters should together give a good basis of comparison between the different industries, and thus give an opportunity to identify similarities and differences. Some of the utilization data are given for a case period, which is from 09.03.15 to 22.03.15. While the period is relatively short, it still provides a good background for the parameters desired in this thesis. Since, as mentioned in the previous chapters, schedules repeat themselves over a given period of time (normally a week), schedules times and utilization rates will not change in a short time horizon.

The average parameters will be used for comparison purposes. It is important to note that there are partly large variability, especially when it comes to the utilization rates, over a week, and thus there might be differences in that are not picked up by the averages. These can however be found by studying the individual results, rather than the final summary. For the airline industry there are differences among different business models, and these can also be found studying the detailed results.

10.1 Railway data analysis

10.1.1 NSB

The Norwegian railway company NSB, through Andreas Hægstad, has provided the data for the railway part of the analysis. He has provided access to an NSB database, and also contributed other data through Microsoft Excel spreadsheets.

NSB (2015a) describes itself as a Nordic transport group which mostly is involved in transporting people by bus and train, in addition to freight transport by train, real estate activities and train maintenance. The passenger train division of NSB had a turnover of 6577 million Norwegian kroner (NOK) in 2013, and around 60 million people travels with NSB trains every year. (NSB, 2015b). NSB owns a variety of different trains in order to offer customers adapted services for local trains, regional trains and long distance trains. In total their fleet consists of around 350 trains (NSB, 2015c).

In the following chapters, data from route planning for two case stretches and data about the fleet planning of NSB will be shown. The case stretches chosen are Skøyen – Moss and Oslo – Trondheim. Skøyen – Moss is a shorter regional stretch used heavily by commuters while Oslo – Trondheim is a long distance stretch in Norwegian terms. Thanks to the access to the NSB databases, the fleet and material utilization for the given time period are available in high detail for all NSB train types.

To analyze the route planning in the case stretches in terms of slack it is necessary to be aware of what NSB is using as a baseline for estimating stops at stations and turnaround times, in addition to the recovery time mentioned in a previous chapter.

When it comes to stops at stations, Schrader (2014) says that this consists of a constant and a variable part. The constant is a sum of all the physical activities taking place during a stop, while the variable is dependent on the number of passengers. The constant part he says is estimated to be ca. 25 seconds, while embarking is between 0.85 and 1.15 seconds per passenger and disembarking is 0.75 to 0.95 seconds per passenger. For simplicity's sake, 1 second per passenger is used when evaluating slack in the stops. How NSB estimate turnaround times, and examples of turnaround times for different types of trains, are shown in appendix 3.

10.1.2 NSB: Skøyen – Moss

Skøyen – Moss is a local train in the Oslo region, and is heavy utilized by commuters seeing as it passes through Oslo central station. It has hourly departures in each direction throughout the whole day, with a few added departures during peak. Train type 72 is used on the stretch, and according to NSB this train type has 310 seats per train set. (2015c). A train set consists of four wagons with 2 doors on each side of each wagon. Estimated and scheduled run times for Skøyen – Moss are shown in table 10.

	Estimated run time	Additions	Run time with additions	% added	Min %	Max%	Stop times	Scheduled time
Moss - Skøyen	42,7	5,8	48,5	**13,6 %**	13	15	7,3	55,8
Skøyen - Moss	43,2	6,8	50,0	**15,7 %**	10	25	11,3	61,3

Table 10. Run time data for Skøyen - Moss (NSB, 2015)

Based on table 10 it can be seen that the percentage added is 13.6% and 15.7% in each direction respectively. This is noticeably higher than the addition of 10% mentioned by Schrader (2014), but as mentioned earlier additions are also made individually where they are deemed necessary. In this case it is likely that the trip through Oslo is the reason for the extra additions, seeing as this station is known to be somewhat of a bottleneck. To reach the required robustness and punctuality of the stretch these additions may be warranted.

	Moss - Skøyen		Skøyen - Moss	
	Stop time (seconds)	=No. possible passengers per critical door	Stop time (seconds)	=No. possible passengers per critical door
Kambo	30	5	30	5
Sonsveien	30	5	30	5
Vestby	42	17	42	17
Ås	48	23	48	23
Ski	60	35	60	35
Kolbotn	48	23	48	23
Oslo S.	120	95	300	275
Nationaltheatret	60	35	60	35

Table 11. Stop times for Skøyen - Moss. (NSB, 2015)

Table 11 shows the station stops for the stretch, and how many passengers this amounts to through critical doors assuming 25 seconds constant time and 1 second per passenger. Based on the capacity of 310 passengers and that all stops, except at Oslo S., is less than a minute, none of them seem to be excessive and point to the use of slack. The one exception might be the stop at Oslo S. in the direction from Skøyen to Moss. This stop is for 6 minutes, and as can be seen in table 11, would allow around 275 people to embark or disembark through one single door.

As shown in appendix 3, train type 72 has 6 minutes as the necessary turnaround time for single train sets and 7 minutes for double train sets used in peak traffic hours. Note that this does not include embarking and disembarking of passengers. Saether (2014) found that the time between arrivals and departures were 23 minutes for most cases. It was also found that it is the same exact train that runs the line throughout a day in most cases. Together this means that there are slack implemented in the turnaround at Moss. This is also supported by Saether (2014) which found that the timetable for Skøyen – Moss were robust for delays up to around 20 minutes at Moss station. The turnaround ratio at Moss station are shown in table 12.

	Turnaround time	Turnaround ratio
Type 72	23	3,29-3,83

Table 12. Turnaround times at Moss.

10.1.3 NSB: Oslo – Trondheim

Oslo- Trondheim is a long distance stretch between the largest and third largest city in Norway. There are four daily departures in each direction, including a night train that arrives early in the morning. Type 73 is the most used train on the stretch, and this train has four wagons that holds just over 200 passengers. (NSB, 2015c) The older train EL18 is also utilized on the stretch. Estimated and scheduled run times for the two types of trains are shown in tables 13 and 14.

EL18	Estimated run time	Additions	Run time with additions	% added	Min %	Max %	Stop times	Scheduled run time
Oslo - Trondheim	338,1	38,3	376,4	11,3 %	6	27	28,0	404,4
Trondheim - Oslo	339,5	26,2	365,7	7,7 %	4	30	33,2	398,9

Table 13. Run time data for Oslo - Trondheim, train type EL18 (NSB, 2015)

Type 73	Estimated run time	Additions	Run time with additions	% added	Min %	Max %	Stop times	Scheduled run time
Oslo - Trondheim	335,8	28,6	364,4	8,5 %	6	27	28,0	392,4
Trondheim - Oslo	333,4	26,7	360,1	8,0 %	6	30	30,6	390,7

Table 14. Run time data for Oslo - Trondheim, train type 73(NSB, 2015)

In this case it can be seen from the tables that the percentage added spans from 7.7% to 11.3%, which is in line, and actually below, what Schrader (2015) said was needed to give a robust schedule. From the maximum percentage it can however be seen that on some stretches there are very high additions that are added to obviously known problem areas. One reason for the low total additions could be that once the trains gets outside the city areas of Oslo and Trondheim there are much less traffic, and thus the likelihood of secondary delays are considerably lower than the case of Skøyen – Moss.

Turnaround times at Trondheim central station can be seen in table 15. Some background information about these turnaround were given by Andreas Hægstad at NSB. Firstly, long distance trains are planned with 15 minutes in tracks on arrival at the terminus and 20 to 30 minutes in tracks before departure to allow passengers to get off and on. The turnaround ratio for type 73 is thus based on an estimated possible turnaround of 45 minutes. Note that this might be low, considering it does not take in to account cleaning and similar.

	Turnaround time	Turnaround ratio
Type 73	95	2,11
Type EL18	89-147	1-1,65

Table 15. Turnaround times at Trondheim S.

For the train type EL18 it is necessary to turn around the locomotive, and in this cases the train also has to change wagons from day to night and vice versa. According to Hægstad this means that while one of the scheduled turnarounds for this train type is 89 minutes there is "very little" amounts of slack in this case. This has therefore been set to a turnaround ratio of 1. Assuming that doing the operations in the "reverse order" requires the same amount of time, the turnaround time of 147 minutes gives a turnaround ratio of 1,65.

EL18	Oslo - Trondheim		Trondheim - Oslo	
	Stop time (seconds)	=No. possible passengers per critical door	Stop time (seconds)	=No. possible passengers per critical door
Lillestrøm	90	65	120	95
Gardermoen	120	95	120	95
Hamar	120	95	120	95
Lillehammer	120	95	120	95
Hunderfossen			60	35
Ringebu	60	35	60	35
Vinstra	60	35	60	35
Otta	60	35	60	35
Dombås	120	95	120	95
Hjerkinn	60	35	60	35
Kongsvoll			60	35
Oppdal	120	95	180	155
Berkåk	60	35	60	35
Støren	60	35	60	35
Heimdal	60	35	30	5

Table 16. Stop times for Oslo-Trondheim, train type EL18. (NSB, 2015)

	Oslo - Trondheim		Trondheim - Oslo	
	Stop time (seconds)	=No. possible passengers per critical door	Stop time (seconds)	=No. possible passengers per critical door
Lillestrøm	90	65	120	95
Gardermoen	120	95	120	95
Hamar	120	95	120	95
Lillehammer	120	95	120	95
Ringebu	60	35	60	35
Vinstra	60	35	60	35
Otta	60	35	60	35
Dombås	120	95	120	95
Hjerkinn	60	35	60	35
Oppdal	120	95	120	95
Berkåk	60	35	60	35
Støren	60	35	60	35
Heimdal	60	35	60	35

Table 17. Stop times for Oslo-Trondheim, train type 73. (NSB, 2015)

Tables 16 and 17 shows the stop times at the stations along the Oslo – Trondheim line. It can be seen that the stops are between 60 and 120 seconds long, and thus there is no grounds to claim that these contain any slack. The stops of 2 minutes seem to be longer than required since this allows 95 people to pass through each critical door. Since this is a long distance train, it would however be natural to assume that passengers might for example have more luggage than on a commuter train. The estimation of 1 second per passenger might thus be a bit low in this case.

10.1.4 NSB: Fleet planning

Table 19 and 20 shows the fleet and materials utilization for all NSB train types for week 11 and 12 respectively. Table 18 shows the available fleet size of each train type, on which the utilization rates are based. It can be seen that the fleet sizes vary greatly between the different train types and this has to be taken in to account when looking at the utilizations.

A quick look at the tables easily reveals that there are large variations in the utilization among the train types and for each train during a week. This is also shown in the bottom lines showing the average, min, max and standard deviation among the different train types.

The average fleet utilization is 67% and 66% per day for week 11 and 12 respectively for each train type, meaning that about 2 out of 3 trains are used during each day on average. Note however that the standard deviations are large, and thus there are large variations between train types and between the days of the week. The materials utilization is on average 27% and 26%, meaning that each train are used for an average of around 6 and a half hours each day. In this case, the standard deviation is even larger relative to the size of the average, and thus the variations are again large both between train types and during weekdays for each individual type.

Train type	Fleet size
69-2	14
69-3	39
69-E	2
69-G	10
70	16
72	36
73	14
73B	6
74	23
75	40 (41 two last days)
92	14
93	15
Y1	2

Table 18. Supplement to table 19 and 20, number of each train type. (NSB, 2015)

		Week 11			
Train type		Average/day	Min	Max	Std. dev.
69-2	Fleet utilization	0,51	0,14	0,79	0,23
	Materials utilization	0,07	0,03	0,11	0,02
69-3	Fleet utilization	0,61	0,18	0,82	0,29
	Materials utilization	0,17	0,05	0,22	0,08
69-E	Fleet utilization	0,21	0,5	0,5	0,00
	Materials utilization	0,15	0,35	0,35	0,00
69-G	Fleet utilization	0,70	0,4	0,9	0,21
	Materials utilization	0,34	0,24	0,4	0,05
70	Fleet utilization	0,76	0,75	0,81	0,02
	Materials utilization	0,17	0,17	0,17	0,00
72	Fleet utilization	0,77	0,5	0,92	0,19
	Materials utilization	0,31	0,18	0,37	0,08
73	Fleet utilization	0,73	0,5	0,79	0,11
	Materials utilization	0,28	0,17	0,36	0,06
73B	Fleet utilization	0,93	0,67	1	0,13
	Materials utilization	0,48	0,37	0,56	0,06
74	Fleet utilization	0,89	0,78	0,96	0,06
	Materials utilization	0,46	0,34	0,6	0,08
75	Fleet utilization	0,80	0,53	0,93	0,19
	Materials utilization	0,31	0,22	0,36	0,06
92	Fleet utilization	0,76	0,57	0,86	0,09
	Materials utilization	0,35	0,21	0,44	0,08
93	Fleet utilization	0,68	0,33	0,93	0,21
	Materials utilization	0,22	0,06	0,29	0,09
Y1	Fleet utilization	0,36	0,5	0,5	0,00
	Materials utilization	0,21	0,17	0,8	0,28
Average	Fleet utilization	0,67	0,14	1	0,20
	Materials utilization	0,27	0,03	0,8	0,12

Table 19. Utilization for NSB, week 11. (NSB, 2015)

		Week 12			
Train type		**Average/day**	**Min**	**Max**	**Std. dev.**
69-2	Fleet utilization	0,37	0,21	0,57	0,15
	Materials utilization	0,07	0,05	0,09	0,02
69-3	Fleet utilization	0,51	0,21	0,85	0,25
	Materials utilization	0,13	0,03	0,22	0,07
69-G	Fleet utilization	0,73	0,4	0,9	0,20
	Materials utilization	0,32	0,24	0,35	0,05
70	Fleet utilization	0,55	0	0,81	0,36
	Materials utilization	0,13	0	0,19	0,08
72	Fleet utilization	0,64	0,31	0,92	0,25
	Materials utilization	0,25	0,14	0,36	0,10
73	Fleet utilization	0,82	0,71	0,86	0,07
	Materials utilization	0,30	0,2	0,37	0,06
73B	Fleet utilization	0,93	0,83	1	0,09
	Materials utilization	0,46	0,36	0,56	0,07
74	Fleet utilization	0,88	0,74	0,96	0,07
	Materials utilization	0,43	0,32	0,5	0,07
75	Fleet utilization	0,77	0,49	0,88	0,15
	Materials utilization	0,31	0,22	0,35	0,05
92	Fleet utilization	0,73	0,57	0,86	0,09
	Materials utilization	0,35	0,21	0,44	0,08
93	Fleet utilization	0,65	0,27	0,8	0,17
	Materials utilization	0,25	0,21	0,27	0,02
Y1	Fleet utilization	0,36	0	0,5	0,24
	Materials utilization	0,13	0	0,18	0,09
Average	Fleet utilization	0,66	0	1	0,18
	Materials utilization	0,26	0	0,56	0,12

Table 20. Utilization for NSB, week 12. (NSB, 2015)

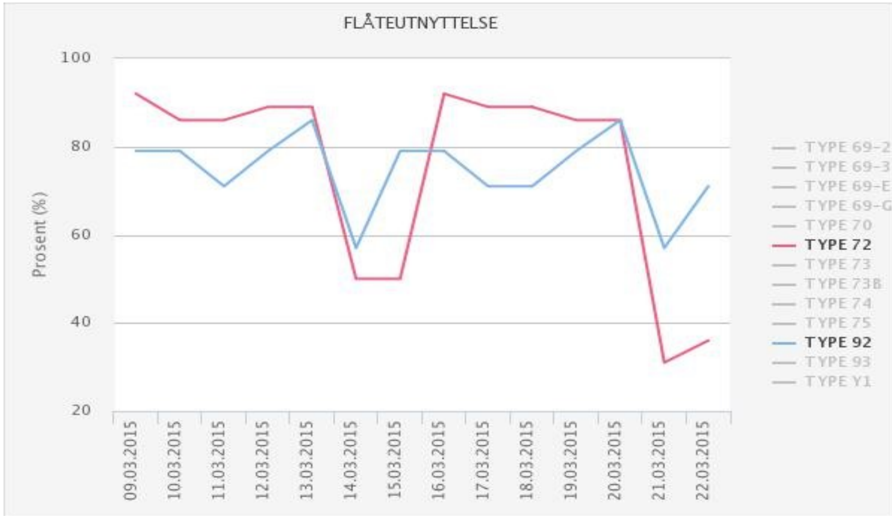

Figure 13. Fleet utilization for train types 72 and 92. (NSB, 2015)

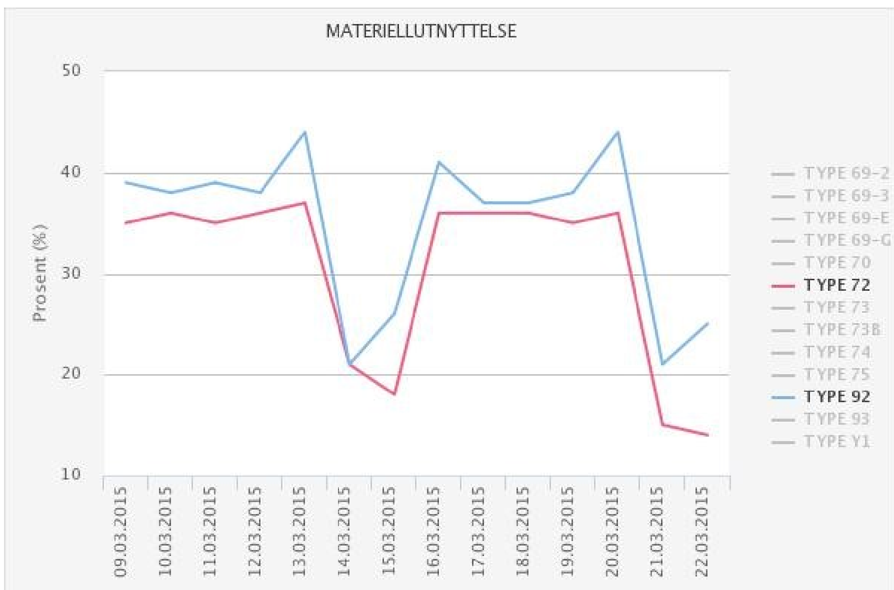

Figure 14. Materials utilization for train types 72 and 92. (NSB, 2015)

Figures 13 and 14 shows the fleet and materials utilization for the train types used in the case stretches mentioned in previous chapters. It is easy to see that the graphs shows the same trends for both train types. The utilizations are relatively high during the week, while they are low during weekends. Also note that the fleet utilization are higher for type 72, while the materials utilization are higher for the long distance train type 92. The fact that the materials utilization is higher for type 92 makes sense, seeing as long distance trains have fewer stops per unit of time, and also drive for much longer periods of time before reaching their final destination where there are normally longer stops for turnaround or similar.

10.1.5 NSB: Iceberg benchmarking

Thanks to NSB and Andreas Hægstad, access was also granted to some fleet utilization data from a benchmarking project called Iceberg. Due to the nature of the data, the names and fleet sizes of the participants (except NSB) has been anonymized. The Iceberg project is made up of train companies from many different countries, and is reviewing local trains around and in big cities. Table 21 shows the estimated fleet utilizations of the different companies during peak hours and interpeak hours.

Company	A	B	C	D	E	F	G	I	J	K	NSB	M	N	O	P
Estimated fleet utilization in peak	0,95	0,89	1,00	0,97	1,28	0,96	0,90	0,99	0,92	0,97	1,00	0,93	0,89	0,95	1,00
Estimated fleet utilization interpeak	0,81	0,77	0,46	0,68	0,50	0,65	N/A	0,51	N/A	0,78	0,49	N/A	0,60	N/A	0,58

Table 21. Fleet utilization data from the Iceberg benchmarking study. (NSB, 2015)

Based on table 21 it can be seen that all companies have a high utilization during peak hours, while during interpeak hours there are larger differences. Statistics from table 21 are shown in table 22. As could be expected from table 21 the average utilization during peak is close to 100%, with a relatively low standard deviation of about ten percent of the average. Note that the maximum estimated fleet utilization is actually more than one, which means that the company in this case needs more carts per train than it has available to fully meet demand. The average utilization for interpeak is significantly lower, and has a higher standard deviation. This variation in interpeak services shows that there are large differences in the demand levels throughout a day, and that these vary from country to country.

Fleet Utilization	Average	Min	Max	Std. dev.
Peak	0,97	0,89	1,28	0,09
Interpeak	0,62	0,46	0,81	0,13

Table 22. Fleet utilization data from the Iceberg benchmarking study. (NSB, 2015)

10.1.6 Summary

Based on the results from the data analyses presented in chapter 10.1, it is possible to do a summary of the railway results related to the four parameters mentioned in the introduction to chapter 10. Table 23 shows the results of the railway data analysis sorted on each parameter. The table mainly uses the results of the NSB data since this data is the most comprehensive and detailed.

Slack	Recovery time	Turnaround ratio	Fleet utilization	Materials utilization
Railway	~10%	1-3,83	~66%-67%	~26%-27%

Table 23. Summary of the railway data analysis.

As it was shown in the parts about run time, there was a variation in the additions made both between different lines and between different stretches within each line. With the exception of some stretches were very large additions were made, most additions did however revolve around the addition of 10% mentioned by Schrader (2014) as a necessity in order to make the timetable robust.

Turnaround ratios vary from 1, meaning no slack, to 3,83 which on the other hand implies that there is a large amount of slack. There are in other words a large spread in the size of the turnaround ratios, which in this case mostly differs between long distance and commuter trains. In general it seems like slack is implemented in the turnarounds, and that a turnaround ratio of 1 is an exception.

The fleet and materials utilization shown in table 23 are the average weekly utilization of the different fleet types at NSB's disposal. Tables 19 and 20 shows that there are large variations between the fleet types, and table 18 shows that the fleet sizes also varies significantly. Variations between days of the week and between peak and interpeak hours are also significant, and the results must thus be interpreted with this in mind. The results from the Iceberg benchmarking study shows these variations, but the interpeak average utilization rate of 62% also shows that the total average fleet utilization rates of NSB seem to be representative.

10.2 Urban transport data analysis

All the data in the urban transport data analysis is related to operations organized by Ruter. Ruter (2015) is responsible for the planning, coordination, ordering and marketing in Oslo and Akershus. It is co-owned by the municipality of Oslo and the county of Akershus, and is responsible for over half of the urban transport in Norway. Ruter themselves do not own any means of transportation, and as such the different operators that are contracted by Ruter carry out all operations. NSB is responsible for the local trains.

The data in this section is thus provided form the operators, after referral from Ruter. One section will make use of data regarding bus operations while another will be related to the subway. Who supplied the data and more specific details concerning the data is provided in the respective chapters.

10.2.1 Ruter: Bus

Bus data from Ruter was provided by Helena Volen. The data was given as punctuality data for 09.12.13 to 13.12.13 for the line Skøyen – Galgeberg in the period 07.00 to 09.00. Bus companies use such data to evaluate their timetables based on punctuality and the punctuality distribution. Figure 15 shows the run time distributions for the line, which has a scheduled run time of 32 minutes in both directions.

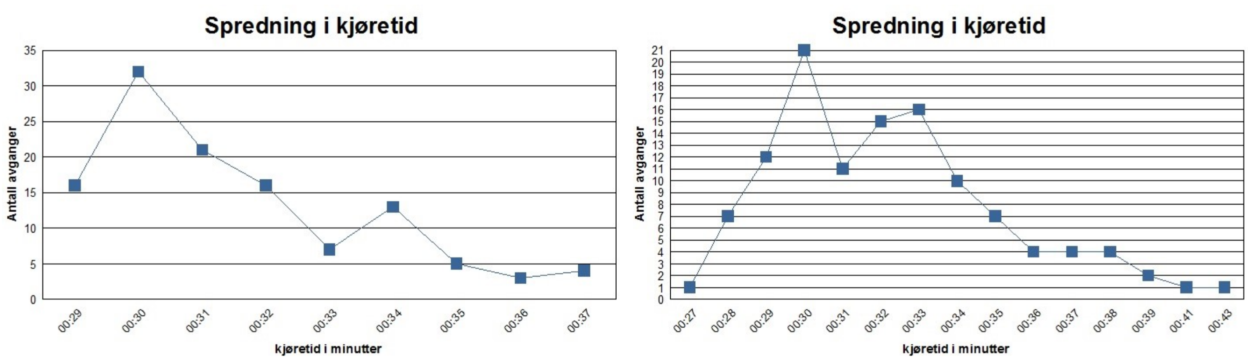

Figure 15. Run time distributions for Skøyen - Galgeberg and Galgeberg - Skøyen. (Ruter, 2015)

For Skøyen – Galgeberg the 10th and 90th percentiles are, as given by Ruter, 29:41 and 35:21 minutes, while for Galgeberg – Skøyen they are 29:22 and 37:16 respectively. Based on these numbers together with figure 15 it is clear that the scheduled run time is well above the 10th percentile, but also below the 90th. It can also be seen that in this period there were actually a high number of late arrivals for the Galgeberg – Skøyen line.

Since the scheduled run time is not actually calculated for Ruter, but adjusted through the used of data analysis, it is not possible to calculate the recovery time in this case. It is however clear that for Ruter the scheduled run time is a trade-off between punctuality and utilization. High punctuality can be achieved by setting a high schedule time, but this will of course reduce potential utilization of vehicles. There are no required turnaround times for buses, if they are delayed to the final stop they can just keep going. If they arrive early, they will wait until the scheduled departure time.

10.2.2 Ruter: Subway

Sporveien T-bane is the operator responsible for subways. Their head of analysis, Helge Holtebekk, provided the information and data in this section. When it comes to the scheduled run times, Sporveien only use measured times that are adjusted (up and down) based on punctuality and regularity. Since there are no theoretically estimated run times it is not possible to calculate the added running time. Turnaround times are not specifically given, but Holtebekk says that they focus on maintaining a predictable timetable with even frequencies. This means that they do not optimize on turnaround times. And that they have implemented slack in this case.

The subway utilization data is given for week 11 and 12, and their subway fleet consists of 115 train sets. Each sets is made up of three wagons. Fleet utilization data is based on how many train sets have been used each day, while the materials utilization is based on accumulated wagon hours. Table 24 shows the fleet utilization for the case period.

		Train sets in use	Fleet utilization			Train sets in use	Fleet utilization
Week 11	**09.03.2015**	102	0,89	**Week 12**	**16.03.2015**	102	0,89
	10.03.2015	102	0,89		**17.03.2015**	102	0,89
	11.03.2015	102	0,89		**18.03.2015**	102	0,89
	12.03.2015	102	0,89		**19.03.2015**	102	0,89
	13.03.2015	102	0,89		**20.03.2015**	102	0,89
	14.03.2015	76	0,66		**21.03.2015**	75	0,65
	15.03.2015	52	0,45		**22.03.2015**	56	0,49
	Average		0,79		**Average**		0,80

Table 24.Fleet utilization for Ruter subway during week 11 and 12, 2015. (Based on Ruter, 2015)

The table shows that during all weekdays the fleet utilization is high and identical for both weeks, while the utilization during weekends are drastically lowered. On Sundays, the utilization is close to half of that of weekdays, with Saturdays as a middle ground. This is shown graphically in figure 16.

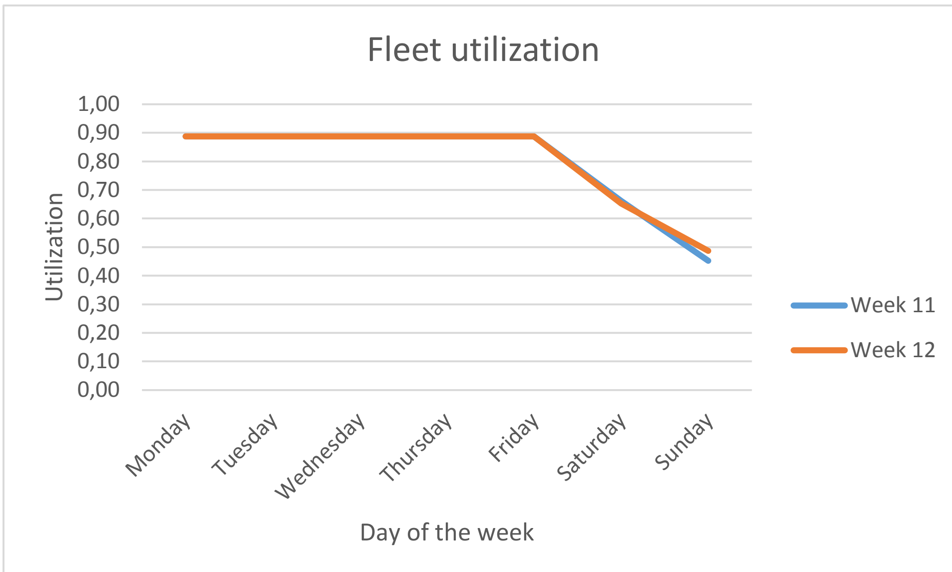

Figure 16. Fleet utilization for Ruter subway during week 11 and 12, 2015. (Based on Ruter, 2015)

Materials utilization data is shown in table 25. It can easily be seen that the materials utilization follows the same pattern as the fleet utilization.

		Time in use	Materials Utilization			Time in use	Materials Utilization
Week 11	**09.03.2015**	237736	0,48	Week 12	**16.03.2015**	237440	0,48
	10.03.2015	237580	0,48		**17.03.2015**	237736	0,48
	11.03.2015	234190	0,47		**18.03.2015**	237736	0,48
	12.03.2015	237664	0,48		**19.03.2015**	237574	0,48
	13.03.2015	238254	0,48		**20.03.2015**	236539	0,48
	14.03.2015	165812	0,33		**21.03.2015**	152690	0,31
	15.03.2015	128840	0,26		**22.03.2015**	108961	0,22
	Total	1480076	0,43		**Total**	1448676	0,42

Table 25. Materials utilization for Ruter subway during week 11 and 12, 2015. (Based on Ruter, 2015)

Table 25 shows that the utilization is pretty similar for both weeks, and this is shown in figure 17 as well. It also shows that utilization is the same (with the exception of 11.03) during Monday to Friday for both weeks. During the weekends, the utilization diminish significantly, with Sundays showing the lowest utilization for both weeks. There is however a small difference between the utilization on the weekends of the two weeks.

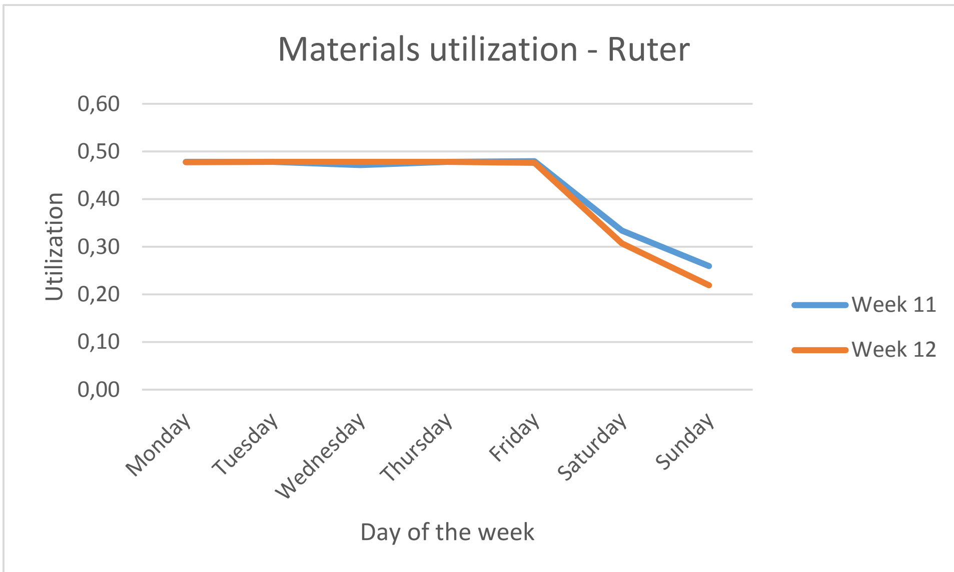

Figure 17. Materials utilization for Ruter subway during week 11 and 12, 2015. (Based on Ruter, 2015)

10.2.3 Summary

Based on the results from the data analyses presented in chapter 10.2, it is possible to do a summary of the bus and subway analysis related to the four parameters mentioned in the introduction to chapter 10.

The bus data was only able to show that the scheduling is a trade-off between punctuality and utilization, and the recovery time seeing as the theoretical run time is not calculated. Slack in the timetable will lead to increased punctuality, but at the same time, it will decrease the potential vehicle utilization. By using punctuality data, such as the data shown earlier, the companies can thus decide on the schedule times based on predefined definitions of accepted punctuality.

Ruter subway use the same methodology as Ruter bus to decide on their scheduling, and as such the recovery time cannot be calculated in these cases. The turnaround ratio could not be calculated, but Holtebekk confirmed the active use of slack to achieve a satisfying timetable for passengers. Table 26 shows the results of the urban transport analysis summarized for comparison, based on the data provided by Ruter.

Slack	Recovery time	Turnaround ratio	Fleet utilization	Materials utilization
Subway	N/A	N/A	0,79-0,80	0,42-0,43

Table 26. Summary of the urban transport data analysis.

The data analyses about Ruter subway showed the fleet and materials utilization for the case period. It was indicated that the fleet and materials utilization followed the same pattern throughout the week, with steady utilization rates on weekdays and a significant decrease in activity for Saturday and especially Sunday. The rates shown in table 26 are the averages for the whole week in order to be able to make a comparison with the other modes of transportation.

10.3 Airline data analysis

10.3.1 Norwegian long haul

Norwegian long haul is a subsidiary of Norwegian Air Shuttle. Norwegian (2015b) says that it is the second largest airline in Scandinavia, and that it is the third largest low cost carrier (LCC) in Europe. They fly to 130 destinations in Europe, North Africa, the Middle East, Thailand and the United States. In 2014 the carrier transported 24 million passengers, and their current fleet consists of 96 airplanes (Norwegian, 2015c).

Norwegians long haul division had seven Boeing 787-8 Dreamliner in its fleet at the time of the data gathering (they now have 8) which covers routes to 4 destinations in Europe, 5 in the US and 1 in Thailand, and it is these aircraft and routes that will be analyzed in the following.

The data was gathered from Norwegian (2015a), searching through the relevant routes for departure and arrival times. Flightradar24 (2015) was used to pinpoint which airplane flew which route, in order to construct the timetable and the materials schedule for the period 09.03.15 to 22.03.15. Appendix 1 shows the constructed timetable and related data. It also shows that the timetable repeats itself on a weekly basis, which fits the claim of Bazargan (2010) that timetables are cyclical on a weekly basis for long haul flights.

10.3.2 Norwegian long haul: Route planning

Based on the schedule shown in appendix 2 it is possible to show the durations of the ground stops in the different airports served by Norwegian long haul. Since the purpose of this is summary is to reveal slack in the turnaround times, only ground stops where the plane has departed on the same day is included in table 27.

Norwegian long haul maintains a fleet consisting only of Boeing 787 Dreamliners. According to Boeing (2015) an estimate of the turnaround time for the 787 is around 45 minutes for ground stops at “turnaround stations”, while stops at “en route stations” can be performed in just under 30 minutes. The details of these estimates can be seen in appendix 3. The estimate of 30 minutes is for turnarounds without galley, lavatory and cabin service, and can thus not be used for Norwegians’ long haul flights. The details also shows that these estimates are made for close to optimal conditions and that realistically the minimum turnaround times will be somewhat higher.

	Ground stops (min)		Estimated turnaround	Turnaround ratio	
Airport	Min	Max		Min	Max
OSL	100	250	45	2,22	5,56
ARN	115	270	45	2,56	6,00
CPH	130	220	45	2,89	4,89
LGW	125	345	45	2,78	7,67
JFK	90	90	45	2,00	2,00
LAX	120	120	45	2,67	2,67
OAK	120	120	45	2,67	2,67
FLL	115	175	45	2,56	3,89
MCO	120	120	45	2,67	2,67
BKK	120	200	45	2,67	4,44

Table 27. Norwegian Long Haul ground stops at the different airports served.

Table 27 shows the ground stops and turnaround ratios for Norwegian long haul. Ground stops vary from 90 to 345 minutes, but the most common ground stop times are around 120 minutes. A notable exception is New York JFK where the turnaround time is restricted to 90 minutes. The maximum ground stops in Europe of 4-6 hours are obviously not close to the minimum turnaround. This might however include light maintenance or other similar activities.

For the grounds stops of between 90 and around 180 minutes however, it can be argued that the only purpose is to turn the plane around as fast as possible (within reasonable cost) so that it is ready for a new flight. Based on the estimates made by Boeing (2015) it can be seen from table 27 that the turnaround ratios are between 2 and 3.89, which indicates that there are significant amounts of slack in the ground stops seeing as the shortest one is twice the length of Boeings' estimations.

10.3.3 Norwegian long haul: Fleet planning

Fleet utilization is a hard to develop from the available data, since it is a challenge to define what is considered an airplane in use and what is considered an airplane not in use without any knowledge of how the fleet planers are thinking. It is thus not possible to make a detailed view of the fleet utilization for Norwegian Long Haul. What can be done, however, is to make a graphical overview of how many of Norwegians planes are in use the same time. In this case, "in use" means that the plane is accumulating block hours. This shows how many planes you need to run the timetable, and thus also their maximum fleet utilization. Figure 18 and 19 shows an overview of how many airplanes that are in use at the same time for week 11 and 12 respectively.

Based on figure 18 and 19 it is possible to conclude that the timetable for week 11 and 12 requires 6 airplanes to run, as the maximum number of planes in use at the same time is 6. This means that there always is one aircraft not in service, and that the maximum fleet utilization is 0,86. Looking at figure 18 it seems like 6 aircraft are required on most of Monday, Tuesday, Thursday, Saturday and Sunday, while most of Wednesday and Friday require 5.

On Tuesday of week 12 there was a cancelation, and this is the reason for why the graphs differ. It is also important that the times in the graph are not exact, and can thus not be used for more detailed analyses.

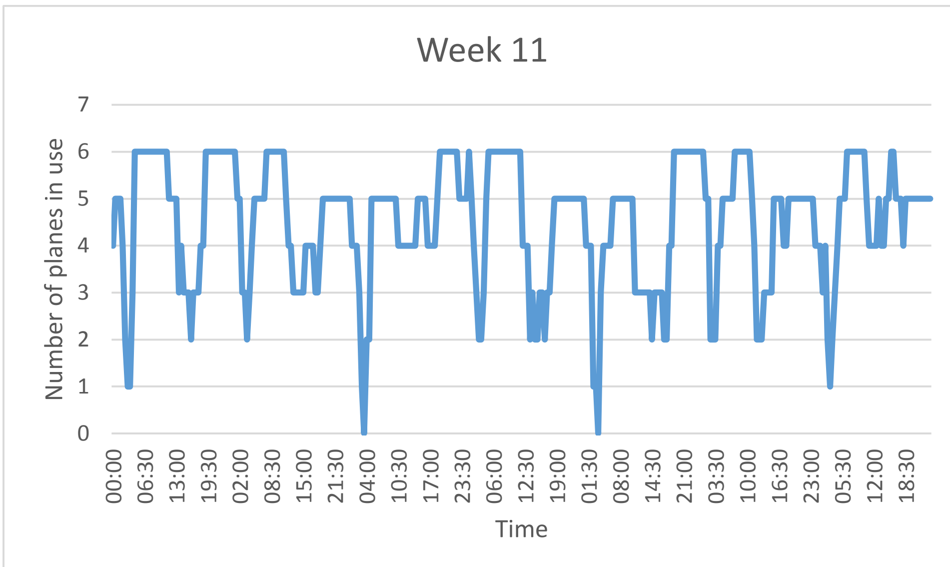

Figure 18. Number of Norwegian Long Haul planes in use, week 11.

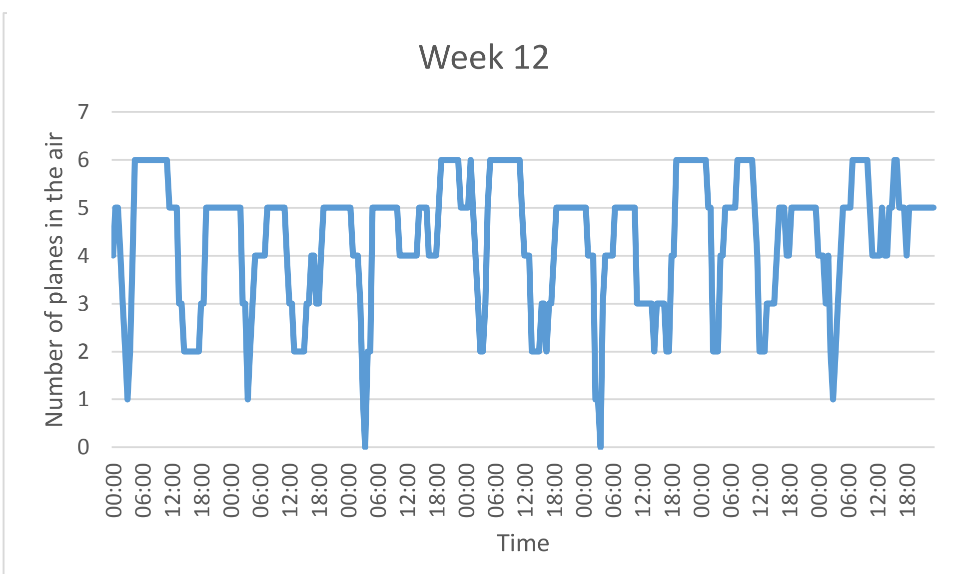

Figure 19. Number of Norwegian Long Haul planes in use, week 12.

Even though this overview does not take in to account scheduled maintenance and similar activities that would be scheduled for when the aircraft are not in service, it shows a clear image that there are some slack incorporated in the schedule so that there are back-up airplanes available if there are technical issues or other reasons.

Using the timetable and materials schedule constructed on the basis mentioned earlier, it is possible to find the materials utilization rate for Norwegian Long Haul during the case period. The utilization rate considers cancellations, but it does not take in to account delays or early arrivals/departures, and thus assumes that the flight times given by Norwegian are accurate to such an extent that it can be used in a qualitative discussion. Ferry flights are also excluded.

Table 28 shows the materials utilization of the Boeing 787-8 fleet on each day of the case period, as well as the total materials utilization for the whole week. Utilization rates for each individual airplane can be seen in appendix 2. The table shows that the utilization rates are evenly distributed, with a peak at Sundays and a low at Thursdays. The weekly utilization rates suggests that the Dreamliners were in the air for an average of 15,6 hours per day in week 11 and 14,88 hours per day in week 12.

	Date	Materials Utilization		Date	Materials Utilization
Week 11	09.mar	0,69	**Week 12**	16.mar	0,62
	10.mar	0,65		17.mar	0,56
	11.mar	0,64		18.mar	0,64
	12.mar	0,64		19.mar	0,64
	13.mar	0,58		20.mar	0,58
	14.mar	0,64		21.mar	0,64
	15.mar	0,66		22.mar	0,66
	Total	**0,64**		**Total**	**0,62**

Table 28. Materials utilization for Norwegian Long Haul in week 11 and 12, 2015

These numbers can be summarized as shown in table 29. It is shown that the utilization is about the same for each week. The timetables are identical for each week, and the difference is thus due to cancellations in the second week. It also strengthens the impression that the schedule is evenly distributed, seeing the relatively low standard deviation.

Total	Utilization	Min	Max	Std.dev
Week 11	0,64	0,58	0,69	0,0318
Week 12	0,62	0,56	0,66	0,0363

Table 29. Materials utilization for Norwegian Long haul in week 11 and 12, 2015.

All the data used for Norwegian Long Haul can as previously mentioned to be found in appendix2. It is also worth mentioning that there is an error in the constructed timetable, seeing as on the 18th of march the timetable shows that the same aircraft both lands and takes off at 15.20. This is marked with red letters. While this is of course not possible, the most natural explanation is that there has been a delay that has not been picked up by the author. The utilization rate of this single aircraft will therefore be too high on the given date, but if the assumption of a delay holds up, this will even out on the day after by being lower than it should. In any case, the total utilization of the Dreamliner fleet is not largely affected by this, and should not affect the result in a critical manner.

10.3.4 Airline data comparison of several American airlines

MiT (2015a) has summarized utilization and fleet data for most of the large American airlines for a long period, in a project called Airline Data Project. These data are publicly available and the base data will be used in this thesis for further analysis and comparison with the other data included in the thesis.

Fleet sizes		Total fleet		Small narrowbody		Widebody	
		2012	2013	2012	2013	2012	2013
Network carriers	American	597	612	198	187	120	117
	Delta	707	715	331	346	136	137
	United	698	698	208	197	154	150
LCC	Southwest	621	601	608	559	N/A	N/A
	Jetblue	174	185	150	151	N/A	N/A
Other	Alaska	120	128	47	47	N/A	N/A
	Hawaiian	42	45	18	18	24	27
	Allegiant	60	63	56	57	N/A	N/A

Table 30. Fleet sizes of the American airlines involved in the study. (MiT, 2015a)

Table 30 shows the fleet sizes of the airlines participating in the airline data project. It is easy to see that the fleet sizes are immensely larger than that of Norwegian Longhaul, which was used for data analysis in the previous chapter. The data is also available for much longer periods of time.

Tables 31 and 32 shows the utilization data for 2012 for the airlines listed in table 21. The data is presented for each of the categories of airlines, and as a total for all of them. The choice of showing the utilization for the total-, small narrowbody and widebody fleets is due to an interest in showing the differences between the subfleets in addition to the differences between the types of airlines.

Looking at table 31 and 32 it is seen that there are several differences in utilization. These includes differences between the different categories of airlines, and differences between subfleets. Note that the airlines in the category "other" are not very similar in any way, while in the other categories the airlines share similarities in both business model and, looking at the tables, fleet utilization. There is a distinct difference between the utilization of the network airlines and the LCC airlines, and the variety within the categories are lower than that of all the airlines as a whole.

Materials Utilization 2012		Network	LCC	Other	All Airlines
Average	Total fleet	0,43	0,48	0,36	0,42
	Small Narrowbody	0,38	0,52	0,29	0,38
	Widebody	0,50	N/A	0,50	0,50
Minimum	Total fleet	0,41	0,48	0,23	0,23
	Small Narrowbody	0,36	0,48	0,23	0,23
	Widebody	0,48	N/A	0,50	0,48
Maximum	Total fleet	0,44	0,49	0,44	0,49
	Small Narrowbody	0,42	0,57	0,37	0,57
	Widebody	0,52	N/A	0,50	0,52

Table 31. Materials utilization of several American airlines for 2012. (Based on MiT, 2015a)

Materials Utilization 2013		Network	LCC	Other	All Airlines
Average	Total fleet	0,42	0,49	0,36	0,42
	Small Narrowbody	0,39	0,55	0,29	0,39
	Widebody	0,50	N/A	0,50	0,50
Minimum	Total fleet	0,41	0,49	0,22	0,22
	Small Narrowbody	0,37	0,49	0,23	0,23
	Widebody	0,47	N/A	0,50	0,47
Maximum	Total fleet	0,44	0,50	0,44	0,50
	Small Narrowbody	0,42	0,61	0,38	0,61
	Widebody	0,52	N/A	0,50	0,52

Table 32. Materials utilization of several American airlines for 2013. (Based on MiT, 2015a)

10.3.5 Turnaround times at Værnes airport, Trondheim

Thanks to data provided from Avinor at Værnes airport for the period 01.01.15 to 30.04.15, it was possible to find the scheduled turnaround times for airlines not based at the airport. The table does not include overnight stops. Note that the airlines have been anonymized, but their aircraft of choice for the routes to Trondheim, including number of seats, and their scheduled turnaround times can be seen in table 33. Flightradar24.com (2015) showed the aircraft type used, while the webpages of the airlines provide the number of seats.

Airline	Aircraft	No. Seats	Turnaround	Possible turnaround	Turnaround ratio
A	B757	183	50 min	38 min	1,32
B	E190	100	30-35 min	15 min	2-2,33
C	E170	88	35-40 min	15 min	2,33-2,67
D	A320	180	30 min	22 min	1,36

Table 33. Turnaround times at Værnes Airport, Trondheim. (Based on Avinor, 2015)

The manufacturers of the aircraft in table 33 provide estimates of the turnaround times for each aircraft. While they emphasize that these times are merely an example, and that they will depend on myriad of factors, it is still interesting to mention them for comparison. See appendix 3 for details on the turnaround estimations.

Both Boeing (2002) and Airbus (2015) give detailed estimates of the possible turnaround times for their respective aircraft. They separate between a "full turnarounds" and turnarounds made outside the home base of the aircraft that are usually less comprehensive. Based on the assumptions made in the estimates, it is clear that they assume mostly ideal circumstances. Embraer (2015) only say that an E-jet (Embraer 170/175/190/195) "can be turned around in as few as 15 minutes", and the following analysis will assume that the same ideal circumstances as in the previous are used for these estimates. Remembering the chapters about airline scheduling it is natural to conclude that these times are too short to be of any practical use since ideal circumstances are rare. They still however provide a good baseline for identifying slack and for comparison.

Since detailed information about what is done during a turnaround and the equipment used is not available, it is not possible to make exact conclusions regarding slack in this case. It is however possible to discuss the topic, and see some trends related to the business models and compare the turnarounds to that of the manufacturers. For this discussion, it is assumed that the E-jets are boarded using only one door since the turnaround times are more than double the advertised possible turnaround times by Embraer themselves. The ratios in these cases would thus be lower in practice, and assumedly lower than two.

Airline A has a turnaround time of 50 minutes at Værnes. The numbers from Boeing (2002) would imply that this means that Airline A has a more extensive turnaround, which could include refueling, galley services, water service, etc. It is seen that the turnaround ratio is the same as for Airline D, but in this case the base time is longer, so there is reason to believe that there are some slack.

Airline B is a traditional FSC. They provide a huge network all over the world using the hub-and-spoke model. Based on the turnaround times given and assuming only one door is used for boarding, the impression is that Airline B operates turnaround times aimed at a middle ground between low turnaround times and being punctual, which is of crucial importance when it comes to the FSCs' connectivity at their hub.

Airline C using a smaller version of the same aircraft as Airline B, but has 5-10 minutes longer turnaround times. This clearly indicates that Airline C has implemented some slack in their turnarounds, assuming that everything is done in a similar matter as for Airline B.

Airline D uses the A320 when flying to Værnes, and as seen in table 33 they have a turnaround time of only 30 minutes. Based on the assumption that the estimated minimum turnaround time at an outstation of 22 minutes is too low for practical use, this would indicate that there is little slack in Airline D's scheduled turnaround. Airline D is an LCC, and this is thus fitting their business model.

10.3.6 Summary

Based on chapter 10.3, this chapter will make a summary, shown in table 34, of the results from the airline part of the analysis. Most of the airline data analysis is based on the construction and decomposition of the Norwegian Long Haul timetable. Important results were however also found from the MiT (2015) airline data project and from data provided by Avinor (2015) at Trondheim airport Værnes.

Slack	Recovery time	Turnaround Ratio	Fleet utilization	Materials Utilization
Airline	N/A	1,32-2	N/A	~36%-48%
Airline - Long Haul	N/A	2-3,89	~71%-86%	~50%-64%

Table 34. Summary of the airline data analysis.

Several distinctions in the airline industry are important to have in mind when interpreting the results of such an analysis. The first is the business models and the second is short haul vs. long haul. Business models relates to FSCs vs. LCCs and the use of hub-and-spoke or point-to-point network among other factors, all described in chapter 9.

When it comes to turnaround times it has been shown that for airlines serving Værnes airport have turnaround ratios of between 1,32 and 2 when compared to close to ideal estimates. This implies that for the lowest ratios there are low amounts of slack in practice, while for the highest there are definitely some slack implemented. Norwegian Long Haul shows ratios between 2 and 3,89 for a similar case, and thus there are definitely some slack in the scheduled turnarounds.

The fleet utilization of Norwegian Long Haul is between 71% and 86% in the case period. Note that their fleet size is very limited. Their materials utilization of 64% is significantly higher than the 50% of the American network carriers. Materials utilization for all the American airlines mentioned range between 36% and 48%, and also in this case there are significant differences between the LCCs and the FSCs. Looking at the narrow body numbers the difference is even larger, seeing as the long haul materials utilization of the network carriers push their average up.

11. Discussion

11.1 Slack in theory

Definitions of the word slack were introduced early in this thesis, and they included "loose", "reduced intensity" and "lack of activity" (The Oxford online dictionaries, 2015a; Thesaurus.com, 2015). Slack is thus a word surrounded by mostly negative connotations and could potentially be associated with a situation of laziness or calm.

In Lean manufacturing, which has its origins from the Toyota production system (TPS), one of the main principles is the elimination of waste (Womack and Jones, 2003). The meaning of waste in this context includes everything that does not *create value* for the end customer. While producing defects is an obvious waste, the Lean manufacturing ideology also view the traditional manufacturing activity of inventory as waste, while other wastes include waiting and unnecessary transportation. In many ways, it could thus be claimed that Lean manufacturing aim at streamlining production and eliminating all slack, based on how slack was defined in the previous paragraph.

Slack as an explicit term is rarely mentioned in literature, but there are many terms similar to slack. Some of these were mentioned in chapter 3.2 and included redundancy (Olsson, 2006), reserves/back-up (Olsson, 2006), buffer (Galbraith, 1984), and contingency. All of these could be placed under the umbrella term slack. Galbraith (1984) mentions slack resources explicitly, which he says could mean extending completion dates, raising budget targets, having buffer inventories and similar. The greater the uncertainty the greater the magnitude of slack needed to reduce an overload. Implementing such resources seem to differ substantially from Lean.

As was discussed in chapter 5.6, however, Lean manufacturing was originally meant for a closed of factory where processes could be controlled and uncertainty is low. It was shown that according to Lee (2002) the Lean (or efficient) supply chain is only appropriate in situations with low uncertainty in both the demand side and the supply side. Coping with high uncertainty called for inventories and similar measures in what was named an agile supply chain, which is in line with the slack resources described by Galbraith (1984).

It is also worth noting that in the case of agile supply chains the slack resources help *create value* for the end customer. In that way the resources are not waste as it was defined in the Lean philosophy, but instead helps increase the quality of the product or service provided.

In Total Quality Management (TQM) it is widely accepted that variation is the paramount cause of poor quality (Deming, 2000). Excessive variation leads to non-satisfied customers, which in turn affect the companies' income and reputation. This means that slack resources contributing to reducing variation in processes could potentially contribute to create value for the end customer.

Due to the importance of customer focus, it is important to be conscious of the performance objectives mentioned by Slack, Chambers and Johnston (2010). Depending on the relative weighting between the objectives, slack resources could prove necessary to satisfy order winning criteria, or even order qualifying criteria in some cases. The weighting of the objectives will vary between industries, and potentially between segments of customers within some industries. In many cases though, the order qualifying criteria will be mostly similar across segments.

In transportation industries, one of the factors often mentioned as the most important in terms of customer satisfaction is punctuality/reliability. Both railway, urban transportation and airline researchers mention on-time performance as one of the overall most important factors for customers (Profilidis, 2014; Seco and Goncalves, 2007; Holloway, 2008). This implies that in many cases, except for perhaps leisure travelers, acceptable punctuality and reliability levels could be considered order qualifiers across the transportation industries. Consistent poor performance will in fact lead to passengers choosing competitors or other modes of transportation.

Achieving the desired punctuality levels relies heavily on the scheduling process. The transportation scheduling process consists of four basic components: Network route design, setting timetables, scheduling vehicles to trips and assignment of crew (Ceder, 2001). These activities are normally performed in sequence, meaning that the network and timetable design is used as a baseline for vehicle and crew scheduling. Because of this slack in timetables are usually the focus in literature, and vehicle utilization is often found to have a background in how intensive the schedules are. The use of back-up resources are however often mentioned.

Robustness is a concept frequently mentioned in relation to scheduling in literature concerning all the transportation modes mentioned in this thesis. There are several definitions of robustness, but the basic meaning in most cases is that a robust timetable is able to absorb small disturbances without intervention (i.e. capable to cope with uncertainty) (Salido, Barber and Ingolotti, 2008; Cats and Jenelius, 2005; Holloway, 2008). Introducing robustness in a schedule is a commonly accepted way to increase punctuality, and robustness measures include increased buffer times, reducing capacity, and holding reserve capacity among other. These measures fit the description of slack resources as they were previously defined.

Since punctuality is such an important factor for the customers of transportation companies it is clear that slack resources could indeed increase the perceived quality of the service provided. For many travelers, in particular business travelers, it could also be claimed that acceptable punctuality levels are order qualifying criteria, and thus not something transportation companies can disregard.

Slack resources do however come at a price, and in the case of transferring passengers, long transfer times due to excessive buffer times could be seen as an inconvenience (Cadarso and Marin, 2012). There is as such a trade-off between cost and acceptable punctuality and regularity levels. This means that there is a motivation to optimize the use of slack resources, both when it comes to the size of the resources and its placement in the schedules to minimize costs and maximize customer satisfaction.

11.2 Slack in practice

Chapter 10 of this thesis showed several analyses of data concerning different transportation modes and different areas within each mode. Four parameters were defined in the beginning of the chapter in order to be able to compare the use of slack in different transportation modes. The parameters also make it possible to summarize the patchwork of different sources, data and angles presented. A summary showing an overview of the results presented in chapter 10 are given in table 35, but all results given in chapter 10 are used as a background for the following discussion.

Slack	Recovery time	Turnaround ratio	Fleet utilization	Materials utilization
Railway	~10%	~1-3,83	~66%-67%	~26%-27%
Subway	N/A	N/A	~79%-80%	~42%-43%
Airline	N/A	~1,32-2	N/A	~36%-48%
Airline - Long Haul	N/A	~2-3,89	~71%-86%	~50%-64%

Table 35. Summary of the data analyses.

Recovery time proved to be the hardest parameter to compare. In the railway, it is customary to estimate a theoretical running time, and then add recovery time to increase the reset capabilities (robustness) of the schedule (Hansen and Pachl, 2008). In urban transport however, it is not customary to do theoretical calculations of the run time. Both Ruter bus, Ruter subway and the bus company Kolumbus explained that instead they continually monitor the punctuality of the lines, and adjust the running times up or down based on the results. A similar method is used in the airline industry (Holloway, 2008). The results in this parameter are thus limited to the railway.

In terms of the turnaround ratio there are some ambiguous results. The railway showed a large span in turnaround ratios, but the turnaround ratio of 1 seemed more of an exception than the norm. Implementation of slack were thus identified in this case. The long haul airline analyzed showed a turnaround ratio of 2 and above, which clearly indicates slack. Airlines operating to Værnes Airport did on the other hand have turnaround ratios of 2 and less, which is starting to approach the limit of what can be considered slack seeing as a ratio of 1 is only possible during optimal conditions. The airlines making use of the lowest ratio are so-called LCCs, and thus confirm the theory surrounding their business model. Helge Holtebekk at Ruter subway said that they use slack at stops and turnarounds in order to keep a satisfying frequency based on demand.

Fleet utilization rates are fairly high for all modes of transportation, with the railway somewhat lagging behind. Note however that the railway company analyzed operates several types of trains, and that the numbers shown are the average of the average utilization of these types. There are partly large differences in utilization among train types. The numbers for the long haul airline analyzed are scattered, mostly due to the very limited fleet size. Of the three modes analyzed it is in fact the subway that shows the highest most consistent fleet utilization rate. Note also that the railway and subway show significant reduction in utilization on weekends, while the long haul airline has an evenly distributed rate. All modes have utilization rates that show signs of slack. While there is no way of telling how many, or for how long, vehicles are scheduled for maintenance and similar without more information, the utilization rates are consistently low enough to imply that there should be back-up vehicles available.

Materials utilization shows the largest differences between the transportation modes of the four parameters. The railway shows a material utilization of only 26-27%, which could be characterized as low. Subway and airline material utilization in general show similarities, with airline long haul utilization markedly ahead. Note that in the case of long haul flights there is the advantage of flying across time zones, which in practice means that schedules can make use of all 24 hours of a day. For railway, urban transport and short haul flights there are significantly reduced or no activity at all during a period of the night. Chapter 10.3.4 shows more segmented airline fleet utilization rates. When comparing these to the subway materials utilization it is seen that it is comparable to that of network carriers, while low cost carriers have a higher utilization.

Based on the results from the data analysis and the literature review it is possible to position the different transportation industries and segments within industries in a figure similar to figure 6. The positioning will be made based on qualitative judgements, while making use of a modified version of table 35 as a quantitative contribution. This is shown in table 36.

Slack	Recovery time	Turnaround ratio	Fleet utilization	Materials utilization	Slack Coefficient
Railway	N/A	2	3	4	**0,89**
Subway	N/A	N/A	1	2	**0,42**
Airline	N/A	1	N/A	3	**0,54**
Airline - Long Haul	N/A	3	2	1	**0,64**

Table 36. Relativized version of the results shown in figure 35.

Table 36 shows the results from table 35 in relativized terms. The modes have been ranked in each parameter, where 1 implies the least slack and 3/4 the highest amount of slack. While some trends are easy to spot from just looking at the rankings in the table, a form of summarization is required to draw any conclusion. Note that there are variations in both the number of modes represented in each parameter and in how many parameters each mode contributes. This means that it is not feasible to just summarize or show the average ranking.

The “Slack coefficient” shown in the far right column is made on the background of the following procedure: For each mode, the rank in a parameter is divided by the number of modes represented in the given parameter. These results are summed for each mode, and this sum is divided by the number of parameters in which the mode has provided results. For the railway this means that the slack coefficient is calculated as follows: (2/3 + 3/3 + 4/4) / 3 = 0,89.

Based on the coefficients in table 36, the amount of slack in railways are set to high, while the subway are set to medium in relative terms. For the airline case, the results are two-sided. Table 35 shows that the airline results are scattered, and it was partly shown in chapter 10.3 that this relate to the business models. Using only LCC data would put the airline slack coefficient below the subway, while network carrier data are similar to the currently presented coefficient.

In order to position the transportation modes in a figure similar to figure 6, the axes have to be modified slightly. The y-axis showing “amount of slack” will be divided in low, medium and high, and transportation modes will be placed based on relative comparisons using both table 36 and qualitative assesments. The x-axis showing uncertainty will on the other hand be given values of 1 through 5, where 1 is the lowest and 5 the highest. Categorization on the x-axis will be made on the background of uncertainty and consequence, where consequences are defined to mean the consequence of poor quality for both company and customer.

From the table 36 it can be seen that the railway had the most slack in the data analysis, and the amount in relative terms was set to high. As it was pointed out in chapter 7 about railways, however, the railway operates under heavy constrains compared to road and air travel due to it only having one degree of freedom (Olsson and Veiseth, 2011). This leads to a high interdependence between all actors, which means that uncertainty is high. Poor quality performance could have large consequences beyond a single train. Due to this the railway is given the highest score for uncertainty.

The subway operates under similar constraints as the railway, but their area of operations is more closed off and have fewer actors involved. Because of this, the potential consequences are not as severe as they could be for the railway, and it is given the score of 3. The data analysis also showed that even though the subway had implemented slack measures, they were at lower levels of slack implemented than the railway, thus giving the subway medium amounts of slack.

Bus transportation were not represented among the 4 parameters in the data analysis, and is because of this placed purely based on qualitative reflections surrounding the literature review. This should be kept in mind when reviewing the placements. Bus transportation can be divided in two categories, namely bus transportation with short and long headways.

Bus travel with short headway could in many cases mean that the headway between buses is as little as 5-10 minutes. In these cases the consequence is close to negligible and uncertainty low, because new buses will arrive shortly after. Uncertainty is thus given the score of 1. For the same reason, the profit of implementing slack resources in this case is small, putting the amount of slack at small.

For longer headways both consequence and the upside to implementing slack are significantly higher. In this case, the consequence of poor quality is higher since there might be no alternatives to waiting for the next bus (Guihaire and Hao, 2008). The implementation of slack could increase quality for the customer. Given this, the uncertainty is scored as 3 and the amount of slack set to medium.

The airline industry could possibly be divided in several categories, including long haul vs. short haul, and point-to-point vs. hub-and-spoke. The literature presented on airlines revolve more around the latter, and since the airline data analysis contain some of both categorizations the point-to-point vs. hub-and-spoke categorization is chosen as for positioning in the figure.

Low cost carriers are traditionally the users of the point-to-point model. The model is recognized by high aircraft utilization and short turnarounds, in other words low amounts of slack (Cento, 2009). Based on this and the data analysis, where LCC data presented lower amounts of slack than the subway and network airlines, the amount of slack is set to low. The uncertainty and consequences are in most cases relatively isolated, and is given a score of 2.

Network carriers using the hub-and-spoke network will on the other hand use slack to make sure that transfers at their hubs function smoothly (Cento, 2009). Consequences and uncertainty are significantly higher than in the point-to-point case, seeing as a hub-and-spoke model function as a coherent system that are more interdependent. Because of this and the results of the data analysis, amounts of slack are set to medium and uncertainty is given a score of 4.

The proposed categorizations are summarized in table 37. Note that all categorizations are subject to discussion due to their highly qualitative nature, but disagreements should in most cases lead to small changes.

	Uncertainty	Amount of slack
Railway	5	High
Subway	3	Medium
Bus - Short headway	1	Low
Bus - Large headway	3	Medium
Airline - Point-to-Point	2	Low
Airline - Hub-and-Spoke	4	Medium

Table 37. Comparison of the different transportation modes.

Based on the arguments in table 37, it is possible to create figure 20. The figure indicates that there is a relation between uncertainty and the amount of slack implemented or recommended to implement. This would however have to be explored further in order to fully conclude.

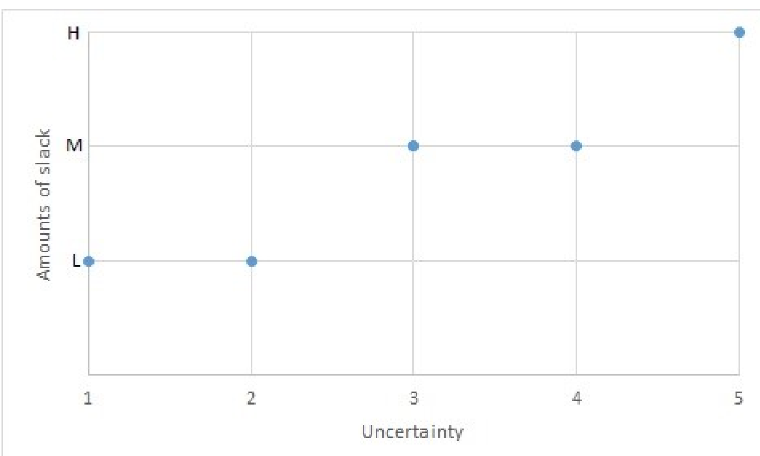

Figure 20. Uncertainty vs. Amounts of slack.

12. Conclusion

The purpose of this thesis has been to define the meaning of slack in organizational context before reviewing how slack is viewed in manufacturing and logistics theory. Finally, an attempt has been made at reviewing literature and analyzing data in terms of slack in transportation industries. In the transportation industries the scope has been narrowed to include timetable planning and fleet/vehicle planning only.

Definitions of the word slack were introduced early in this thesis, and they included "loose", "reduced intensity" and "lack of activity" (The Oxford online dictionaries, 2015a; Thesaurus.com, 2015). Galbraith (1984) mentions the implementation of slack resources, which include extending completion dates, raising budget targets, having buffer inventory and the likes. Based on these definitions it is possible to say that in a business context slack means allowing processes to run in a less than optimal way in terms of cost and/or time.

Through reviews of common manufacturing and logistics ideologies like Lean manufacturing, Total Quality Management (TQM), the lean and agile supply chains and performance objectives, two main aspects of slack has been identified. When slack is present due to factors like poor processes and bad decision making it should be considered waste and measures should thereby be implemented to reduce and remove it. If slack resources on the other hand are consciously used as a tool to cope with uncertainty, it can in fact be an enabler for quality. In these cases, focus should be on optimizing the size and placement of the slack resources.

Moving on to the transportation part of the thesis it has been shown that the focus on slack is mainly related to the timetables. Adding buffer times to schedules in the form of both recovery time and prolonged turnaround times is commonly considered a tool to improve the robustness of schedules. This has an impact on the punctuality of the schedules, and is thus a measure that can be used to improve perceived quality by customers. There is however a trade-off between cost and punctuality seeing as larger buffer times will lead to a lower utilization of rolling stock, buses or airplanes, among other consequences. Back-up, or reserve, rolling stock, buses or airplanes are also frequently mentioned as possible slack resources that can be used to maintain service as advertised in the timetables.

In chapter 11, it was shown that the different transportation modes mentioned in this thesis have implemented different amounts of slack in the categories used for review in the thesis. This was based on quantitative results from the data analyses and qualitative observations from the literature review. The railway showed the overall highest amounts of slack implemented, with network airlines and the subway following with medium amounts of slack implemented in relative terms. Low cost airlines using the point-to-point network model use low amounts of slack. While not included in the data analyses, bus services with large headways show similar characteristics as the subway and network airlines. Bus services with short headways are prone to implement low amounts of slack due to their low uncertainty and small upside to implement slack.

The different modes of transportation have many similarities when it comes to the scheduling processes, but there are also significant differences. It was pointed out that the railway was the only industry to do theoretical calculations of the run time. This made comparison of the consciously added recovery time impossible. Due to the significant differences between the operating conditions the different industries operate under it is also clear that direct comparison of the use of slack in turnarounds, fleet utilization and materials utilization only shows a part of the picture. A bus can move relatively freely around in a city, while the railway is a heavily interdependent system where every movement is subject to approval. A direct consequence of these differences is that the uncertainty and consequences of failure are different from industry to industry. This, among other factors, has to be taken in to account when comparing the amounts of slack. In chapter 11 it was shown that there are indications of a relationship between the amounts of slack and uncertainty.

Further research could be directed towards quantifying the amounts of slack and the uncertainty in a more precise manner. Quantifying the relationship indicated in this thesis more accurately would allow a better and more direct comparison between the different industries and segments. This could allow a proper comparison, all characteristics and parameters taken into account.

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Appendix 1: Pre-study report – TPK4920

Table of contents

1. Background for the topic

My specialization project TPK4520, conducted in the fall of 2014, was called "Secondary Delays Within the Same Rolling Stock Circulation Plan", and had punctuality in railways as the overall main topic. It is often normal to use the specialization project as a precursor to the master thesis and this will also be the case for my thesis work.

While the report in the specialization project was written within a relatively small framework based on tasks given by IPK, the master thesis is more tailored to suit my professional interests. Professor Nils Olsson has gained a good view of my interests after being my supervisor for the specialization project, and could thus suggest interesting topics for the master thesis. After a discussion in a research group called "Presis", Professor Olsson, together with other members, had come to a suggestion about what could be an interesting base for a master thesis topic.

The topic presented by professor Olsson was "slack in production planning" in relation to railway and punctuality. As mentioned, this topic has a direct link to the previously completed specialization project. Further on it was explained that the goal of such a master thesis would be to use existing theoretical and empirical data from production- and logistics theory on the topic of slack, and relate this to findings from railway production planning in particular. If possible, i.e. if data is made available, a possibility could also be to compare production planning in different transportation modes.

2. Problem definition

The purpose of this thesis will therefore be to study the use of slack by transport companies in their production plans. Slack as a concept in logistics and production planning will be used as the theoretical basis, while the empirical part will include analysis of data from railway production as a minimum. The problem definition will therefore be:

1. The concept of slack
    1.1. What is the definition of slack?
    1.2. Which different aspects of slack in general can be identified?
2. Slack in transportation production plans
    2.1. Which types of slack is applicable in transport?
    2.2. What are the experiences from the use of slack in transport planning and operations?
    2.3. Are there differences in the use of slack among different transport industries?

The official description of the master thesis is the following:
"The thesis will study the use of slack in production plans in transport companies. The theoretical part addresses the concept of slack in logistics and production planning, while the empirical part will include analysis of data from railway production."

3. Scope and limitations

The thesis will, as can be deduced from the problem definition, focus on the topic of “slack in production planning”. This will include both slack in general production planning and logistics, and slack in production planning specific to each of the mentioned transportation industries.

In order to give the reader the opportunity to fully appreciate the content of the thesis it will also be necessary to include some general information about production planning and logistics. This will be done by presenting different common basic strategies in production and logistics planning, and highlighting the factors that separates them. As production strategies is a very large area, this part will be short and very general. The reason it is there is to show how strategies that include the use of slack compares to strategies that do not. When turning towards slack in production planning the thesis will aim to go more in depth and give a thorough walkthrough of definitions, aspects, benefits, drawbacks and the likes.

Since the thesis is intended to compare the use of slack in different transportation industries, it is also natural to include some general information about the industries in order to highlight similarities and differences. This will be done by giving a brief introduction to the respective industries, again to show the larger picture and how they can be compared to each other. Information about production planning will follow, before the focus again will be on how slack is used in this planning in the different industries.

At the point in time when this pre-study report is written, the scope and limitations of the data analysis is yet to be determined. This is because it has not yet been decided what the analysis should look at, and it is not clear which data will be available for use. That said the goal will be to try to find some data and results from production planning that in a reasonable way can be compared. This could be related to timetabling, vehicles (rolling stock/planes/buses/etc.) planning and utilization or similar.

4. Relevant literature

The first part of the work will be to conduct a literature study. There are several different kinds of literature needed to answer the questions in the problem definition. Firstly, it is necessary to find both basic and more detailed knowledge about production and logistics theories to build a background before narrowing in on slack in particular.

The basic knowledge about production and logistics is assumed to be most easily accessible in textbooks about both operations management and the respective fields. Some such books have been part of the curriculum in courses attended at NTNU, and it is possible that some of the lectures from these courses also could prove useful. More recent and specific information about the definitions and use of slack will mainly be gathered from research papers and journals.

Before the data analysis, the thesis report will contain some general knowledge related to transport production planning and some information about the different transport industries in order to allow the reader to fully appreciate the analysis and to give the final discussion and conclusion more weight. This information will be found in research papers, journals, webpages of relevant actors and possibly gained from involved companies through both conversations and access to company knowledge.

Google Scholar and Bibsys ASK will be used as the main tools for finding and gathering literature. Both are known to provide reliable and solid data, and based on experience from the specialization project it is deemed that these, in addition to tips from professor Olsson and others, will provide the theoretical background necessary for this thesis.

5. Intended methodology

Olsson (2011) says that there are several reasons to include a description of the methodology used in reports and theses. These reasons include being conscious of ones one work in order to do quality assurance of the work, giving the reader the possibility to judge the base of conclusions and to give others the possibility to continue the work. This underlines the need for a well thought through approach to the methods used in the thesis work.

He goes on to say that it is common to separate between quantitative and qualitative methods. The two can also be combined. Quantitative methods are methods that makes of use of measureable and quantifiable data, and can thus provide exact results. These methods focus on precision and are recognized by a high degree of verifiability. Qualitative methods on the other hand are based on textual or spoken information. The main focus in these methods are often to achieve an overall understanding of the issue at hand.

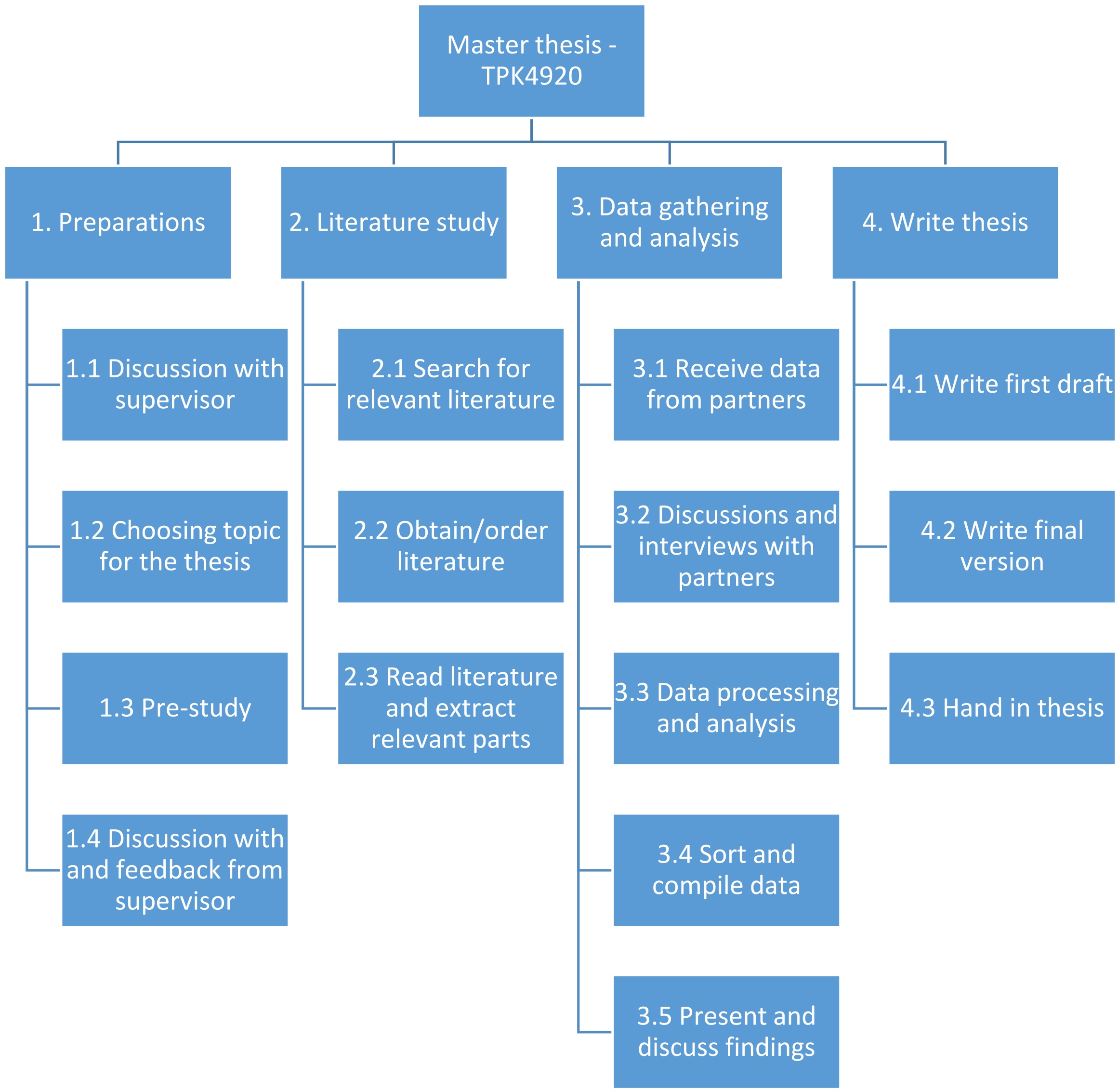
In this thesis, both of the methods will be used. Qualitative methods will be used in order to establish a theoretical background for production planning and logistics management, as well as the term slack in both these fields. This will be done through a thorough literature review. Qualitative methods will also be used in for the necessary introduction to the different transport industries. Possible interviews with partners will also considered as qualitative methods.

The data analysis on the other hand is quantitative method territory. In contradiction to the previously mentioned parts whose main goal is to give a brief overall understanding of the areas in question, the data analysis aims to provide explicit numerical answers based on the data sets provided by the partners. These data sets will be limited to a certain time frame and possibly a specific stretch, location or similar.

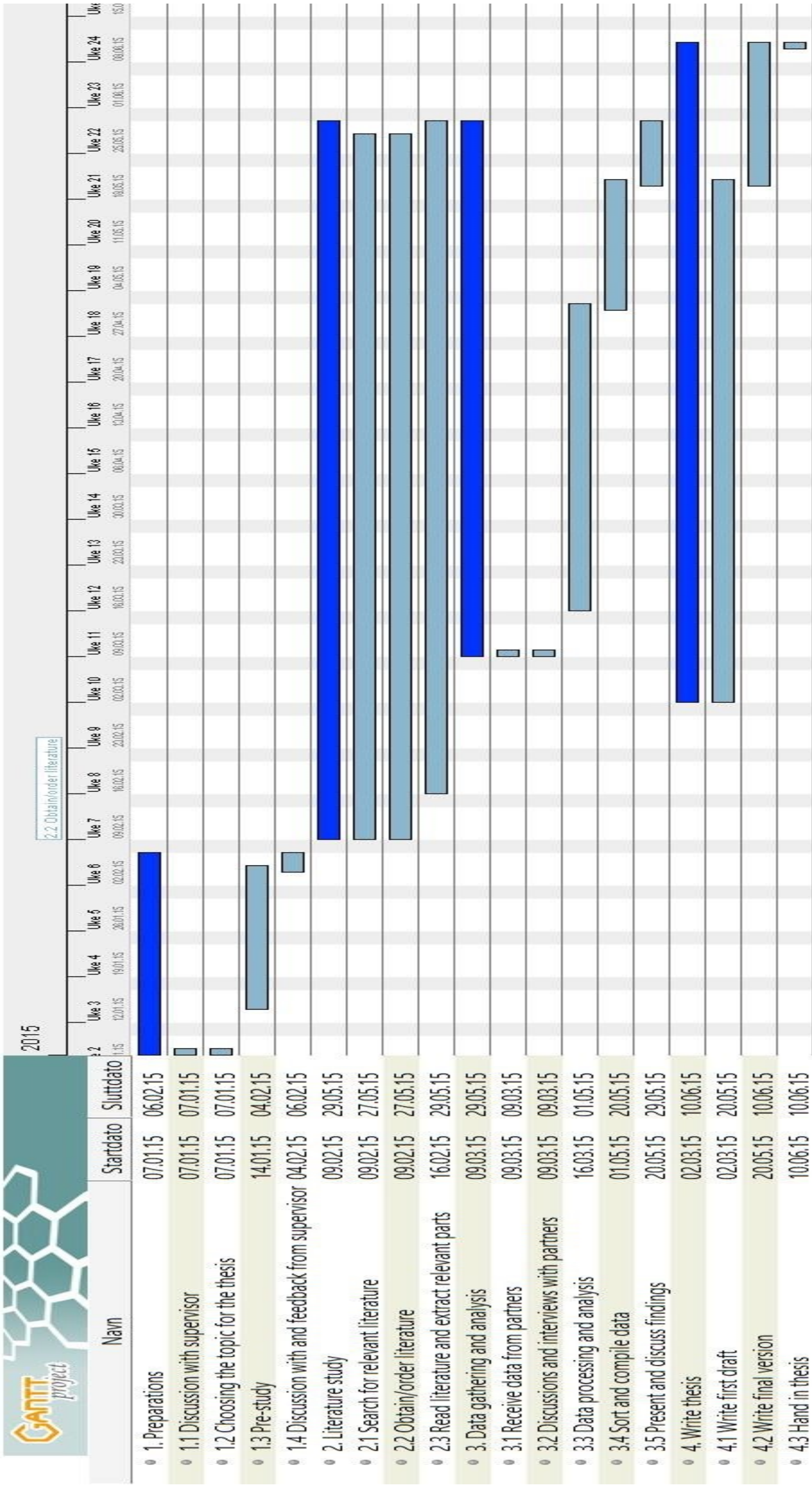
Finally, the discussion and conclusion of the thesis will be a combination of the two methods. The final conclusions and recommendations of the report will mainly be of a qualitative matter. This implies that the answers found in the data analysis is mainly meant to underline and strengthen the findings of the literature review and theoretical chapters. That said the data analysis should also provide some results that on their own could show to be useful.

6. Preliminary table of contents

7. Work breakdown structure (WBS)



8. Preliminary plan for the spring semester



8.1 Comments to the preliminary plan

As can be seen in the Gantt-char shown in the previous page, all of the main activities shown in the WBS, except the preparations, will run through more or less the whole semester. In another words, the thesis process will have a very limited amount of milestones except for the final delivery. The preparations and possibly the completion of data delivery will thus be the only potential milestones during the working process.

The reason for this is mainly that the literature study will be done as an iterative process. After finding some potentially useable literature, it will have to be read, and relevant data will be extracted and written down to fit the thesis. This process will have to be repeated as the thesis takes form, to adjust for potential changes and when discovering needs for more theoretical basis for the data analysis. Based on experience it is not possible, or desired, to declare this part as "complete" before nearing the very end of the work.

The data analysis process will also run through most of the spring semester, and is also subject to potential changes along the way. The deadline of having a first draft ready around 3 weeks before the final delivery is based on experience from the specialization project, and is an estimate of how long it takes to make the final changes and adjustments, as well as the formatting.

9. References

Olsson, N (2011), *Praktisk Rapportskriving.* 1.utg. Trondheim: Tapir Akademiske Forlag

Appendix 2: Norwegian Long Haul

All times in GMT+1 — Week 11 — Kilder: Norwegian.no(13.03), flightradar24.com,

		Monday 09.03		Tuesday 10.03		Wednesday 11.03		Thursday 12.03		Friday 13.03		Saturday 14.03		Sunday 15.03	
Flight number	Route	Departure	Arrival	Departure	Arrival	Departure	Arrival	Departure	Arrival	Departure	Arrival	Departure	Arrival	Departure	Arrival
DY7001	OSL-JFK		02.30	18.35			03.00	17.35		17.35	02.00		02.00	18.05	
DY7002	JFK-OSL	04.00	11.00			04.30	11.30			03.30	10.30	03.30	10.30		
DY7031	OSL-FLL	16.45			03.00					14.40			01.00		
DY7032	FLL-OSL			04.55	13.30							03.00	11.35		
DY7051	OSL-MCO			16.15			02.30					13.15	23.30		
DY7052	MCO-OSL					04.30	13.25							01.30	10.25
DY7201	OSL-BKK	13.35			00.55	13.35			00.55			13.35		12.40	00.55
DY7204/DY72	BKK-OSL	00.15	13.05	03.00	15.50			03.00	15.50					03.00	15.50
DY7005	ARN-JFK	17.25			02.00	17.55			02.30	17.25			02.00		
DY7006	JFK-ARN			03.30	10.45			04.00	11.15			03.30	10.45		
DY7035	ARN-FLL		02.00					16.30			03.00			15.30	
DY7036	FLL-ARN	04.00	12.55							05.55	13.50				
DY7067	ARN-OAK	18.30			05.00					18.30			05.00		
DY7068	OAK-ARN			07.00	17.00							07.00	17.00		
DY7205	ARN-BKK		00.00	13.35		11.40	00.35/22.40	13.35			00.35			06.15	17.15
DY7206/DY72	BKK-ARN	03.20	15.45			03.35	16.00	00.40	13.05	03.35	16.00				
DY7011	CPH-JFK	18.30			03.00	18.30			03.00	18.30			03.00		
DY7012	JFK-CPH			04.30	11.40			04.30	11.40			04.30	11.40		
DY7041	CPH-FLL					15.20			02.00			15.20			02.00
DY7042	FLL-CPH							04.00	12.55					04.00	12.55
DY7091	CPH-LAX			15.10			02.30					15.10			02.30
DY7092	LAX-CPH					04.30	15.20							04.30	15.20
DY7209	CPH-BKK		02.05					15.05			02.05			15.05	
DY7210	BKK-CPH	04.10	16.35							04.10	16.35				
DY7015	LGW-JFK			18.10			02.00	18.10			02.00	18.10			02.00
DY7016	JFK-LGW					03.30	10.00			03.30	10.25			03.30	10.10
DY7045	LGW-FLL	15.55			02.00					15.55			02.00		
DY7046	FLL-LGW			04.00	12.25							04.55	13.25		
DY7095	LGW-LAX		01.20			14.00			01.20					13.50	
DY7096	LAX-LGW	03.20	13.50					03.20	13.50						

All times in GMT+1		Week 12						Kilder: Norwegian.no(13.03), flightradar24.com							
		Monday 16.03		Tuesday 17.03		Wednesday 18.03		Thursday 19.03		Friday 20.03		Saturday 21.03		Sunday 22.03	
Flight number	Route	Departure	Arrival	Departure	Arrival	Departure	Arrival	Departure	Arrival	Departure	Arrival	Departure	Arrival	Departure	Arrival
DY7001	OSL-JFK		02.30	18.35			03.00	17.35		17.35	02.00		02.00	18.05	
DY7002	JFK-OSL	04.00	11.00			04.30	11.30			03.30	10.30	03.30	10.30		
DY7031	OSL-FLL	16.45			03.00					14.40			01.00		
DY7032	FLL-OSL			04.55	13.30							03.00	11.35		
DY7051	OSL-MCO			16.15			02.30					13.15	23.30		
DY7052	MCO-OSL					04.30	13.25							01.30	10.25
DY7201	OSL-BKK	13.35			00.55	13.35			00.55			13.35		12.40	00.55
DY7204/DY72	BKK-OSL	00.15	13.05	03.00	15.50			03.00	15.50					03.00	15.50
DY7005	ARN-JFK	17.25			02.00	17.55			02.30	17.25			02.00		
DY7006	JFK-ARN			03.30	10.45			04.00	11.15			03.30	10.45		
DY7035	ARN-FLL		02.00					16.30			03.00			15.30	
DY7036	FLL-ARN	04.00	12.55							05.55	13.50				
DY7067	ARN-OAK	18.30			05.00					18.30			05.00		
DY7068	OAK-ARN			07.00	17.00							07.00	17.00		
DY7205	ARN-BKK		00.00	13.35		11.40	00.35/22.40	13.35			00.35			06.15	17.15
DY7206/DY72	BKK-ARN	03.20	15.45			03.35	16.00	00.40	13.05	03.35	16.00				
DY7011	CPH-JFK	18.30			03.00	18.30			03.00	18.30			03.00		
DY7012	JFK-CPH			04.30	11.40			04.30	11.40			04.30	11.40		
DY7041	CPH-FLL					15.20			02.00			15.20			02.00
DY7042	FLL-CPH							04.00	12.55					04.00	12.55
DY7091	CPH-LAX			15.10			02.30					15.10			02.30
DY7092	LAX-CPH					04.30	15.20							04.30	15.20
DY7209	CPH-BKK		02.05					15.05			02.05			15.05	
DY7210	BKK-CPH	04.10	16.35							04.10	16.35				
DY7015	LGW-JFK			18.10			02.00	18.10			02.00	18.10			02.00
DY7016	JFK-LGW					03.30	10.00			03.30	10.25			03.30	10.10
DY7045	LGW-FLL	15.55			02.00					15.55			02.00		
DY7046	FLL-LGW			04.00	12.25							04.55	13.25		
DY7095	LGW-LAX		01.20			14.00			01.20					13.50	
DY7096	LAX-LGW	03.20	13.50					03.20	13.50						

Sling	Reg.
1	EI-LNA
2	EI-LNB
3	EI-LNC
4	EI-LND
5	EI-LNE
6	EI-LNF
7	EI-LNG

Timezones (Scandinavia set to zero)	
OSL,ARN,CPH	0
LGW	+1
JFK, MCO, FLL	+5
OAK, LAX	+8
BKK	-6

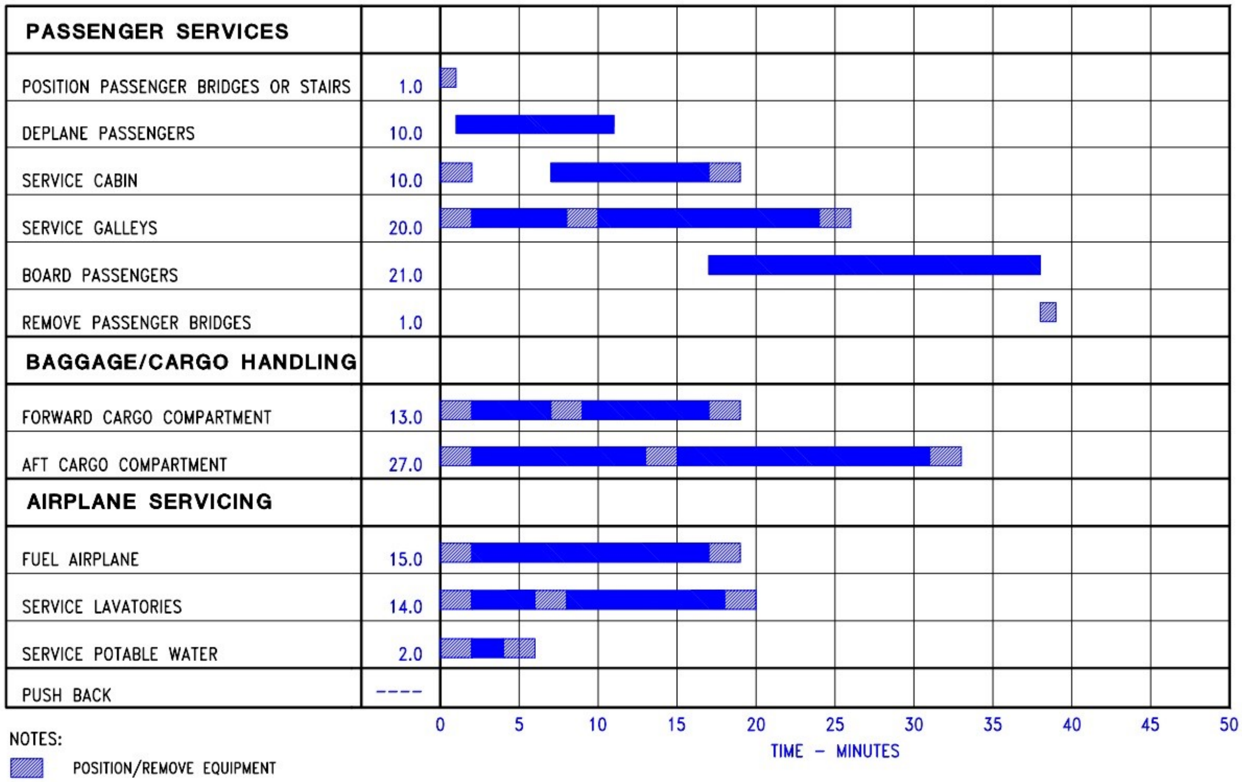
Abb.	Airport
OSL	Oslo Gardermoen Airport
ARN	Stockholm Arlanda Airport
CPH	Copenhagen Kastrup Airport
LGW	London Gatwick Aiport
JFK	New York John F. Kennedy Airport
LAX	Los Angeles International Airport
OAK	Oakland International Airport
FLL	Fort Lauderdale Hollywood International Airport
MCO	Orlando International Airport
BKK	Bangkok Suvarnabhumi Airport

	Week 11															
	09.mar		10.mar		11.mar		12.mar		13.mar		14.mar		15.mar		Total	
	In traffic (min)	Utilization	In traffic (min)	Utilization	In traffic (min)	Utilization	In traffic (min)	Utilization	In traffic (min)	Utilization	In traffic (min)	Utilization	In traffic (min)	Utilization	In traffic (min)	Utilization
EI-LNA	1050	0,73	1180	0,82	1145	0,80	1210	0,84	1110	0,77	900	0,63	660	0,46	**7255**	**0,72**
EI-LNB	870	0,60	0	0,00	520	0,36	655	0,45	330	0,23	1130	0,78	1190	0,83	**4695**	**0,47**
EI-LNC	1195	0,83	1150	0,80	1225	0,85	825	0,57	385	0,27	1165	0,81	1180	0,82	**7125**	**0,71**
EI-LND	330	0,23	1140	0,79	1130	0,78	1145	0,80	870	0,60	530	0,37	800	0,56	**5945**	**0,59**
EI-LNE	1205	0,84	1160	0,81	685	0,48	385	0,27	1020	0,71	980	0,68	1130	0,78	**6565**	**0,65**
EI-LNF	1075	0,75	900	0,63	660	0,46	1195	0,83	1050	0,73	555	0,39	510	0,35	**5945**	**0,59**
EI-LNG	1195	0,83	975	0,68	1110	0,77	1060	0,74	1100	0,76	1190	0,83	1215	0,84	**7845**	**0,78**
Total	**6920**	**0,69**	**6505**	**0,65**	**6475**	**0,64**	**6475**	**0,64**	**5865**	**0,58**	**6450**	**0,64**	**6685**	**0,66**	**45375**	**0,64**

	Week 12															
	16.mar		17.mar		18.mar		19.mar		20.mar		21.mar		22.mar		Total	
	In traffic (min)	Utilization	In traffic (min)	Utilization	In traffic (min)	Utilization	In traffic (min)	Utilization	In traffic (min)	Utilization	In traffic (min)	Utilization	In traffic (min)	Utilization	In traffic (min)	Utilization
EI-LNA	1205	0,84	1160	0,81	1015	0,70	995	0,69	1020	0,71	980	0,68	1130	0,78	**7505**	**0,74**
EI-LNB	1200	0,83	1140	0,79	1320	0,92	1190	0,83	1265	0,88	555	0,39	510	0,35	**7180**	**0,71**
EI-LNC	570	0,40	325	0,23	1225	0,85	825	0,57	385	0,27	1155	0,80	1215	0,84	**5700**	**0,57**
EI-LND	0	0,00	0	0,00	0	0,00	0	0,00	0	0,00	520	0,36	1190	0,83	**1710**	**0,17**
EI-LNE	1195	0,83	975	0,68	1110	0,77	1060	0,74	1100	0,76	1200	0,83	1180	0,82	**7820**	**0,78**
EI-LNF	1050	0,73	1180	0,82	1145	0,80	1210	0,84	1110	0,77	1140	0,79	800	0,56	**7635**	**0,76**
EI-LNG	1075	0,75	900	0,63	660	0,46	1195	0,83	985	0,68	900	0,63	660	0,46	**6375**	**0,63**
Total	**6295**	**0,62**	**5680**	**0,56**	**6475**	**0,64**	**6475**	**0,64**	**5865**	**0,58**	**6450**	**0,64**	**6685**	**0,66**	**43925**	**0,62**

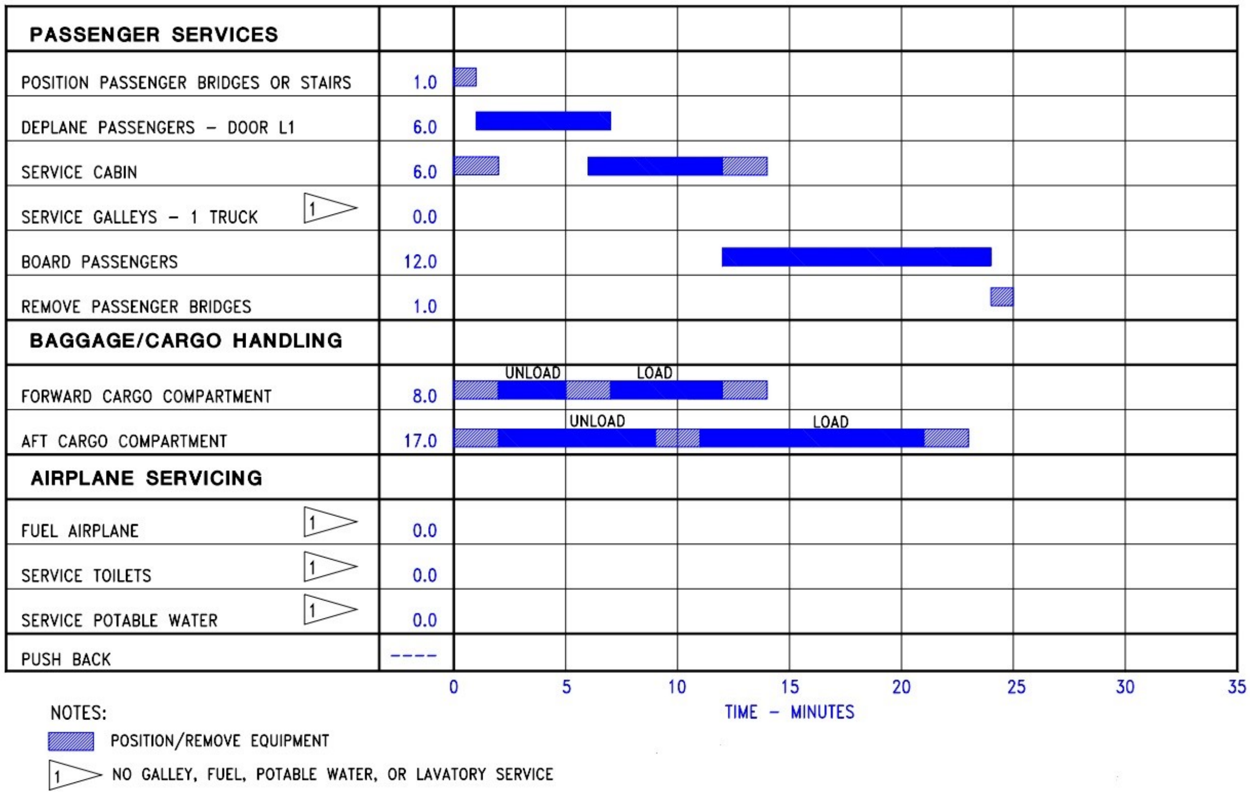
Appendix 3: Turnaround estimations

Boeing 757



TERMINAL OPERATIONS - TURNAROUND STATION. MODEL 757-200 (Boeing, 2002, p. 86)

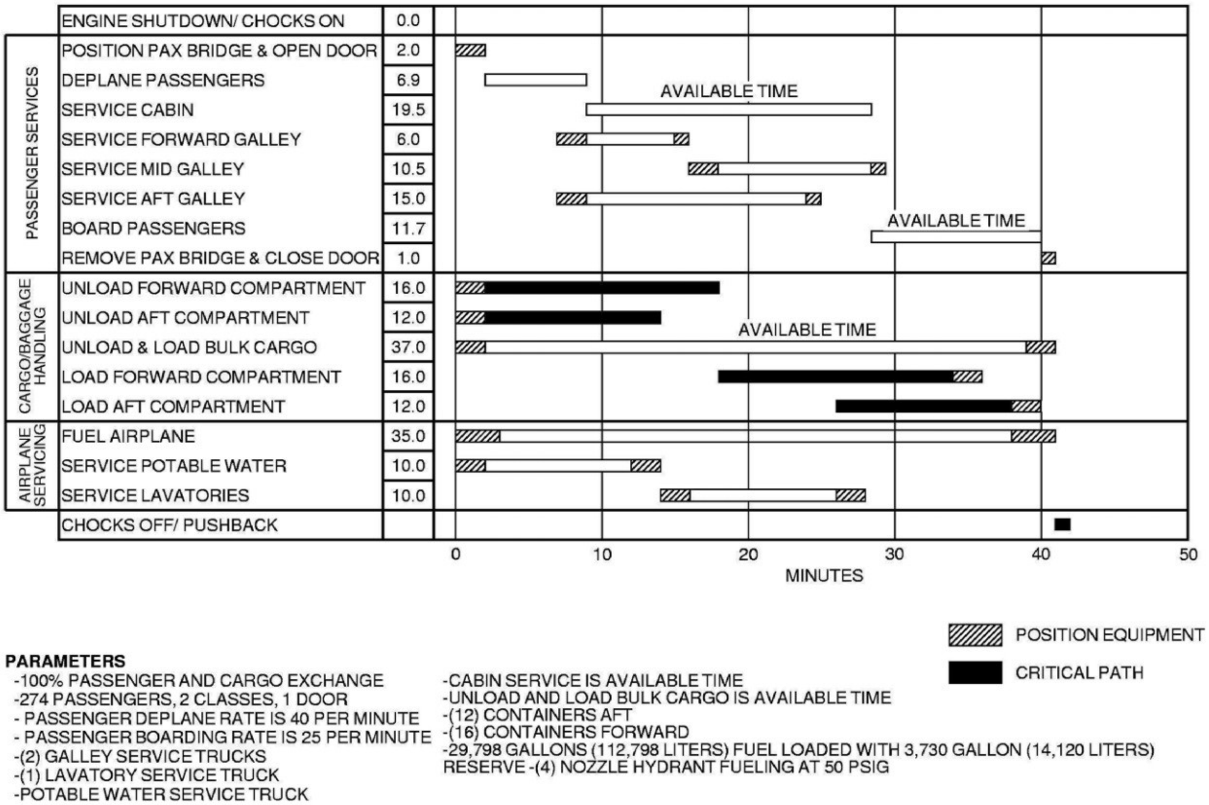
- Mixed class 186 passengers
- 100% load factor
- Deplane rate: 18 passengers per minute
- Enplane rate: 9 passenger per minute
- 100% passenger, baggage and cargo exchange



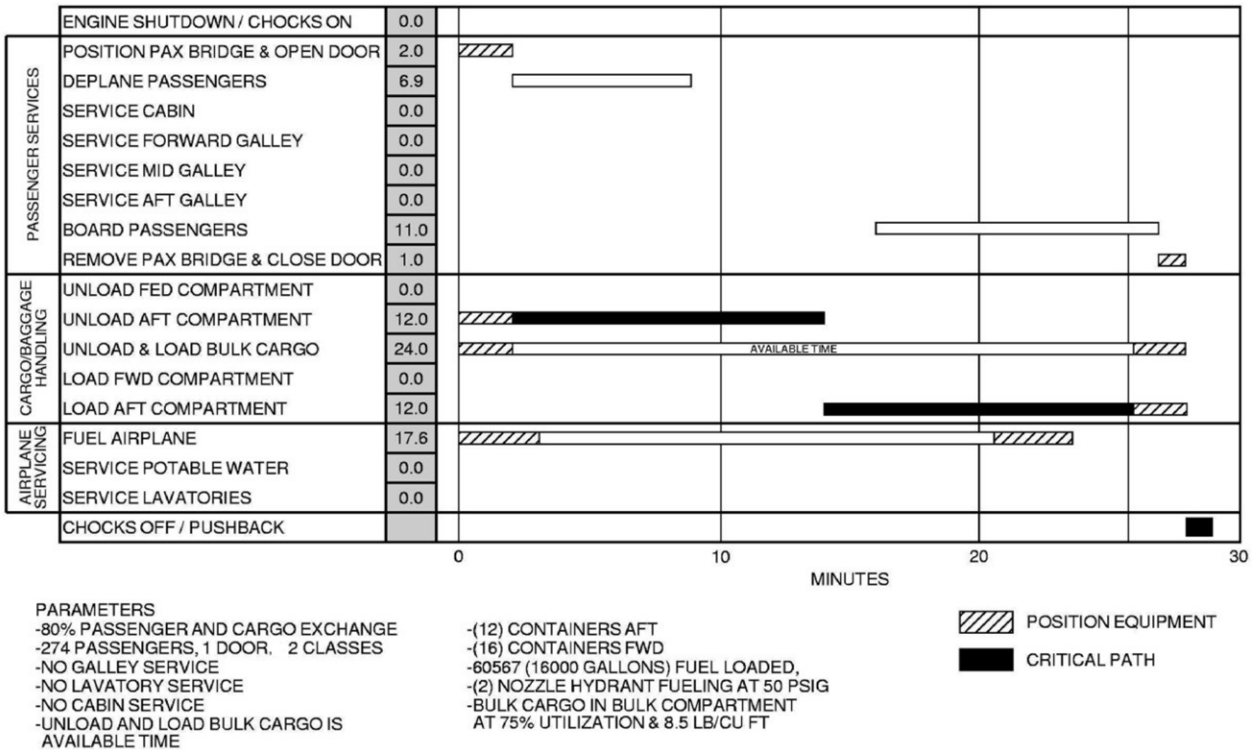
TERMINAL OPERATIONS - EN ROUTE STATION. MODEL 757-200. (Boeing, 2002, p.89)

- 60% passenger baggage and cargo exchange
- 186 passengers
- 100% load factor
- 1.3 bags per passenger
- Deplane and boarding times based on rates of 18 and 9 passengers per minute respectively
- 67% bags aft, 33% bags fwd.

Boeing 787:



TERMINAL OPERATIONS, TURNTIME ANALYSIS - TURNAROUND STATION. MODEL 787-8. (Boeing, 2014, p.62)



TERMINAL OPERATIONS, TURNTIME ANALYSIS –EN ROUTE STATION. MODEL 787-8. (Boeing, 2012, p.64)

Embraer E-jets:

E170/E190: «Since they are designed for fast, efficient, simultaneous, multi-point ground servicing thanks to four main cabin doors and two easily accessible cargo holds, E-Jets can turnaround in as few as 15 minutes. “ (Embraer, 2015)

Airbus A320

Terminal Operations - Full Servicing Turn Round Time

1. This section provides a typical turn round time chart showing the typical time for ramp activities during aircraft turn round. Actual times may vary due to each operator's specific practices, resources, equipment and operating conditions.
2. Assumptions used for full servicing turn round time chart

A. PASSENGER HANDLING

150 pax: 12 F/C + 138 Y/C.

All passengers deplane and board the aircraft.

1 Passenger Boarding Bridge (PBB) used at door L1.

Equipment positioning + opening door = +2 min.

Closing door + equipment removal = +1.5 min.

No Passenger with Reduced Mobility (PRM) on board.

Deplaning:

- 150 pax at door L1
- Deplaning rate = 20 pax/min per door
- Priority deplaning for premium passengers.

Boarding:

- 150 pax at door L1
- Boarding rate = 12 pax/min per door
- Last Pax Seating allowance (LPS) + headcounting = +2 min.

B. CARGO 2 cargo loaders + 1 belt loader.

Opening door + equipment positioning = +2 min.

Equipment removal + closing door = +1.5 min.

100% cargo exchange (baggage only):

- FWD cargo compartment: 3 containers
- AFT cargo compartment: 4 containers
- Bulk compartment: 500 kg (1 102 lb).

Container unloading/loading times:

- Unloading = 1.5 min/container
- Loading = 1.5 min/container.

Bulk unloading/loading times:

- Unloading = 120 kg/min (265 lb/min)
- Loading = 100 kg/min (220 lb/min).

C. REFUELING

20 000 l (5 283 US gal) at 50 psig (3.45 bars-rel), one hose (right wing). Dispenser positioning/removal + connection/disconnection times = +2.5 min.

D. CLEANING

Cleaning is performed in available time.

E. CATERING

1 catering truck for servicing galleys sequentially at doors R1 and R2.

Equipment positioning + opening door = +2 min.

Closing door + equipment removal = +1.5 min.

Time to drive from one door to the other = +2 min.

Full Size Trolley Equivalent (FSTE) to unload and load: 11 FSTE

- 4 FSTE at door R1
- 7 FSTE at door R2.

Time for trolley exchange = 1.2 min per FSTE.

F. GROUND HANDLING/GENERAL SERVICING

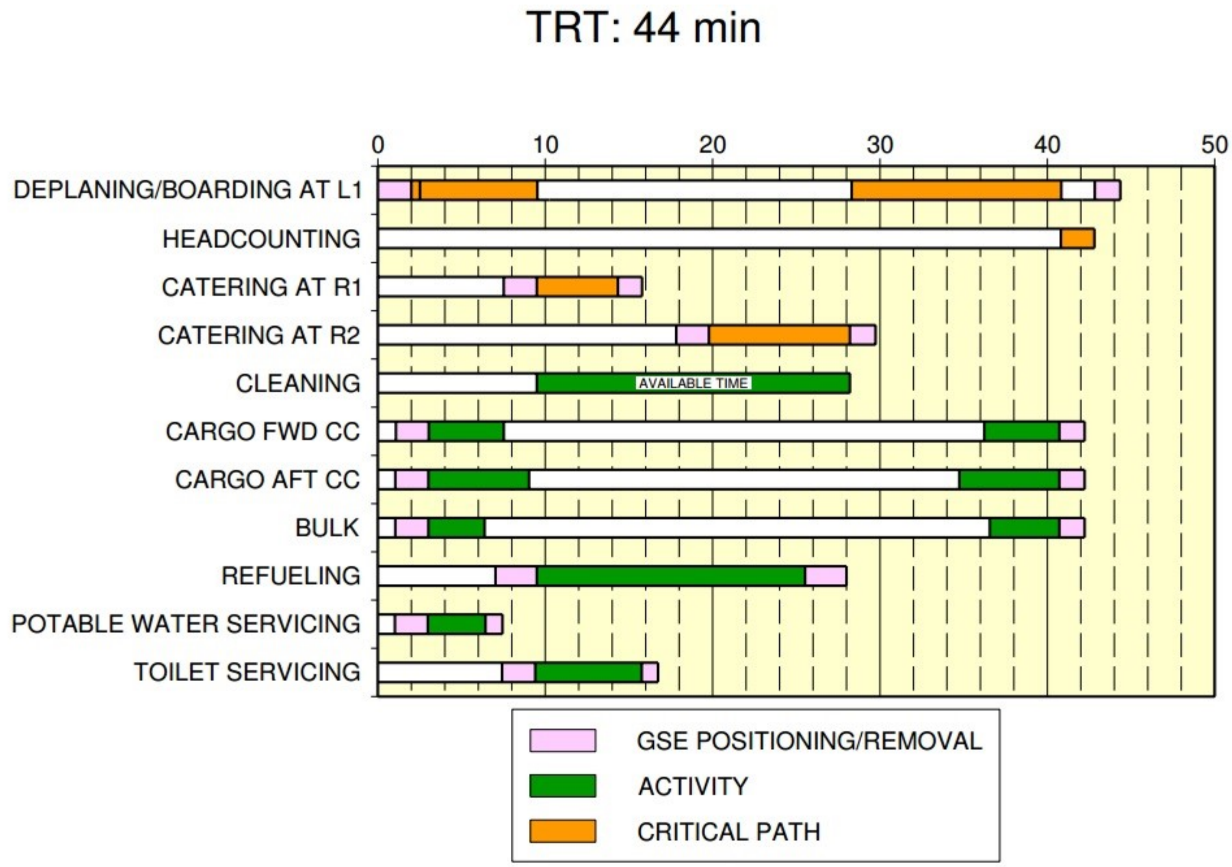
Start of operations:

- Bridges/stairs: t0 = 0
- Other equipment: t = t0 + 1 min.

Ground Power Unit (GPU): up to 90 kVA.

Air conditioning: one hose.

Potable water servicing: 100% uplift, 200 l (53 US gal). Toilet servicing: draining + rinsing.



Airbus A320 full servicing turnaround (Airbus, 2015, ch. 5-2-0 p.3)

- Terminal Operations - Outstation Turn Round Time

1. This section provides a typical turn round time chart showing the typical time for ramp activities during aircraft turn round. Actual times may vary due to each operator's specific practices, resources, equipment and operating conditions.

2. Assumptions used for outstation turn round time chart

A. PASSENGER HANDLING

180 pax (all Y/C).

All passengers deplane and board the aircraft.

2 stairways used at doors L1 & L2.

Equipment positioning + opening door = +2 min.

Closing door + equipment removal = +1.5 min.

No Passenger with Reduced Mobility (PRM) on board.

Deplaning:

- 90 pax at door L1
- 90 pax at door L2
- Deplaning rate = 18 pax/min per door.

Boarding:

- 90 pax at door L1
- 90 pax at door L2
- Boarding rate = 12 pax/min per door
- Last Pax Seating allowance (LPS) + headcounting = +2 min.

B. CARGO

2 cargo loaders.

Opening door + equipment positioning = +2 min.

Equipment removal + closing door = +1.5 min.

100% cargo exchange:

- FWD cargo compartment: 3 containers
- AFT cargo compartment: 4 containers.

Container unloading/loading times:

- Unloading = 1.5 min/container
- Loading = 1.5 min/container.

C. REFUELING

No refueling.

D. CLEANING

Cleaning is performed in available time.

E. CATERING

One catering truck for servicing the galleys as required.

F. GROUND HANDLING/GENERAL SERVICING

Start of operations:

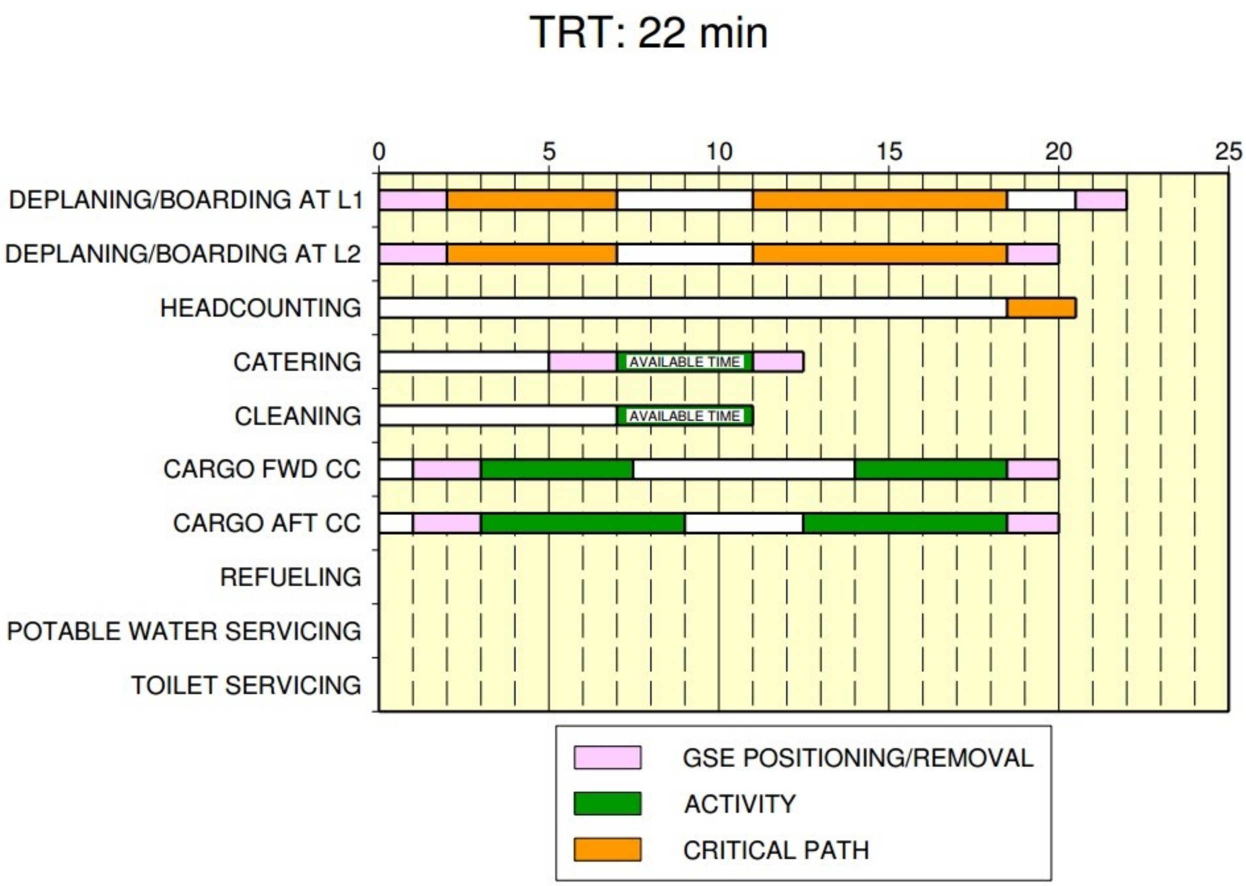
- Bridges/stairs: t0 = 0
- Other equipment: t = t0 + 1 min.

Ground Power Unit (GPU): up to 90 kVA.

Air conditioning: one hose.

No potable water servicing.

No toilet servicing.



Airbus A320 outstation turnaround times (Airbus, 2015, ch. 5-3-0 p.3)

NSB

Tidskomponenter i ruteplanleggingen

Snutid

Komponenter av teknisk snutid

Ankomst endestasjon	
Rigge ned førerrommet ATC, GSM-R, passasjerinformasjon	½ min
Kle på seg, pakke sekken	1 min
Bytte førerrom	1 … 4 min
Rigge opp førerrommet ATC, GSM-R, passasjerinformasjon	2 min
Bremseprøve	1 … 5 min
Evt. skjøte eller dele togsettet	3 … 8 min
Evt. kjøre rundt med lokomotivet	10 … 15 min
Evt. kjøre til/fra vendeanlegg	1 … 3 min
Kjøre fra endestasjon	

Eksempler tekniske snutider (NSB-materiell)

Materielltype	Snutid	
	Enkeltsett	Dobbeltsett
69	9½ min	10½ min
72	6 min	7 min
73	6 min	8 min
75	5 min	7 min
92	4 min	6 min

NSB turnaround estimations. (Schrader, 2014)