Desicion Support for Depot Planning in the Railway Industry

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Preface

This M.Sc. thesis has been prepared by Peter Føns during the period from the 5^{th} of September, 2005 to the 7^{th} of April, 2006. This work has been carried out in a collaboration between Informatics and Mathematical Modelling (IMM) at the Technical University of Denmark (DTU) and Carmen Systems AB (Carmen).

I have been supervised by associate professor Jesper Larsen, IMM, DTU and Ph.D. Jesper Hansen, Carmen. This thesis is the final requirement to obtain the degree: Master of Science in Engineering.

Readers of this thesis are assumed to have some knowledge of Operations Research (OR).

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Abstract

In this project a prototype to increase the efficiency of depot planning in the railway industry has been developed. Depot planning or shunt planning is one of the final steps in the planning process of a passenger railway system. It focuses on the logistics within a station. Usually most of the shunt activities occur around the peak hours in the morning and afternoon and at the end of the day. The prototype is built as a decision support system, which helps the planners quickly making feasible and robust depot plans.

Several aspects of depot planning are examined in the project. The main problem is to determine the parking of train units on the shunt tracks. Different mathematical models and approaches are proposed for the problem. The models are solved by using mathematical software. In addition the prototype contains several methods to identify and correct possible conflicts between the timetable and the infrastructure prior to the solution procedure for the parking problem. The robustness of the depot plans are also taken into consideration in the solution process.

The efficiency of the prototype has been examined by small test cases. Furthermore the prototype has been applied to 6 depots at DSB S-tog. The experiments show that high-quality depot plans are typically found within few minutes of computation time.

Keywords: Depot planning, Shunt planning, Shunting, Decision Support System, Railway planning, Operations Research.

Resumé

I projektet er udviklet en prototype til at forbedre effektiviteten af depotplanlægning i togindustrien. Depotplanlægning eller rangerplanlægning er en af de sidste procedurer i planlægningsprocessen af et togsystem til passagertrafik. Det fokuserer på logistikken inden for den enkelte station. Sædvanligvis foregår de fleste rangeraktiviteter omkring myldretid om morgenen og om eftermiddagen og når dagen er omme. Prototypen er bygget som et beslutningsstøttesystem, der skal hjælpe planlæggerne med hurtigt at lave mulige og robuste depotplaner.

Flere aspekter omkring depotplanlægning undersøges i projektet. Hovedproblemet er at bestemme, hvordan togenhederne skal parkeres på sidesporene. Forskellige matematiske modeller og fremgangsmåder til problemet præsenteres. Modellerne er løst ved hjælp af matematisk programmel. Desuden indeholder prototypen flere metoder til at identificere og rette eventuelle konflikter mellem køreplanen og infrastrukturen forud for løsningsproceduren til parkeringsproblemet. Robustheden af køreplanerne er også taget i betragtning i løsningsprocessen.

Effektiviteten af prototypen undersøges ved hjælp af små test eksempler. Endvidere afprøves prototypen på 6 depoter ved DSB S-tog. Eksperimenterne viser, at det normalt er muligt at generere lovlige og robuste depotplaner sædvanligivs fundet inden for få minutter.

Acknowledgements

First of all I will like to thank family and friends for supporting me throughout the work with the thesis. I will also like to thank the people at DSB S-tog for helping me understand important aspects of depot planning and Thomas Krog Christensen for proofreading the entire thesis.

Finally a special thanks goes to my two supervisors Jesper Larsen, IMM, DTU and Jesper Hansen, Carmen for valuable discussions about depot planning and thesis writing, and for both being very helpful in general.

Contents

Chapter 1

Introduction

Depot planning is one of the final steps in the planning process of a passenger railway system. It focuses on the planning of activities within a station. These activities are referred to as shunt activities. Trains arrive to and depart from the station platforms during the day. In the morning and before peak hours train units are moved (shunted) from the shunt tracks to the platforms to either start operating a train or to be attached to an existing train. After peak hours and at the end of the day the opposite occurs, where train units are shunted from the platforms to the shunt tracks. The overall goal of depot planning is to create a feasible plan with low costs for parking the train units on the shunt tracks with respect to the timetable and the station layout[1].

1.1 Project description

At many railway companies depot planning is done manually or with minimal decision support for the planners. To increase the efficiency of depot planning and the previous steps of the planning process DSB S-tog a/s (S-tog) has hired the company Carmen Systems AB (Carmen) to develop an integrated system for the railway planning. The system is developed under the title Carmen Rail

[1]Referred to as the station topology throughout the thesis.

Solution.

The objective of this project is to develop a prototype for depot planning. The prototype is built as a decision support system and can be seen as an automated tool for supporting the planners. It uses the timetable and the station topologies together with input from the planner to generate feasible depot plans. The generation is based on different algorithms and optimization procedures. The prototype has a text-based interface, but feasible depot plans can be visualized with the simulation program Arena.

The main focus in the prototype is to determine the parking of train units. This problem is referred to as the parking problem. Prior to the parking problem a thorough analysis is applied in the prototype. This analysis identifies possible infeasibilities between the timetable and the station topology. The planner can adjust several parameters in order to correct the infeasibilities or decide to use other solution procedures. Different strategies are included in the prototype to examine the robustness of a feasible depot plan or identify the problems in an infeasible depot plan.

The development of the prototype is based on the timetable and the depots used at S-tog. The prototype can also be used by other railway companies, but it may require different kind of modifications.

The project is made in collaboration with Carmen.

1.2 Structure of the thesis

The thesis is divided into 10 chapters. Chapter 2 contains a general introduction to decision support systems and presents the main methods used in the prototype. The next chapter introduces the reader to the railway industry and gives a description of DSB S-tog a/s and Carmen Systems AB. Furthermore concepts used in the thesis are explained. A review of the existing literature is given in chapter 4. This includes literature on train shunting, shunting in general, optimization in railway planning and decision support systems in the railway industry.

Chapter 5 describes the theory and solution procedure of the parking problem used in the prototype. Chapter 6 contains other theoretical aspects of the parking problem and a different solution procedure to the problem based on a Branch-and-Cut approach. The main description of the prototype is in chapter 7. This chapter includes a thorough examination of the problem analysis process and the feedback from the depot planning. Furthermore it contains a section about the visualization in Arena.

Chapter 8 contains different experiments with the prototype and the application to S-tog. A discussion of further research is in chapter 9, whereas the conclusions of the project are in chapter 10. Appendix A shows some of the different test results from the experiments. Notice that in order to limit the size of the thesis, not all the output of the experiments are included in the appendix.

The prototype and all the code, the model in Arena, and the data used in the experiments are included on the enclosed CD-ROM.

Chapter 2

Decision Support Systems

In this chapter I will give an introduction to decision support systems and describe some of the different techniques used in the systems. Finally I will explain the main methods in the decision support system (prototype) developed in this project.

2.1 Introduction and techniques

A decision support system (DSS) is basically a business application, which work as an interactive computer-supported system intended to help managers make decisions, Clausen [Cla05]. Most often the goal of a DSS is not to produce a complete solution, but more to support the decision maker in his/hers solution process. To make the implementation of a DSS a success, it is important that the DSS is made completely controllable and transparent to the user.

An important aspect of the DSS is the planning horizon of the decision to be made. For some decisions a fast feedback is required, where longer time can be used on other decisions. Notice that the quality of the decision is often based on the time available. The goal of the DSS is to help the decision maker find the best possible solution, but sometimes this can be hard to quantify or the decision involves several objectives i.e. a multi-criteria decision problem. These aspects often complicate the design of the DSS.

Most often the DSS is based on a model. If the model can be expressed with mathematical functions and relations it is called a mathematical model. In case of linear functions the model is called a linear programming model (LP-model) and can be solved by using mathematical software. If the decision variables in the model are integer or binary variables, the complexity of the model increases.

Other mathematical methods to base the DSS on include constraint programming and heuristics. Constraint programming is a technology that combines mathematical based methods and search based methods known from artificial intelligence. Heuristics are approximation algorithms, which try to find a good and possibly optimal solution quickly. Heuristics are split into two categories: Constructions-heuristics and improvement-heuristics. Constructions-heuristics build from scratch a feasible solution to the decision problem, where improvement-heuristics (as the name imply) improve an existing solution. The technique is to search in the neighborhood also called local search for a better solution. Some of the classical improvement-heuristics are metaheuristics as simulated annealing, tabu search, genetic algorithms etc. [Cla05].

If the functions cannot be expressed mathematically the use of simulation can be applied to the DSS. The idea behind simulation is to build a model, which tries to imitate the real world. In one type of simulation, discrete event simulation, an event calendar keeps track of all the events that cause changes in the system. The simulation model can evaluate different scenarios based on deterministic or stochastic data. The results can be used to find bottlenecks in the model, optimize procedures etc.

Optimization and simulation are the traditional techniques from an operations researcher point of view, but other methods for a DSS exist. Some of these techniques are artificial intelligence, neural networks, probabilistic net or stochastic programming. Each of the methods has its pros and cons and can be applied individually or in connections with other techniques.

Besides choosing the time horizon and techniques used in the DSS, the developer of the system has to consider the knowledge available and the quality of the proposed decision. Making the DSS as specific as possible will often increase the quality of the proposed decision. In this context it is important to have good quality measures.

2.2 The methods used in the prototype

The different planning problems in passenger railway transportation are characterized by planning horizon and location (either central or local). Typically the depot planning is part of the local procedures of the operational planning. At this level the last details of the timetable are planned and the rolling stock and crew schedules are constructed. Depending on the railway company the operational planning is carried out a small number of times each year. A more thorough analysis of railway planning is in section 4.3.

The approach to solve the main problem of the depot planning i.e. the parking problem leads to a 0-1 IP-model referring to a model consisting only of binary decision variables. In the prototype it has been chosen to use mathematical software (CPLEX) to solve the model. Prior to solving the model, algorithms and heuristics are applied to the problem in order to generate feasible track assignments and find possible infeasibilities between the timetable and the station topologies. If infeasibilities exist the heuristics contain different strategies for correcting or removing them.

Discrete event simulation has also been applied to the prototype, but it is only used to visualize the different depot plans. Thereby, the user is given the possibility to observe, how the situation at the station changes step by step.

The prototype is developed specifically for depot planning at S-tog. At the same time the algorithms and methods are made as general as possible, but it may require minor modifications or adjustments, if the prototype is going to be applied to depots at other railway companies. Section 8.1 specifies and evaluates some of the quality measures for the prototype.

CHAPTER 3

The Railway Industry

In 1847 the first Danish railway was opened between Copenhagen and Roskilde. In the last 159 years the trains and the railways have experienced a major development[1]. At the moment the industry undergo a period of modernisation, caused by rapid technological developments, the environmental needs and the ageing of existing equipment, Kvist et al. [KHSB02]. On the political scene the railway industry is also on the agenda in order to make it easier to travel through Europe by train.

Compared with other kinds of transport, train traffic has far more restrictions e.g. safety systems, railway infrastructure and much more. This leads to fewer opportunities for overtakings, alternative routes in case of delays etc. In the following a description of DSB S-tog a/s and Carmen Systems AB is given.

3.1 Company profile of DSB S-tog a/s

DSB S-tog a/s (S-tog) is the Danish train company responsible for the trains in the greater Copenhagen area. S-tog is owned by DSB, the Danish State Railways, which runs most of the passenger trains in Denmark. The public

[1]Some people argue that the railways in Denmark have not changed much...

transport network in Copenhagen also includes busses, metro and a number of small train networks, which S-tog is not responsible for. Much of the information in the following is taken from the DSB S-tog a/s Annual Report 2004.

S-tog has the responsibility of planning and implementing timetables for the S-trains and is in charge of quality control and maintenance. The crew used in the S-trains is also planned and scheduled by S-tog. On the other hand S-tog is not responsible for maintenance of tracks, signals, stations, security systems etc. This is taken care of by Banedanmark, a company run by the Department of Transport and Energy.

Figure 3.1: The S-tog network at the beginning of 2005.

The S-tog network consists of 170 kilometers double tracks and 85 stations. The network is constantly occupied by approximately 80 trains during the day and there are 1100 departures daily, Hofman and Madsen [HM05]. The S-tog network is displayed in Figure 3.1. It is from the beginning of 2005, which corresponds to the time of the depot plans examined in chapter 8. The figure shows the stations, the train series and the lines in the current plan. The numbers in the figure refer to the different zones relating to the cost of traveling.

There are 5 main train series in the S-tog network: Køge-Hillerød, Høje Taastrup-Holte, Frederikssund-Farum, Ballerup-Klampenborg and Ny Ellebjerg-Hellerup. All the train series run through the central segment around Copenhagen Central Station (København H) except Ny Ellebjerg-Hellerup, which runs around the city and therefore denoted "The Ring". The train series are covered by 12 lines, indicated by different colours and letters A, B, C, E, F and H. Furthermore some lines are denoted with a $^{+}$, which indicates the lines are only running during daily hours. The x-lines are only used during the peak hours in the morning and in the afternoon. Each line has a fixed stopping pattern and two end stations (terminuses). The timetable for S-tog is cyclic with a 20 minutes period, but each train series is covered by more than one line, so most stations have a better frequency than the 20 minutes standard frequency for each individual line. Regional trains link with S-tog network at some of the larger station e.g. Høje Taastrup, Valby, Hellerup, Nørreport and Copenhagen Central Station. At Nørreport, Vanløse and Flintholm the S-tog network intertwines with the metro.

3.1.1 Customers

S-tog serves around 90 million customers per year i.e. 240,000 customers use the trains each day. On average 92% of the population in the greater Copenhagen area use the S-trains to some extent [HM05]. Figure 3.2 shows the number of passengers in each month of 2005. Since the largest customer group for the S-trains is customers traveling to work, school, university etc., the number of passengers is lowest in July. Figure 3.3 illustrates the number of passengers in each hour of a typical day. It is possible to see that the peak hours are around 7:00 and 8:00 in the morning and again from 15:00 to 17:00 in the afternoon.

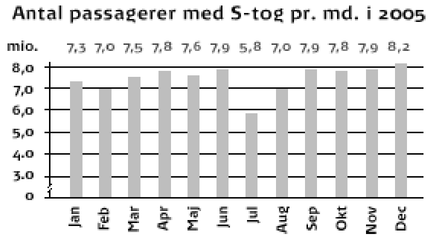

Figure 3.2: Passengers in 2005.

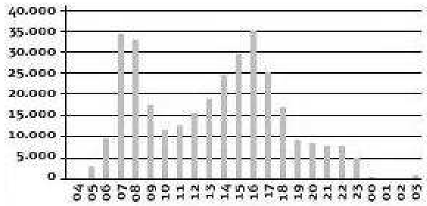

Figure 3.3: Passengers during a day.

3.1.2 Rolling stock

S-tog uses three different types of trains called 2nd, 3rd and 4th generation, where the 4th generation trains are the newest. A picture of the three generations is in Figure 3.4.

Figure 3.4: Three generations. To the left a 4th generation S-train, in the middle a 3rd generation S-train and to the right a 2nd generation S-train [Chr06].

In Table 3.1 the S-train fleet at the end of 2004 is presented. In 2005 lines A and E were covered by the new 4th generation trains, whereas lines B, C and H were covered by all three types of trains. "The Ring", line F, was, and still is, always covered by 3rd generation trains. It is not possible to make any combination of the trains across the three different generations. S-tog has bought new 4th generation trains, so the 2nd and 3rd generation trains slowly can be phased out. All the generations are powered by electricity.

Maintenance of the trains can only be done at Høje Taastrup, so all the trains have to terminate at this station within given intervals to get a service inspection. A train can normally drive 22,000 kilometers or approximately 60 days before a maintenance check is needed.

Type	# Trains	Size	Name
2nd generation	43	4 train units	RENO
3rd generation	8	4 train units	ASEA
4th generation	92	4 train units (8 coach trains)	LHB
	14	2 train units (4 coach trains)	LHF

Table 3.1: S-tog rolling stock at the end of 2004.

3.1.3 Depots

There are 9 material depots in the S-tog network, where trains can be stored or shunting can occur. The two main depots are Copenhagen Central Station (København H) and Høje Taastrup. Both of these depots are manually operated. The depot in Hundige contains a preparation centre, where external cleaning of the trains is carried out. Internal cleaning can be handled at all the depots. The remaining 6 depots are: Ballerup, Farum, Frederikssund, Hillerød, Klampenborg and Køge. These 6 depots are the focus in the development of the prototype in this project. Figure 3.4 shows a picture from the depot in Farum.

3.2 Company profile of Carmen Systems AB

Carmen Systems AB (Carmen) is a Swedish based company founded in 1986 as a department under the car company Volvo. It focuses on develop, market and implement resource optimization solutions for clients found primarily in the transportation sector. There are around 310 employees at the moment. The headquarter is in Gothenburg, Sweden, but there are offices in Amsterdam, Austin (Texas), Brisbane, Copenhagen, Madrid, Monterrey (Mexico), Montreal, Paris, Singapore and Stockholm. The 3^{rd} of March 2006 The Boeing Company acquired 100% of Carmen Systems AB.

In this project I have mainly been working with the office in Copenhagen, which

Figure 3.5: A picture from the depot in Farum [Chr06].

is a branch of the office in Stockholm. The two offices are working under the name Carmen Consulting.

3.3 Concepts

In this section some useful concepts are described. These will be used throughout the thesis. The concepts are inspired by the literature and the notation used at S-tog and Carmen.

3.3.1 General concepts

Train unit A single train vehicle.

Rolling stock The term used to describe the vehicles used in the railway industry excluding the locomotive.

Line Is a series of stations in the network defined by two terminuses.

Timetable The plan the trains follow.

Platform A track where the passengers get on and off the trains.

Shunting Shunting is the process of moving train units or other material from one track to another.

Shunt track A track connected to one or more platforms, where rolling stock is parked when it is not needed to operate the timetable.

Shunt yard The area where the shunt tracks are.

Depot A depot is a station with a shunt yard.

Driver A person performing all the tasks in the shunt yard including driving the train units from a platform to a shunt track and vice versa.

Infrastructure The entire network on which the trains are applied. The infrastructure includes the stations, the tracks, the shunt yards etc.

Station topology The term is similar to station layout, which defines the infrastructure of a station/depot.

3.3.2 Specific concepts in the thesis

Block A number of connected train units that are kept together from their arrival at the station and until their departure from the station.

Block ID An ID used to characterize a block.

Block type The type of the train units in the block. It is assumed that all train units in a block are of the same type.

Free track A track which can be approached from both ends.

LIFO track A track which only can be approached from one end. Hence the trains will depart the track by the last-in-first-out principle.

Leg A leg denotes the trip (train number) of the arriving train to the station or the departing train from the station.

Position in leg The term is referring to the position of the block in the arriving/departing leg. Typically this is either 1 or 2.

Detach Defines that the block is disconnected from a train at the platform.

Attach Defines that the block is connected to a train already at the platform.

Intermediate shunting move A move of a block from one shunt track to another shunt track. The move always takes place after the first parking of the block.

Platform parking Defines that the block is parked at the platform. This is usually used during the night.

Event calendar A calendar, which consists of a series of events in chronological order.

Depot plan A final plan showing how the blocks are parked at the depot. It is similar to an event calendar, but it includes all the tracks used for the parkings.

Chapter 4

Literature review

In the last years several articles have been published about the use of operations research techniques in the railway industry. Many of the articles are from the Netherlands, where there has been and is currently a great focus on the area. The focus includes collaborations between universities and NS Reizigers, the main Dutch passenger railway operator. In this chapter I will describe and comment articles about train shunting. Furthermore I will look at articles, which examine railway planning in a broader perspective and describe some of the decision support systems in the railway industry. These articles give an understanding of concepts behind decision support systems and the planning process and the terminology used in the railway industry.

4.1 Literature from the Netherlands about train shunting

The following articles about train shunting are written in chronological order and are all based on the work by Blasum et al. [BBH+00], Winter [Win99] and Winter and Zimmermann [WZ00], which examine some of the problems about dispatching trams in a depot. Winter [Win99] includes length restrictions, mixed arrivals and departures and an application at a bus depot in his work. Several variants of the studied problems are shown to be $\mathcal{NP}$-hard.

Shunting of Passenger Train Units in a Railway Station

Freling et al. [FLKH02] introduce the problem of shunting train units in a railway station (depot planning). The authors state the problem definition of the *Train Unit Shunting Problem* (TUSP) and give an illustrative example of how to create a shunt plan. Furthermore they show some theoretical aspects of the TUSP e.g. the TUSP is $\mathcal{NP}$-hard. A mathematical model for the TUSP is set up, which leads to a two step solution procedure:

1. Matching of arriving and departing train units.
2. Parking of train units.

For solving the matching of arriving and departing train units called the *Train Matching Problem* (TMP), the authors describe a model, which can be solved quite efficiently by using the standard MIP solver of CPLEX. The parking subproblem, the *Track Assignment Problem* (TAP), is formulated as a Set Partitioning Problem. The feasibility of a track assignment is taken into account implicitly, which is a major advantage of the formulation. The disadvantage is the fact that the number of potential track assignments may be exponential in the number of train units. Hence the authors propose a column generation approach, where a dynamic programming algorithm is used to find a feasible track assignment for the subproblem. This dynamic programming algorithm is based on a new underlying network structure. The network structure depends on the nature of the shunt track i.e. a free track or a LIFO track and the number of blocks to be shunted. An arc in the network is the cost of assigning a certain block to a the shunt track. Hence the strategy behind the dynamic algorithm is to find the feasible paths in the network that dominate others based on assignment cost, remaining length of the shunt track and the earliest departure time of the blocks already in the path.

The solution method is applied to the station Zwolle in the northeastern part of the Netherlands. Different scenarios are set up, which differ from each other by the objective function in the matching step, the approach type of the free tracks and the day of the week. The matching step takes for all scenarios only a couple of seconds and results in around 68 blocks. The total running time for the parking step lies roughly between 20 and 60 minutes, which makes this step by far the most computer intensive. In all scenarios except two the solution method is able to park all blocks and obtain good solutions with reasonable gaps (under 4%) compared to the lower bounds calculated by a LP-relaxation of the parking subproblem.

Applying Operations Research techniques of train shunting

Lentink et al. [LFKW03] describe their research of applying operations research techniques to the shunting problem. The authors present the different elements of the shunting problem and set up a solution procedure for the main part of the problem. This solution procedure includes four subproblems/steps:

1. Matching of arriving and departing train units.
2. Estimating routing costs of train units.
3. Parking of train units on the shunt tracks.
4. Routing of train units.

The focus in the article is on step 2 and step 4. In order to handle the two steps the authors present a new approach to describe the infrastructure of a station. This representation detects possible routing conflicts, which cannot be found by the typical representation. Using this representation they describe a search algorithm for finding optimal routes of the train units. This search algorithm, Occupied Network A* search, is an extension of the A* search, which is a well known search algorithm from the field of artificial intelligence. In ONA* search some stop criteria are added, so the algorithm can be used even though part of the network is occupied or unavailable at the time. The algorithm searches routes sequentially, because searching the routes simultaneously is extremely time-consuming in practical cases. A major disadvantage of searching the routes sequentially is the loss of guaranteed optimality. In order to reduce this setback a 2-opt improvement strategy is implemented.

The solution procedure is applied to two stations in the Netherlands, Enschede and Zwolle. The subproblem with matching of arriving and departing train units takes in both cases few seconds and result in around 57 and 69 blocks to be parked respectively. As in the previous article the parking step is found to be by far the most computer intensive step. The authors have created 4 scenarios for the subproblem with different objectives. The routing of train units imply that it is useful to apply the 2-opt improvement strategy once.

Shunting of Passenger Train Units: an Integrated Approach

Schrijver et al. [SLK05] describe an integrated approach for solving the TUSP. The authors integrate the matching problem and the parking problem in one model, which is extended in various ways in order to make different models incorporate complicating details from practice. The basic model includes only LIFO tracks. This complicated model contains for a real-life instance as Zwolle over 300.000 constraints. They tackle this problem by making improvements to the basic model by aggregating the crossing constraints and aggregating other constraints to clique inequalities. The improvements reduce the number of constraints greatly, but instead the number of variables increases.

Next they propose a new model with restriction on the number of mixed tracks i.e. tracks containing different types of train units. Finally the basic model is extended to include free tracks. However, this roughly increases the number of decision variables by a factor 4, so the model will not be able to solve real-life instances in the Dutch railway. Instead the arrival and departure side is modeled as a decision variable, which reduces the number of decision variables greatly. The authors indicate some computational results, but none of them are presented in the paper. Furthermore many open issues are stated.

4.1.1 Comments on the articles about train shunting

The article [FLKH02] is the first from the Dutch authors about the shunting problem. Even though the subject is complicated the authors give an excellent and thorough introduction to the problem. Their solution method by splitting the TUSP into two subproblems seems to be an excellent approach and it has been reused in other articles as well as in the strategy used by Carmen. The solution procedure forms the foundation of this thesis.

The second article [LFKW03] examines other aspects of the shunting problem. It gives a thorough introduction and describes some of the different characteristics related to the shunting problem. From a practical point of view it has an exciting section about how the solution approach presented in the article will support the planner. It shows how the planner can guide the optimization by adjusting penalties and parameters. The routing of train units is an interesting section, which is aimed at large and complex stations. Compared to the Dutch stations most of the depots handled in this thesis are relatively small and there exists only one route from a shunt track to a platform. At the same time the timetable from S-tog is fairly structured, so simultaneously moves are extremely rare. This is the reason, why routing of train units has not been analyzed in this project.

In the last article [SLK05] the authors try to integrate the matching and parking. Unfortunately the integrated problem is theoretically much harder to solve than solving the two subproblems separately. Hence this article is more difficult to read than the two other articles. At the same time I find it unstructured and the lack of computational results is very critical. Thus, the strength of the integrated approach is questionable.

At the end of March 2006 I was able to get Ramon M. Lentink's Ph.D. thesis "Algorithmic Decision Support for Shunt Planning" [Len06], which he has just finished. Ramon M. Lentink is co-author of the three Dutch articles above. Even though I have only read briefly in the Ph.D. thesis, I have found similarities between his and my research. I have not had the time to go into details with his work, but I found it interesting in continuation of this project.

4.2 Literature on shunting in general

The following two articles examine special cases of the TUSP. The first article, Gallo and Di Miele [GM01], is written before the three articles above and together with [BBH$^+$00], [WZ00] and [Win99] it encircles the shunting problem. The second article, Stefano and Koči [SK04], gives an interesting graph theoretical approach to the shunting problem.

Dispatching Buses in Parking Depots

Gallo and Di Miele [GM01] present the problem of managing the parking space in a vehicle depot optimal. The authors refer to the problem as the *dispatching problem*. Their initial solution approach is based on a Quadratic Assignment model from [WZ00]. The dispatching of the buses takes place in a first-in-first-out order, which mimic the operations in a queue. The goal is to find a matching of arriving and departing vehicles and optimize the parking of vehicles with respect to the capacity of the columns at the depot. In an optimal solution the number of crossings[1] is minimized. In [WZ00] the dispatching problem is shown to be $\mathcal{NP}$-hard. Hence for large instances the problem is very hard to solve exactly, which is also seen by the high solution times in [WZ00]. To improve the structure of the basic model the authors present a two-level model. This two-level model focus on the matching in the first step and on the parking in the second step.

[1] A crossing arise each time a parked vehicle must be moved to clear the way for a leaving vehicle.

As an alternative to the two-level model a heuristic approach is described that takes advantage of the problem's structure. The solution algorithm follows a Lagrangean Decompostion approach, where Lagrangean relaxation is used to generate an upper bound for the overall maximization problem. In the next step the solution reaches feasibility by fixing some of the variables. A heuristic procedure is applied as postoptimization.

The authors apply their approaches on some real cases from the Florence Public Transportation Company. The solution value is given by the number of crossings. In 7 out of 10 test cases the exact two-level model was not able to obtain a solution due to the problem size. The decomposition approach was able to solve all test cases, and it provides reasonably good solutions at low computational cost at 8 of them. Finally the authors include an extension of their model in order to take into account arrivals and departures of buses that are mixed in time. They do not present any experimental results with this extended model.

A Graph Theoretical Approach To The Shunting Problem

Stefano and Koči [SK04] describe a graph theoretical approach to the shunting problem. The main goal of the article is to investigate the difficult constraints regarding the type of depot and the arrival and departure sequences using graph theory. Constraints concerning the size of the trains and the track capacities are not taken into consideration. The authors consider the theoretical part of the problem and do not look at any practical cases. In the article two types of depots are defined, a *marshalling yard* and a *shunting yard*. Tracks in a marshalling yard can be approach from both sides (free tracks), where tracks in a shunting yard only can be approach from one side (LIFO tracks).

In the first part of the article, it is assumed that the first departure takes place after the last arrival. This imitates a depot at night. They state four different types of problems based on input to the shunt track from one side or both sides (single/double) and single/double output from the shunt track. The problems are referred to as the SISO, DISO, SIDO and DIDO problem. The objectives in all the problems are to minimize the number of tracks used to park all the trains. For the SISO problem a graph is constructed based on the arrival and departure sequence of the n train units. The minimum number of tracks needed can be found by determine the chromatic number[2] of the graph. In case of the DISO and SIDO problems the situation is more complicated and includes

[2]The chromatic number of a graph G is the smallest number of colors $\chi(G)$ needed to color the vertices of G, so that no two adjacent vertices share the same color, Bondy and Monty [BM76].

the construction of a *valley hypergraph*[3]. The coloring of a general 3-uniform hypergraph is hard and a greedy algorithm is introduced to determine an upper bound of the number of tracks needed. The DIDO problem is even harder, because in order to find the minimum number of tracks needed, it involves a coloring of 4-uniform hypergraph.

Next the authors consider day depots i.e. where arrivals and departures are mixed in time. Only the SISO problem is examined for a shunting yard. By analyzing the arrival and departure time of each block, it is possible to find train units, which overlap each other. Hence if two intervals overlap, the corresponding train units cannot be put at the same track of the shunting yard. By identifying these overlaps an 'overlap' graph also called conflict graph can be constructed. The minimum number of tracks needed to solve the SISO problem on a shunting yard is the chromatic number of the conflict graph. Unfortunately conflict graphs are equivalent to circle graphs and the chromatic number problem for circle graphs is reported to be $\mathcal{NP}$-complete. For a marshalling yard it makes no difference, whether arrivals and departures are mixed or not mixed in time.

4.2.1 Comments on the articles about shunting in general

Both articles give an excellent analysis of the problems about shunting/dispatching in general. The experimental results in [GM01] show that relative small instances can be very hard and actually impossible to solve exactly, when the nature of the problem is complex. Both articles indicate that the difficulty of the problem increases significantly, when arrivals and departures are mixed in time. I will examine the graph theoretical approach from [SK04] further in section 6.3.

4.3 Literature on optimization in railway planning

In this section I present a thorough review of Huisman et al. [HKLV05]. Other surveys on operations research methods in the railway industry exist e.g. Cordeau et al. [CTV98], but Huisman et al. [HKLV05] is to the best of my knowledge the only one that specifically focus on passenger railway transportation.

[3]A hypergraph is a graph in which generalized edges (called hyperedges) may connect more than two vertices. In this particular example the graph is a 3-uniform hypergraph.

Operations Research in Passenger Railway Transportation

Huisman et al. [HKLV05] give an overview of operations research models and techniques used in passenger railway transportation. The authors divide the planning problems into four levels based on the planning horizon and the physical location of the particular problem. The four levels are: Strategic, tactical, operational and short-term. Furthermore local planning and real-time control are discussed.

The strategic planning involves rolling stock management, crew management and line planning. Rolling stock management has a planning horizon of 10-20 years. It has not received much attention in the scientific literature, but it has direct implications for the passenger service and involves large amounts of money, so the need for quantitative models to support the decision is highly important in practice. Crew management deals with strategic issues related to the long term availability of drivers and conductors. Crew management has a planning horizon of 2-5 years, since it takes time before newly hired crew is fully operational. Additionally the crews can have a work guarantee for a number of years. Finally the strategic planning involves line planning. Several models for solving variants of line planning problems have been presented in the literature in the last years. One of the main complications in the line planning problems is that passenger behavior has to be considered as well.

The tactical planning consists of timetabling and 8 o'clock rolling stock assignment. The planning horizon for these activities are usually 1 year. Most European railway companies have cyclic timetables i.e. each line operate in a cyclic/periodic pattern. Several models have been developed in order to design good cyclic timetables. A good timetable is equal to a robust timetable i.e. the reliability of the timetable has to be high in order to handle delays, small disturbances etc. Different techniques have been applied to forecast the reliability of a given timetable. This includes max-plus algebra (an analytical approach), stochastic analysis and simulation. The timetable improvement is often based on a trial-and-error method, but other approaches have been applied as putting an objective into the design of the timetable or integrating the timetabling and evaluation models. The 8 o'clock rolling stock assignment is the allocation of rolling stock to trains that are operated around eight o'clock in the morning. The idea behind the approach is, that if it is possible to determine an appropriate allocation of the rolling stock to the trains during the morning peak, then it is possible the rest of the day. The solution includes what types and subtypes of rolling stock to assign to each line and how many units to allocate to the trains.

Rolling stock circulation and crew scheduling are part of the operation planning, which has a planning horizon of around 2 month, but this depends heavily on the railway company. In the rolling stock circulation problem the appropriate allocation of rolling stock units to trips to be operated is determined. This allocation is based on the timetable, the expected number of passengers and the numbers of train units (per subtype) that can be used. Furthermore the maximum train lengths per trip and the capacities at the stations have to be respected. There exists several articles about appropriate solution approaches to the problem. Crew scheduling is one of the most successful OR applications in the transportation industry[4]. Different program packages are used at the railway companies in Europe. The crew scheduling problem can be formulated as a generalized set covering problem, where columns are pairings[5] and rows are legs. Each leg has to be covered be exactly one pairing. The formulation makes it suitable for applying different OR-techniques as LP-relaxation or lagrangian relaxation, column generation and Branch-and-Price.

The short-term planning, normally done on a daily basis, is dealing with modifications that have an influence on the rolling stock and the crew schedules e.g. large maintenance projects or construction works on the extension of the train network. In the Dutch railway system the short-term planning also includes the maintenance routing of rolling stock. Each day it is determined, which rolling stock units that need to be taken away from the operations in order to undergo a maintenance check. The problem of efficiently routing these train units to a maintenance facility can be formulated as an integer multi-commodity min-cost flow problem.

The local planning at the stations consists of routing of trains, shunting and crew rostering. A mathematical model is stated for the routing problem, where the objective is to route as many trains as possible. The timetable of arrivals and departures, the infrastructure of the station and the safety system are given for the problem. In the part about shunting the authors give a thorough review of the two previously presented articles, [FLKH02] and [LFKW03]. In the crew rostering problem, the duties resulting from the crew scheduling problem are combined into a number of rosters for a certain period. This problem is solved per station. Where most airline companies use other roster approaches, most European public transportation companies use cyclic/periodic rosters. Finally the authors describe how operations research techniques can be used in real-time control and refer to an article about solving the real-time scheduling problem in the airline industry.

[4] Carmen is the market leader of this application in the aviation industry.

[5] A pairing is a group of tasks (legs) that are possible to perform sequentially. Usually the pairing starts and ends the same place.

4.4 Literature on decision support systems in the railway industry

The following two articles focus on the use of decision support systems in the railway industry. The first article, Kvist et al. [KHSB02], examines decision support in the train dispatching process, while the second article, Hoogheimstra and Teunisse [HT98], describes a decision support system applied in practice at the Dutch railway system. The system is used to create timetables.

Decision support in the train dispatching process

Kvist et al. [KHSB02] describe how decision support can be used in the train dispatching process. The article is developed in a collaboration between the universities in Uppsala and Dalarne and the Swedish train network operator Banverket. The focus in the article is to identify and show, how a decision support system can help the train dispatchers i.e. the people how operate the real-time planning. This is done by examining, how the dispatchers has handled the process of conflict solution and re-planning earlier, and thereby develop simple, easy to use and practicable support tools.

Disturbances occur often in the train system. Primary delays are a direct effect of the actual disturbance, while secondary delays are the trains that interact with the primary delayed trains. The job of the dispatcher is to minimize the number and length of secondary delays by changing the original timetable and make other adjustments. Decision support systems can be used in this re-planning process to support the dispatcher in making the right decision.

The authors indicate by looking at existing literature that the focus in the decision support system community has been on issues concerning ”executives” and their decision support and not on real-time decision making. Hence the authors examine another area called Dynamic Decision Making, which is more appropriate approach in this particular case. One of the goals of the support tool is to give the dispatcher a higher understanding of his/hers tasks.

The rest of the article describes how the authors have cooperated with the dispatchers to analyze the handling of conflict solution and re-planning. The following requirements have been found to a decision support system:

1. Identify the reason behind a disturbance and from this the following conflicts. It is important that the system at least is capable of notifying the

dispatcher about an arising conflict.

2. Find possible solutions, suggest alternative solutions and predict the effect of alternative solutions.

The authors will describe the implementation and evaluation of the decision support system in future articles.

The use of simulation in the planning of the Dutch railway system

Hoogheimstra and Teunisse [HT98] describe the decision support system DONS (Designer of Network Schedules) to create timetables. This article focuses on evaluating the robustness of the created timetables by applying a simulator as an advanced analysis function. The authors give an introduction to planning of railway infrastructure and timetable planning. They also state the importance of reliability and punctuality in the timetable. If small disturbances occur, the planner will try to re-establish the original plan, while major disturbances will lead to a re-scheduling. DONS supports the execution of each step of the planning process by interaction with the planner. When a timetable is constructed, the network performance is evaluated by using the DONS-simulation tool. This enables the authors to study the network behavior when submitted to disturbances in the timetable. The goal is to increase the robustness of the final timetable.

The authors also present how to model the infrastructure and how to integrate the DONS-simulator with the existing system. The paper does not contain any final results of the research, since the DONS-simulator only exists as a prototype and has, when the article was written, not been implemented yet.

Chapter 5

The Parking Problem

As described in chapter 4 depot planning or shunt planning has to some degree been studied in the literature and is referred to as the *Train Unit Shunting Problem* (TUSP) in [FLKH02], [LFKW03] and [SLK05]. In the literature the TUSP basically consists of:

1. Matching of arriving and departing train units.
2. Parking of the train units on the shunt tracks.

The TUSP is based on a railway station, a shunt yard and a timetable. The applied strategy from Carmen is to solve the matching of arriving and departing train units (connections) in the previous steps[1] of the planning process underlying the railway system [Car05]. Hence all connections between the train units are known before the depot planning is analyzed. I have chosen to apply the same strategy, which means the main focus of the depot planning is how to park the train units. This chapter presents the solution procedure for the parking problem in the prototype.

[1] At Carmen these steps are known as the composition problem and the rotation problem.

5.1 Problem definition

The objective of the parking problem is to find an optimal plan for parking the train units, usually denoted blocks, on the shunt tracks. The problem is far from trivial, because space and time are usually scarce. Train units may also block for other train units, if they are parked at certain shunt tracks. Furthermore the capacities of the shunt tracks have to be respected. The arrivals and departures of the blocks may be mixed in time i.e. within the planning period the first departure may take place before the last arrival.

If the connection led to that the blocks departed from the shunt tracks in a last-in-first-out order, it would not be a problem to create feasible depot plans. Unfortunately this is most often not the case due to restrictions about the maintenance of train units and other dependences in the previous steps of the planning process.

5.2 Solution procedure

From the predefined connections i.e. the matching of arriving and departing train units, a set of blocks B to be assigned to the shunt tracks exists. Only blocks that need to be parked are considered i.e. arriving train units, which remain on the platform track for a period and then depart, are removed from B. Each remaining block contains a number of train units that are kept together from their arrival at the station and until their departure from the station. The trips (train numbers), which the blocks arrive from or depart to, are defined as legs according to the notation used at Carmen. A block consists of the following 14 records:

- The type of the train units/block[2].
- The size of the block[3].
- Arrival leg and departure leg.
- Arrival platform and departure platform.
- Arrival time and departure time.

[2]It is assumed that the train units in the block are of the same type.
[3]The size is the number of train units in the block.

- Number of blocks to be shunted from the arriving leg and number of blocks to be shunted to the departing leg[4].
- Position in the arriving leg and position in the departing leg.
- Is detached at the platform from arriving leg or is attached at the platform to departing leg.

A topology exists for each station, which determines the feasible combinations between platforms and shunt tracks. In addition the topology specifies blocks that are parked beforehand i.e. prior to the planning period. Given this information blocks are assigned to shunt tracks in the *Track Assignment Problem* (TAP). The main objective of the TAP is to find a feasible solution, where the routing costs are minimized.

According to Theorem 4 in [FLKH02], the TAP can be solved in an amount of time that is polynomial in the number of blocks to be shunted, if the topology of the shunt yard is fixed and if each train is composed of a number of train units that does not exceed a certain upper bound.

5.2.1 Feasible assignments

A subset of blocks assigned to a shunt track during the planning period is denoted as a track assignment. The assignment is feasible if the following conditions hold:

1. The assignment does not contain crossings[5],
2. The total size of the blocks on the shunt track does not exceed the track capacity, and
3. Every block in the assignment is allowed to park on the track[6].

Table 5.1 shows an example of a timetable with 4 blocks[7]. Each row represents a block with arrival and departure data e.g. block 1, type LHB and with the size corresponding to 4 train units, arrives from leg 55148 at platform 1 Monday at

[4] This information is used to keep connected blocks together as much as possible.

[5] A crossing is defined as a situation where a block i obstructs a block j during the departure or arrival of block j.

[6] Based on the feasible combinations between platforms and shunt tracks at the station.

[7] Note that not all data of the blocks are included in the table.

16:42 and departs to leg 55222 from platform 1 Tuesday at 7:08. The bindings between the arriving and departing trains are based on the predefined connections. Using the data from the table feasible assignments for a shunt track with the capacity of 8 train units are found. It is assumed that each of the 4 blocks is allowed to park on the shunt track.

			Arriving train			Departing train		
Block ID	Type	Size	Time	Leg	Pl.	Time	Leg	Pl.
1	LHB	4	Mo. 16:42	55148	1	Tu. 7:08	55222	1
2	LHB	4	Mo. 17:02	55149	1	Tu. 7:28	55223	1
3	LHB	4	Mo. 19:22	55156	1	Tu. 5:48	50219	2
4	LHB	4	Tu. 7:18	50120	2	Tu. 9:28	50230	2

Table 5.1: An example with 4 blocks.

The feasible assignments are presented in Table 5.2. The set of blocks in Table 5.1 is ordered by non-decreasing arrival time, so the order of block ID's on the shunt track is always increasing.

Assignment	Order
1	1
2	1 ; 3
3	1 ; 3 ; 4
4	1 ; 4
5	2
6	2 ; 3
7	3
8	3 ; 4
9	4

Table 5.2: Feasible assignments represented by block ID from Table 5.1.

Table 5.2 shows that there are 9 different feasible assignments for a shunt track with a capacity of 8 train units. Assignment 3 with the three blocks 1, 3 and 4 does not violate the capacity condition, because block 1 and block 3 depart before block 4 arrives. On the other hand an assignment with block 1 and block 2 or with block 2 and block 4 is infeasible, because both assignments contain a crossing. Hence these assignments are not in Table 5.2.

The number of feasible assignments may be exponential in the number of blocks, but it also depends heavily on the timetable, the predefined connections and the station topology. If e.g. the arriving train units during the day depart according to the first-in-first-out principle, the number of feasible assignments will decrease dramatically. In order to generate a large number of feasible assignments for the solution procedure, this must be taken into consideration when constructing the timetable and the connections in the previous steps of the planning process.

5.2.2 Mathematical formulation

The TAP can be formulated as a Set Partitioning Problem, see Hillier and Lieberman [HL01]. The general model of the TAP is described in [FLKH02].

Sets

B is the set of blocks and S is defined as the set of shunt tracks. Additionally, F^s is defined as the set of feasible assignments on track $s \in S$. Then F_b^s is a subset of F^s containing the feasible assignments on track $s \in S$ with block $b \in B$.

Variables

In the model the following binary decision variables exist:

$$x_f^s = \begin{cases} 1 & \text{if assignment } f \in F^s \text{ is used on shunt track } s \in S, \\ 0 & \text{otherwise.} \end{cases}$$

$$y_b = \begin{cases} 1 & \text{if block } b \in B \text{ is not parked on any shunt track } s \in S, \\ 0 & \text{otherwise.} \end{cases}$$

Objective function

A cost c_f^s is connected to each feasible assignment f on track s. This cost can be an estimate of the routing costs of the different blocks in the assignment. It may also include some penalties, if certain rules are not satisfied. These rules are e.g. to avoid broken departures[8] or only to park blocks of the same type on a shunt track. The parameter d models a penalty if a block is not assigned to any track.

[8] A broken departure exists when blocks leave in the same departing train, but come from different arriving trains and are parked on different shunt tracks.

The objective is to minimize the total costs of a depot plan, such that as many blocks as possible are assigned to the shunt tracks. The function is as follows

$$\text{minimize} \sum_{s \in S} \sum_{f \in F^s} c_f^s x_f^s + d \sum_{b \in B} y_b \tag{5.1}$$

Constraints

The following types of constraints exist in the model.

1. These constraints state that each block $b \in B$ is covered by exactly one assignment on one shunt track or the block is not parked at all. The constraints are as follows

$$\sum_{s \in S} \sum_{f \in F_b^s} x_f^s + y_b = 1 \qquad \forall b \in B \tag{5.2}$$

2. These constraints determine that each shunt track $s \in S$ can have at most one assignment. This leads to the following formulation

$$\sum_{f \in F^s} x_f^s \leq 1 \qquad \forall s \in S \tag{5.3}$$

3. Finally all the variables are binary decision variables

$$x_f^s \in \{0, 1\} \qquad \forall s \in S, \forall f \in F^s \tag{5.4}$$

$$y_b \in \{0, 1\} \qquad \forall b \in B \tag{5.5}$$

A solution of the TAP defined by (5.1)-(5.5) will give a depot plan. If one or more of the blocks cannot be parked, the final depot plan has to be revised. I will go into details with revision strategies in section 7.5.

5.2.2.1 Other models with special extensions

Different extensions have been made to the TAP in order to adapt the model for S-tog. The first model takes platforms into consideration as shunt tracks, whereas the second model takes advantage of symmetry in the model under certain circumstances. The models are presented below.

Due to capacity problems at some shunt yards it has been proposed that platforms with a certain penalty can be used as shunt tracks during the night, where there are no activities. The only constraint is that at least one platform has to be available during the night for possible maintenance activities etc. Only blocks that depart first in the morning are considered to be potential for parking at the platforms. Hence only one feasible assignment for each platform during the night exists. To incorporate this extension in the model the binary decision variable z^p is introduced, where P is the set of platforms. P_b contains the night assignment with block $b \in B$. This leads to

$$z^p = \begin{cases} 1 & \text{if the night assignment is used on platform } p \in P, \\ 0 & \text{otherwise.} \end{cases}$$

A parameter g^p models the penalty for using the platform $p \in P$. This special version of the track assignment problem (STAP) is formulated as follows:

$$\text{STAP: } \min \sum_{s\in S}\sum_{f\in F^s} c_f^s x_f^s + \sum_{p\in P} g^p z^p + d\sum_{b\in B} y_b \quad (5.6)$$

$$\text{s.t.} \sum_{s\in S}\sum_{f\in F_b^s} x_f^s + \sum_{p\in P_b} z^p + y_b = 1 \qquad \forall b \in B \quad (5.7)$$

$$\sum_{f\in F^s} x_f^s \leq 1 \qquad \forall s \in S \quad (5.8)$$

$$\sum_{p\in P} z^p \leq 1 \quad (5.9)$$

$$x_f^s \in \{0,1\} \qquad \forall s \in S, \forall f \in F^s \quad (5.10)$$

$$y_b \in \{0,1\} \qquad \forall b \in B \quad (5.11)$$

$$z^p \in \{0,1\} \qquad \forall p \in P \quad (5.12)$$

The next model makes use of symmetry. If the route costs are not directly correlated with the movement distance of the blocks, some shunt tracks may have the same costs for each assignment. If also these shunt tracks are empty at the beginning of the planning period, and the blocks under consideration are allowed to park on the tracks, the shunt tracks are assumed to be symmetric. Hence all the feasible assignments are identical for these shunt tracks. To include this in the model the set Q is defined as the set of different shunt tracks. The parameter m^q defines the number of symmetrical tracks of the type $q \in Q$. The use of platforms as shunt tracks at night is taken into consideration as well. This symmetrical version of the track assignment problem (SYTAP) is formulated as follows:

$$
\begin{aligned}
\text{SYTAP: } \min \quad & \sum_{q\in Q}\sum_{f\in F^q} c_f^q x_f^q + \sum_{p\in P} g^p z^p + d\sum_{b\in B} y_b && && (5.13)\\
\text{s.t.} \quad & \sum_{q\in Q}\sum_{f\in F_b^q} x_f^q + \sum_{p\in P_b} z^p + y_b = 1 && \forall b \in B && (5.14)\\
& \sum_{f\in F^q} x_f^q \le m^q && \forall q \in Q && (5.15)\\
& \sum_{p\in P} z^p \le 1 && && (5.16)\\
& x_f^q \in \{0,1\} && \forall q \in Q, \forall f \in F^s && (5.17)\\
& y_b \in \{0,1\} && \forall b \in B && (5.18)\\
& z^p \in \{0,1\} && \forall p \in P && (5.19)
\end{aligned}
$$

The advantage of the SYTAP is that the number of binary decision variables are greatly decreased, so larger instances of the problem can be solved.

5.2.3 Structure of the solution procedure

The advantage of the formulations of the STAP (5.6)-(5.12) and the SYTAP (5.13)-(5.19) is that all the considerations about generating feasible track assignments are taken into account implicitly i.e. all track assignments are found before solving the model. The basic idea behind the solution approach is based on the approach from [FLKH02]. In the article they propose a column generation framework in order to handle the exponential number of feasible assignments. Instead of adopting this approach, it has been chosen to generate all feasible assignments, because the number of blocks to be shunted is considerably smaller compared to the article. If symmetry of two or more shunt tracks is present it is an advantage to use the SYTAP, because it is faster and can handle a larger number of blocks.

First all feasible track assignments are found by using the algorithm described in the following section. Based on these assignments the STAP or the SYTAP is solved by using the standard MIP solver of CPLEX 9.1.

5.2.4 The network algorithm

A solution algorithm has been made in order to determine all feasible track assignments. In this procedure it is assumed that all shunt tracks are LIFO tracks i.e. the tracks can only be approach from one side and the last arriving block must leave first. Furthermore I assume that the set of blocks that need to be parked is ordered by non-decreasing arrival time as in the example in Table 5.1.

A network structure is introduced to find the feasible track assignments. In this network each block $b \in B$ with ID x is represented by a layer R_x consisting of two nodes: b^x_{park} and b^x_{not}. The first node b^x_{park} corresponds to park block b with ID x on the shunt track currently under consideration, while the second node b^x_{not} implies not to park block b with ID x on the shunt track. Beside the layers, the network consists of an initial state (source) and an end state (sink). An arc is defined by (u, v), so node u is in layer R_x and node v is in layer R_{x+1}. The initial state is defined as the layer R_0 and the end state as the layer $R_{|B|+1}$. Using this notation the network $G = (N, A)$ can be described as follows:

$$N = \bigcup_{x=0}^{|B|+1} R_x \tag{5.20}$$

$$\begin{aligned} A = \{ & (b^x_i, b^{x+1}_j) \mid x = 0, \ldots, |B|, \\ & i \in R_x, j \in R_{x+1}, \text{ and } (b^x_i, b^{x+1}_j) \text{ is feasible} \} \end{aligned} \tag{5.21}$$

Hence the arcs in the network are directed from the initial state to the two nodes in the first layer, from the two nodes in the last layer to the end state, and between two nodes in consecutive layers if the path is feasible i.e. satisfy the three conditions mentioned in section 5.2.1. In the next paragraph I describe, how these conditions are checked. The network in Figure 5.1 uses the example in Table 5.1 with 4 blocks. The bold arcs represent a path through the network i.e. the feasible assignment 2 with blocks 1 and 3 in Table 5.1. The remaining arcs are part of the other feasible assignments. An arc may be feasible in one assignment and infeasible in another assignment, because the preceding paths are different. Notice that in this example there is no arc between the nodes b^1_{park} and b^2_{park}, because this assignment will contain a crossing. Hence the assignment is always infeasible.

Based on this network structure the general idea is to find all feasible paths through the network i.e. all feasible assignments. In order to check that the feasibility conditions are satisfied, the following notation is introduced. A feasible path at node u is denoted p_u. The pool of feasible assignments P consists of all the different paths p_{end}. The time of a node is defined as the arrival time

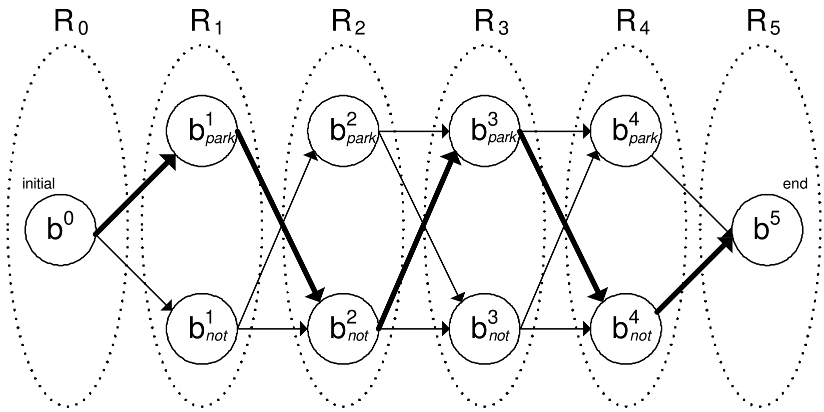

Figure 5.1: The network corresponding to the example in Table 5.1.

of the block in the corresponding layer. L_p is defined as the remaining capacity of the shunt track i.e. the capacity of the track minus the size of all blocks on the track at the time of node u. D_p is the earliest departure time of the blocks in path p_u, which did not leave yet at the time of node u. Hence D^{uv} is the set of blocks departing between the times of nodes u and v. For all nodes v, l_v and d_v are defined as the size and the departure time of the block corresponding to node v respectively. If v is a 'not node', l_v equals 0. The layers are ordered by non-decreasing arrival times.

Extending the path p_u with the arc (u, v) is feasible if and only if v is a 'not node' or

(i) $l_v \leq L_p + \sum_{b \in D^{uv}} l_b$ and

(ii) $d_v \leq \min_{b \in (p_u \setminus D^{uv})} d_b$ and

(iii) block v is allowed to park on the shunt track[9].

If v is a 'not node', nothing changes on the shunt track and the extension to the path will always be feasible. Criterion (i) states that the remaining track capacity plus the size of the blocks departing between the times of nodes u and v have to be greater than or equal to the size of block v. The next criterion (ii) avoids crossings. Because there is only one side open at a LIFO track, the

[9]Based on the feasible combinations between platforms and shunt tracks.

departure time of block v has to be less than or equal to the earliest departure time of the blocks in path p_u, which do not depart between the times of nodes u and v. Finally v has to be allowed to park on the track.

If the criteria are feasible, a new path is found and the variables for the path p_v^{new} are updated as follows:

$$\begin{aligned} L_{p_v^{new}} &= L_p - l_v + \sum_{b \in D^{uv}} l_b \\ D_{p_v^{new}} &= \begin{cases} \min\limits_{b \in (p_u \setminus D^{uv})} d_b & \text{if } v \text{ is a 'not node'} \\ d_v & \text{otherwise.} \end{cases} \end{aligned}$$

When node v is equal to the end node a new feasible assignment is found and added to the pool of feasible assignments P. With this layered network structure the number of arcs $|A|$ remains relatively small for a LIFO track:

$$|A| \leq 2^2(|B| - 1) + 2 \cdot 2 \tag{5.22}$$

The right side of (5.22) makes an upper bound of the number of arcs in the network. The deviation from the maximum number of arcs is determined by the predefined connections, which may lead to non-existing arcs e.g. between b_{park}^1 and b_{park}^2 in Figure 5.1. The advantage of the 'not node' is that it decreases the number of arcs in the network, because arcs exist only between blocks in consecutive layers.

5.3 Implementation

The solution procedure to the parking problem has been implemented in the prototype, which will be described in chapter 7. The prototype including the generation of feasible track assignments has been written in Java[10]. By using the ILOG[11] Concert Technology it is possible to incorporate and use CPLEX 9.1 in the prototype to solve the model. This gives the advantage of developing an integrated program with easy readable input and output files.

The code developed to generate all the feasible track assignments uses a depth first search strategy, see Wolsey [Wol98], to the network algorithm. The depth first search strategy is based on a recursive function which examines, based on the three criteria in section 5.2.4, whether it is possible to extend the path

[10] The prototype consists of around 2500 lines of code divided into a number of different objects.

[11] The developer of the CPLEX solver.

with a new block. When all the feasible track assignments are found with the first arriving block, the search continues with the next arriving block etc. The approach speeds up the process of generating feasible track assignments.

Chapter 6

Generalizations of the Parking Problem

In this chapter I will describe some of the other theoretical aspects of the depot planning. Furthermore I will examine another approach to the parking problem.

6.1 Free tracks

In contrast to LIFO tracks free tracks are open in both ends. This complicates the solution procedure, because blocks not necessarily arrive and depart from the same end. S-tog does not have free tracks at any of the 6 depots[1] the prototype is designed for. Nevertheless, in this section the network algorithm for free tracks in order to find feasible track assignments is presented.

The main ideas behind the network algorithm for free tracks are from [FLKH02], but the mathematics behind do not exist in the literature. Recall the network structure to find feasible assignments from section 5.2.4. In the network for free tracks the blocks can arrive and depart from both ends. The two ends are denoted N and S and are referred to as terminals. Hence each block $b \in B$ with

[1] In Klampenborg there is one free track, but it can only be used as a LIFO track due to restrictions in the station topology.

ID x is represented by the layer R_x consisting of five nodes b^x_{NN}, b^x_{NS}, b^x_{SN}, b^x_{SS} and b^x_{not}. The first node b^x_{NN} corresponds to block b with ID x arrive and depart from the N terminal of the shunt track currently under consideration. The second node b^x_{NS} implies that block b with ID x arrive from the N terminal and depart from the S terminal of the shunt track etc. The last node b^x_{not} is not to park the block on the shunt track. With the new definitions of each layer R_x, the network for free tracks can be described as the network for LIFO tracks in (5.20)-(5.21).

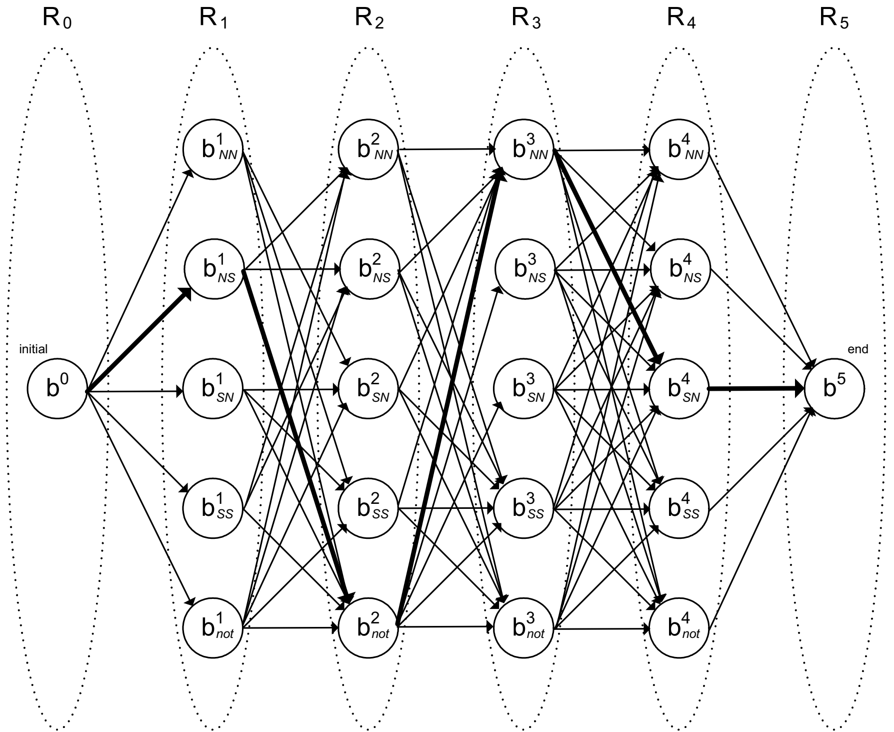

Figure 6.1: The network for a free shunt track based on the example in Table 5.1.

In the network for free tracks the arcs are directed from the initial state to the five nodes in the first layer, from the five nodes in the last layer to the end state, and between five nodes in consecutive layers if the path is feasible. Later in this section I will describe how to check whether a path is feasible. The network for a free track with a capacity of 8 train units based on the four block example in Table 5.1 is presented in Figure 6.1. The bold arcs represent a path through the network, where block 1 arrives from N and departs from S, block 3 arrives from N and departs from N and block 4 arrives from S and departs from N. This path is feasible because block 1 departs from the shunt track before block 4 arrives to the shunt track, see Table 5.1. The remaining arcs are part of the other feasible assignments. Notice that in this example there are no arcs from e.g. the node b^2_{SN} and to the nodes b^3_{NS} and b^3_{SN}, because these assignments will contain a crossing and are therefore infeasible.

Using this network structure for free tracks, it is possible to find all feasible assignments i.e. all feasible paths through the network. Recall the notation from section 5.2.4. p_u is a feasible path at node u. The time of a node is the arrival time of the block in the corresponding layer. L_p is the remaining capacity of the shunt track at the time of node u. For all nodes v, l_v and d_v are the size and the departure time of the block corresponding to node v respectively. If v is a 'not node', l_v equals 0. Because the blocks can arrive and depart from both ends the following definitions are introduced:

- $D^{uv,N}$ is the set of blocks in path p_u departing from N between the times of nodes u and v.
- D^N is the set of blocks in path p_u departing from N.
- $D^{uv,S}$ is the set of blocks in path p_u departing from S between the times of nodes u and v.
- D^S is the set of blocks in path p_u departing from S.

Extending the path p_u with the arc (u, v), where the block corresponding to node v arrives and departs from N is feasible if and only if v is a 'not node' or

(i) $l_v \leq L_p + \sum_{b \in (D^{uv,N} \cup D^{uv,S})} l_b$ and

(ii) $d_v \leq \min_{b \in (D^N \setminus D^{uv,N})} d_b$ and

(iii) block v is allowed to park on the track.

If v is a 'not node' nothing changes on the track and the extension to the path will always be feasible. Criterion (i) states that the remaining track capacity plus the size of the blocks departing between the times of nodes u and v from both terminals have to be greater than or equal to the size of block v. The next criterion (ii) is to avoid crossings. Because the block v arrives and departs from N, the departure time of v has to be less than or equal to the earliest departure time of the blocks that depart from N, but do not depart between the times of nodes u and v. Finally v has to be allowed to park on the shunt track.

If instead the path p_u is to be extended with the arc (u, v), where the block corresponding to node v arrives from N and departs from S the following criteria have to be satisfied

(I) $l_v \leq L_p + \sum_{b \in D^{uv,N} \cup D^{uv,S}} l_b$ and

(II) $d_v \geq \max_{b \in D^S} d_b$ and

(III) no blocks depart from N after the arrival of block v i.e. $D^{uv,N} = D^N$ and

(IV) block v is allowed to park on the track.

Criterion (I) is the same as criterion (i) from the previous check. The next criterion (II) states that, because block v departs from S, the departure time of block v has to be larger than or equal to the latest departure time of the blocks that depart from S. Since block v arrives from N, criterion (III) restricts that D^N is empty after the arrival of block v. The last criterion is to make sure that v is allowed to park on the shunt track.

The criteria are similar to (I)-(IV) when examining a block arriving from S and departing from N. The feasibility of the extension with a block arriving from S and departing from S is checked with similar criteria to (i)-(iii). When the node v is equal to the end node, a new feasible assignment is found and added to the pool of feasible assignment P_{free}. Based on equation (5.22) the number of arcs $|A|$ for a free track with this network structure is:

$$|A| \leq 5^2(|B| - 1) + 2 \cdot 5 \tag{6.1}$$

The predefined connections determine the number of infeasible arcs in the network. Examining Figure 6.1 with the feasibility criteria above means that the total number of feasible assignments is 149, if the shunt track was a free track.

6.2 Time windows

In the parking problem the arrival and departure times of each block are defined by two specific times/dates. The assumption is that the moves between platforms and shunt tracks will not interfere with any other simultaneous moves concerning the remaining infrastructure. In practice this may not be the case. One way of handling this problem is to penalize shunting moves that are to be performed simultaneously in the previous steps of the planning process. Thereby, the input to the depot planning is led to consist of less simultaneous moves. Another and more extensive approach is to introduce time windows in the solution procedure.

The time window is defining a period in which the shunting has to be done. Hence simultaneously moves can easily be avoided. If a certain time is preferred in the time window, a penalty for each minute the move deviates from the specified time can be added. Currently at S-tog the train units are shunted just after the arrival at the platform. The time of the move back from the shunt track to the platform is not fixed. In most cases this time is between 5 to 19 minutes before the actual departure time. In general the time windows can be defined by the following definitions. An arriving train unit has to be shunted between its arrival and before the subsequent train units arrive at the platform. Likewise for departures, the train units must be shunted to the platform before the departure time given in the timetable and after previous train units occupying the platform have left. The length of a time window may also depend on the depot and the time of the day.

To include time windows in the model will complicate the solution procedure. Two blocks having arrivals times sufficiently close to each other makes it, with the introduction of time windows, possible to park the second block before the first block. Hence the basis of the layered network structure with the non-decreasing arrival times cannot be used. Furthermore a solution found where arrival times and departures times are stretched compared to the regular times may indicate an non-robust plan. The depot plan would often not be able to absorb even minor delays in the shunting process. For that reason it has been chosen not to include time windows in the prototype.

6.3 Branch-and-Cut approach

In this section I will describe a whole different solution procedure to the parking problem. This procedure is based on a Branch-and-Cut approach to the problem. It is inspired by the graph theoretical approach in [SK04].

In the mathematical formulation, section 5.2.2, the difficult constraints with respect to the feasibility of a track assignment are taken into account implicitly i.e. all feasible assignments are generated *before* solving the model. With the Branch-and-Cut approach I will show another strategy, where the generating of feasible assignments is a part of the solving process.

6.3.1 Mathematical formulation

The basic mathematical model to use for the Branch-and-Cut approach is presented below. The model is denoted BM.

Sets

B is the set of blocks and S is defined as the set of shunt tracks.

Variables

In the model the following binary decision variables exist:

$$x_b^s = \begin{cases} 1 & \text{if block } b \in B \text{ is parked on shunt track } s \in S, \\ 0 & \text{otherwise.} \end{cases}$$

$$y_b = \begin{cases} 1 & \text{if block } b \in B \text{ is not parked on any shunt track } s \in S, \\ 0 & \text{otherwise.} \end{cases}$$

Objective function

A cost c_b^s is connected to park each block b on track s. This cost can be e.g. an estimate of the routing costs. It can also include some penalties if certain rules are not satisfied. The parameter d models a penalty if a block b is not assigned to any track. The objective is to minimize the total costs of a depot plan, such that as many blocks as possible are assigned to the shunt tracks. The function is as follows

$$\text{minimize} \sum_{s \in S} \sum_{b \in B} c_b^s x_b^s + d \sum_{b \in B} y_b \tag{6.2}$$

Constraints

The following types of constraints exist in the model.

1. These constraints state that each block $b \in B$ is parked on exactly one shunt track or is not parked at all. The constraints are as follows

$$\sum_{s \in S} x_b^s + y_b = 1 \qquad \forall b \in B \tag{6.3}$$

2. All the variables are binary decision variables

$$x_b^s \in \{0,1\} \qquad \forall s \in S, \forall b \in B \tag{6.4}$$

$$y_b \in \{0,1\} \qquad \forall b \in B \tag{6.5}$$

The model BM (6.2)-(6.5) does not contain any constraints, which ensure a solution is feasible. Instead a conflict graph is used to identify crossings in the solution. It is assumed that all tracks are LIFO tracks. Recall the example in Table 5.1 with the four blocks. Each interval in Figure 6.2 represents the time each block spends at the shunt yard. The order of the blocks can also be seen in the event calendar, Table 6.1, where A is an arrival and D a departure.

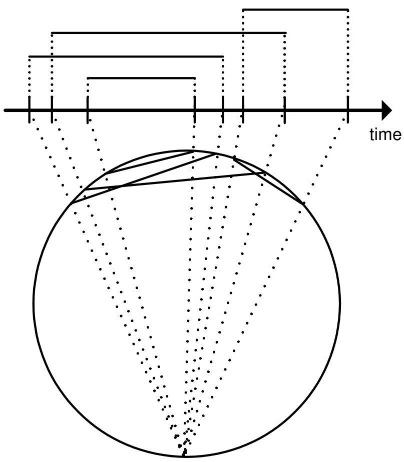

Figure 6.2: Arrivals and departures of the four blocks in Table 5.1.

Event calendar	
Block ID	Event
1	A
2	A
3	A
3	D
1	D
4	A
2	D
4	D

Table 6.1: The event calendar corresponding to Figure 6.2.

Figure 6.2 shows that there is a one-to-one correspondence between each interval and a chord in a cycle. Two intervals overlap if they intersect but neither properly contains each other. An overlap indicates that the corresponding blocks cannot be parked on the same shunt track. By denoting $\mathcal{I}$ the set of intervals and $I_b \in \mathcal{I}$ the interval associated to block b, it is possible to construct an undirected graph $G[\mathcal{I}] = (V, E)$, where $V = \{b | I_b \in \mathcal{I}\}$ and $E = \{(b, c) | I_b \text{ and } I_c \text{ overlap}\}$.

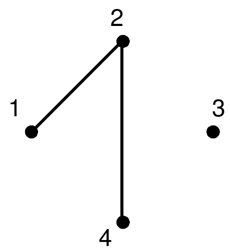

Figure 6.3: The conflict graph based on the example in Figure 6.2.

The graph $G[\mathcal{I}]$ is called a conflict graph. The conflict graph for the example in Figure 6.2 is presented in Figure 6.3. The number of conflicts is 2.

The conflict graph in Figure 6.3 is used to identify whether a solution to the BM contains crossings. If this is the case constraints are added to the BM, which cuts of the old infeasible solution. Then the new model is solved and by using the conflict graph it is examined, whether the new solution is feasible or not etc. The conflict graph can also be used to determine the minimum number of tracks needed at the shunt yard. This is equal to the chromatic number of the graph, see [BM76]. Unfortunately the chromatic number problem from conflict graphs is $\mathcal{NP}$-complete [SK04].

If there were two shunt tracks with a capacity of 8 train units for the example in Table 5.1, the Branch-and-Cut solution procedure would after a few iterations find a feasible depot plan. Unfortunately this is not always the case. First of all the number of cuts to be generated will grow exponentially in the number of blocks to be shunted. Secondly the capacities of the shunt tracks are not taken into consideration in the above approach. Adding constraints to the model, where the number of parkings on a shunt track is less than or equal to the capacity of the shunt track, will cut of feasible solutions, because some blocks may depart before other blocks arrive, see e.g. assignment 3 in Table 5.2. Instead each solution of the BM has be to analyzed in order to see, whether the capacities of the shunt tracks are respected. Based on this analysis different cuts can be added to the BM. The number of capacity cuts will also grow exponentially in the number of blocks to be shunted.

Because of the large number of cuts to add and the thorough analysis needed after each solution, it has been chosen not to use the Branch-and-Cut approach in the prototype. Still it could be interesting to develop another prototype based on the Branch-and-Cut approach and compare the results with the prototype developed in this project.

Chapter 7

The Prototype

In this project I have developed a prototype of a decision support system for depot planning. Besides the solution procedure for the parking problem described in chapter 5, this system contains a Feasibility Check and an intuitive text-based interface for guiding the depot planning in the optimization procedure and for interactively examine the solutions. Furthermore a graphical representation of the solution is provided via the simulation program Arena. The system can be seen as an automated tool for supporting the planner. These depot plans are the closing stone of the complete planning process underlying a railway system. Every modification of the timetable or the rolling stock circulation will require modification of the depot plans at some stations. Hence in practice it is more important that depot plans can be generated quickly rather than optimal.

As mentioned in chapter 5, the entity block is defined as one or more train units that remain together for the entire planning period at a particular station. The prototype developed takes the blocks that have to be shunted and creates a depot plan. It is up to the planner to decide length of the planning period. Typically the depot planning is solved for a 24 hour period and each station is solved independently. In the weekend it is most practical to solve the depot planning for the entire period. Most stations do not contain spare train units, so the shunt tracks will usually be empty one or more times during a working day. Hence a reasonable approach is to solve the depot planning from an empty shunt yard to an empty shunt yard. If the shunt tracks are empty several times during the day, the planning periods can be split into different instances, since each period is independent of the others. It is also possible in the prototype to place blocks at the shunt tracks before the beginning of the planning period. This feature can to some extent also be used split a large planning period into smaller ones.

The topology of each station is defined by a number of platforms, a number of shunt tracks and the connections between them. Each platform or shunt track are defined by a capacity[1]. All of the tracks have to be of the LIFO type. At many stations it is possible to drive from every platform to all shunt tracks. Unfortunately some stations contain restrictions or signals, which make certain connections between platforms and shunt tracks infeasible to use[2]. One of these restrictions is that the blocks cannot pass the main track at the station during shunting, while the normal traffic is dense. Hence at some stations blocks arriving at a particular platform can only be shunted to a certain group of shunt tracks. Another problem is, if a block arrives at one platform and departs from another platform and the two platforms do not have any feasible shunt tracks in common. Figure 7.1 and Figure 7.2 show two examples of station topologies.

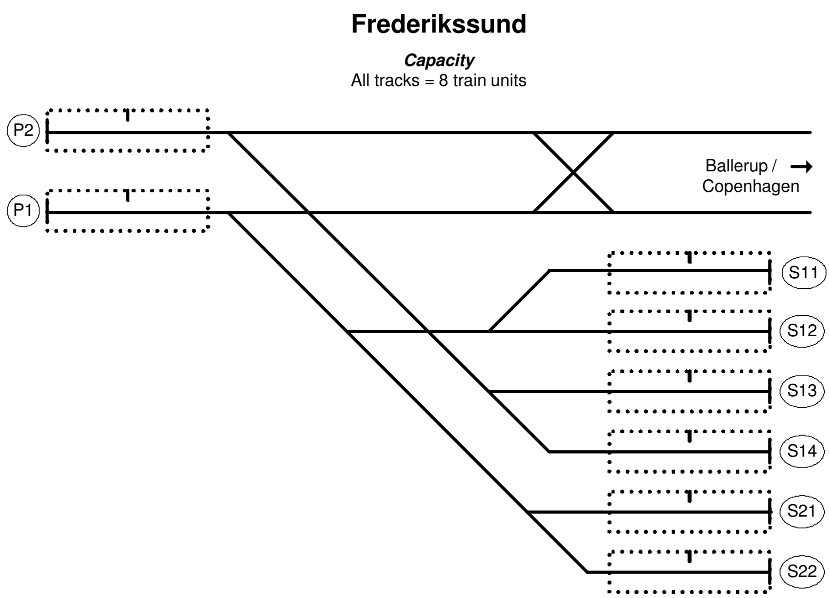

Figure 7.1: The station topology of Frederikssund.

[1]The capacity is given by the number of train units able to park at the track.
[2]These restrictions are based on information from S-tog.

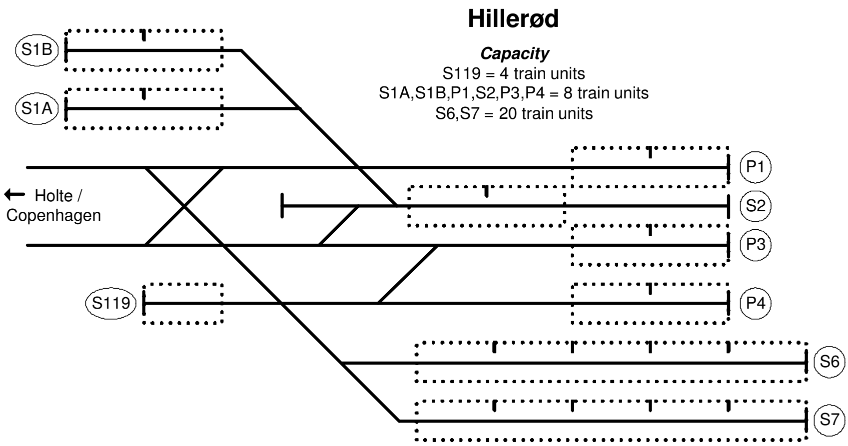

Figure 7.2: The station topology of Hillerød.

Figure 7.1 is in Frederikssund, while Figure 7.2 is in Hillerød. The station topology in Frederikssund is simple. Every shunt track has a capacity of 8 train units. The only restriction to be aware of is, that train units cannot be shunted from platform 2 to shunt track 21 and shunt track 22 and vice versa. In Hillerød the topology is more complicated. Only shunt track 1A and shunt track 1B are available from platform 1, while shunt tracks 119, 6 and 7 are available from platform 3 and platform 4. Shunt track 2 does not contain the possibility for cleaning. Hence it cannot be used directly from one of the platforms. Instead it can be used if some of the train units are moved from one shunt track to another shunt track. This move is called an intermediate shunting move. In section 7.2 I describe how the prototype examines the station topology in the solution procedure.

The developed prototype can been applied to 6 of the 9 depots at S-tog. The two main depots at Copenhagen Central Station and Høje Taastrup are both manually operated and hence not included in this project. The depot in Hundige consists of a preparation centre, which changes the basis of the problem and makes planning of shunting movements completely different from the other depots. For this reason it has been chosen not to examine the depot further. The 6 remaining depots are: Ballerup, Farum, Frederikssund, Hillerød, Klampenborg and Køge. In all of these 6 depots the shunt tracks are LIFO tracks. Hence the prototype is made only for depots consisting of LIFO tracks, but using the approach from section 6.1 the extension to handle free tracks as well is uncomplicated to implement.

7.1 Structure of the prototype

The prototype works as a decision support system. It guides the user to find feasible depot plans by using input to control the algorithms and the optimization. Figure 7.3 shows the structure of the prototype.

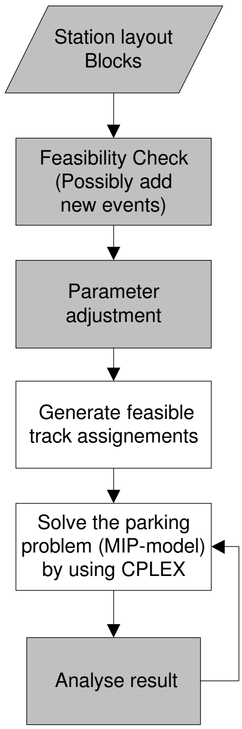

Figure 7.3: The flowchart of the prototype. The grey boxes indicate interaction with the user, while the parallelogram defines the input to the prototype.

The problem at each station is solved independently. Hence the input to the prototype is a station topology and the blocks to be shunted at the station in the planning period. These blocks are identified by using information from the previous steps in the planning process. Each block contains the 14 records mentioned in section 5.2.

Figure 7.3 shows that after the initialization phase the prototype consists of five phases: Feasibility Check, parameter adjustment, generating track assignments, solving the model and analyzing the result. The Feasibility Check and the parameter adjustment are new to the solution procedure, while generating track assignments and solving the model is part of the parking problem described in chapter 5. Notice that it is possible to solve the problem again after analyzing the result. This is based on a Branch-and-Cut algorithm, which will be described in details in section 7.5.

7.2 Feasibility Check - Problem Analysis

The idea behind the Feasibility Check is to detect and correct infeasibilities before actually solving the parking problem. This is done by analyzing the input data i.e. the blocks to be shunted and the station topology. To the best of my knowledge it is the first time an input analysis is applied to the shunting problem.

Based on the blocks to be shunted it is possible to create an event calendar E. Initially this event calendar consists of a set of arrival events A and a set of departure events D i.e. each event $i \in E = A \cup D$. Figure 7.4 shows an example of an event calendar. Each event i is given with a time t_i, a platform track p_i, the length l_i and type x_i and other information based on the involved block. $t_{next^a(i)}$ is the time of next arrival event at the platforms, when event i occurs. $t_{next^d(i)}$ is the time of the next departure event. $t_{prev^a(i)}$ and $t_{prev^d(i)}$ represent the time of the previous arrival event and the time of the previous departure event respectively. The event calendar forms the basis for the analysis of the input.

The Feasibility Check consists of four different checks. These checks involve:

1. Determining the minimum number of drivers[3] needed.
2. The use of platforms as shunt tracks at night.
3. The need of intermediate shunting moves because the arrival platform and departure platform of a block are different and do not have any feasible shunt tracks in common. These moves are denoted intermediate shunting moves type 1.
4. The need of intermediate shunting moves due to capacity problems at certain shunt tracks. These moves are denoted intermediate shunting moves type 2.

[3]A driver performs all the tasks in the shunt yard including driving the train units from a platform to a shunt track and vice versa.

```
---Starting depot planning for HI---

Block |  New  | Type | Size | Day & Time |  From/to   |   Track    |          Activity          |     From/to     | Stock
[
0     |   -   | LHB  | 4    | Mo - 08:25 | 41123-2    | P3         | Arrive at platform - Det.  |    41228-1      | 4,
1     |   -   | LHB  | 8    | Mo - 08:45 | 41124-1    | P4         | Arrive at platform         |    41245-1      | 12,
0     |   -   | LHB  | 4    | Mo - 08:56 |    41228-1 | P3         | Depart from platform       | 41123-2         | 8,
2     |   -   | LHB  | 4    | Mo - 09:05 | 41125-2    | P3         | Arrive at platform - Det.  |    41230-1      | 12,
3     |   -   | LHB  | 8    | Mo - 09:25 | 41126-1    | P4         | Arrive at platform         |    41247-1      | 20,
2     |   -   | LHB  | 4    | Mo - 09:36 |    41230-1 | P3         | Depart from platform       | 41125-2         | 16,
1     |   -   | LHB  | 8    | Mo - 14:36 |    41245-1 | P4         | Depart from platform       | 41124-1         | 8,
3     |   -   | LHB  | 8    | Mo - 15:16 |    41247-1 | P3         | Depart from platform       | 41126-1         | 0,
4     |   -   | LHB  | 4    | Mo - 17:05 | 41149-2    | P3         | Arrive at platform - Det.  |    41254-1      | 4,
5     |   -   | LHB  | 4    | Mo - 17:15 | 10149-2    | P1         | Arrive at platform - Det.  |    10222-2      | 8,
6     |   -   | LHB  | 8    | Mo - 17:25 | 41150-1    | P4         | Arrive at platform         |    41221-1      | 16,
7     |   -   | LHB  | 4    | Mo - 17:35 | 10150-2    | P1         | Arrive at platform - Det.  |    10221-2      | 20,
4     |   -   | LHB  | 4    | Mo - 17:36 |    41254-1 | P3         | Depart from platform       | 41149-2         | 16,
8     |   -   | LHB  | 4    | Mo - 17:45 | 41151-2    | P3         | Arrive at platform - Det.  |    41256-1      | 20,
9     |   -   | LHB  | 4    | Mo - 17:55 | 10151-2    | P1         | Arrive at platform - Det.  |    10216-1      | 24,
10    |   -   | LHB  | 8    | Mo - 18:05 | 41152-1    | P4         | Arrive at platform         |    41220-1      | 32,
11    |   -   | LHB  | 4    | Mo - 18:15 | 10152-2    | P1         | Arrive at platform - Det.  |    10223-2      | 36,
8     |   -   | LHB  | 4    | Mo - 18:16 |    41256-1 | P3         | Depart from platform       | 41151-2         | 32,
12    |   -   | LHB  | 4    | Mo - 19:25 | 41156-2    | P3         | Arrive at platform         |    10225-2      | 36,
13    |   -   | LHB  | 4    | Mo - 19:45 | 41157-2    | P3         | Arrive at platform         |    10226-2      | 40,
14    |   -   | LHB  | 4    | Tu - 00:35 | 10171-1    | P1         | Arrive at platform         |    10217-1      | 44,
15    |   -   | LHB  | 4    | Tu - 00:55 | 10100-2    | P1         | Arrive at platform         |    10224-2      | 48,
16    |   -   | LHB  | 4    | Tu - 01:10 | 10901-1    | P4         | Arrive at platform         |    12017-1      | 52,
17    |   -   | LHB  | 4    | Tu - 01:15 | 10101-1    | P1         | Arrive at platform         |    10218-1      | 56,
18    |   -   | LHB  | 4    | Tu - 01:30 | 10902-1    | P4         | Arrive at platform         |    12016-1      | 60,
18    |   -   | LHB  | 4    | Tu - 04:40 |    12016-1 | P4         | Depart from platform       | 10902-1         | 56,
9     |   -   | LHB  | 4    | Tu - 04:46 |    10216-1 | P1         | Depart from platform       | 10151-2         | 52,
14    |   -   | LHB  | 4    | Tu - 04:46 |    10217-1 | P1         | Depart from platform       | 10171-1         | 48,
16    |   -   | LHB  | 4    | Tu - 05:00 |    12017-1 | P4         | Depart from platform       | 10901-1         | 44,
17    |   -   | LHB  | 4    | Tu - 05:26 |    10218-1 | P1         | Depart from platform       | 10101-1         | 40,
10    |   -   | LHB  | 8    | Tu - 06:16 |    41220-1 | P3         | Depart from platform       | 41152-1         | 32,
7     |   -   | LHB  | 4    | Tu - 06:26 |    10221-2 | P1         | Depart from platform - Att. | 10150-2        | 28,
6     |   -   | LHB  | 8    | Tu - 06:36 |    41221-1 | P3         | Depart from platform       | 41150-1         | 20,
5     |   -   | LHB  | 4    | Tu - 06:46 |    10222-2 | P1         | Depart from platform - Att. | 10149-2        | 16,
11    |   -   | LHB  | 4    | Tu - 07:06 |    10223-2 | P1         | Depart from platform - Att. | 10152-2        | 12,
15    |   -   | LHB  | 4    | Tu - 07:26 |    10224-2 | P1         | Depart from platform - Att. | 10100-2        | 8,
12    |   -   | LHB  | 4    | Tu - 07:46 |    10225-2 | P1         | Depart from platform - Att. | 41156-2        | 4,
13    |   -   | LHB  | 4    | Tu - 08:06 |    10226-2 | P1         | Depart from platform - Att. | 41157-2        | 0]
```

Figure 7.4: An event calendar from a working day period in Hillerød.

Check 2, 3 and 4 may lead to new events, which are added to the event calendar. The final event calendar is used as input for the parking problem.

7.2.1 Determining the minimum number of drivers needed

The first check is to determine the minimum number of drivers needed in order to operate the event calendar. In the depot plans S-tog are using, they operate with an arrival time, a departure time and a time for beginning the move from the shunt track to the platform. Normally this time is between 5 minutes and 19 minutes before the actual departure from the platform. The planners at S-tog find and adjust these times after the depot plans are made, so it is possible for the driver or drivers to perform the events. This makes the analysis of the departure events ambiguous, since the time of a departure event does not represent the time a driver is needed. Hence in this check it is only the arrival events, which are examined. This examination will give a lower bound of the number of drivers needed.

Algorithm 1 DriversNeeded(event calendar E)

```
minTime ← ∞
for all i ∈ A do
    timeBetween ← t_i - t_{prev^a(i)}
    minTime ← min(minTime, timeBetween)
end for
if minTime ≥ 20 min. then
    drivers ← 1
else
    drivers ← 2
end if
return drivers
```

Algorithm 1 represents a simple algorithm to analyze the event calendar. The algorithm finds the minimum time between two arrival events in order to determine whether one driver or two drivers are needed. According to S-tog one driver is enough, if the trains run on a 20 minutes basis, otherwise two drivers are needed. The result of this step is used in some of the following checks to determine the time needed between events in the event calendar, if new events are added.

7.2.2 The use of platforms as shunt tracks at night

The second check examines the overall capacity needed at the shunt yard. If the check indicates that there is insufficient capacity at the shunt yard, the user can allow to use platforms as shunt tracks at night. S-tog has the restriction that at least one platform has to be available at night for possible maintenance activities etc. The flowchart of the check is presented in Figure 7.5.

The first step in the check is to compare the capacity at the shunt yard with the maximum number of train units in the planning period, see Algorithm 2. An arrival event is added to the stock at the station, and a departure event is subtracted from the stock. The maximum number of train units in the planning period is returned.

If $maxStock$ is larger than the capacity at the shunt yard, it is not be possible to generate a feasible depot plan without the use of one or more platforms as shunt tracks.

It is assumed, which is also the most sensible, to park the block that is used first in the morning at the platform. If two blocks depart together first in the

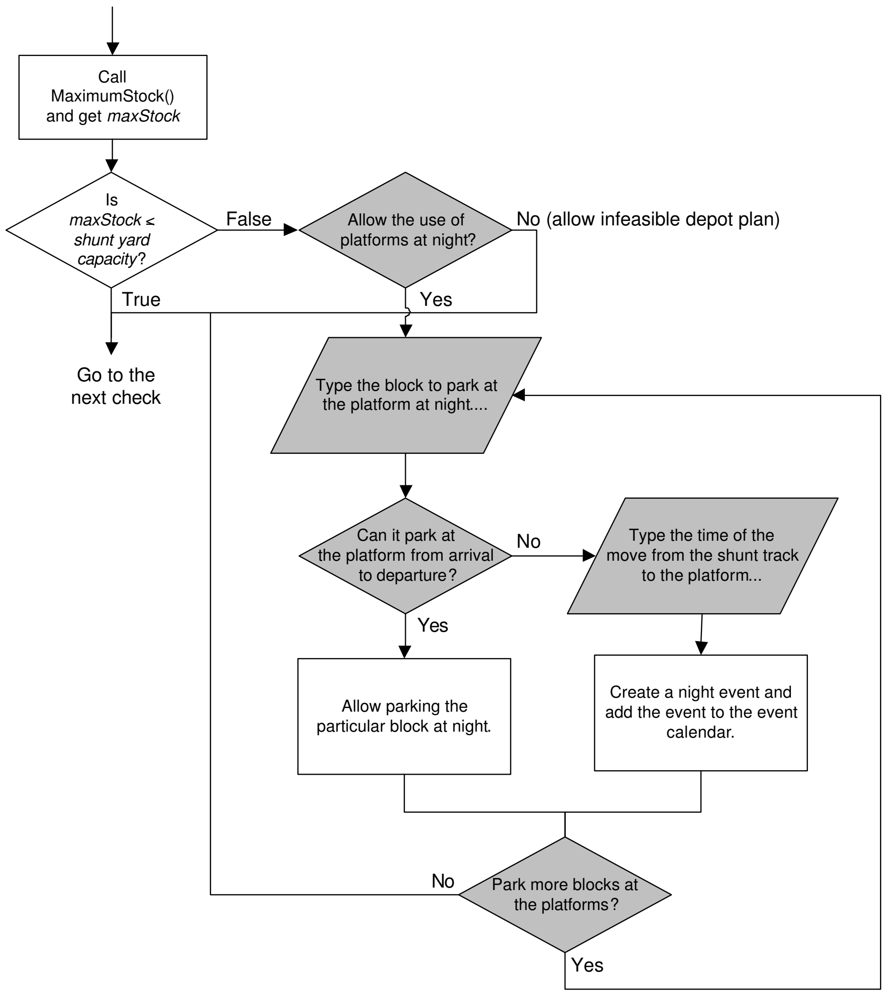

Figure 7.5: The flowchart of check 2 - the use of platforms as shunt tracks at night. The grey boxes indicate interaction with the user.

morning both of them should be parked at the platform at night. If the block that departs first in the morning is the last to arrive it is easy to handle, since this block does not have to move to the shunt yard at all. If this is not the case the block has to be at a shunt track from its arrival and until there are no activities left at the platform that particular day. Even though there are no activities at the platform during the evening the planner may not be interested

Algorithm 2 MaximumStock(event calendar E)

$maxStock = 0$
for all $i \in E$ **do**
    if $i \in A$ **then**
        $stock \leftarrow stock + l_i$
    else
        $stock \leftarrow stock$ - l_i
    end if
    $maxStock \leftarrow \max(maxStock, stock)$
end for
return $maxStock$

in parking the block directly at the platform, since having train units parked at the platform with activities at the other platforms is not considered as good practice. In this case the planner will like first to move the block to a shunt track and then back to the platform later in the evening/night.

Finding the time with no activities left at a particular platform is not only a question about examining the event calendar of the blocks to be shunted, but also to take the overall timetable into consideration. There may be several train units arriving and departing from the platform without any of them being considered for shunting. For that reason the prototype is made so it is the user, who specifies what block to park at the platform and the time for the move between the shunt track and the platform.

If a block, that is supposed to park at the platform overnight, is moved to the shunt track before it is moved to the platform an additional event called night event is needed. This night event is based on the time typed by the user and the information from the block being moved. The set of night events is denoted N. N is added to E, so after the check the event calendar $E = A \cup D \cup N$. Notice in Figure 7.5 that a new event is not added to the event calendar, if the block can park at the platform from its arrival to its departure. Instead a flag is set in the data structure of the block, so later in the solution procedure the program knows it is possible to park the block at the platform. At least one platform has to be available at night for other activities.

7.2.3 Intermediate shunting moves type 1

As mentioned in the beginning of this chapter some stations may have restrictions that make certain connections between platforms and shunt tracks infeasible to use. Hence a problem arises if a block arrives at one platform and departs from another platform and the two platforms do not have any feasible shunt tracks in common. In order to generate feasible depot plans it is necessary to introduce intermediate shunting moves i.e. train units are moved from one shunt track to another shunt track. This check, the third check, identifies whether one or more blocks of this type exist. If that is the case it finds feasible times for the intermediate shunting moves and creates the events. The flowchart of the check is presented in Figure 7.6.

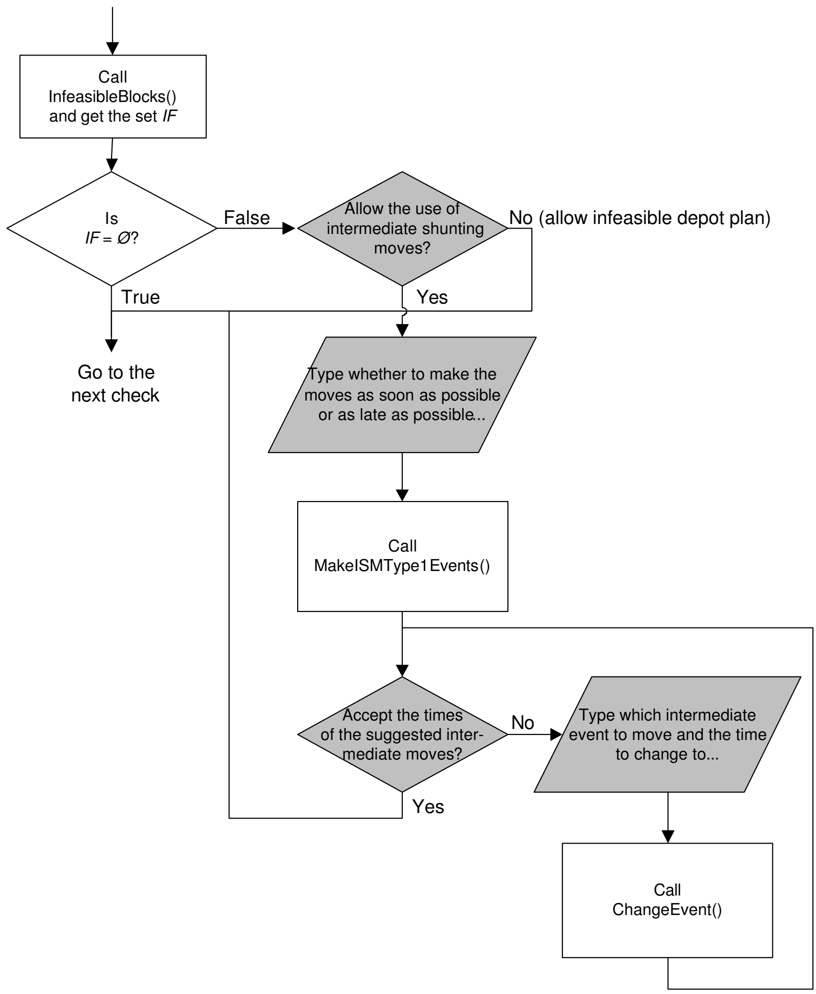

Figure 7.6: The flowchart of check 3 - intermediate shunting moves type 1. The grey boxes indicate interaction with the user.

The first step of this check is to identify the blocks in the event calendar with the above infeasibilities. Algorithm 3 represents this step. The set IF contains the "infeasible" blocks.

Algorithm 3 InfeasibleBlocks(station topology ST, event calendar E)

$IF = \emptyset$
for all $i \in E$ **do**
  if $i \in A$ **then**
    $arrPlatform \leftarrow p_i$
    $activeBlock \leftarrow$ block of i
    find in E the departure event j of $activeBlock$
    $depPlatform \leftarrow p_j$
    find feasible shunt tracks FAR from $arrPlatform$ based on ST
    find feasible shunt tracks FDR from $depPlatform$ based on ST
    if $FAR \cap FDR = \emptyset$ **then**
      add $activeBlock$ to IF
    end if
  end if
end for
return IF

If $IF = \emptyset$ the event calendar does not contain any infeasibilities. Otherwise one or more blocks have to be moved from one shunt track to another shunt track in order to create a feasible depot plan. A heuristic has been formulated which finds the times of the intermediate shunting moves and creates the events. It will effect the entire solution procedure (the structure and the number of feasible track assignments) at what times the intermediate shunting moves occur. Hence the idea behind the heuristic is to suggest a strategy for the intermediate shunting moves that will give the best chances of generating a feasible depot plan.

Another approach, which has not been implemented, is to propose a number of different time slots for each intermediate shunting move e.g. three time slots. Then the best time slots are found, when the model is solved in CPLEX. The problem with this approach is, that the number of blocks will grow rapidly for each intermediate shunting move. Hence it is much harder for the solver to find a solution. In section 7.2.5 I show how the new events are converted to new blocks, which are added to the collection of the original blocks. Basically the problem is that not only the new block is effected by the time of the new event, but also the original block from where the event arises. Thus this block would have to exist in a number of different copies (the same number as time slots) with different arrival time or departure time. The approach is even worse for the intermediate shunting moves type 2 examined in the next section, since two intermediate shunting events arise for each block that has to be moved. This will make the number of blocks grow even faster.

Algorithm 4 MakeISMType1Events(event calendar E, set of blocks IF, boolean $asap$, int $drivers$)

```
if drivers ≥ 2 then
   timeBetween ← 10 min.
else
   timeBetween ← 20 min.
end if
I1 = ∅
for all b ∈ IF do
   if asap then
      find in E arrival event i of block b
      timeNew ← t_i + timeBetween
      timeNext ← min(t_{next^a(i)}, t_{next^d(i)})
      while timeNew > (timeNext − timeBetween) do
         timeNew ← timeNext + timeBetween
         i ← i + 1
         timeNext ← min(t_{next^a(i)}, t_{next^d(i)})
      end while
   else
      find in E departure event j of block b
      timeNew ← t_j − timeBetween
      timePrev ← max(t_{prev^a(j)}, t_{prev^d(j)})
      while timeNew < (timePrev + timeBetween) do
         timeNew ← timePrev − timeBetween
         j ← j − 1
         timePrev ← max(t_{prev^a(j)}, t_{prev^d(j)})
      end while
   end if
   create a new event k based on timeNew and data from block b
   add k to I1
end for
set E = E ∪ I1
```

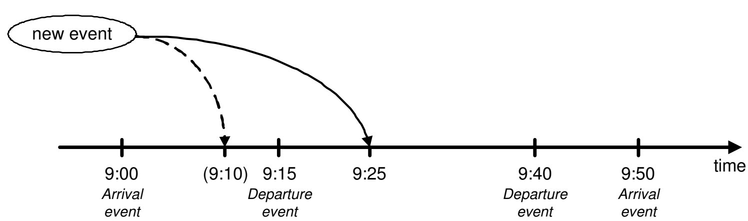

Figure 7.7: How a new event is added to the event calendar.

Algorithm 4 shows the heuristic for finding the times of the intermediate shunting moves type 1 and creating the events. There are two different strategies in the heuristic. The first strategy is to move the block as soon as possible and the second strategy is to move the block as late as possible. Which strategy to use depends on the event calendar and the capacity of the shunt tracks involved. The number of drivers from the first check determines the time needed between a new event and the existing events in the calendar. Figure 7.7 shows how a new event is added, when the event calendar is scanned forward corresponding to move the block as soon as possible. The procedure is similar when the event calendar is scanned backwards. In this example the number of drivers is 2, so there has to be 10 minutes between the events. The new event cannot be added 10 minutes after the arrival event at 9:00, because in that case there would only be 5 minutes to next event. Instead the new event can be scheduled at 9:25, since the time to the next event is 15 minutes. The set of intermediate shunting events type 1 is denoted $I1$. $I1$ is added to E at the end of the heuristic, so after the check the event calendar $E = A \cup D \cup N \cup I1$.

Notice that the user manually can change the time of an intermediate shunting event. Algorithm 5 represents this procedure. The algorithm is also used in the fourth check to change the time of an intermediate shunting event.

Algorithm 5 ChangeEvent(event calendar E, event i, time t)

1: find i in E
2: change the time of i to t
3: update E

7.2.4 Intermediate shunting moves type 2

The fourth and final check examines the need of intermediate shunting moves because of insufficient capacity at certain shunt tracks. This situation arises, if train units arrive at a particular platform and the feasible shunt tracks to this platform are filled up, while there is capacity left at other shunt tracks. Hence an intermediate shunting move of one or more of the blocks already parked at the shunt tracks with insufficient capacity will make it possible to generate a feasible depot plan. Notice that for each intermediate shunting move from the shunt tracks with insufficient capacity, there has to be an intermediate shunting move back to these shunt tracks in order to have a feasible connection to the departure platform of the block. For these blocks the arrival platform is the same as the departure platform. The flowchart of the check is presented in Figure 7.8.

The first step in this check is to identify a possible group of shunt tracks with

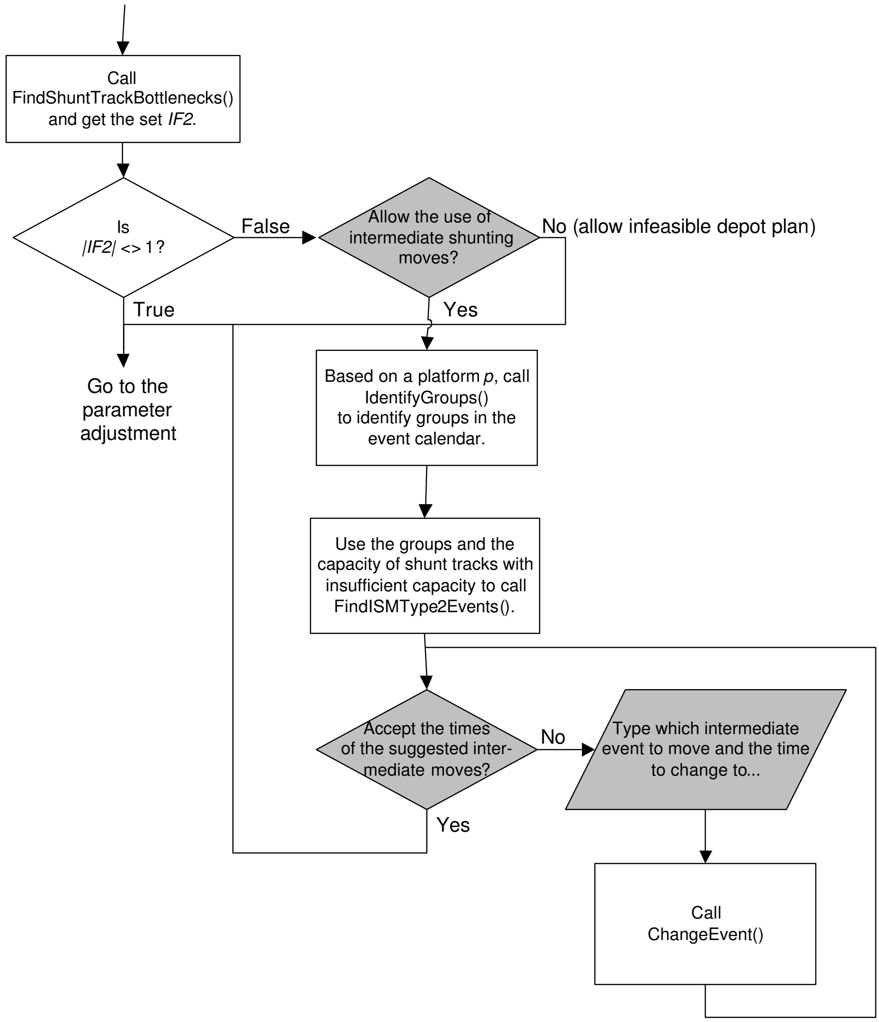

Figure 7.8: The flowchart of check 4 - intermediate shunting moves type 2. The grey boxes indicate interaction with the user.

insufficient capacity, see Algorithm 6. Initially intermediate shunting moves type 1 are ignored in the algorithm. The set $IF2$ contains the platforms connected to groups of shunt tracks with insufficient capacity. If $IF2 = \emptyset$ the rest of this check is discarded. If on the other hand $IF2$ contains two or more platforms connected to different groups of shunt tracks the prototype will skip the check and go on to the parameter adjustment. To have two or more different groups of shunt tracks with insufficient capacity in the same planning period, but not at the same time, is extremely complicated to handle. It may be possible to generate a feasible depot plan, but only with an intensive and complex use of intermediate shunting moves. For that reason it has been chosen only to let the prototype be able to handle one group of shunt tracks with insufficient capacity.

Algorithm 6 FindShuntTrackBottlenecks(station topology ST, event cal. E)

```
IF2 = ∅
for all p ∈ P do
   find feasible shunt tracks FR from p based on ST
   for all s ∈ FR do
      tracksCapacity = tracksCapacity + capacity of shunt track s
   end for
   for all i ∈ E do
      if i ∈ A AND p_i = p then
         capacity ← capacity + l_i
      else if (i ∈ D OR i ∈ N) AND p_i = p then
         capacity ← capacity − l_i
      end if
      maxCapacity ← max(maxCapacity, capacity)
   end for
   if maxCapacity > tracksCapacity then
      add p to IF2
   end if
end for
return IF2
```

If $IF2$ contains one platform a group of shunt tracks with insufficient capacity has been identified. In order to create a feasible depot plan one or more of the blocks parked at these shunt tracks have to be moved to other shunt tracks. A heuristic is formulated which identifies the blocks to move and the times of the moves, and creates the events. The first step of this heuristic is to find the blocks to move. Most often the shunt activities happen in groups i.e. activities in the morning, activities in the afternoon and activities around midnight. To identify these periods with shunt activities a *group* structure has been made. This structure consists of all the blocks that arrive in the same period i.e. the time between the arrivals of the blocks are 20 minutes or less. It is assumed there is not time for intermediate shunting moves type 2 between the activities in a group. Hence the intermediate shunting moves have to be placed between the groups. Algorithm 7 shows the step of detecting groups based on the platform the blocks have a problem of been shunted from. A group g is a set of blocks, where the time between the arrivals to the platform is 20 minutes or less. The function returns the set G, which contains the different groups from the event calendar. Notice that the blocks that arrive and depart to the other platforms are not put into any groups.

Algorithm 7 IdentifyGroups(event calendar E, platform p)

```
g = ∅
G = ∅
lastArrival ← −∞
for all i ∈ E do
  if i ∈ A AND p_i = p then
    activeBlock ← block of i
    find in E the departure event j of activeBlock
    if p_j = p then
      if t_i ≤ (lastArrival + 20min.) then
        add activeBlock to g
      else
        if g ≠ ∅ then
          add g to G
        end if
        create a new group g which initially consists of activeBlock
      end if
      lastArrival ← t_i
    end if
  end if
end for
if g ≠ ∅ then
  add g to G
end if
return G
```

The first objective in placing the new events is to detect between what groups intermediate shunting moves are necessary. Afterwards the blocks and the times of the intermediate shunting activities are found. Algortihm 8 represents the main function of the step. The set G contains the different groups i.e. $g_j \in G, j = 0, 1, \ldots, n$. The size of a group s_j is the number of train units in group j. The start time of a group is the arrival time of the first block in the group, while the end time is the arrival time of the last block in the group. p is the platform connected to the group of shunt tracks with insufficient capacity. u_j is the number of train units at the shunt tracks connected to p before the start time of group j. This parameter is based on the information from the event calendar. It is important to update u_j each time a new event has been added.

In Algorithm 8, the variable $insfCapacity = s_{(j+1)} + u_{(j+1)} - trackCapacity$ states the number of train units to perform intermediate shunting moves on between the groups g_j and $g_{(j+1)}$. If $insfCapacity$ is larger than 0 one or more intermediate shunting moves are needed. The strategy in the heuristic is to perform the move on the block with the latest departure time in the groups from g_0 to g_j. This is the most logical, since otherwise it will occupy the shunt tracks

Algorithm 8 FindISMType2Events(set of groups G, int $trackCapacity$)

$j = 0$
$activeGroup \leftarrow g_j$
$n = |G|$
while $j < n$ **do**
  $insfCapacity \leftarrow s_{(j+1)} + u_{(j+1)} - trackCapacity$
  if $insfCapacity > 0$ **then**
    while $insfCapacity > 0$ **do**
      $activeBlock \leftarrow$ block with the latest departure in the groups g_0 to g_j
      $activeGroup \leftarrow$ the group $activeBlock$ is part of
      CreateISMType2Events($activeBlock$, $activeGroup$)
      update u_j for every group in G
      $insfCapacity \leftarrow insfCapacity -$ size of $activeBlock$
    end while
    The user can change the times of the suggested intermediate shunting moves.
  end if
  $j \leftarrow$ the index of $activeGroup$
  $j \leftarrow j + 1$
  $activeGroup \leftarrow g_j$
end while

with insufficient capacity for the longest period. After the block has been found two intermediate shunting moves are created with CreateISMType2Events, see Algorithm 9. The *activeGroup* is set to the group the block is part of. Afterwards u_j is updated for every group in G. If $insfCapacity$ is still larger than 0 another block is found and new intermediate shunting moves are added to the event calendar. The user have the possibility manually to change the time of the intermediate shunting events. Subsequently the algorithm examines the next group in G.

Algorithm 9, CreateISMType2Events, creates two intermediate shunting moves based on *activeBlock* and *activeGroup*. As in the third check the time of the intermediate shunting moves will effect the entire solution procedure. Again the idea behind the heuristic is to suggest a strategy for the intermediate shunting moves that will give the best chances of finding a feasible depot plan. In the algorithm $next^a(i)$ is the next arrival event in the event calendar after i, while $next^d(i)$ is the next departure event. $next(i)$ is the next event independent of the type of the event. The number of drivers from the first check in the Feasibility Check determines the time needed between a new event and the existing events in the calendar, this time is denoted *timeBetween*. The first intermediate shunting move away from the shunt tracks with insufficient capacity occurs after the last arrival of *activeGroup*. The set of these events, intermediate shunting events type 2 "departures", is denoted *I2D* [4]. The time of the

[4] The events are called departures, since the blocks are departing from the shunt tracks

intermediate shunting move is set to be *timeBetween* after the last arrival of the *activeGroup* **unless**:

(*i*) the next event is not an intermediate shunting event type 2 ”departure”, and

(*ii*) there is not time in the event calendar, see Figure 7.7, **or** the departure time of *activeBlock* is earlier than the departure time of the next arriving block in the event calendar.

If criterion (*i*) and criterion (*ii*) are fulfilled the algorithm goes one step forward in the event calendar and checks whether it is possible to place the intermediate move after the next event and so on. Criterion (*i*) is based on the assumption that intermediate shunting moves can happen together, so if the next event is an intermediate shunting event type 2 ”departure”, the intermediate shunting move is set to the same time as that event. The first part of criterion (*ii*) is known from the section 7.2.3, while the idea of the second part is that the next arriving block would obstruct *activeBlock* **if** the two blocks were parked on the same shunt track. Thus it is only logical to place the intermediate move, if the departure time of *activeBlock* is later than the departure time of the next arriving block in the event calendar. When the most rational time is found of the intermediate shunting move away from the shunt tracks with insufficient capacity a new event is created and added to *I*2*D*.

The procedure is almost analogous when analyzing the intermediate shunting move back to the shunt tracks with insufficient capacity. The move is set to occur before the departure of the *activeBlock* and when there is time, see Figure 7.7. The set of intermediate shunting events type 2 ”arrivals” is denoted *I*2*A*. Again intermediate shunting moves of this type can happen together, so if the previous event is an intermediate shunting event type 2 ”arrival”, the intermediate shunting move is set to the same time as that event. Based on the identified time, a new intermediate shunting event is created and added to *I*2*A*.

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with insufficient capacity.

Algorithm 9 CreateISMType2Events(event calendar E, block $activeBlock$, group $activeGroup$)

if $drivers \geq 2$ **then**
    $timeBetween \leftarrow 10$ min.
else
    $timeBetween \leftarrow 20$ min.
end if
$I2D = \emptyset$
$I2A = \emptyset$
find last arrival event i in $activeGroup$
$depTime \leftarrow t_i + timeBetween$
$timeNext \leftarrow \min(t_{next^a(i)}, t_{next^d(i)})$
while ($next(i) \notin I2D$) AND (($depTime > timeNext - timeBetween$) OR (dep. time of $activeBlock <$ the dep. time of the block of $next^a(i)$))) **do**
    $depTime \leftarrow timeNext + timeBetween$
    $i \leftarrow i + 1$
    $timeNext \leftarrow \min(t_{next^a(i)}, t_{next^d(i)})$
end while
if $next(i) \in I2D$ **then**
    $depTime \leftarrow t_{next(i)}$
end if
create a new event k based on $depTime$ and data from $activeBlock$
add k to $I2D$
find the departure event j of $activeBlock$
$arrTime \leftarrow t_j - timeBetween$
$timePrev \leftarrow \max(t_{prev^a(j)}, t_{prev^d(j)})$
while ($prev(j) \notin I2A$) AND ($arrTime < timePrev + timeBetween$) **do**
    $timeNew \leftarrow timePrev - timeBetween$
    $j \leftarrow j - 1$
    $timePrev \leftarrow \max(t_{prev^a(j)}, t_{prev^d(j)})$
end while
if $prev(j) \in I2A$ **then**
    $arrTime \leftarrow t_{prev(j)}$
end if
create a new event m based on $arrTime$ and data from $activeBlock$
add m to $I2A$
update the event calendar $E = E \cup I2D \cup I2A$

7.2.5 The final step in the Feasibility Check

The four checks result in an event calendar E consisting of arrival events and departure events and possible night events, intermediate shunting events type 1, intermediate shunting events type 2 "departures" and intermediate shunting events type 2 "arrivals". The input to the parking problem is a list of blocks to be shunted, so all the events in the event calendar have to be set up as blocks.

The new events will lead to new blocks and cause the departure time of some of the original blocks to change. Hence the original block will departure at the same time the new block corresponding to the new event will arrive. Notice that in the final depot plan the new and the original block correspond to the same block. In the solution procedure it is assumed that from platform 0 all shunt tracks are feasible. Thereby an intermediate shunting move can take place from all shunt tracks to all other shunt tracks.

Figure 7.9 shows an example of the new blocks, when an intermediate shunting event type 2 "departure" and an intermediate shunting event type 2 "arrival" are added to the event calendar. The departure time of the original block is changed to the time of the first intermediate shunting event. The arrival time of the new block (New block 1) is the time of the event, while the departure time is the time of the second intermediate shunting event. The arrival platform and the departure platform of New block 1 are set to 0. The arrival time of New block 2 is the time of the event, while the departure time is the departure time of the original block. The arrival platform and the departure platform of New block 2 are set to the same as the original block. How the new blocks are created for all the new events is presented in Table 7.1. The arrival and departure events that are not effected by the new events can directly be translated to blocks. The blocks are sorted according to their arrival time, so the input to the parking problem is in ascending order.

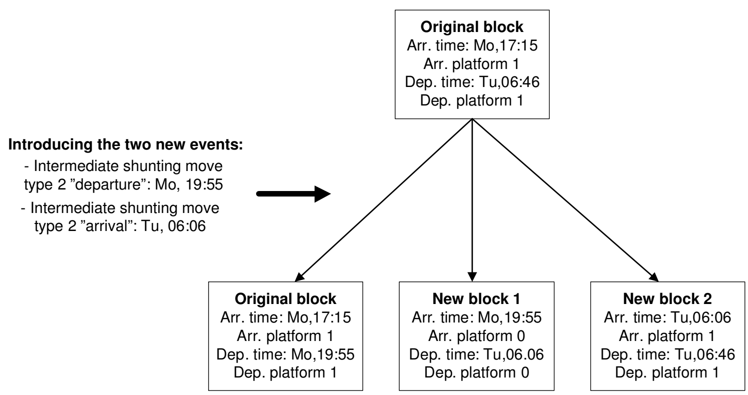

Figure 7.9: How new blocks are created when two intermediate shunting events type 2 ("departure" and "arrival") are added to the event calendar.

Night event:	A new block is created with the arrival time of the event and the departure time of the block corresponding to the event (original block). The departure time of the original block is changed to the time of this event. The new block is set to park at the platform at night.
Intermediate shunting event type 1:	A new block is created with the arrival time of the event and the departure time of the original block. The departure time of the original block is changed to the time of this event. The arrival platform and the departure platform of the new block are set to the departure platform of the original block, while the departure platform of the original block is changed to be the same as the arrival track.
Intermediate shunting event type 2 "departure":	A new block is created with the arrival time of the event and the departure time of the original block (this will be changed at the intermediate shunting event type 2 "arrival"). The arrival platform and the departure platform of the new block are set to platform 0.
Intermediate shunting event type 2 "arrival":	A new block is created with the arrival time of the event and the departure time of the original block of the intermediate shunting move. The departure time of the original block is changed to the time of the first intermediate shunting move, while the departure time of the block corresponding to the first intermediate shunting move is changed to the time of this event. The arrival platform and the departure platform of the new block are set to the same as the original block.

Table 7.1: How new blocks are created based on the new events.

7.3 Parameter adjustment

In this step the user can adjust and set different parameters in order to guide the optimization in the parking step. The parameters involve how to solve the model, and what kind of penalties to use in the solution procedure. This is done by attaching certain weights to elements of the objective function. Besides the parameters the solution procedure can also handle a non empty shunt yard at the start of the planning period. This is in the current implementation part of the initial input to the prototype.

The first setting is to decide whether to use the symmetric model (5.13)-(5.19) from chapter 5 or not. Using the symmetric model decreases the number of binary decision variables greatly, so larger instances can be solved. The disadvantage of using the model is that the prototype cannot distinguish between the different shunt tracks. Hence applying a penalty for using certain shunt tracks or setting the cost of each assignment to the exact routing cost of moving the blocks are not possible. The idea of applying an individual cost to each assignment based on the routing cost has not been implemented in the current prototype, since the focus is on quickly generating good and not necessarily optimal feasible depot plans[5]. Hence in the model in the solution procedure all feasible track assignments are initially given the same cost of 1. If the user wants an individual cost to each assignment it can easily be implemented.

The next settings decide whether to apply some penalties for specific assignments. Applying these penalties will guide the optimization. Some of the penalties are also discussed in [LFKW03]. In the models in section 5.2.2 the penalty d for not parking blocks is already present. This penalty is large, so blocks are always parked if possible. If the blocks cannot be parked special attention from the user is needed. He can either plan to park the block at another time or check whether the train units can remain at the platform. The other penalties the planner can decide whether to apply are the following:

1. Penalties for parking blocks with different subtypes on the same shunt track. This will lead the user towards solutions, where blocks of the same subtype are parked on the same shunt track.

2. Penalties for broken arrivals and departures. A broken arrival arises when blocks arrive in the same arriving leg, but depart in different departing legs and are parked on different shunt tracks. Hence the preferred strategy is to park these blocks next to each other on the same shunt track and in the right order, so the blocks can be considered as one block when they are routed to the departure platform. This will result is less work and reduce the cost. A broken departure is the opposite situation.

3. Decrease the penalties for not parking blocks that are detached at the platform. If a block that is detached at the platform cannot be parked, it may be possible to postpone the detachment until the train has driven another cycle i.e. the train drives to the other end station and back again. Hence dealing with detached train units, that cannot be parked at the station, are at first hand easier to solve, which is the reason for lowering the non-parking cost for these blocks. The issue is that the problem of parking these blocks is just postponed, so the user still has to make sure that it is possible to park the block later. This can be examined by adjusting the arrival times for the blocks in the input to the prototype and solve the problem again.

[5] According to S-tog two feasible depot plans, where the only difference is the order of the shunt tracks, are considered to be equally good.

4. Penalties for using certain shunt tracks. The penalty can only be applied, if symmetry has not been applied to the model. It is used to possibly avoid activities at some shunt tracks due to strategic importance for related processes, such as cleaning, maintenance etc.

7.4 The parking step

When the Feasibility Check and parameter adjustment are completed the problem is set up for the parking step. This step uses the procedure from chapter 5 to generate feasible assignments and solve either STAP model or SYTAP model based the decisions above in CPLEX.

7.4.1 Solution

CPLEX returns the solution status, the objective value and which variables are set. These variables are connected to the event calendar, so the final depot plan is an event calendar where the found shunt tracks are shown. If one or more blocks could not be parked the missing shunt tracks are indicated by question marks. In case of the event calendar contains intermediate shunting events the final depot plan will contain two shunt tracks for these events. Figure 7.10 shows an example of a final depot plan from the depot in Hillerød.

7.5 Feedback from depot planning

The solution procedure will always result in a depot plan. In this depot plan either all blocks are parked or one or more blocks cannot be parked at the station. In both situations it is interesting to know, whether it is the only solution to problem i.e. does there exist other solutions with the same objective value? One of the procedures for examining this is to use a Branch-and-Cut algorithm. The idea behind the Branch-and-Cut algorithm is iteratively to add constraints to the model, which cut off the old solutions, see [Wol98]. Hence solving the model with a new constraint results in a new solution.

In the prototype the user can decide whether to apply the Branch-and-Cut algorithm. In case of a feasible depot plan, where all blocks are parked at the station, the Branch-and-Cut algorithm will be able to identify the number of plans with the same objective value. This can to some degree be used to show

```
All 27 blocks have been assigned to a track!

Block |  New  | Type | Size | Day & Time |  From/to  |   Track   |          Activity          |     From/to      | Stock
[
0     |   -   | LHB  | 4    | Mo - 08:25 | 41123-2   | P3  /S119 | Arrive at platform - Det.  |     41228-1      | 4,
1     |   -   | LHB  | 8    | Mo - 08:45 | 41124-1   | P4  /S6   | Arrive at platform         |     41245-1      | 12,
0     |   -   | LHB  | 4    | Mo - 08:56 |   41228-1 | S119/P3   | Depart from platform       | 41123-2          | 8,
2     |   -   | LHB  | 4    | Mo - 09:05 | 41125-2   | P3  /S119 | Arrive at platform - Det.  |     41230-1      | 12,
3     |   -   | LHB  | 8    | Mo - 09:25 | 41126-1   | P4  /S7   | Arrive at platform         |     41247-1      | 20,
2     |   -   | LHB  | 4    | Mo - 09:36 |   41230-1 | S119/P3   | Depart from platform       | 41125-2          | 16,
1     |   -   | LHB  | 8    | Mo - 14:36 |   41245-1 | S6  /P4   | Depart from platform       | 41124-1          | 8,
3     |   -   | LHB  | 8    | Mo - 15:16 |   41247-1 | S7  /P3   | Depart from platform       | 41126-1          | 0,
4     |   -   | LHB  | 4    | Mo - 17:05 | 41149-2   | P3  /S6   | Arrive at platform - Det.  |     41254-1      | 4,
5     |   -   | LHB  | 4    | Mo - 17:15 | 10149-2   | P1  /S1A  | Arrive at platform - Det.  |     10222-2      | 8,
6     |   -   | LHB  | 8    | Mo - 17:25 | 41150-1   | P4  /S7   | Arrive at platform         |     41221-1      | 16,
7     |   -   | LHB  | 4    | Mo - 17:35 | 10150-2   | P1  /S1A  | Arrive at platform - Det.  |     10221-2      | 20,
4     |   -   | LHB  | 4    | Mo - 17:36 |   41254-1 | S6  /P3   | Depart from platform       | 41149-2          | 16,
8     |   -   | LHB  | 4    | Mo - 17:45 | 41151-2   | P3  /S6   | Arrive at platform - Det.  |     41256-1      | 20,
9     |   -   | LHB  | 4    | Mo - 17:55 | 10151-2   | P1  /S1B  | Arrive at platform - Det.  |     10216-1      | 24,
10    |   -   | LHB  | 8    | Mo - 18:05 | 41152-1   | P4  /S7   | Arrive at platform         |     41220-1      | 32,
11    |   -   | LHB  | 4    | Mo - 18:15 | 10152-2   | P1  /S1B  | Arrive at platform - Det.  |     10223-2      | 36,
8     |   -   | LHB  | 4    | Mo - 18:16 |   41256-1 | S6  /P3   | Depart from platform       | 41151-2          | 32,
12    |   -   | LHB  | 4    | Mo - 19:25 | 41156-2   | P3  /S119 | Arrive at platform         |     10225-2      | 36,
13    |   -   | LHB  | 4    | Mo - 19:45 | 41157-2   | P3  /S6   | Arrive at platform         |     10226-2      | 40,
14    | ISM11 | LHB  | 4    | Mo - 19:55 |           | S1B /S6   | Intermediate shunting move | 10152-2/10223-2  | -,
15    | ISM21 | LHB  | 4    | Mo - 19:55 |           | S1A /S6   | Intermediate shunting move | 10149-2/10222-2  | -,
16    | ISM31 | LHB  | 4    | Mo - 19:55 |           | S1A /S7   | Intermediate shunting move | 10150-2/10221-2  | -,
17    |   -   | LHB  | 4    | Tu - 00:35 | 10171-1   | P1  /S1B  | Arrive at platform         |     10217-1      | 44,
18    |   -   | LHB  | 4    | Tu - 00:55 | 10100-2   | P1  /S1A  | Arrive at platform         |     10224-2      | 48,
19    |   -   | LHB  | 4    | Tu - 01:10 | 10901-1   | P4  /S6   | Arrive at platform         |     12017-1      | 52,
20    |   -   | LHB  | 4    | Tu - 01:15 | 10101-1   | P1  /S1A  | Arrive at platform         |     10218-1      | 56,
21    |   -   | LHB  | 4    | Tu - 01:30 | 10902-1   | P4  /S6   | Arrive at platform         |     12016-1      | 60,
21    |   -   | LHB  | 4    | Tu - 04:40 |   12016-1 | S6  /P4   | Depart from platform       | 10902-1          | 56,
9     |   -   | LHB  | 4    | Tu - 04:46 |   10216-1 | S1B /P1   | Depart from platform       | 10151-2          | 52,
17    |   -   | LHB  | 4    | Tu - 04:46 |   10217-1 | S1B /P1   | Depart from platform       | 10171-1          | 48,
19    |   -   | LHB  | 4    | Tu - 05:00 |   12017-1 | S6  /P4   | Depart from platform       | 10901-1          | 44,
20    |   -   | LHB  | 4    | Tu - 05:26 |   10218-1 | S1A /P1   | Depart from platform       | 10101-1          | 40,
22    | ISM22 | LHB  | 4    | Tu - 06:06 |           | S6  /S1A  | Intermediate shunting move | 10149-2/10222-2  | -,
23    | ISM32 | LHB  | 4    | Tu - 06:06 |           | S7  /S1B  | Intermediate shunting move | 10150-2/10221-2  | -,
10    |   -   | LHB  | 8    | Tu - 06:16 |   41220-1 | S7  /P3   | Depart from platform       | 41152-1          | 32,
7     |   -   | LHB  | 4    | Tu - 06:26 |   10221-2 | S1B /P1   | Depart from platform - Att. | 10150-2         | 28,
6     |   -   | LHB  | 8    | Tu - 06:36 |   41221-1 | S7  /P3   | Depart from platform       | 41150-1          | 20,
5     |   -   | LHB  | 4    | Tu - 06:46 |   10222-2 | S1A /P1   | Depart from platform - Att. | 10149-2         | 16,
24    | ISM12 | LHB  | 4    | Tu - 06:56 |           | S6  /S1A  | Intermediate shunting move | 10152-2/10223-2  | -,
11    |   -   | LHB  | 4    | Tu - 07:06 |   10223-2 | S1A /P1   | Depart from platform - Att. | 10152-2         | 12,
18    |   -   | LHB  | 4    | Tu - 07:26 |   10224-2 | S1A /P1   | Depart from platform - Att. | 10100-2         | 8,
25    | ISM01 | LHB  | 4    | Tu - 07:36 |           | S119/S1B  | Intermediate shunting move | 41156-2/10225-2  | -,
12    |   -   | LHB  | 4    | Tu - 07:46 |   10225-2 | S1B /P1   | Depart from platform - Att. | 41156-2         | 4,
26    | ISM02 | LHB  | 4    | Tu - 07:56 |           | S6  /S1B  | Intermediate shunting move | 41157-2/10226-2  | -,
13    |   -   | LHB  | 4    | Tu - 08:06 |   10226-2 | S1B /P1   | Depart from platform - Att. | 41157-2         | 0]
```

Figure 7.10: An example of a final depot plan.

the robustness of the current solution, since many different depot plans indicate flexibility in the shunting process. Some instances exist where this is not the case e.g. if two blocks depart immediately after their arrivals they can presumably be parked at all shunt tracks. This will lead to many different depot plans with the same objective value. Even though these two blocks are very flexible in the shunting process, the remaining blocks may be very inflexible. Hence the number of feasible depot plans with same objective value can only be used as an indication of the robustness and not as a complete robustness analysis. Notice that the different solutions are not symmetric solutions, if the symmetric model is used. If one or more blocks cannot be parked, the Branch-and-Cut algorithm can be used to examine whether these blocks are the only ones that cannot be parked. This is a very important aspect, since the block that cannot be parked may not be the block causing the troubles in the shunting process. Hence it is interesting to examine and identify all the blocks that cannot be parked.

If one or more blocks cannot be parked different approaches can be applied. If the final depot plan contains night events or intermediate shunting events the first step is to run the program again but change the times of one of more of the events. Even though the strategy behind the new events is suggesting the times with the best chances of finding a feasible depot plan, there may be other times of the events that are better in certain instances. In the case where the final infeasible depot plan does not contain any night events, it is possible to run the program again and manually set the solution procedure to use platforms as shunt tracks at night in order to increase the capacity of the depot. Both approaches may lead to a feasible depot plan.

If none of the two approaches can be applied or do not work, other steps have to be taken. This involves analyzing and adjusting the previous steps in the planning process underlying the railway system. Thereby the number of detachments at the station may be reduced or the number of platform connections, i.e. leg connections which do not involve the shunt yard may increase. Both initiatives will lead to a reduction in the number of blocks to be shunted. Another strategy is to examine whether arrival or departure times of the problematic blocks can be changed. The idea is to run the prototype again with the new input and analyze the result. Hence creating feasible depot plans can be an iterative process.

7.6 Capabilities and limitations

In this section I will sum up the capabilities and limitations of the prototype. The current implementation of the prototype has several features that give the user the opportunity to guide the optimization in the direction he/she wants. A text-based interface shows throughout the procedure an event calendar, which informs the user of the current status of the depot planning. This event calendar forms also the basis for the decisions to be made by the user. The characteristics of the prototype are the following:

- The station topology defines the number of platforms, the number of shunt tracks and the restrictions at the station i.e. infeasible shunt tracks from certain platforms etc.
- All shunt tracks are assumed to be of the LIFO type.
- Initially in the planning period the shunt yard can either be empty or contain one or more blocks.

- A Feasibility Check, which analyzes the input data, exists. It determines the minimum number of drivers, the need of using platforms as shunt tracks at night and the need of intermediate shunting moves between shunt tracks in order to create more effective track meters.
- A symmetric model can be used in the solution procedure. This reduces the running time and makes the prototype able to handle larger instances.
- Several parameters can be adjusted before the optimization is run. These parameters set different kind of penalties for certain track assignments.
- The optimization is done in CPLEX by using ILOG Concert Technology.
- The result of the optimization is converted to an event calendar, which shows the final depot plan.
- A Branch-and-Cut algorithm can be applied to examine other solutions with the same objective value. It can be used both when the depot plan is feasible and when one or more blocks cannot be parked.

The prototype can as previously mentioned be applied to 6 of the 9 depots at S-tog, see chapter 8. In the current implementation the prototype has a few limitations. Some of these can easily be implemented, while others demand more work. Some of the limitations are:

- Free tracks are not included in the prototype. The mathematical approach to handle the free tracks is presented in section 6.1. Using this approach makes the extension to the prototype uncomplicated to implement. Notice that the introducing of free tracks will make the number of track assignments increase dramatically. This will increase the need of a column generation framework to decrease the size of the solution model.
- Intermediate shunting moves can only be applied under certain circumstances e.g. when there only exists one group of shunt tracks with insufficient capacity. Hence if the station topology and the event calendar are complex, it may not be possible to add the intermediate shunting moves type 2.
- If one or more blocks cannot be parked there is no automatic feedback from the depot planning. The Branch-and-Cut algorithm is applied manually to identify the problems in the shunting process. The automatic feedback is complex to make, since the solution has to be analyzed thoroughly in order to conclude what changes to make e.g. change the time of one or more events or reduce the number of blocks to be shunted.

7.7 Visualization with Arena

Simulation is normally used as a tool to analyze and evaluate a real system. In the literature it is known to be an analytical technique in which a mathematical or logical model of a real system is run in compressed time to perform experiments and evaluate system performance, Kelton et al. [KSS04]. Simulation is also an excellent tool when the examined system does not exist or is difficult to observe.

In this project mathematical models form the basic of the prototype, so it has been chosen not to use simulation as an analytical or mathematical tool. Instead simulation is used to visualize the different depot plans. This makes is possible to go through the event calendar step by step and see how the situation at the station changes.

The simulation program Arena is used to develop the model for the visualization. It is the same model used for all the 6 depots in the S-tog network, but each model has a unique station topology. The input to the model is based on the final depot plan. In this plan a shunt track is assigned to each block. If intermediate shunting moves exist more shunt tracks are assigned to the original block. In the case where a block is being parked at the platform, the platform is assigned to the block. Figure 7.11 presents a flowchart of the model. The shunt tracks or the platform assigned to a block are referred to as parking tracks. The blocks are entities, which traverse the model during the simulation. This entity is pictured by the 4 connected train units in the figure. Each block holds information based on the final depot plan about size, arrival time, departure time and the duration and parking track of each parking. The parking tracks corresponding to the shunt tracks and platforms are the locations the blocks are routed to and from. The green boxes in the figure imply the blocks are routed from one location to another or are arriving to/departing from the station. The red box indicates the parking at the track.

By using the model in Figure 7.11 it is possible to visualize the different depot plans. The duration of the simulation corresponds to the planning period. Figure 7.12 shows a picture of the visualization of the depot in Hillerød for a working day period. The depot plan in this example is the plan in Figure 7.10. The time is 00:55 and a block is just about to be parked at shunt track 1A coming from platform 1. Figure 7.13 shows an example from Frederikssund.

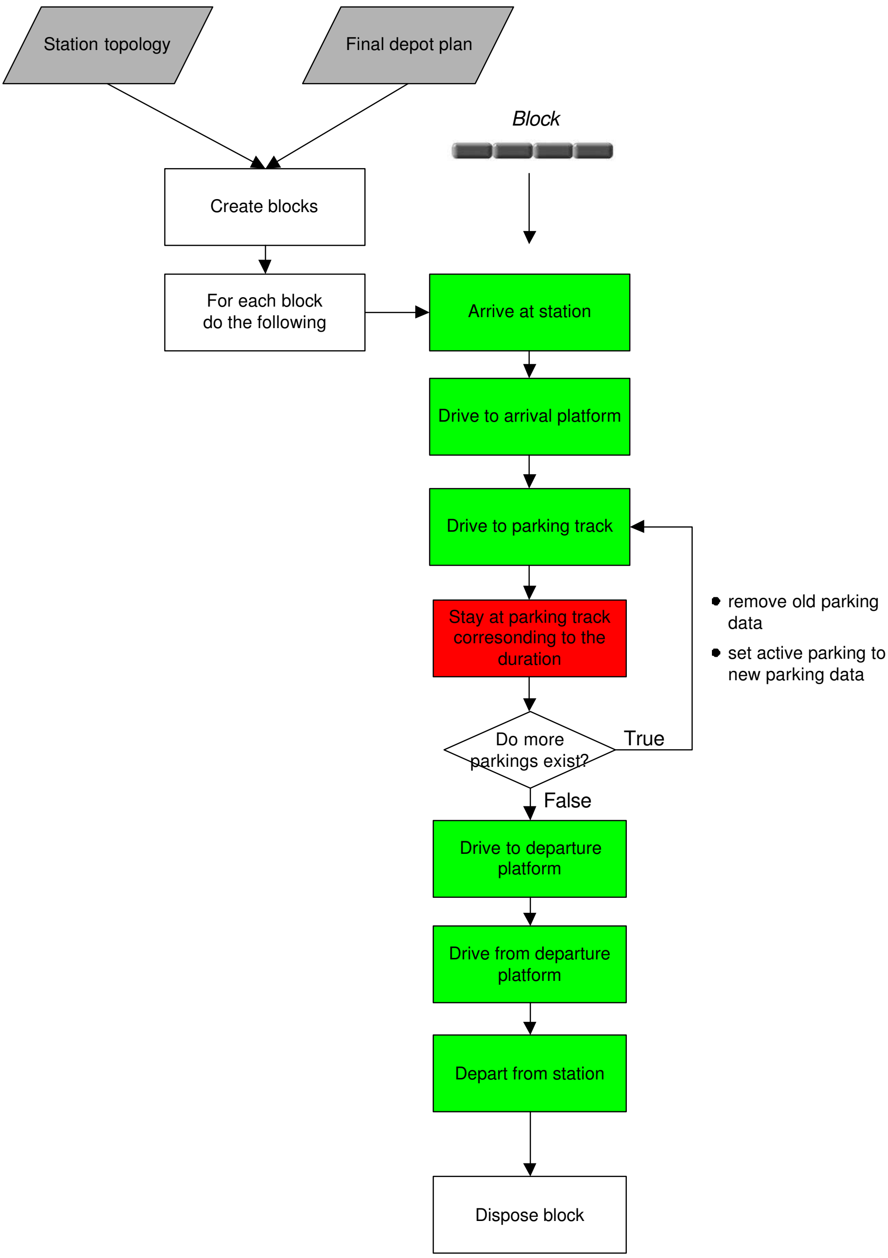

Figure 7.11: A flowchart of the model in Arena.

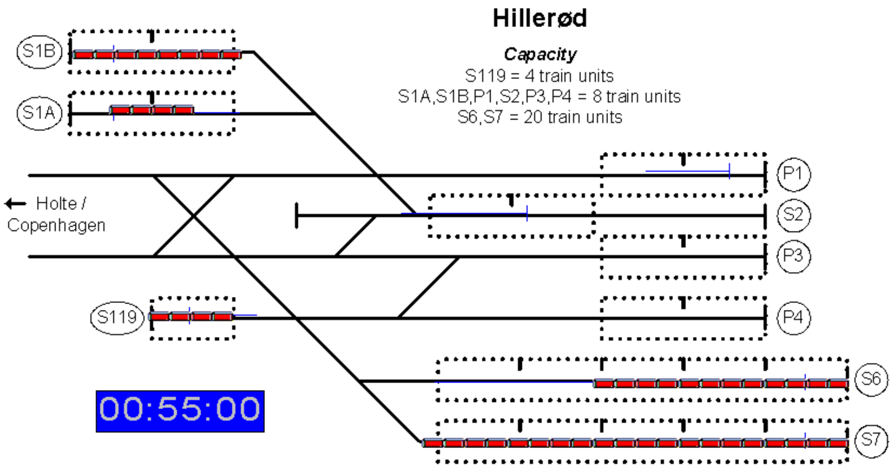

Figure 7.12: A picture from the visualization of the depot in Hillerød.

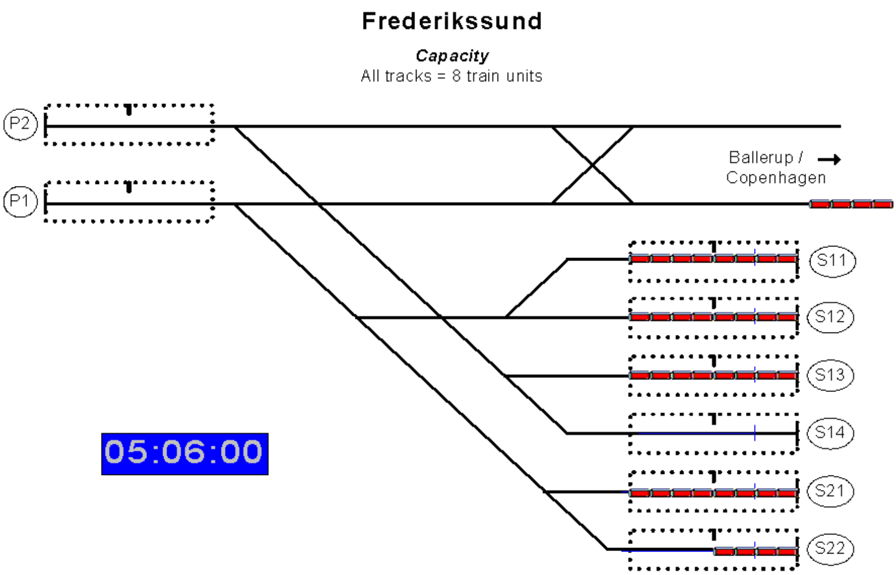

Figure 7.13: A picture from the visualization of the depot in Frederikssund.

Chapter 8

Experiments

In this chapter I will test the prototype and analyze the results. The input to the prototype i.e. the station topology and the blocks to be shunted have been found in the previous steps of the planning process. The matching of arriving and departing train units has also been defined. Because the prototype is only handling depots with LIFO tracks, the matching is crucial to the feasibility of the final depot plan. The following section examines the properties of this. In section 8.2 the prototype is applied to the depots at S-tog. Section 8.3 examines an alternative depot. An overview of the experiments and some conclusions are found in section 8.4 and section 8.5 respectively. In section 8.6 I compare the prototype with results from the literature. All computations were carried out on a Sun Fire V440 with four 1062 MHz UltraSPARC IIIi processors and 8 GB of memory[1].

8.1 Crossings

If the train units depart from the depot in such a way, that the last to arrive is the first to leave it is easy to make a feasible depot plan, since there do not

[1]Only an unknown percentage of the computer power has been available during the computations.

exist any crossings in the event calendar. Unfortunately this is most often not the case. To examine how the number of crossings influences the possibility of generating a feasible depot plan, I have created a small test case with 6 blocks to be shunted. All of the blocks have the length corresponding to 4 train units. In the first example all blocks are set to arrive before the first departure occur. Figure 8.1 shows an example of a planning period. It is based on the same principles as Figure 6.2 from section 6.3 about the Branch-and-Cut solution procedure. The order of the blocks can be seen in the event calendar, Table 8.1.

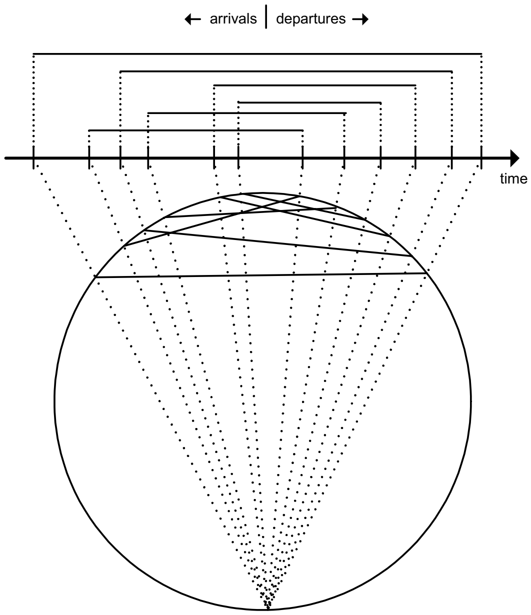

Figure 8.1: Arrivals and departures of 6 blocks - here the number of crossings is 6.

Event calendar	
Block ID	Event
1	A
2	A
3	A
4	A
5	A
6	A
2	D
4	D
6	D
5	D
3	D
1	D

Table 8.1: The event calendar corresponding to Figure 8.1

The number of crossings in an event calendar is determined by number of intersections between the chords in Figure 8.1. Since the first departure is after the last arrival, all intervals share at least a point. In the example in Figure 8.1 the number of crossings is 6.

Besides the number of crossings it is the station topology, which determines the difficulty of the problem. If the depot for instance consists of 6 shunt tracks it will always be possible to generate a feasible depot plan of 6 blocks independent of the number of crossings. On the other hand if the depot only consists of 1 shunt track it will only be possible to make a feasible depot plan if the number of crossings is 0 i.e. the event calendar does not contain any crossings at all

- here the use of platforms as shunt tracks is not considered. Based on the test case with 6 blocks it is possible to generate 720 different event calendars. In all the event calendars the first departure occur after the last arrival. The numbers of crossings in these 720 different event calendars are between 0 and 15 (15 crossings arises when the train units leave the shunt yard according to the first-in-first-out principle). Table 8.2 shows the number of event calendars based on the number of crossings.

Crossings:	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Calendars:	1	5	14	29	49	71	90	101	101	90	71	49	29	14	5	1

Table 8.2: The number of different event calendars with 6 blocks.

It is possible to examine the possibility of generating a feasible depot plan in each of the 720 instances. Notice that the use of platforms as shunt tracks and intermediate shunting moves are not considered in the test. Different topologies are used to analyze the complexity of the shunting problem. Figure 8.2 represents the percentage of feasible depot plans as a function of the number of crossings. The topology is in this case 3 shunt tracks with the capacity of 8 train units each. All the blocks can use all the shunt tracks. Hence the overall capacity is 24 train units, which will be fully utilized because the test case contains 6 blocks of 4 train units each. Figure 8.2 shows e.g. that a feasible depot plan can be found in all of the 29 instances with 4 crossings. On the other hand in only 20% of the 71 instances with 10 crossings a feasible depot plan can be found.

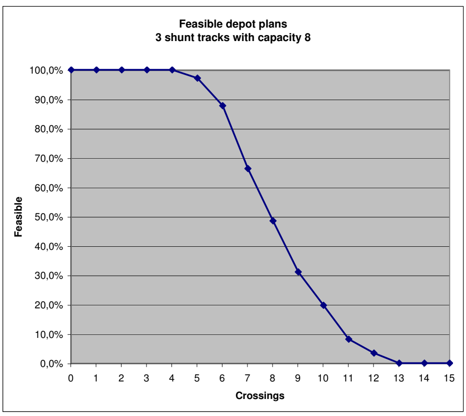

Figure 8.2: Feasible depot plans. 3 shunt tracks with the capacity of 8 train units.

Figure 8.2 indicates that the problems of generating feasible depot plans begin, when the event calendar contains 5 crossings. For each extra crossing there is a decrease in the percentage of feasible depot plans. When the number of crossings is 13 or above there do not exist any feasible depot plans. The topology in Figure 8.2 with 3 shunt tracks is rather flexible. Whether a topology is flexible or inflexible is determined by the number of shunt tracks and the length of the shunt tracks. The flexible topologies are characterized by many and short shunt tracks, while the inflexible topologies typically consist of a few and long shunt tracks. This notation is used throughout the chapter. To examine the behaviour with more inflexible topologies two experiments are made. The first topology consists of 2 shunt tracks with the capacity of 12 train units each, whereas the second topology consists of 2 shunt tracks with capacity 8 and 16 respectively. The results are shown in Figure 8.3 and Figure 8.4.

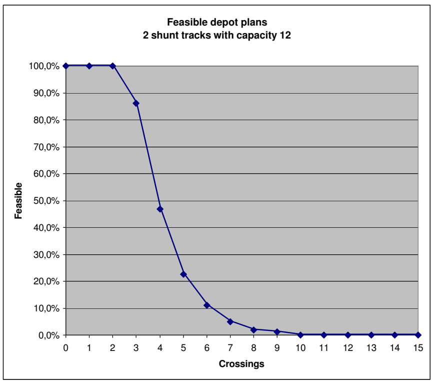

Figure 8.3: Feasible depot plans. 2 shunt tracks with the capacity of 12 train units.

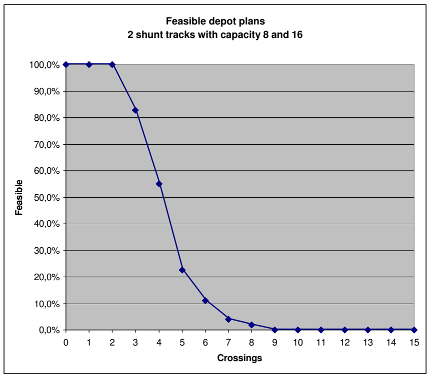

Figure 8.4: Feasible depot plans. 2 shunt tracks with the capacity of 8 train units and 16 train units respectively.

Figure 8.3 and Figure 8.4 indicate as expected that, even though the overall capacity of the shunt yards are the same as in Figure 8.2, it is much harder to find feasible depot plans, when the number of shunt tracks is smaller. The two figures are almost identical, but there are some small differences. When the number of crossings is 3 the percentage of feasible depot plans is highest in Figure 8.3, while the percentage is highest in Figure 8.4 when the number of crossings is 4. The decrease in the percentage of feasible depot plans is in both figures more steep than Figure 8.2. This indicates that small changes in the event calendar, i.e. connections between arriving and departing train units are changes, will have a larger impact on the difficulty of the problem, when the topology is inflexible.

Figure 8.5 represents a topology that is very flexible i.e. 4 shunt tracks, where 2 of the tracks have a capacity of 8 train units and the last 2 tracks have a capacity of 4 train units. Here it is only when the instances contain 10 or more crossings, that a feasible depot plan may be hard to find. Again the decrease in the percentage of feasible depot plans is more steep than Figure 8.2. Hence small changes in the event calendar have also large impact on the difficulty of the problem when the topology is very flexible.

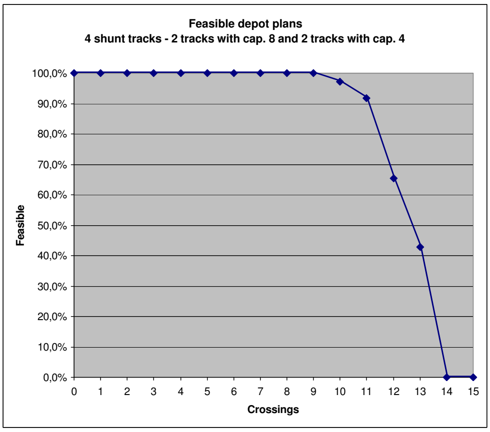

Figure 8.5: Feasible depot plans. 4 shunt tracks, where 2 tracks have a capacity of 8 train units and the other 2 tracks have a capacity of 4 train units.

Now I turn to the situation when arrivals and departures are mixed in time, Figure 8.6 and Table 8.3 show an example. The number of event calendars based on the number of crossings is shown in Table 8.4. Notice that the maximum number of crossings is 10 with this order of arrivals and departures.

Crossings:	0	1	2	3	4	5	6	7	8	9	10
Calendars:	1	5	14	27	39	44	39	27	14	5	1

Table 8.4: The number of different event calendars with 6 blocks - mixed arrivals and departures.

Figure 8.7 shows the results with 3 shunt tracks with the capacity of 8 train units each and mixed arrivals and departures. For most of the instances it is possible to generate a feasible depot. This is also expected, since the capacity of the shunt yard is not fully utilized, when the first departure occur. Actually the order of arrivals and departures makes it possible to generate feasible depot plans with only 2 shunt tracks with the capacity of 8 train units each. The

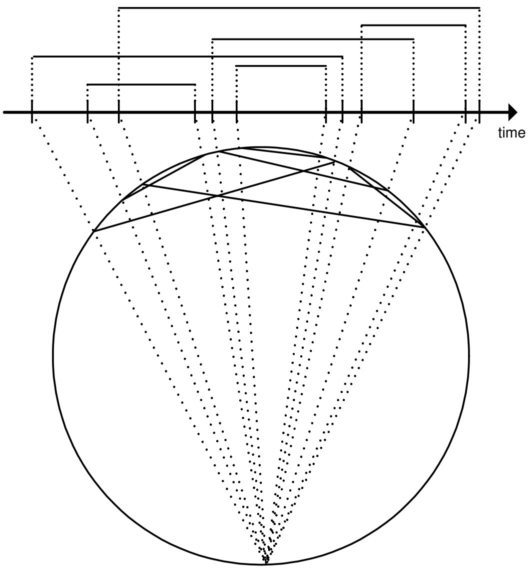

Figure 8.6: Arrivals and departures are mixed in time - here the number of crossings is 4.

Event calendar	
Block ID	Event
1	A
2	A
3	A
2	D
4	A
5	A
5	D
1	D
6	A
4	D
6	D
3	D

Table 8.3: The event calendar corresponding to Figure 8.6

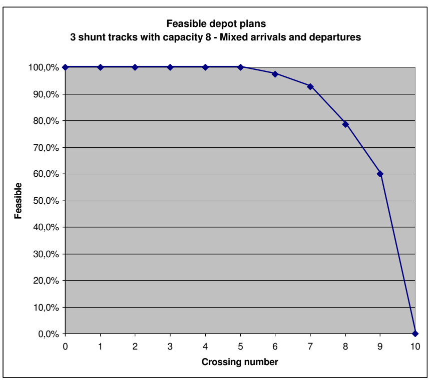

Figure 8.7: Feasible depot plans. 3 shunt tracks with the capacity of 8 train units. The arrivals and departures are mixed in time.

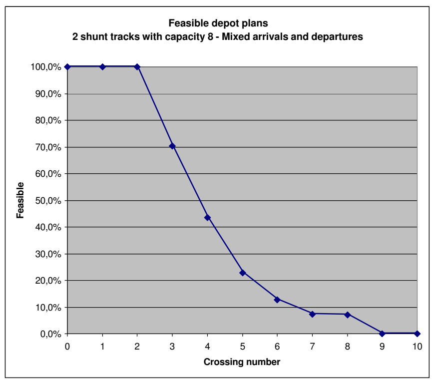

Figure 8.8: Feasible depot plans. 2 shunt tracks with the capacity of 8 train units. The arrivals and departures are mixed in time.

result is shown in Figure 8.8. This figure is similar to Figure 8.3 and Figure 8.4, because only having 2 shunt tracks at disposal makes the topology inflexible.

The above results shows that the topology of the station has the biggest influence on the difficulty of the depot planning. In addition having a surplus of track capacity at a station will ease the depot planning, especially if the station consists of many small tracks. Furthermore the figures above indicate as expected that the number of crossings also has an influence on the difficulty. The use of platforms as shunt tracks has not been considered in the examples. Utilizing this extra capacity at the platforms can in most cases, if there is only one non-parked block, make an infeasible depot plan feasible.

The number of crossings in the event calendar and the topology of the station are used to analyze the results in the following sections.

8.2 Application to DSB S-tog

The prototype presented in this project has been applied to the 6 depots at S-tog. These 6 depots are Ballerup, Farum, Frederikssund, Hillerød, Klampenborg and Køge. Each of the depots has a unique topology. Generally there are 2 planning periods for each depot. The first period is a working day period from around 8 o'clock in the morning to 8 o'clock the next morning. The second period is from around 8 o'clock Friday morning to 8 o'clock Monday morning. Hence the depot planning is done in one step over the entire weekend. At some depots it is possible to split the weekend into two or more planning periods.

I will examine and analyze each of the 6 depots. As a basis for the tests I use the depot plans 2005-1, which S-tog has used. All of these plans are known to be feasible. Hence a part of the test is to study, whether the prototype is able to obtain the same results. This can be used to validate the prototype. Furthermore the robustness of the generated plans as described in section 7.5 is discussed. Finally it is examined how much it will influence the shunting process, if some of the connections between the blocks are changed i.e. the number of crossings is changed.

8.2.1 Ballerup (BA)

The depot Ballerup lies between Frederikssund and Copenhagen Central Station, see Figure 3.1. The lines H and H+ go through the station, while line C has Ballerup as terminus. The topology of the station is presented in Figure 8.9. The shunt yard consists of 4 shunt tracks, where 2 tracks have a capacity of 16 train units and the other 2 tracks have a capacity of 8 train units. Hence the overall capacity at the depot is 48 train units. All 4 shunt tracks are feasible from both platforms.

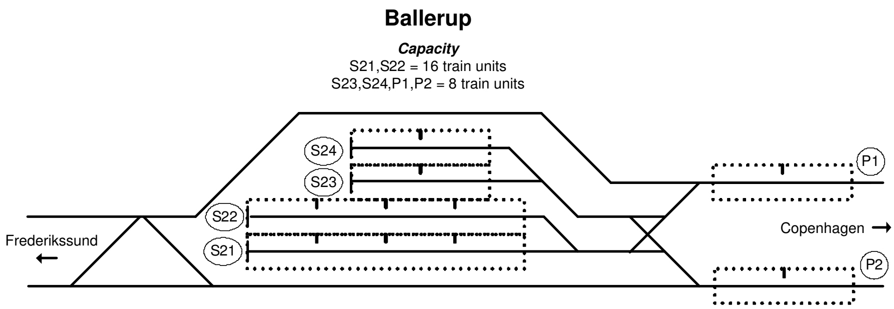

Figure 8.9: The station topology of Ballerup.

In the depot plans 2005-1 the shunting activities at Ballerup are very simple. On a working day there are only 2 blocks to be shunted, which makes depot planning trivial (see appendix A.1). In the 2005-1 plan the crossing number is 1 i.e. the 2 blocks cross each other. This makes it necessary to use two shunt tracks e.g. shunt track 21 and 22. During the weekend the shunting activities are also very simple. According to appendix A.2, 2 blocks have to be shunted each day during the weekend. Since the shunt yard is empty Saturday and Sunday morning the depot planning can be split up into three planning periods, which are solved independently. In this particular case it is not necessary, because of the small number of blocks to be shunted. I have chosen not to examine the depot further.

8.2.2 Farum (FM)

Farum is the terminus of line H and line H+. The topology of the station is presented in Figure 8.10. The shunt yard consists of 3 shunt tracks with a capacity of 8 train units each making the total capacity of the depot 24 train units. All 3 shunt tracks are feasible from both platforms. Figure 8.11 shows a picture from the depot in Farum. It is taken just after departure from platform 1. The picture in Figure 8.12 is taken behind the shunt tracks.

In the depot plans 2005-1 the number of blocks to be shunted during a working day is 11, while it is 24 blocks during the weekend. First the prototype is tested with the blocks and the connections from the 2005-1 plans. The event calendar for a working day period can be seen in Figure 8.13.

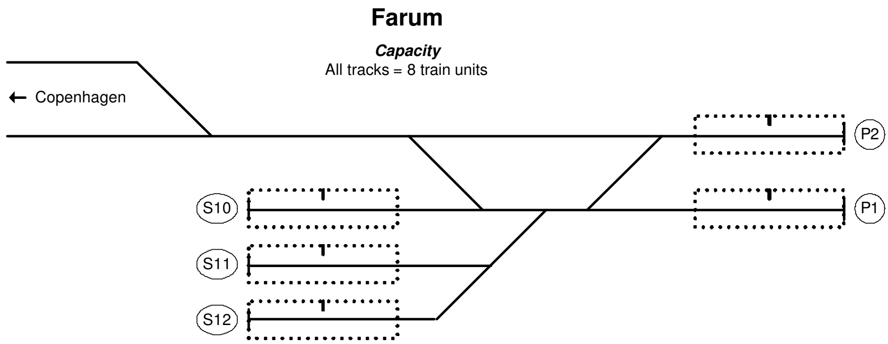

Figure 8.10: The station topology of Farum.

Figure 8.11: The depot in Farum, February 2004 [Chr06].

Figure 8.12: The backside of the shunt yard in Farum, February 2004 [Chr06].

The number of crossings in the event calendar is 14. The maximum number with this order of arrivals and departures is found to be 27. The first check of the Feasibility Check shows that only one driver is needed based on the arrivals in the event calendar. The second check indicates that there is not enough capacity at the shunt yard, since the stock during the planning period reaches 28 train units and the overall capacity of the shunt yard is only 24 train units. To solve this conflict it is allowed to use platforms as shunt tracks at night. By examining the event calendar, Figure 8.13, block 10 is found to be a good candidate for platform parking, since it is the first to depart in the morning and the last to arrive in the evening. Hence block 10 is allowed to park at platform 2 from its arrival to its departure, see Figure 8.14.

```
---Starting depot planning for FM---

Block |  New  | Type | Size | Day & Time |  From/to   |   Track   |          Activity            |     From/to      | Stock
[
0     |   -   | LHB  | 4    | Mo - 08:32 | 50123-2    | P2        | Arrive at platform - Det.    |    50249-2       | 4,
1     |   -   | LHB  | 4    | Mo - 08:52 | 50124-2    | P2        | Arrive at platform - Det.    |    50230-1       | 8,
2     |   -   | LHB  | 4    | Mo - 09:12 | 50125-2    | P2        | Arrive at platform           |    50248-2       | 12,
3     |   -   | LHB  | 4    | Mo - 09:12 | 50125-1    | P2        | Arrive at platform           |    50246-2       | 16,
1     |   -   | LHB  | 4    | Mo - 09:28 |    50230-1 | P2        | Depart from platform         | 50124-2          | 12,
3     |   -   | LHB  | 4    | Mo - 14:48 |    50246-2 | P2        | Depart from platform - Att.  | 50125-1          | 8,
2     |   -   | LHB  | 4    | Mo - 15:28 |    50248-2 | P2        | Depart from platform - Att.  | 50125-2          | 4,
0     |   -   | LHB  | 4    | Mo - 15:48 |    50249-2 | P2        | Depart from platform - Att.  | 50123-2          | 0,
4     |   -   | LHB  | 4    | Mo - 16:42 | 55148-2    | P1        | Arrive at platform - Det.    |    50218-2       | 4,
5     |   -   | LHB  | 4    | Mo - 17:02 | 55149-2    | P1        | Arrive at platform - Det.    |    50217-2       | 8,
6     |   -   | LHB  | 4    | Mo - 19:22 | 55156-1    | P1        | Arrive at platform           |    56019-1       | 12,
7     |   -   | LHB  | 4    | Mo - 19:42 | 55157-1    | P1        | Arrive at platform           |    50219-2       | 16,
8     |   -   | LHB  | 4    | Tu - 00:32 | 50171-2    | P2        | Arrive at platform           |    55221-1       | 20,
9     |   -   | LHB  | 4    | Tu - 00:52 | 50100-2    | P2        | Arrive at platform           |    55220-1       | 24,
10    |   -   | LHB  | 4    | Tu - 01:12 | 50101-2    | P2        | Arrive at platform           |    50216-1       | 28,
10    |   -   | LHB  | 4    | Tu - 04:48 |    50216-1 | P2        | Depart from platform         | 50101-2          | 24,
5     |   -   | LHB  | 4    | Tu - 05:08 |    50217-2 | P2        | Depart from platform         | 55149-2          | 20,
4     |   -   | LHB  | 4    | Tu - 05:28 |    50218-2 | P2        | Depart from platform         | 55148-2          | 16,
7     |   -   | LHB  | 4    | Tu - 05:48 |    50219-2 | P2        | Depart from platform         | 55157-1          | 12,
6     |   -   | LHB  | 4    | Tu - 05:58 |    56019-1 | P1        | Depart from platform         | 55156-1          | 8,
9     |   -   | LHB  | 4    | Tu - 06:18 |    55220-1 | P1        | Depart from platform         | 50100-2          | 4,
8     |   -   | LHB  | 4    | Tu - 06:38 |    55221-1 | P1        | Depart from platform         | 50171-2          | 0]

- The number of crossings in the timetable is 14 (the maximum number is 27).
```

Figure 8.13: The event calendar for a working day period in Farum.

```
2. Checking the capacity needed at the shunt yard.

- The maximum number of units at the shunt yard during the planning period is 28.
- There is not enough capacity at the shunt yard (the capacity is only 24 units)!
- Allow the use of platforms as depot tracks at night (yes/no)?
y
- Write the block you allow to park at the platforms at night (e.g 3)?
10
- Is it possible to park the block at the platform from arrival to departure (yes/no)?
y
```

Figure 8.14: The result of the second check for a working day period in Farum.

According to the Feasibility Check no new events are added in the third and the fourth check. Next step of the solution procedure is to set the different parameters for the optimization. The first parameter is to use symmetry in the optimization. This is chosen, since there are not any shunt tracks with penalties. The next parameters decide whether to set penalties for parking blocks with different subtypes on the same shunt track, penalties for broken arrivals and departures and whether to decrease the penalties for not parking blocks that are detached at the platform. All of the parameters are set. The prototype solves the parking problem and a feasible depot plan is found according to Figure 8.15.

The running time of the parking problem is 0.771 sec., where 64% of the time has been used to generate the model. By applying the Branch-and-Cut algorithm it is possible to identify the number of non-symmetric feasible depot plans with the same objective value. In this case the number is found to be 12. According to Figure 8.15 the shunt yard is empty in the middle of the planning period, so the shunting process can be considered as two independent procedures. Generally

```
All 11 blocks have been assigned to a track!

Block |  New  | Type | Size | Day & Time |  From/to    |  Track   |          Activity          |    From/to      | Stock
[
0     |   -   | LHB  | 4    | Mo - 08:32 | 50123-2     | P2  /S10 | Arrive at platform - Det.  |    50249-2      | 4,
1     |   -   | LHB  | 4    | Mo - 08:52 | 50124-2     | P2  /S10 | Arrive at platform - Det.  |    50230-1      | 8,
2     |   -   | LHB  | 4    | Mo - 09:12 | 50125-2     | P2  /S11 | Arrive at platform         |    50248-2      | 12,
3     |   -   | LHB  | 4    | Mo - 09:12 | 50125-1     | P2  /S11 | Arrive at platform         |    50246-2      | 16,
1     |   -   | LHB  | 4    | Mo - 09:28 |     50230-1 | S10 /P2  | Depart from platform       | 50124-2         | 12,
3     |   -   | LHB  | 4    | Mo - 14:48 |     50246-2 | S11 /P2  | Depart from platform - Att. | 50125-1        | 8,
2     |   -   | LHB  | 4    | Mo - 15:28 |     50248-2 | S11 /P2  | Depart from platform - Att. | 50125-2        | 4,
0     |   -   | LHB  | 4    | Mo - 15:48 |     50249-2 | S10 /P2  | Depart from platform - Att. | 50123-2        | 0,
4     |   -   | LHB  | 4    | Mo - 16:42 | 55148-2     | P1  /S12 | Arrive at platform - Det.  |    50218-2      | 4,
5     |   -   | LHB  | 4    | Mo - 17:02 | 55149-2     | P1  /S12 | Arrive at platform - Det.  |    50217-2      | 8,
6     |   -   | LHB  | 4    | Mo - 19:22 | 55156-1     | P1  /S11 | Arrive at platform         |    56019-1      | 12,
7     |   -   | LHB  | 4    | Mo - 19:42 | 55157-1     | P1  /S11 | Arrive at platform         |    50219-2      | 16,
8     |   -   | LHB  | 4    | Tu - 00:32 | 50171-2     | P2  /S10 | Arrive at platform         |    55221-1      | 20,
9     |   -   | LHB  | 4    | Tu - 00:52 | 50100-2     | P2  /S10 | Arrive at platform         |    55220-1      | 24,
10    |   -   | LHB  | 4    | Tu - 01:12 | 50101-2     | P2       | Arrive at platform (stay)  |    50216-1      | 28,
10    |   -   | LHB  | 4    | Tu - 04:48 |     50216-1 | P2       | Depart from platform       | 50101-2         | 24,
5     |   -   | LHB  | 4    | Tu - 05:08 |     50217-2 | S12 /P2  | Depart from platform       | 55149-2         | 20,
4     |   -   | LHB  | 4    | Tu - 05:28 |     50218-2 | S12 /P2  | Depart from platform       | 55148-2         | 16,
7     |   -   | LHB  | 4    | Tu - 05:48 |     50219-2 | S11 /P2  | Depart from platform       | 55157-1         | 12,
6     |   -   | LHB  | 4    | Tu - 05:58 |     56019-1 | S11 /P1  | Depart from platform       | 55156-1         | 8,
9     |   -   | LHB  | 4    | Tu - 06:18 |     55220-1 | S10 /P1  | Depart from platform       | 50100-2         | 4,
8     |   -   | LHB  | 4    | Tu - 06:38 |     55221-1 | S10 /P1  | Depart from platform       | 50171-2         | 0]

Generate solutions time 54 msec.
Generate model time 495 msec.
Write model time 25 msec.
Solve model time 197 msec.
Overall solution time 771 msec.
```

Figure 8.15: The final depot plan for a working day period in Farum.

this will make the number of non-symmetric feasible depot plans increase. So having 12 depot plans with the same objective value is decent, but it does not indicate a very robust solution.

A planning period over the weekend in Farum consists of 24 blocks in the 2005-1 depot plan. The solution procedure is presented in appendix A.3. The number of crossings in the event calendar is 22 out of a maximum of 78. To ensure enough capacity at the depot three platform parkings are introduced. One block is parked at the platform from Friday to Saturday, another block from Saturday to Sunday and finally another block from Sunday to Monday. The platform parkings make it possible for the program to generate a feasible depot plan, where all 24 blocks are assigned to a track. The running time of the parking problem is 22.8 sec., where generating the model takes around 39% of the time and solving the model takes about 37% of the time. Applying the Branch-and-Cut algorithm indicates more than 50 different non-symmetric feasible depot plans with the same objective value (the prototype stops when it reaches 50). The planning period over the weekend can be split into two independent planning periods. As mentioned above this may be part of the reason for the large number of different feasible depot plans. Still it seems the solution is robust i.e. many other feasible depot plans exist, which makes it possible to absorb delays, human mistakes etc. in the shunting process.

The number of crossings in the working day planning period was 14 out of a maximum of 27. Examining the event calendar for the working day period shows as mentioned above that the period can be split into two independent planning periods. Looking at the period from 16 o'clock in the afternoon to 8 o'clock the next morning and discard block 10, which has to be parked at the platform, leave us with 6 blocks to be shunted. The order of these 6 blocks, see the left column in Figure 8.13, gives 12 crossings. In section 8.1 the number of crossings with 6 blocks was examined. Figure 8.2 showed that with 3 shunt tracks with a capacity of 8 train units each only 3% (corresponding to one instance) of the event calendars with 12 crossings were able to generate a feasible depot plan. Thus this one instance corresponds to the event calendar in Figure 8.13. Hence if the event calendar contained more crossings in the period from 16 o'clock in the afternoon to 8 o'clock the next morning, it would not be possible to generate a feasible depot plan.

Looking at the period from 8 o'clock in the morning to 16 o'clock in the afternoon, only 4 blocks have to be shunted, see Figure 8.13. It is possible to increase the overall number of crossings by changing the connections among these 4 blocks. If the blocks instead of the order 1-3-2-0 are set to depart in the order 0-1-3-2 the total number of crossings increases to 17. The result in appendix A.4 shows that it is still possible to generate a feasible depot plan. The number of non-symmetric feasible depot plans with the same objective value is only 6 indicating that the solution is not very robust. The results at Farum imply that the connections in the depot plans 2005-1 are almost as tight as possible.

8.2.3 Frederikssund (FS)

Frederikssund in the other terminus of line H and line H+. The topology of the station is presented in Figure 7.1 in chapter 7. The shunt yard consists of 6 shunt tracks with a capacity of 8 train units each making the total capacity of the depot 48 train units. All 6 shunt tracks are feasible from platform 1, while only the shunt tracks 11, 12, 13 and 14 are feasible from platform 2.

In the depot plans 2005-1 the number of blocks to be shunted during a working day is 15, while it is 29 during the weekend. The solution procedures for the two planning periods are found in appendix A.5 and appendix A.6 respectively. In both cases there are enough capacity at the shunt yard and no new events are added in the other checks of the Feasibility Check. A feasible depot plan is found in both periods. The event calendar for the working day period contains 39 crossings out of a maximum of 71. The running time of the prototype for the period is 0.981 sec., where 55% of the time is used to generate the model and 28% of the time is used solve the model. The weekend period contains 100 crossings out of a maximum of 186. The running time is in this case 9.05 sec. Here 23% of the time is used to generate the model, while 60% of the time is used solve the model. This indicates that the larger the problem is the more time is used on solving the model. When applying the Branch-and-Cut algorithm both instances lead to more than 50 different non-symmetric feasible depot plans with the same objective value. Examining the event calendars closer shows that both at the working day period and the weekend period the capacity at the shunt yard is not fully utilized. At the same time the topology of Frederikssund is flexible, because it has many short shunt tracks instead of few long ones. Both conditions improves the chances of generating a feasible depot plan even though the number of crossings is high.

```
---Starting depot planning for FS---

Block |  New  | Type | Size | Day & Time | From/to    |   Track    |          Activity           |     From/to     | Stock
[
0     |   -   | LHB  | 4    | Mo - 08:43 | 55223-1    | P2         | Arrive at platform - Det.   |     55149-1     | 4,
1     |   -   | LHB  | 4    | Mo - 09:53 | 50227-1    | P1         | Arrive at platform - Det.   |     55148-1     | 8,
1     |   -   | LHB  | 4    | Mo - 15:16 |    55148-1 | P2         | Depart from platform - Att. | 50227-1         | 4,
0     |   -   | LHB  | 4    | Mo - 15:36 |    55149-1 | P2         | Depart from platform - Att. | 55223-1         | 0,
2     |   -   | LHB  | 4    | Mo - 16:13 | 50246-1    | P1         | Arrive at platform - Det.   |     50118-1     | 4,
3     |   -   | LHB  | 4    | Mo - 16:53 | 50248-1    | P1         | Arrive at platform - Det.   |     50116-1     | 8,
4     |   -   | LHB  | 4    | Mo - 17:13 | 50249-1    | P1         | Arrive at platform - Det.   |     50120-1     | 12,
5     |   -   | LHB  | 4    | Mo - 18:23 | 55252-1    | P2         | Arrive at platform          |     50117-1     | 16,
6     |   -   | LHB  | 4    | Mo - 18:43 | 55253-1    | P2         | Arrive at platform          |     55120-1     | 20,
7     |   -   | LHB  | 4    | Mo - 19:03 | 55254-1    | P2         | Arrive at platform          |     55124-1     | 24,
8     |   -   | LHB  | 4    | Mo - 19:23 | 55255-1    | P2         | Arrive at platform          |     55123-1     | 28,
9     |   -   | LHB  | 4    | Mo - 19:43 | 55256-1    | P2         | Arrive at platform          |     50124-1     | 32,
10    |   -   | LHB  | 4    | Mo - 20:03 | 55257-1    | P2         | Arrive at platform          |     50123-1     | 36,
11    |   -   | LHB  | 4    | Tu - 00:53 | 50200-1    | P1         | Arrive at platform          |     50119-1     | 40,
12    |   -   | LHB  | 4    | Tu - 01:13 | 50201-1    | P1         | Arrive at platform          |     55121-1     | 44,
3     |   -   | LHB  | 4    | Tu - 04:46 |    50116-1 | P1         | Depart from platform        | 50248-1         | 40,
5     |   -   | LHB  | 4    | Tu - 05:06 |    50117-1 | P1         | Depart from platform        | 55252-1         | 36,
2     |   -   | LHB  | 4    | Tu - 05:26 |    50118-1 | P1         | Depart from platform        | 50246-1         | 32,
11    |   -   | LHB  | 4    | Tu - 05:46 |    50119-1 | P1         | Depart from platform        | 50200-1         | 28,
13    |   -   | LHB  | 4    | Tu - 05:53 | 50215-1    | P1         | Arrive at platform          |     50122-1     | 32,
14    |   -   | LHB  | 4    | Tu - 05:53 | 50215-2    | P1         | Arrive at platform          |     55122-1     | 36,
6     |   -   | LHB  | 4    | Tu - 05:56 |    55120-1 | P2         | Depart from platform        | 55253-1         | 32,
4     |   -   | LHB  | 4    | Tu - 06:06 |    50120-1 | P1         | Depart from platform        | 50249-1         | 28,
12    |   -   | LHB  | 4    | Tu - 06:16 |    55121-1 | P2         | Depart from platform        | 50201-1         | 24,
14    |   -   | LHB  | 4    | Tu - 06:36 |    55122-1 | P2         | Depart from platform        | 50215-2         | 20,
13    |   -   | LHB  | 4    | Tu - 06:46 |    50122-1 | P1         | Depart from platform - Att. | 50215-1         | 16,
8     |   -   | LHB  | 4    | Tu - 06:56 |    55123-1 | P2         | Depart from platform        | 55255-1         | 12,
10    |   -   | LHB  | 4    | Tu - 07:06 |    50123-1 | P1         | Depart from platform - Att. | 55257-1         | 8,
7     |   -   | LHB  | 4    | Tu - 07:16 |    55124-1 | P2         | Depart from platform        | 55254-1         | 4,
9     |   -   | LHB  | 4    | Tu - 07:26 |    50124-1 | P1         | Depart from platform - Att. | 55256-1         | 0]

- The number of crossings in the timetable is 44 (the maximum number is 71).
```

Figure 8.16: An alternative event calendar for a working day period in Frederikssund.

A test is made where the number of crossings in the event calendar for the working day period is increased, see Figure 8.16. The departure leg and time of block 5 are substituted with the departure leg and time of block 12. This increases the number of crossings to 44. Running the prototype with the default set of parameters results in a infeasible depot plan - block 9 cannot be parked. Applying the Branch-and-Cut algorithm shows that 5 other infeasible depot plans exist with the same objective value. In these plans the block, which cannot be parked, is block 6, block 7, block 8, block 10 and block 12 respectively. To overcome this problem the prototype is run again with the possibility of manually set platforms as shunt tracks at night. This is used at block 6, since

```
All 16 blocks have been assigned to a track!

Block |  New   | Type | Size | Day & Time |  From/to   |   Track    |           Activity           |     From/to      | Stock
[
0     |   -    | LHB  | 4    | Mo - 08:43 | 55223-1    | P2  /S11   | Arrive at platform - Det.    |    55149-1       | 4,
1     |   -    | LHB  | 4    | Mo - 09:53 | 50227-1    | P1  /S11   | Arrive at platform - Det.    |    55148-1       | 8,
1     |   -    | LHB  | 4    | Mo - 15:16 |    55148-1 | S11 /P2    | Depart from platform - Att.  | 50227-1          | 4,
0     |   -    | LHB  | 4    | Mo - 15:36 |    55149-1 | S11 /P2    | Depart from platform - Att.  | 55223-1          | 0,
2     |   -    | LHB  | 4    | Mo - 16:13 | 50246-1    | P1  /S21   | Arrive at platform - Det.    |    50118-1       | 4,
3     |   -    | LHB  | 4    | Mo - 16:53 | 50248-1    | P1  /S21   | Arrive at platform - Det.    |    50116-1       | 8,
4     |   -    | LHB  | 4    | Mo - 17:13 | 50249-1    | P1  /S22   | Arrive at platform - Det.    |    50120-1       | 12,
5     |   -    | LHB  | 4    | Mo - 18:23 | 55252-1    | P2  /S12   | Arrive at platform           |    50117-1       | 16,
6     |   -    | LHB  | 4    | Mo - 18:43 | 55253-1    | P2  /S12   | Arrive at platform           |    55120-1       | 20,
7     |   -    | LHB  | 4    | Mo - 19:03 | 55254-1    | P2  /S11   | Arrive at platform           |    55124-1       | 24,
8     |   -    | LHB  | 4    | Mo - 19:23 | 55255-1    | P2  /S11   | Arrive at platform           |    55123-1       | 28,
9     |   -    | LHB  | 4    | Mo - 19:43 | 55256-1    | P2  /S13   | Arrive at platform           |    50124-1       | 32,
10    |   -    | LHB  | 4    | Mo - 20:03 | 55257-1    | P2  /S13   | Arrive at platform           |    50123-1       | 36,
11    | NGT-1  | LHB  | 4    | Tu - 00:30 |            | S12 /P2    | Move to platform             | 55253-1/55120-1  | -,
12    |   -    | LHB  | 4    | Tu - 00:53 | 50200-1    | P1  /S22   | Arrive at platform           |    50119-1       | 36,
13    |   -    | LHB  | 4    | Tu - 01:13 | 50201-1    | P1  /S14   | Arrive at platform           |    55121-1       | 40,
3     |   -    | LHB  | 4    | Tu - 04:46 |    50116-1 | S21 /P1    | Depart from platform         | 50248-1          | 36,
5     |   -    | LHB  | 4    | Tu - 05:06 |    50117-1 | S12 /P1    | Depart from platform         | 55252-1          | 32,
2     |   -    | LHB  | 4    | Tu - 05:26 |    50118-1 | S21 /P1    | Depart from platform         | 50246-1          | 28,
12    |   -    | LHB  | 4    | Tu - 05:46 |    50119-1 | S22 /P1    | Depart from platform         | 50200-1          | 24,
14    |   -    | LHB  | 4    | Tu - 05:53 | 50215-1    | P1  /S12   | Arrive at platform           |    50122-1       | 28,
15    |   -    | LHB  | 4    | Tu - 05:53 | 50215-2    | P1  /S12   | Arrive at platform           |    55122-1       | 32,
6     |   -    | LHB  | 4    | Tu - 05:56 |    55120-1 | P2  /P2    | Depart from platform         | 55253-1          | 32,
4     |   -    | LHB  | 4    | Tu - 06:06 |    50120-1 | S22 /P1    | Depart from platform         | 50249-1          | 28,
13    |   -    | LHB  | 4    | Tu - 06:16 |    55121-1 | S14 /P2    | Depart from platform         | 50201-1          | 24,
15    |   -    | LHB  | 4    | Tu - 06:36 |    55122-1 | S12 /P2    | Depart from platform         | 50215-2          | 20,
14    |   -    | LHB  | 4    | Tu - 06:46 |    50122-1 | S12 /P1    | Depart from platform - Att.  | 50215-1          | 16,
8     |   -    | LHB  | 4    | Tu - 06:56 |    55123-1 | S11 /P2    | Depart from platform         | 55255-1          | 12,
10    |   -    | LHB  | 4    | Tu - 07:06 |    50123-1 | S13 /P1    | Depart from platform - Att.  | 55257-1          | 8,
7     |   -    | LHB  | 4    | Tu - 07:16 |    55124-1 | S11 /P2    | Depart from platform         | 55254-1          | 4,
9     |   -    | LHB  | 4    | Tu - 07:26 |    50124-1 | S13 /P1    | Depart from platform - Att.  | 55256-1          | 0]

Generate solutions time 136 msec.
Generate model time 86 msec.
Write model time 26 msec.
Solve model time 55 msec.
Overall solution time 303 msec.
```

Figure 8.17: The final depot plan for the alternative event calendar in a working day period in Frederikssund.

it is the first to depart in the morning from platform 2. It cannot stay at the platform from its arrival to its departure, because there are other activities at the platform. Instead it is moved to the platform Tuesday 00:30, since it is not considered as good practice to let trains stay at the platform to early in the evening even though the platform is free. Solving the model with the new event results in a feasible depot plan where platform 2 is used as shunt track at night, see Figure 8.17. Using the Branch-and-Cut algorithm gives over 50 different non-symmetric feasible depot plans with the same objective value. The test implies that Frederikssund is a flexible depot.

8.2.4 Hillerød (HI)

Hillerød is the most complex of the 6 depots. It is the terminus of line A and E. Furthermore it is used for line B and B+, because the depot in Holte was closed some years ago. The topology of the station is presented in Figure 8.18, the same figure as Figure 7.2 in chapter 7. The shunt yard consists of 6 shunt tracks and 3 platforms. Shunt track 119 has a capacity of 4 train units, shunt tracks 1A, 1B and 2 have a capacity of 8 train units each, and finally shunt tracks 6 and 7 have a capacity of 20 train units each. This makes the total capacity of the depot 68 train units. The depot is complex because not all shunt tracks are feasible from all platforms. Furthermore cleaning is not possible at shunt track 2, so it can only be used if intermediate shunting movements occur. Shunt track 1A and shunt track 1B are feasible from platform 1, while shunt tracks 119, 6 and 7 are feasible from platform 3 and platform 4.

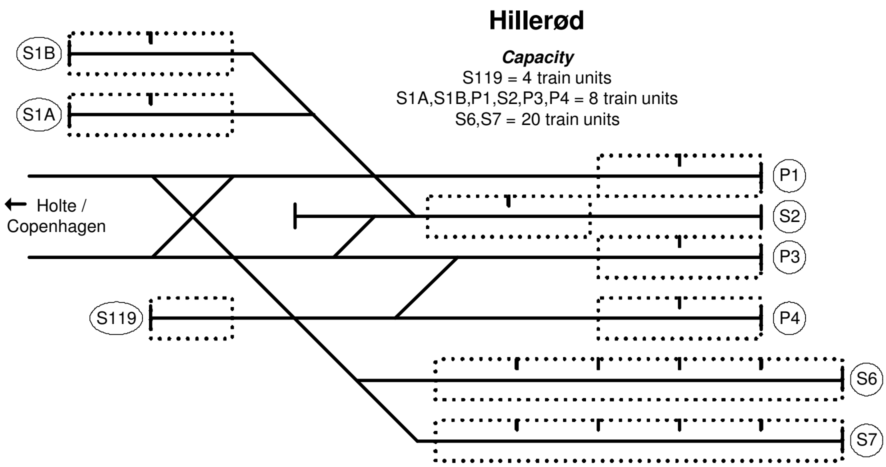

Figure 8.18: The station topology of Hillerød.

Another issue to be aware of in Hillerød is the direction of the shunt tracks. The order of the train units arriving to platform 1 changes if the train units park at shunt track 1A or 1B. This is not the case for the train units arriving to platform 3 and 4, since the terminals of shunt tracks 6 and 7 are in the same direction as the platforms. Shunt track 119 has only capacity for one block of 4 train units, so the direction of the shunt track is not an issue. To handle the problem the order of the blocks arriving together in the event calendar is changed based on the arrival platform. In case of intermediate shunting moves of more blocks at the same time between e.g. shunt track 1A and shunt track 6, the order of the blocks will change.

In the depot plan 2005-1 the number of blocks to be shunted during the working day is 19. The solution procedure is presented in appendix A.7. The number of crossings is 41 out of a maximum of 91. The first check in the Feasibility Check indicates that at least two drives are needed to operate the event calendar. The maximum number of train units during the planning period is 60, so there is enough capacity at the shunt yard. The third check detects a problem, because block 12 and block 13 arrive at platform 3 and depart from platform 1 and the two platforms do not have any feasible shunt tracks in common. To solve this problem, the prototype suggests to accept intermediate shunting moves. It is decided to make each of the intermediate shunting moves just before the departure of each block. In the fourth check the prototype identifies that the group of shunt tracks connected to platform 1 (shunt track 1A and 1B) has insufficient capacity. To help this the prototype suggests three intermediate shunting moves to get the blocks from shunt track 1A or 1B to the other shunt tracks and later three intermediate shunting moves back to either shunt track 1A or 1B, so the blocks can depart from platform 1. The times of the moves suggested by the prototype are accepted. These can manually be changed, if it is not possible to generate a feasible depot plan. The default parameters are chosen in the optimization process. The new events increase the total number of blocks from 19 to 27. A feasible depot plan is found with 8 intermediate shunting moves, see Figure 7.10 in chapter 7. Shunt track 2 is not used in the final depot plan. The running time of the prototype for the period is 3.14 sec., which is spend almost equally on generating track assignment, generating the model and solving the model. The Branch-and-Cut algorithm identifies over 50 different non-symmetric feasible depot plans with the same objective value.

The weekend period in the 2005-1 plan contains 39 blocks to be shunted. The number of crossings is 69 out of a maximum of 311. As in the working day period the prototype suggests intermediate shunting moves in order to make a feasible depot plan. Altogether 12 intermediate shunting moves are added to the event calendar making the total number of blocks increase to 51. The solution procedure is presented in appendix A.8. It has been possible for the prototype to find a feasible depot plan with 12 intermediate shunting moves after 4703 sec. or approximately 78 min. As expected this shows that the problem grows exponentially in the number of blocks to be shunted. The number of different track assignments in the model is around 1700000 even though symmetry is used. 40% of the time has been spent on generating the model, while 56% of the time has been spent on solving the model. Applying the Branch-and-Cut algorithm gives (after running for around 30 hours!) over 50 different non-symmetric feasible depot plans with the same objective value.

To examine how the number of crossings effect the possibility of generating a feasible depot plan in Hillerød I have made an alternative event calendar for the working day period. In this event calendar the departure leg and time of block 5 are substituted with the departure leg and time of block 17 and the departure leg and time of block 7 is substituted with the departure leg and time of block 9. The changes increase the number of crossings to 49. The solution procedure is in appendix A.9. Because of the changes to the event calendar two of the intermediate shunting moves are performed on block 9 instead of block 7. The prototype is still able to find a feasible depot plan in 3.57 sec., which is approximately the same as the regular working day period.

The concept of analyzing the number of crossings is more ambiguous, when the topology of the station is as complex as in Hillerød. An event calendar with a small number of crossings can easily be very hard to solve, if all the traffic is at certain platforms etc. At the same time intermediate shunting moves can make it is possible to generate a feasible depot plan even though the event calendar contains a high number of crossings. It could be interesting to examine whether some of the track restrictions could be removed, so the situation in Hillerød would be less complex.

8.2.5 Klampenborg (KL)

Klampenborg is the terminus of line F+, line C and line Bx. The topology of the station is presented in Figure 8.19. The shunt yard consists of 3 shunt tracks, where 2 tracks have a capacity of 8 train units each and the last track has a capacity of 4 train unit. This makes the total capacity of the depot 20 train units. All 3 shunt tracks are feasible from platform 6 and platform 7. None of the shunt tracks are feasible from platform 5. Notice that shunt track 8 originally was a free track i.e. open in both ends. The last part of the track (marked on Figure 8.19) has been closed down some years ago making shunt track 8 a LIFO-track.

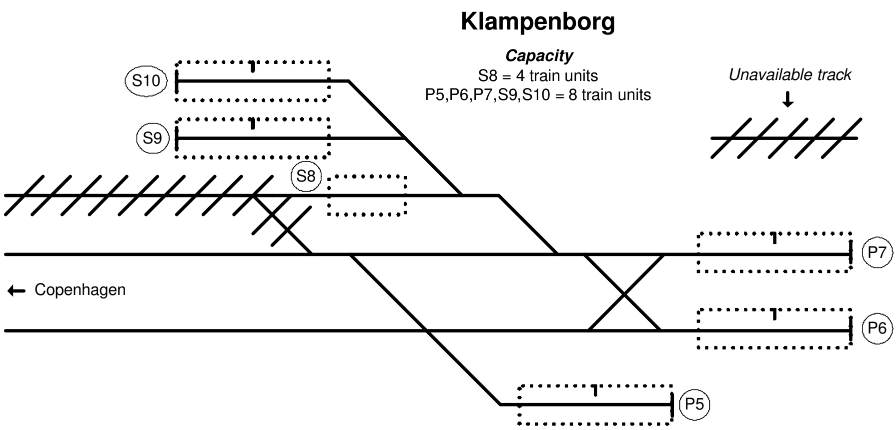

Figure 8.19: The station topology of Klampenborg.

The depot plans 2005-1 for Klampenborg is split into two periods. The working day period runs from Sunday morning to Monday morning, Monday morning to Tuesday morning etc. The weekend period runs from Saturday morning to Monday morning. The working day period contains 6 blocks to be shunted. The number of crossings is 3 out of a maximum of 15. Due to capacity problems, the prototype introduces the use of platform 5 as a shunt track during the night. This is also the only track the block arriving and departing to platform 5 can park on, since no shunt tracks are feasible from platform 5. The solution procedure for the working day period is in appendix A.10. A feasible depot plan is found in 0.598 sec. The number of different plans with the same objective value is 7.

The weekend period contains 12 blocks to be shunted. The number of crossings is 8 out of a maximum of 30. Again platform 5 is used as shunt track during night. The solution procedure for the weekend period is in appendix A.11. It takes 0.657 sec. to find a feasible depot plan, which is approximately the same as the working day period even though the number of blocks is doubled. Applying the Branch-and-Cut algorithm leads to over 50 different non-symmetric feasible depot plans. The high number of different plans is partly due to the fact that the shunt yard is empty Sunday morning, hence the weekend period can be split up into two independent periods. It has been chosen not to analyze the depot any further.

8.2.6 Køge (KJ)

The last of depots in the S-tog network to apply the prototype on is Køge. Køge is one of the terminuses of line A+, line E and line Ex. The topology of the station is presented in Figure 8.20. The shunt yard consists of 5 shunt tracks with a capacity of 8 train units each. Hence the overall capacity of the shunt yard is 40 train units. All shunt tracks are feasible from both platforms. Figure 8.21 shows a picture from the depot a foggy morning in November 2002.

The depot plan 2005-1 for the working day period consists of 22 blocks. The solution procedure is presented in A.12. The number of crossings is 62 out of a maximum of 108. The first check indicates that two drivers are necessary to operate the timetable. The next check detects a problem, since the maximum number of train units during the planning period is 48, while the capacity at the shunt yard is only 40 train units. To solve this problem two blocks (block 15 and 16) are using platform 6 as shunt track during the night. They arrive to the depot Mo,19:22 and Mo,19:42 respectively. Since it is not considered as good practice to let the blocks park at the platform during the evening, the new events are introduced at Tu,00:30 i.e. the moves from the shunt tracks to

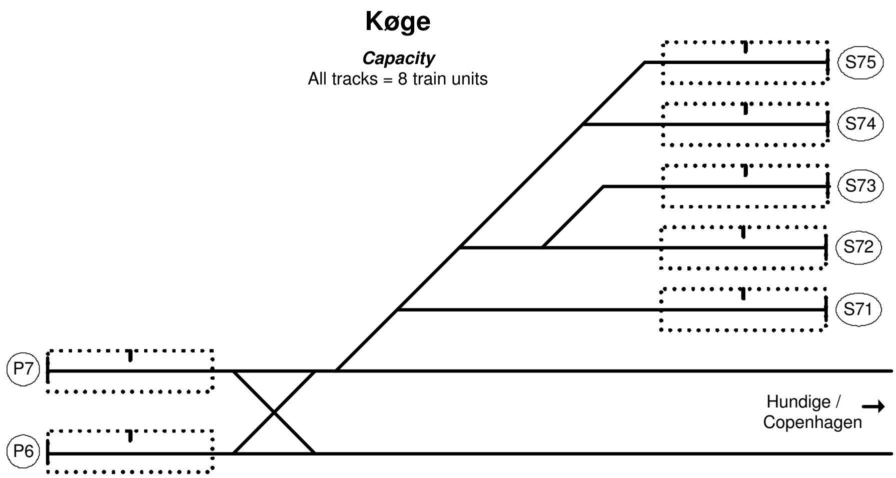

Figure 8.20: The station topology of Køge.

Figure 8.21: The 5 shunt tracks in Køge, November 2002 [Chr06].

platform 6. The third and the fourth check do not detect any problems. A feasible depot plan is found in 2.54 sec., where platform 6 is used as shunt track during the night. The number of different non-symmetric feasible depot plans with the same objective value is over 50.

The number of blocks to be shunted in the 2005-1 weekend period is 37. The solution procedure is in A.13. The number of crossings is 93 out of a maximum of 213. Again the capacity at the shunt yard is a problem. Unfortunately it cannot be solved by introducing the platforms as shunt tracks, since the last block to arrive is not the first to depart, and activities at platform 7 prevent the first departing blocks in the morning to be parked at the platform in the evening. Hence it is chosen not to use platforms as shunt tracks at night even though, an infeasible depot plan will come up. The optimization shows that two blocks cannot be parked during the planning period. The infeasible depot plan is found in 297 sec. or approximately 5 minutes. These two blocks arrive Friday afternoon/evening and depart Monday morning. Looking at the real depot plan from S-tog shows, that they have only found a feasible depot plan, because the two blocks are parked at platform 6 during the night and then the blocks are moved back to the shunt tracks in the morning i.e. introducing new intermediate shunting events. This is done Saturday and Sunday morning. Instead of adopting this idea, I will examine the changes needed in the connections in order to generate a feasible depot plan with the implemented prototype. If the following departure legs and times are changed it is possible to generate a feasible depot plan: Block 19 with block 11, block 18 with block 11 (the old block 19) and finally block 23 with block 30. Now it is possible to use the platforms as shunt tracks during the night. A feasible depot plan is found in 806 sec., see Figure 8.22. Notice that it has been necessary to discard the platform constraint[2] in the model in the solution procedure for the weekend period. This has been chosen since the constraint states that if only one platform is available during the night, it has to be the same in the entire planning period. This is actually not necessary in the weekend, since e.g. platform 6 can be available Friday night and Saturday night, while it is platform 7 Sunday night. Discarding the constraint makes it possible to generate a feasible depot plan.

There are 800000 feasible track assignments in the model above. Examining Figure 8.22 shows the number of train units at the depot is down to 4 at 16:00 Friday afternoon. By splitting the weekend period into two periods i.e. a period from Friday morning to 16:00 Friday afternoon and a period from 16:00 Friday afternoon to Monday morning it is possible to reduce the overall running time. Solving the first period takes only 0.505 sec. This solution is used as input to the second period. Symmetry cannot be used in the second period, because the shunt tracks are different due to the preparking of the train unit. Still the number of feasible track assignments is reduced to around 130000, which makes the prototype able to find the feasible depot plan in Figure 8.22 in 148 seconds. Hence the model size and overall running time are reduced by more than a factor 5.

[2]This constraint states that at least one platform is available during the night.

```
All 38 blocks have been assigned to a track!

Block |  New  | Type | Size | Day & Time |  From/to   |   Track    |          Activity           |     From/to     | Stock
[
0     |   -   | LHB  | 4    | Fr - 08:32 | 41223-1    | P7  /S71   | Arrive at platform - Det.   |    41146-1      | 4,
1     |   -   | LHB  | 4    | Fr - 08:42 | 15224-1    | P6  /S72   | Arrive at platform - Det.   |    15146-1      | 8,
2     |   -   | LHB  | 4    | Fr - 08:52 | 41224-1    | P7  /S73   | Arrive at platform - Det.   |    41147-1      | 12,
3     |   -   | LHB  | 4    | Fr - 09:02 | 15225-1    | P6  /S74   | Arrive at platform - Det.   |    15145-1      | 16,
4     |   -   | LHB  | 4    | Fr - 09:12 | 41225-1    | P7  /S73   | Arrive at platform - Det.   |    41144-1      | 20,
5     |   -   | LHB  | 4    | Fr - 09:22 | 15226-1    | P6  /S75   | Arrive at platform - Det.   |    16958-1      | 24,
6     |   -   | LHB  | 4    | Fr - 09:32 | 41226-1    | P7  /S71   | Arrive at platform - Det.   |    41143-1      | 28,
7     |   -   | LHB  | 4    | Fr - 09:42 | 15227-1    | P6  /S72   | Arrive at platform - Det.   |    41145-1      | 32,
6     |   -   | LHB  | 4    | Fr - 13:48 |    41143-1 | S71 /P7    | Depart from platform - Att. | 41226-1         | 28,
4     |   -   | LHB  | 4    | Fr - 14:08 |    41144-1 | S73 /P7    | Depart from platform - Att. | 41225-1         | 24,
7     |   -   | LHB  | 4    | Fr - 14:28 |    41145-1 | S72 /P7    | Depart from platform - Att. | 15227-1         | 20,
3     |   -   | LHB  | 4    | Fr - 14:38 |    15145-1 | S74 /P6    | Depart from platform - Att. | 15225-1         | 16,
0     |   -   | LHB  | 4    | Fr - 14:48 |    41146-1 | S71 /P7    | Depart from platform - Att. | 41223-1         | 12,
1     |   -   | LHB  | 4    | Fr - 14:58 |    15146-1 | S72 /P6    | Depart from platform - Att. | 15224-1         | 8,
2     |   -   | LHB  | 4    | Fr - 15:08 |    41147-1 | S73 /P7    | Depart from platform - Att. | 41224-1         | 4,
8     |   -   | LHB  | 4    | Fr - 16:12 | 41246-1    | P7  /S72   | Arrive at platform - Det.   |    15135-1      | 8,
9     |   -   | LHB  | 4    | Fr - 16:22 | 15247-1    | P6  /S73   | Arrive at platform - Det.   |    40119-1      | 12,
10    |   -   | LHB  | 4    | Fr - 16:32 | 41247-1    | P7  /S74   | Arrive at platform - Det.   |    15134-1      | 16,
11    |   -   | LHB  | 4    | Fr - 16:42 | 15248-1    | P6  /S73   | Arrive at platform - Det.   |    40118-1      | 20,
12    |   -   | LHB  | 4    | Fr - 16:52 | 41248-1    | P7  /S71   | Arrive at platform - Det.   |    15133-1      | 24,
13    |   -   | LHB  | 4    | Fr - 17:12 | 41249-1    | P7  /S71   | Arrive at platform - Det.   |    15131-1      | 28,
14    |   -   | LHB  | 4    | Fr - 17:32 | 41250-1    | P7  /S74   | Arrive at platform - Det.   |    40120-1      | 32,
5     |   -   | LHB  | 4    | Fr - 18:51 |    16958-1 | S75 /P6    | Depart from platform - Att. | 15226-1         | 28,
15    |   -   | LHB  | 4    | Fr - 19:22 | 15256-2    | P6  /S75   | Arrive at platform          |    45123-1      | 32,
16    |   -   | LHB  | 4    | Fr - 19:42 | 15257-2    | P6  /S75   | Arrive at platform          |    41118-2      | 36,
17    |   -   | LHB  | 4    | Sa - 00:32 | 40271-2    | P7  /S72   | Arrive at platform          |    15132-1      | 40,
18    |   -   | LHB  | 4    | Sa - 00:52 | 40200-2    | P7         | Arrive at platform (stay)   |    40117-1      | 44,
19    |   -   | LHB  | 4    | Sa - 01:12 | 40201-2    | P7         | Arrive at platform (stay)   |    40116-1      | 48,
19    |   -   | LHB  | 4    | Sa - 04:48 |    40116-1 | P7         | Depart from platform        | 40201-2         | 44,
18    |   -   | LHB  | 4    | Sa - 05:08 |    40117-1 | P7         | Depart from platform        | 40200-2         | 40,
11    |   -   | LHB  | 4    | Sa - 05:28 |    40118-1 | S73 /P7    | Depart from platform        | 15248-1         | 36,
9     |   -   | LHB  | 4    | Sa - 05:48 |    40119-1 | S73 /P7    | Depart from platform        | 15247-1         | 32,
20    |   -   | LHB  | 8    | Sa - 05:52 | 40215-1    | P6  /S73   | Arrive at platform          |    15119-1      | 40,
14    |   -   | LHB  | 4    | Sa - 06:08 |    40120-1 | S74 /P7    | Depart from platform        | 41250-1         | 36,
13    |   -   | LHB  | 4    | Sa - 09:58 |    15131-1 | S71 /P6    | Depart from platform        | 41249-1         | 32,
17    |   -   | LHB  | 4    | Sa - 10:18 |    15132-1 | S72 /P6    | Depart from platform        | 40271-2         | 28,
12    |   -   | LHB  | 4    | Sa - 10:38 |    15133-1 | S71 /P6    | Depart from platform        | 41248-1         | 24,
10    |   -   | LHB  | 4    | Sa - 10:58 |    15134-1 | S74 /P6    | Depart from platform        | 41247-1         | 20,
8     |   -   | LHB  | 4    | Sa - 11:18 |    15135-1 | S72 /P6    | Depart from platform        | 41246-1         | 16,
21    |   -   | LHB  | 4    | Sa - 15:22 | 15244-1    | P6  /S71   | Arrive at platform          |    40122-1      | 20,
22    |   -   | LHB  | 4    | Sa - 15:42 | 15245-1    | P6  /S71   | Arrive at platform          |    40121-1      | 24,
23    |   -   | LHB  | 4    | Sa - 16:02 | 15246-1    | P6  /S72   | Arrive at platform          |    40116-1      | 28,
24    |   -   | LHB  | 4    | Sa - 16:22 | 15247-1    | P6  /S72   | Arrive at platform          |    40123-1      | 32,
25    |   -   | LHB  | 4    | Sa - 16:42 | 15248-1    | P6  /S74   | Arrive at platform          |    41119-1      | 36,
26    |   -   | LHB  | 4    | Su - 00:32 | 40271-1    | P7  /S74   | Arrive at platform          |    40125-1      | 40,
27    |   -   | LHB  | 4    | Su - 00:52 | 40200-1    | P7         | Arrive at platform (stay)   |    40120-1      | 44,
28    |   -   | LHB  | 4    | Su - 01:12 | 40201-1    | P7         | Arrive at platform (stay)   |    40119-1      | 48,
28    |   -   | LHB  | 4    | Su - 05:48 |    40119-1 | P7         | Depart from platform        | 40201-1         | 44,
27    |   -   | LHB  | 4    | Su - 06:08 |    40120-1 | P7         | Depart from platform        | 40200-1         | 40,
22    |   -   | LHB  | 4    | Su - 06:28 |    40121-1 | S71 /P7    | Depart from platform        | 15245-1         | 36,
21    |   -   | LHB  | 4    | Su - 06:48 |    40122-1 | S71 /P7    | Depart from platform        | 15244-1         | 32,
29    |   -   | LHB  | 8    | Su - 06:52 | 40218-1    | P6  /S71   | Arrive at platform          |    40117-0      | 40,
24    |   -   | LHB  | 4    | Su - 07:08 |    40123-1 | S72 /P7    | Depart from platform        | 15247-1         | 36,
30    |   -   | LHB  | 4    | Su - 07:12 | 40219-1    | P6  /S72   | Arrive at platform          |    40124-1      | 40,
30    |   -   | LHB  | 4    | Su - 07:28 |    40124-1 | S72 /P7    | Depart from platform        | 40219-1         | 36,
31    |   -   | LHB  | 4    | Su - 07:32 | 40220-1    | P6  /S72   | Arrive at platform          |    40116-2      | 40,
26    |   -   | LHB  | 4    | Su - 07:48 |    40125-1 | S74 /P7    | Depart from platform        | 40271-1         | 36,
32    |   -   | LHB  | 4    | Mn - 00:32 | 40271-1    | P7  /S74   | Arrive at platform          |    41119-2      | 40,
33    | NGT-1 | LHB  | 8    | Mn - 00:40 |            | S73 /P6    | Move to platform            | 40215-1/15119-1 | -,
34    |   -   | LHB  | 4    | Mn - 00:52 | 40200-1    | P7  /S73   | Arrive at platform          |    45125-1      | 36,
35    |   -   | LHB  | 4    | Mn - 01:12 | 40201-1    | P7  /S73   | Arrive at platform          |    45124-1      | 40,
23    |   -   | LHB  | 4    | Mn - 04:48 |    40116-1 | S72 /P7    | Depart from platform        | 15246-1         | 36,
31    |   -   | LHB  | 4    | Mn - 04:48 |    40116-2 | S72 /P7    | Depart from platform        | 40220-1         | 32,
29    |   -   | LHB  | 8    | Mn - 05:08 |    40117-0 | S71 /P7    | Depart from platform        | 40218-1         | 24,
16    |   -   | LHB  | 4    | Mn - 05:28 |    41118-2 | S75 /P7    | Depart from platform        | 15257-2         | 20,
25    |   -   | LHB  | 4    | Mn - 05:48 |    41119-1 | S74 /P7    | Depart from platform        | 15248-1         | 16,
32    |   -   | LHB  | 4    | Mn - 05:48 |    41119-2 | S74 /P7    | Depart from platform        | 40271-1         | 12,
20    |   -   | LHB  | 8    | Mn - 05:58 |    15119-1 | P6  /P6    | Depart from platform        | 40215-1         | 12,
36    |   -   | LHB  | 4    | Mn - 06:02 | 16016-1    | P6  /S71   | Arrive at platform - Det.   |    41121-1      | 16,
37    |   -   | LHB  | 4    | Mn - 06:22 | 16017-1    | P6  /S75   | Arrive at platform - Det.   |    45122-1      | 20,
36    |   -   | LHB  | 4    | Mn - 06:28 |    41121-1 | S71 /P7    | Depart from platform - Att. | 16016-1         | 16,
37    |   -   | LHB  | 4    | Mn - 06:45 |    45122-1 | S75 /P6    | Depart from platform        | 16017-1         | 12,
15    |   -   | LHB  | 4    | Mn - 07:05 |    45123-1 | S75 /P6    | Depart from platform        | 15256-2         | 8,
35    |   -   | LHB  | 4    | Mn - 07:25 |    45124-1 | S73 /P6    | Depart from platform        | 40201-1         | 4,
34    |   -   | LHB  | 4    | Mn - 07:45 |    45125-1 | S73 /P6    | Depart from platform        | 40200-1         | 0]
```

Figure 8.22: The feasible final depot plan for the weekend period in Køge.

8.3 Alternative depot - Shuntvalley (SH)

An alternative depot has been created to show and test the capabilities of the prototype. The topology of the depot, called Shuntvalley (SH), is presented in Figure 8.23. The shunt yard consists of 4 shunt tracks. Shunt track 9 is only feasible from platform 1, while shunt tracks 10, 11 and 12 are feasible from platform 2. The capacity of shunt track 9 is 12 train units, while the capacity of shunt tracks 10, 11 and 12 is 8 train units each. Shunt track 12 is under maintenance, so it is preferred to keep the activity at the shunt track as small as possible.

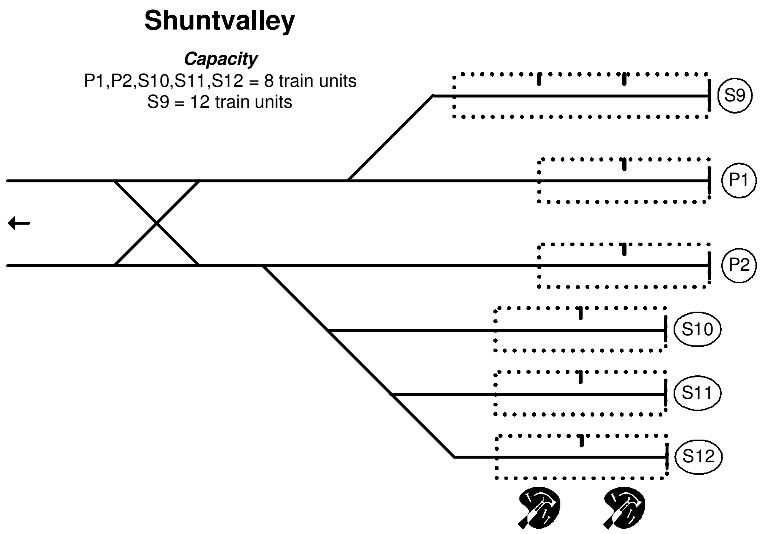

Figure 8.23: The station topology of the alternative depot, Shuntvalley.

The data used to test the depot is based on some of the data from Frederikssund. Figure 8.24 shows the event calendar created for the depot. Notice that the type differs from block to block. The number of crossings is 21 out of a maximum of 41.

The first check in the Feasibility Check indicates that one driver is enough to handle the schedule. There is enough capacity at the shunt yard indicated by the second check. The third check detects a problem, since block 4 arrives at platform 1 and departs from platform 2, hence a intermediate shunting move is needed. Looking at the event calendar it is decided to make the move as soon as possible after arrival. The fourth check does not detect any problems. It is

```
 ---Starting depot planning for SH---

Block |  New  | Type | Size | Day & Time |  From/to   |   Track    |          Activity          |     From/to      | Stock
[
0     |   -   | RENO | 4    | Mo - 08:43 | 55223-1    | P2         | Arrive at platform - Det.  |    55149-1       | 4,
1     |   -   | LHB  | 4    | Mo - 09:53 | 55227-2    | P2         | Arrive at platform - Det.  |    55148-2       | 8,
1     |   -   | LHB  | 4    | Mo - 15:16 |    55148-2 | P2         | Depart from platform - Att. | 55227-2         | 4,
0     |   -   | RENO | 4    | Mo - 15:36 |    55149-1 | P2         | Depart from platform - Att. | 55223-1         | 0,
2     |   -   | LHB  | 4    | Mo - 16:13 | 50246-1    | P1         | Arrive at platform - Det.  |    50118-1       | 4,
3     |   -   | LHB  | 4    | Mo - 16:53 | 50248-2    | P1         | Arrive at platform - Det.  |    50117-1       | 8,
4     |   -   | ASEA | 4    | Mo - 17:13 | 50249-1    | P1         | Arrive at platform - Det.  |    55126-1       | 12,
5     |   -   | RENO | 4    | Mo - 18:23 | 55252-1    | P2         | Arrive at platform         |    55121-1       | 16,
6     |   -   | RENO | 4    | Mo - 18:43 | 55253-1    | P2         | Arrive at platform         |    55120-1       | 20,
7     |   -   | RENO | 4    | Mo - 19:03 | 55254-1    | P2         | Arrive at platform         |    55124-1       | 24,
8     |   -   | ASEA | 4    | Tu - 00:13 | 55255-1    | P2         | Arrive at platform         |    55123-1       | 28,
9     |   -   | ASEA | 4    | Tu - 00:33 | 55256-1    | P2         | Arrive at platform         |    55125-2       | 32,
10    |   -   | LHB  | 4    | Tu - 00:53 | 50200-1    | P1         | Arrive at platform         |    50116-1       | 36,
10    |   -   | LHB  | 4    | Tu - 04:46 |    50116-1 | P1         | Depart from platform       | 50200-1          | 32,
3     |   -   | LHB  | 4    | Tu - 05:06 |    50117-1 | P1         | Depart from platform       | 50248-2          | 28,
2     |   -   | LHB  | 4    | Tu - 05:26 |    50118-1 | P1         | Depart from platform       | 50246-1          | 24,
6     |   -   | RENO | 4    | Tu - 05:56 |    55120-1 | P2         | Depart from platform       | 55253-1          | 20,
5     |   -   | RENO | 4    | Tu - 06:16 |    55121-1 | P2         | Depart from platform       | 55252-1          | 16,
11    |   -   | RENO | 4    | Tu - 06:23 | 55215-1    | P2         | Arrive at platform         |    55122-1       | 20,
8     |   -   | ASEA | 4    | Tu - 06:56 |    55123-1 | P2         | Depart from platform       | 55255-1          | 16,
11    |   -   | RENO | 4    | Tu - 07:06 |    55122-1 | P2         | Depart from platform       | 55215-1          | 12,
7     |   -   | RENO | 4    | Tu - 07:16 |    55124-1 | P2         | Depart from platform       | 55254-1          | 8,
9     |   -   | ASEA | 4    | Tu - 07:26 |    55125-2 | P2         | Depart from platform - Att. | 55256-1         | 4,
4     |   -   | ASEA | 4    | Tu - 07:36 |    55126-1 | P2         | Depart from platform       | 50249-1          | 0]

- The number of crossings in the timetable is 21 (the maximum number is 41).
```

Figure 8.24: The event calendar for the alternative depot in Shuntvalley.

chosen not to use symmetry in the optimization, because instead a penalty is set on shunt track 12 due to maintenance. This will guide the optimization to find a depot plan, where the activity at shunt track 12 is a small as possible. Furthermore penalties for parking blocks with different subtypes on the same shunt track and penalties for broken arrivals and departures are set.

```
All 13 blocks have been assigned to a track!

Block |  New  | Type | Size | Day & Time |  From/to   |   Track    |          Activity          |     From/to      | Stock
[
0     |   -   | RENO | 4    | Mo - 08:43 | 55223-1    | P2  /S11   | Arrive at platform - Det.  |    55149-1       | 4,
1     |   -   | LHB  | 4    | Mo - 09:53 | 55227-2    | P2  /S11   | Arrive at platform - Det.  |    55148-2       | 8,
1     |   -   | LHB  | 4    | Mo - 15:16 |    55148-2 | S11 /P2    | Depart from platform - Att. | 55227-2         | 4,
0     |   -   | RENO | 4    | Mo - 15:36 |    55149-1 | S11 /P2    | Depart from platform - Att. | 55223-1         | 0,
2     |   -   | LHB  | 4    | Mo - 16:13 | 50246-1    | P1  /S9    | Arrive at platform - Det.  |    50118-1       | 4,
3     |   -   | LHB  | 4    | Mo - 16:53 | 50248-2    | P1  /S9    | Arrive at platform - Det.  |    50117-1       | 8,
4     |   -   | ASEA | 4    | Mo - 17:13 | 50249-1    | P1  /S9    | Arrive at platform - Det.  |    55126-1       | 12,
5     | ISM01 | ASEA | 4    | Mo - 17:33 |            | S9  /S12   | Intermediate shunting move | 50249-1/55126-1  | -,
6     |   -   | RENO | 4    | Mo - 18:23 | 55252-1    | P2  /S10   | Arrive at platform         |    55121-1       | 16,
7     |   -   | RENO | 4    | Mo - 18:43 | 55253-1    | P2  /S10   | Arrive at platform         |    55120-1       | 20,
8     |   -   | RENO | 4    | Mo - 19:03 | 55254-1    | P2  /S11   | Arrive at platform         |    55124-1       | 24,
9     |   -   | ASEA | 4    | Tu - 00:13 | 55255-1    | P2  /S11   | Arrive at platform         |    55123-1       | 28,
10    |   -   | ASEA | 4    | Tu - 00:33 | 55256-1    | P2  /S12   | Arrive at platform         |    55125-2       | 32,
11    |   -   | LHB  | 4    | Tu - 00:53 | 50200-1    | P1  /S9    | Arrive at platform         |    50116-1       | 36,
11    |   -   | LHB  | 4    | Tu - 04:46 |    50116-1 | S9  /P1    | Depart from platform       | 50200-1          | 32,
3     |   -   | LHB  | 4    | Tu - 05:06 |    50117-1 | S9  /P1    | Depart from platform       | 50248-2          | 28,
2     |   -   | LHB  | 4    | Tu - 05:26 |    50118-1 | S9  /P1    | Depart from platform       | 50246-1          | 24,
7     |   -   | RENO | 4    | Tu - 05:56 |    55120-1 | S10 /P2    | Depart from platform       | 55253-1          | 20,
6     |   -   | RENO | 4    | Tu - 06:16 |    55121-1 | S10 /P2    | Depart from platform       | 55252-1          | 16,
12    |   -   | RENO | 4    | Tu - 06:23 | 55215-1    | P2  /S10   | Arrive at platform         |    55122-1       | 20,
9     |   -   | ASEA | 4    | Tu - 06:56 |    55123-1 | S11 /P2    | Depart from platform       | 55255-1          | 16,
12    |   -   | RENO | 4    | Tu - 07:06 |    55122-1 | S10 /P2    | Depart from platform       | 55215-1          | 12,
8     |   -   | RENO | 4    | Tu - 07:16 |    55124-1 | S11 /P2    | Depart from platform       | 55254-1          | 8,
10    |   -   | ASEA | 4    | Tu - 07:26 |    55125-2 | S12 /P2    | Depart from platform - Att. | 55256-1         | 4,
4     |   -   | ASEA | 4    | Tu - 07:36 |    55126-1 | S12 /P2    | Depart from platform       | 50249-1          | 0]
```

Figure 8.25: The final depot plan for the alternative depot in Shuntvalley.

The prototype finds the feasible depot plan presented in Figure 8.25 in 0.983 sec. On shunt track 10 there is only parked blocks of type RENO, while shunt track 12 only consists of blocks of the ASEA type. Shunt track 9 and shunt track 11 are a mix of types. There exists 4 different feasible depot plans with the same objective value. The various penalties will also make it harder to find different feasible depot plans with the same objective value. As an example, there exists 16 different feasible depot plans, if the solution procedure is run without the penalties for parking blocks with different subtypes on the same shunt track.

The example shows the it is possible to apply the prototype to other depots than the ones at S-tog. The capabilities and limitations of the prototype is explained in section 7.6.

8.4 Overview of the experiments

In this section I will sum up the results from the experiments. Table 8.5 and Table 8.6 show the performance of prototype based on the 2005-1 depot plans and the performance at the depot in Shuntvalley. Hence the results from the different alternative event calendars at the S-tog depots are not included. The shunt tracks are defined by five numbers, where the first number is the number of shunt tracks with a capacity of 4 train units, the second number shunt tracks with a capacity of 8 train units etc. There do not exist any shunt tracks with a capacity larger than 20 train units among the 7 depots. The periods in the tables are either the working day period (D) or the weekend period (W). For the alternative depot in Shuntvalley (SH), there is one period denoted with an A. In all the experiments except SH symmetry has been applied. Furthermore all the penalties are included in the solution procedures. At SH a penalty is connected to one shunt track (shunt track 12). The number of columns in the tables represents the number of columns in the reduced model after an internal presolving in CPLEX. To apply the Branch-and-Cut algorithm after a depot plan is found, the model has to be written to a file. The row, Writing model, shows the percentages of the running time used on this step in the solution process.

	Depots					
	BA		**FM**		**FS**	
Platforms	2		2		2	
Shunt tracks	{0,2,0,2,0}		{0,3,0,0,0}		{0,6,0,0,0}	
Shunt yard capacity (train units)	48		24		48	
Periods	**D**	**W**	**D**	**W**	**D**	**W**
Crossings in timetable	1	1	14	22	39	100
Max number of crossings	1	3	27	78	71	186
# Block to be shunted	2	6	11	24	15	29
Columns in the model	4	100	163	55257	360	13146
Solution value	2	2	503	503	6	6
# Blocks not parked	0	0	0	0	0	0
Platform parkings	N	N	Y (1)	Y (3)	N	N
Intermediate shunting moves	N	N	N	N	N	N
# Depot plans	4	> 50	12	> 50	> 50	> 50
Running time of parking step (sec.)	0.378	0.627	0.771	22.8	0.981	9.05
Generating assignments (% of time)	6%	7%	7%	12%	12%	13%
Generating model (% of time)	66%	54%	64%	39%	55%	23%
Writing model (% of time)	3%	9%	3%	12%	5%	4%
Solving model (% of time)	25%	30%	26%	37%	28%	60%

Table 8.5: The results from the first 3 depots

	Depots						
	HI		**KL**		**KJ**		**SH**
Platforms	3		3		2		2
Shunt tracks	{1,3,0,0,2}		{1,2,0,0,0}		{0,5,0,0,0}		{0,3,1,0,0}
Shunt yard capacity (train units)	68		20		40		36
Periods	**D**	**W**	**D**	**W**	**D**	**W**	**A**
Crossings in timetable	41	69	3	8	62	93	21
Max number of crossings	91	311	15	30	108	213	41
# Block to be shunted	27	51	6	12	24	37	13
Columns in the model	4922	1727191	22	200	5180	529083	301
Solution value	5	6	503	503	505	2005	254
# Blocks not parked	0	0	0	0	0	2	0
Platform parkings	N	N	Y (1)	Y (2)	Y (2)	N	N
Intermediate shunting moves	Y (8)	Y (12)	N	N	N	N	Y (1)
# Depot plans	> 50	> 50	7	> 50	> 50	1	4
Running time of parking step (sec.)	3.14	4703	0.598	0.657	2.54	297	0.983
Generating assignments (% of time)	25%	3%	18%	16%	27%	8%	24%
Generating model (% of time)	32%	40%	57%	50%	44%	35%	50%
Writing model (% of time)	5%	2%	3%	4%	8%	6%	5%
Solving model (% of time)	39%	56%	21%	30%	21%	52%	20%

Table 8.6: The results from the last 4 depots

The solution value in the tables is the objective value of the optimization. If a shunt track is used in the final depot plan, it costs 1. The use of a platform costs 500. Not to park a block costs 1000 for each block. The solution value of 254 in the SH test case is due to two shunt activities at the penalized shunt track, which gives a penalty of 100 for each activity, and two shunt tracks containing different subtypes. This gives a penalty of 25 for each track. The remaining 4 is because all shunt tracks at the depot are used.

8.5 Conclusion on the experiments

The depot plans 2005-1, which are the bases of the tests, have been used in practice at S-tog. The prototype was able to find feasible depot plans as well in all the test cases except the weekend period in KJ (Køge). This was because, S-tog has used the platform as shunt track during the nights and then moved the train units back to the shunt yard in the mornings. In this prototype it has been chosen not to implement this strategy and therefore, it was not possible to generate a feasible depot plan. In section 8.2.6 it was shown that by only making a few changes to the matching of arriving and departing train units in the weekend period, it was possible to generate a feasible depot plan with the prototype.

Examining Table 8.5 and Table 8.6 clearly shows that the size of the model and by it the running time increase exponentially in the number of blocks to be shunted. But at the same time some of the tests indicate that it is not only the number of blocks, which determines the running time. The four tests FW-W, FS-W, HI-D and KJ-D contain roughly the same amount of blocks to be shunted (between 24 to 29), but the running times are between 2.54 seconds and 22.8 seconds. Examining the tables closely shows there is a big difference between the number of columns in the four experiments. In the FM-W test case, where the running time is 22.8 seconds, there is 55257 columns indicating a large number of feasible track assignments. Hence it takes longer time to find an optimal solution. The large number of feasible track assignments at FM-W is due to the fact that the period can be split into two independent periods. This makes the number of feasible assignments grow strongly. In the two test cases HI-D and KJ-D the number of columns is around 5000, which leads to much faster running times.

Generally in the experiments the running time of the parking step is used on generating the model and solving the model. The generation consists of some nested for-loops, which are very time-consuming. It may be possible to optimize the code in order to decrease the time of this step. The solving step is done in

CPLEX. The performance of CPLEX has improved each time a new version has been released. By applying the newest release, CPLEX 10.0 (February 2006), it will properly be possible to reduce the overall running time.

8.6 Comparison with results in the literature

The performance of the prototype is compared with results in the existing literature. It is only possible to measure the performance of the solution procedure to the parking problem, since the other parts of the prototype do not exist in the literature. The article [FLKH02], which have formed the basis for the parking algorithm, and the Ph.D. thesis [Len06] contain comparable results. Besides the parking problem the two articles include the matching of arriving and departing train units in the solution procedure. This makes the parking problem easier to solve, since the matching determines the number of crossings. On the other hand the program developed in the literature is able to handle free tracks, so the difficulty of the overall parking problem is assumed to be the same as in the prototype. For the prototype developed in this project the matching of arriving and departing train units is part of the input.

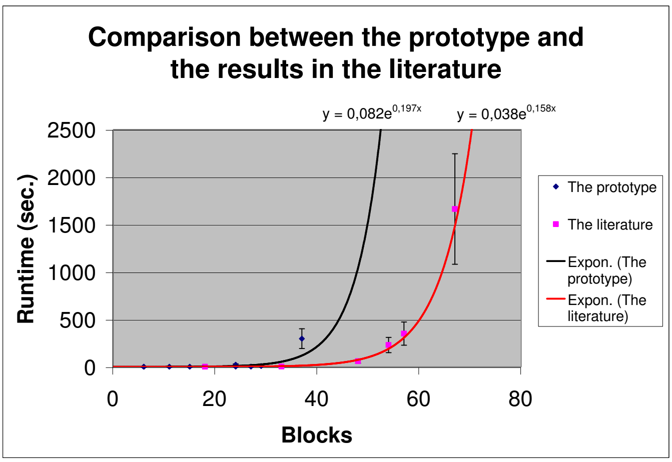

Figure 8.26: Comparison with results in the literature.

Figure 8.26 shows the result of the comparison between the prototype and the results in the literature. Different kind of uncertainties are connected to the figure. First of all the experiments are performed on different computers (a Sun Fire V440 and a Inter Pentium 4 1.6 GHz. processor). Assuming the performance of the two computers are comparable leave us with the uncertainties connected to each test. The Y-Error bars express the standard deviation at each test. The standard deviation is calculated by equation (8.1) using the results from the experiments and from [FLKH02] and [Len06]. In equation (8.1) x_i is value i, N is the number of values and μ is the mean.

$$\sigma = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(x_i - \mu)} \tag{8.1}$$

Figure 8.26 indicates that the results in the literature are better than the results obtain by the prototype. The exponents in the formulas of the trendlines are approximately the same indicating the running times relatively increase by the same values. The difference is that the running time starts to increase steeply around 40 blocks in the results from the prototype, where it is 60 blocks in the literature. This is also expected, since in the literature a column generation framework has been applied to the solution procedure in the parking problem. It makes the solution procedure able of choosing only the best columns for the model. Implementing a column generation framework or using another approach to be able to solve larger instances would be a natural extension to the prototype.

Chapter 9

Further research

Regarding the prototype and the algorithms and methods described in this thesis, several directions are worth further exploration. The prototype has been applied to 6 depots in S-tog's network and a new alternative depot. Each depot has its own peculiarities. Therefore, it would be interesting to consider other depots and to investigate whether modifications or adjustments in the prototype are required. The modifications may include the possibility of handling other types of tracks for instance free tracks. This would also make it possible to apply the prototype to other types of shunting of e.g. buses.

To solve large instances of the problem in a reasonable amount of time it may as previously mentioned require the implementation of a column generation framework. The idea behind the framework is only to include good columns in the model and thereby, reduce the size of the model. Dominance checking of the columns is another approach to reduce the model size.

It would also be interesting to examine other techniques for handling intermediate shunting moves and platform parkings or improve the existing strategies used in the prototype. Suggesting several execution times for each intermediate shunting move is sensible, if a column generation framework or another approach have been implemented to handle the large number of blocks. The procedure for platform parkings can also be automated by introducing an extra more expensive block for each potential platform parking. Hence in the optimization the extra block representing the platform parking is only used, if it is not possible to park the original block at the shunt tracks. The approach has not been implemented in the prototype, because information about regular train activities does not exist. This makes it impossible to determine, if the platforms are available or not.

Another interesting area is how to evaluate the robustness of different depot plans. Besides the Branch-and-Cut algorithm already implemented a further analysis could be applied. This may include developing a stochastic simulation model, where delays are put in the depot plans. By setting up different scenarios it would be possible to measure the robustness of a given depot plan. Furthermore additional robustness measures may be introduced.

Other aspects of depot planning could also be incorporated in the prototype. This includes the routing of train units, the cleaning of train units and a more thorough analysis of the driver availability. The driver analysis could be used in the previous steps of the planning process to ensure that it is possible for the drivers to perform the shunt activities.

A different, but very relevant, further step is to apply a convenient graphical user-interface to the prototype. This interface should communicate with the other parts of the planning system to improve the integration of the entire application.

Chapter 10

Conclusion

The objective of this project was to develop a prototype to increase the efficiency of depot planning. The objective has been achieved by building the prototype as a decision support system, which can be seen as an automated tool for supporting the planners. The main focus in the prototype is to determine the parking of train units. Different algorithms and methods have been implemented to analyze the problem. This analysis includes an identification and correction of possible infeasibilities between the timetable and the station topology. Several parameters can be adjusted in the optimization procedure, where the mathematical software CPLEX 9.1 is used as solver. The robustness of a feasible depot plan is examined by using a Branch-and-Cut algorithm. Other theoretical aspects of the shunting problem have been examined and described as well. The feasible depot plans are visualized via the simulation program Arena.

In order to obtain knowledge about shunting, railway planning and decision support systems several articles from the literature have been studied. This serves together with knowledge about DSB S-tog and the railway system developed by Carmen as a good basis for the understanding of the problem and development of the prototype.

The prototype has been applied to 6 depots at S-tog and an alternative depot. It generates feasible depot plans in all the test cases except one, because of odd platform parkings, in a reasonable amount of time. The results show that the prototype is most effective, when the number of blocks to be shunted is under 40 approximately. The results in the literature from solving the parking problem are slightly better than the results obtained by the prototype. This is mainly because a column generation framework has been applied to the solution procedures in the literature. Implementing a column generation framework or using another approach to reduce the model size is a natural extension to the prototype.

The potential of decision support systems is strongly increasing in all industries, mainly because of the development in hardware and software. The prototype developed in this project shows one approach to designing a decision support system. It is meant to be used as the final step of a complete planning process underlying a railway system, but it can also be added to an existing system. Applying simulation to analyze robustness or adding a graphical user-interface are features that would increase the value of the prototype and make it an excellent tool for planners in the future.

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APPENDIX A

Tests

A.1 Ballerup - Working day (2005-1)

```
 ---Starting depot planning for BA---

Block |  New  | Type | Size | Day & Time |  From/to   |   Track   |          Activity          |     From/to     | Stock
[
0     |   -   | LHB  | 4    | Tu - 01:05 | 30201-1    | P1        | Arrive at platform         |    30116-1      | 4,
1     |   -   | LHB  | 4    | Tu - 01:10 | 50904-1    | P2        | Arrive at platform         |    30117-1      | 8,
0     |   -   | LHB  | 4    | Tu - 04:54 |    30116-1 | P2        | Depart from platform       | 30201-1         | 4,
1     |   -   | LHB  | 4    | Tu - 05:14 |    30117-1 | P2        | Depart from platform       | 50904-1         | 0]

- The number of crossings in the timetable is 1 (the maximum number is 1).

 ---Running feasibility check---

1. Finding the number of drivers needed based on the arrivals in the timetable.

- Based on the arrivals of train units in the timetable TWO drivers are necessary!

2. Checking the capacity needed at the shunt yard.

- The maximum number of units at the shunt yard during the planning period is 8.
- Based on the timetable there is enough capacity at the shunt yard (the capacity is 48 units)!

Check!

3. Checking for infeasiblity in the timetable.

Check!

4. Checking for shunt tracks with insufficient capacity.

Check!

Use symmetry if possible (yes/no)?
y

Set penalty for parking blocks with different subtype on the same shunt track (yes/no)?
y
```

```
Set penalties for broken arrivals and departures (yes/no)?
y

Make blocks that are detached at the station cheaper (yes/no)?
y

Create shunt plan (yes/no)?
y

...Solving the parking problem...

All 2 blocks have been assigned to a track!

Block |  New  | Type | Size | Day & Time |  From/to   |   Track   |          Activity          |     From/to     | Stock
[
0     |   -   | LHB  | 4    | Tu - 01:05 | 30201-1    | P1  /S21  | Arrive at platform         |    30116-1      | 4,
1     |   -   | LHB  | 4    | Tu - 01:10 | 50904-1    | P2  /S23  | Arrive at platform         |    30117-1      | 8,
0     |   -   | LHB  | 4    | Tu - 04:54 |    30116-1 | S21 /P2   | Depart from platform       | 30201-1         | 4,
1     |   -   | LHB  | 4    | Tu - 05:14 |    30117-1 | S23 /P2   | Depart from platform       | 50904-1         | 0]

Generate solutions time 23 msec.
Generate model time 250 msec.
Write model time 10 msec.
Solve model time 95 msec.
Overall solution time 378 msec.
```

A.2 Ballerup - Weekend (2005-1)

```
 ---Starting depot planning for BA---

Block |  New  | Type | Size | Day & Time |  From/to   |   Track   |          Activity          |     From/to     | Stock
[
0     |   -   | LHB  | 4    | Sa - 01:05 | 30201-1    | P1        | Arrive at platform         |    30116-1      | 4,
1     |   -   | LHB  | 4    | Sa - 01:10 | 50904-1    | P2        | Arrive at platform         |    30117-1      | 8,
0     |   -   | LHB  | 4    | Sa - 04:54 |    30116-1 | P2        | Depart from platform       | 30201-1         | 4,
1     |   -   | LHB  | 4    | Sa - 05:14 |    30117-1 | P2        | Depart from platform       | 50904-1         | 0,
2     |   -   | LHB  | 4    | Sa - 05:25 | 30214-2    | P1        | Arrive at platform - Det.  |    30120-1      | 4,
3     |   -   | LHB  | 4    | Su - 01:05 | 30201-1    | P1        | Arrive at platform         |    30119-1      | 8,
3     |   -   | LHB  | 4    | Su - 05:54 |    30119-1 | P2        | Depart from platform       | 30201-1         | 4,
2     |   -   | LHB  | 4    | Su - 06:14 |    30120-1 | P2        | Depart from platform       | 30214-2         | 0,
4     |   -   | LHB  | 4    | Su - 06:25 | 30217-2    | P1        | Arrive at platform - Det.  |    30117-1      | 4,
5     |   -   | LHB  | 4    | Mn - 01:05 | 30201-1    | P1        | Arrive at platform         |    30116-1      | 8,
5     |   -   | LHB  | 4    | Mn - 04:54 |    30116-1 | P2        | Depart from platform       | 30201-1         | 4,
4     |   -   | LHB  | 4    | Mn - 05:14 |    30117-1 | P2        | Depart from platform       | 30217-2         | 0]

- The number of crossings in the timetable is 1 (the maximum number is 3).

 ---Running feasibility check---

1. Finding the number of drivers needed based on the arrivals in the timetable.

- Based on the arrivals of train units in the timetable TWO drivers are necessary!

2. Checking the capacity needed at the shunt yard.

- The maximum number of units at the shunt yard during the planning period is 8.
- Based on the timetable there is enough capacity at the shunt yard (the capacity is 48 units)!

Check!

3. Checking for infeasiblity in the timetable.

Check!

4. Checking for shunt tracks with insufficient capacity.

Check!

Use symmetry if possible (yes/no)?
y

Set penalty for parking blocks with different subtype on the same shunt track (yes/no)?
y

Set penalties for broken arrivals and departures (yes/no)?
y

Make blocks that are detached at the station cheaper (yes/no)?
y

Create shunt plan (yes/no)?
y

...Solving the parking problem...

All 6 blocks have been assigned to a track!

Block |  New  | Type | Size | Day & Time |  From/to   |   Track   |          Activity          |     From/to     | Stock
[
0     |   -   | LHB  | 4    | Sa - 01:05 | 30201-1    | P1  /S23  | Arrive at platform         |    30116-1      | 4,
1     |   -   | LHB  | 4    | Sa - 01:10 | 50904-1    | P2  /S21  | Arrive at platform         |    30117-1      | 8,
0     |   -   | LHB  | 4    | Sa - 04:54 |    30116-1 | S23 /P2   | Depart from platform       | 30201-1         | 4,
1     |   -   | LHB  | 4    | Sa - 05:14 |    30117-1 | S21 /P2   | Depart from platform       | 50904-1         | 0,
2     |   -   | LHB  | 4    | Sa - 05:25 | 30214-2    | P1  /S21  | Arrive at platform - Det.  |    30120-1      | 4,
3     |   -   | LHB  | 4    | Su - 01:05 | 30201-1    | P1  /S21  | Arrive at platform         |    30119-1      | 8,
3     |   -   | LHB  | 4    | Su - 05:54 |    30119-1 | S21 /P2   | Depart from platform       | 30201-1         | 4,
2     |   -   | LHB  | 4    | Su - 06:14 |    30120-1 | S21 /P2   | Depart from platform       | 30214-2         | 0,
4     |   -   | LHB  | 4    | Su - 06:25 | 30217-2    | P1  /S23  | Arrive at platform - Det.  |    30117-1      | 4,
5     |   -   | LHB  | 4    | Mn - 01:05 | 30201-1    | P1  /S21  | Arrive at platform         |    30116-1      | 8,
5     |   -   | LHB  | 4    | Mn - 04:54 |    30116-1 | S21 /P2   | Depart from platform       | 30201-1         | 4,
4     |   -   | LHB  | 4    | Mn - 05:14 |    30117-1 | S23 /P2   | Depart from platform       | 30217-2         | 0]

Generate solutions time 43 msec.
Generate model time 338 msec.
Write model time 57 msec.
Solve model time 189 msec.
Overall solution time 627 msec.
```

A.3 Farum - Weekend (2005-1)

```
 ---Starting depot planning for FM---

Block |  New  | Type | Size | Day & Time |  From/to   |   Track   |           Activity           |    From/to    | Stock
[
0     |   -   | LHB  | 4    | Fr - 07:02 | 55119-2    | P1        | Arrive at platform - Det.    |    50249-2    | 4,
1     |   -   | LHB  | 4    | Fr - 08:12 | 50122-2    | P2        | Arrive at platform - Det.    |    50247-2    | 8,
2     |   -   | LHB  | 4    | Fr - 08:32 | 50123-2    | P2        | Arrive at platform - Det.    |    50248-2    | 12,
3     |   -   | LHB  | 4    | Fr - 08:52 | 50124-2    | P2        | Arrive at platform - Det.    |    50230-1    | 16,
4     |   -   | LHB  | 4    | Fr - 09:12 | 50125-2    | P2        | Arrive at platform           |    50246-2    | 20,
5     |   -   | LHB  | 4    | Fr - 09:12 | 50125-1    | P2        | Arrive at platform           |    50245-2    | 24,
3     |   -   | LHB  | 4    | Fr - 09:28 |    50230-1 | P2        | Depart from platform         | 50124-2       | 20,
5     |   -   | LHB  | 4    | Fr - 14:28 |    50245-2 | P2        | Depart from platform - Att.  | 50125-1       | 16,
4     |   -   | LHB  | 4    | Fr - 14:48 |    50246-2 | P2        | Depart from platform - Att.  | 50125-2       | 12,
1     |   -   | LHB  | 4    | Fr - 15:08 |    50247-2 | P2        | Depart from platform - Att.  | 50122-2       | 8,
2     |   -   | LHB  | 4    | Fr - 15:28 |    50248-2 | P2        | Depart from platform - Att.  | 50123-2       | 4,
0     |   -   | LHB  | 4    | Fr - 15:48 |    50249-2 | P2        | Depart from platform - Att.  | 55119-2       | 0,
6     |   -   | LHB  | 4    | Fr - 17:32 | 50150-2    | P2        | Arrive at platform - Det.    |    55231-1    | 4,
7     |   -   | LHB  | 4    | Fr - 17:52 | 50151-2    | P2        | Arrive at platform - Det.    |    55230-1    | 8,
8     |   -   | LHB  | 4    | Fr - 19:22 | 55156-1    | P1        | Arrive at platform           |    55229-1    | 12,
9     |   -   | LHB  | 4    | Fr - 19:42 | 55157-1    | P1        | Arrive at platform           |    50219-1    | 16,
10    |   -   | LHB  | 4    | Sa - 00:32 | 50171-1    | P2        | Arrive at platform           |    50218-1    | 20,
11    |   -   | LHB  | 4    | Sa - 00:52 | 50100-2    | P2        | Arrive at platform           |    50217-1    | 24,
12    |   -   | LHB  | 4    | Sa - 01:12 | 50101-2    | P2        | Arrive at platform           |    50216-1    | 28,
12    |   -   | LHB  | 4    | Sa - 04:48 |    50216-1 | P2        | Depart from platform         | 50101-2       | 24,
11    |   -   | LHB  | 4    | Sa - 05:08 |    50217-1 | P1        | Depart from platform         | 50100-2       | 20,
10    |   -   | LHB  | 4    | Sa - 05:28 |    50218-1 | P1        | Depart from platform         | 50171-1       | 16,
9     |   -   | LHB  | 4    | Sa - 05:48 |    50219-1 | P2        | Depart from platform         | 55157-1       | 12,
13    |   -   | LHB  | 4    | Sa - 05:52 | 50115-2    | P2        | Arrive at platform - Det.    |    50221-1    | 16,
8     |   -   | LHB  | 4    | Sa - 09:18 |    55229-1 | P1        | Depart from platform         | 55156-1       | 12,
7     |   -   | LHB  | 4    | Sa - 09:38 |    55230-1 | P2        | Depart from platform         | 50151-2       | 8,
6     |   -   | LHB  | 4    | Sa - 09:58 |    55231-1 | P2        | Depart from platform         | 50150-2       | 4,
14    |   -   | LHB  | 4    | Sa - 14:42 | 55142-1    | P1        | Arrive at platform           |    56019-1    | 8,
15    |   -   | LHB  | 4    | Sa - 15:02 | 55143-1    | P1        | Arrive at platform           |    50222-1    | 12,
16    |   -   | LHB  | 4    | Sa - 15:22 | 55144-1    | P1        | Arrive at platform           |    50218-2    | 16,
17    |   -   | LHB  | 4    | Su - 00:32 | 50171-1    | P2        | Arrive at platform           |    50217-2    | 20,
18    |   -   | LHB  | 4    | Su - 00:52 | 50100-1    | P2        | Arrive at platform           |    50220-1    | 24,
19    |   -   | LHB  | 4    | Su - 01:12 | 50101-1    | P2        | Arrive at platform           |    50219-1    | 28,
19    |   -   | LHB  | 4    | Su - 05:48 |    50219-1 | P2        | Depart from platform         | 50101-1       | 24,
18    |   -   | LHB  | 4    | Su - 06:08 |    50220-1 | P2        | Depart from platform         | 50100-1       | 20,
13    |   -   | LHB  | 4    | Su - 06:28 |    50221-1 | P2        | Depart from platform         | 50115-2       | 16,
15    |   -   | LHB  | 4    | Su - 06:48 |    50222-1 | P2        | Depart from platform         | 55143-1       | 12,
20    |   -   | LHB  | 4    | Su - 06:52 | 50118-2    | P2        | Arrive at platform - Det.    |    50219-2    | 16,
21    |   -   | LHB  | 4    | Mn - 00:32 | 50171-1    | P2        | Arrive at platform           |    55221-1    | 20,
22    |   -   | LHB  | 4    | Mn - 00:52 | 50100-1    | P2        | Arrive at platform           |    55220-1    | 24,
23    |   -   | LHB  | 4    | Mn - 01:12 | 50101-1    | P2        | Arrive at platform           |    50216-1    | 28,
23    |   -   | LHB  | 4    | Mn - 04:48 |    50216-1 | P2        | Depart from platform         | 50101-1       | 24,
17    |   -   | LHB  | 4    | Mn - 05:08 |    50217-2 | P2        | Depart from platform         | 50171-1       | 20,
16    |   -   | LHB  | 4    | Mn - 05:28 |    50218-2 | P2        | Depart from platform         | 55144-1       | 16,
20    |   -   | LHB  | 4    | Mn - 05:48 |    50219-2 | P2        | Depart from platform         | 50118-2       | 12,
14    |   -   | LHB  | 4    | Mn - 05:58 |    56019-1 | P1        | Depart from platform         | 55142-1       | 8,
22    |   -   | LHB  | 4    | Mn - 06:18 |    55220-1 | P2        | Depart from platform         | 50100-1       | 4,
21    |   -   | LHB  | 4    | Mn - 06:38 |    55221-1 | P2        | Depart from platform         | 50171-1       | 0]

- The number of crossings in the timetable is 22 (the maximum number is 78).

 ---Running feasibility check---

1. Finding the number of drivers needed based on the arrivals in the timetable.

- Based on the arrivals of train units in the timetable ONE driver is enough!

2. Checking the capacity needed at the shunt yard.

- The maximum number of units at the shunt yard during the planning period is 28.
- There is not enough capacity at the shunt yard (the capacity is only 24 units)!
- Allow the use of platforms as depot tracks at night (yes/no)?
y
- Write the block you allow to park at the platforms at night (e.g 3)?
12
- Is it possible to park the block at the platform from arrival to departure (yes/no)?
y

...The event calendar...

- Park more blocks at the platform at night (the capacity at the shunt yard is 24) (yes/no)?
y
- Write the block you allow to park at the platforms at night (e.g 3)?
19
- Is it possible to park the block at the platform from arrival to departure (yes/no)?
y

...The event calendar...
```

```
- Park more blocks at the platform at night (the capacity at the shunt yard is 24) (yes/no)?
y
- Write the block you allow to park at the platforms at night (e.g 3)?
23
- Is it possible to park the block at the platform from arrival to departure (yes/no)?
y

...The event calendar...

- Park more blocks at the platform at night (the capacity at the shunt yard is 24) (yes/no)?
n

3. Checking for infeasiblity in the timetable.

Check!

4. Checking for shunt tracks with insufficient capacity.

Check!

Use symmetry if possible (yes/no)?
y

Set penalty for parking blocks with different subtype on the same shunt track (yes/no)?
y

Set penalties for broken arrivals and departures (yes/no)?
y

Make blocks that are detached at the station cheaper (yes/no)?
y

Create shunt plan (yes/no)?
y
ILOG CPLEX 9.130, licensed to "university-lyngby", options: e m b q
Tried aggregator 1 time.
MIP Presolve eliminated 1 rows and 1 columns.
Reduced MIP has 25 rows, 55257 columns, and 375922 nonzeros.
Presolve time =    3.12 sec.
Clique table members: 24
MIP emphasis: balance optimality and feasibility
Root relaxation solution time =    2.66 sec.

        Nodes                                         Cuts/
   Node  Left     Objective  IInf  Best Integer     Best Node    ItCnt     Gap         Variable B Parent  Depth

      0     0      503.0000    11                    503.0000      206
*     0+    0                   0    18003.0000      503.0000      206   97.21%
*     0+    0                   0      503.0000      503.0000      206    0.00%
Solution status = Optimal
Solution value = 503
VARIABLE: xB.0.2.6.8.14.15.20,S10 VALUE = 1
[Block no.: 0 , Block type: LHB , Block size: 4
Arrival no.  : 55119-2 , Platform: 1 , Detached: true , Arrival time: Fr, 7:02
Departure no.: 50249-2 , Platform: 2 , Attached: true , Departure time: Fr, 15:48
, Block no.: 2 , Block type: LHB , Block size: 4
Arrival no.  : 50123-2 , Platform: 2 , Detached: true , Arrival time: Fr, 8:32
Departure no.: 50248-2 , Platform: 2 , Attached: true , Departure time: Fr, 15:28
, Block no.: 6 , Block type: LHB , Block size: 4
Arrival no.  : 50150-2 , Platform: 2 , Detached: true , Arrival time: Fr, 17:32
Departure no.: 55231-1 , Platform: 2 , Attached: false , Departure time: Sa, 9:58
, Block no.: 8 , Block type: LHB , Block size: 4
Arrival no.  : 55156-1 , Platform: 1 , Detached: false , Arrival time: Fr, 19:22
Departure no.: 55229-1 , Platform: 1 , Attached: false , Departure time: Sa, 9:18
, Block no.: 14 , Block type: LHB , Block size: 4
Arrival no.  : 55142-1 , Platform: 1 , Detached: false , Arrival time: Sa, 14:42
Departure no.: 56019-1 , Platform: 1 , Attached: false , Departure time: Mn, 5:58
, Block no.: 15 , Block type: LHB , Block size: 4
Arrival no.  : 55143-1 , Platform: 1 , Detached: false , Arrival time: Sa, 15:02
Departure no.: 50222-1 , Platform: 2 , Attached: false , Departure time: Su, 6:48
, Block no.: 20 , Block type: LHB , Block size: 4
Arrival no.  : 50118-2 , Platform: 2 , Detached: true , Arrival time: Su, 6:52
Departure no.: 50219-2 , Platform: 2 , Attached: false , Departure time: Mn, 5:48
]
VARIABLE: xB.1.3.9.10.13.18.21.22,S11 VALUE = 1
[Block no.: 1 , Block type: LHB , Block size: 4
Arrival no.  : 50122-2 , Platform: 2 , Detached: true , Arrival time: Fr, 8:12
Departure no.: 50247-2 , Platform: 2 , Attached: true , Departure time: Fr, 15:08
, Block no.: 3 , Block type: LHB , Block size: 4
Arrival no.  : 50124-2 , Platform: 2 , Detached: true , Arrival time: Fr, 8:52
Departure no.: 50230-1 , Platform: 2 , Attached: false , Departure time: Fr, 9:28
, Block no.: 9 , Block type: LHB , Block size: 4
Arrival no.  : 55157-1 , Platform: 1 , Detached: false , Arrival time: Fr, 19:42
Departure no.: 50219-1 , Platform: 2 , Attached: false , Departure time: Sa, 5:48
, Block no.: 10 , Block type: LHB , Block size: 4
Arrival no.  : 50171-1 , Platform: 2 , Detached: false , Arrival time: Sa, 0:32
```

```
Departure no.: 50218-1 , Platform: 1 , Attached: false , Departure time: Sa, 5:28
, Block no.: 13 , Block type: LHB , Block size: 4
Arrival no.  : 50115-2 , Platform: 2 , Detached: true , Arrival time: Sa, 5:52
Departure no.: 50221-1 , Platform: 2 , Attached: false , Departure time: Su, 6:28
, Block no.: 18 , Block type: LHB , Block size: 4
Arrival no.  : 50100-1 , Platform: 2 , Detached: false , Arrival time: Su, 0:52
Departure no.: 50220-1 , Platform: 2 , Attached: false , Departure time: Su, 6:08
, Block no.: 21 , Block type: LHB , Block size: 4
Arrival no.  : 50171-1 , Platform: 2 , Detached: false , Arrival time: Mn, 0:32
Departure no.: 55221-1 , Platform: 2 , Attached: false , Departure time: Mn, 6:38
, Block no.: 22 , Block type: LHB , Block size: 4
Arrival no.  : 50100-1 , Platform: 2 , Detached: false , Arrival time: Mn, 0:52
Departure no.: 55220-1 , Platform: 2 , Attached: false , Departure time: Mn, 6:18
]
VARIABLE: xB.4.5.7.11.16.17,S12 VALUE = 1
[Block no.: 4 , Block type: LHB , Block size: 4
Arrival no.  : 50125-2 , Platform: 2 , Detached: false , Arrival time: Fr, 9:12
Departure no.: 50246-2 , Platform: 2 , Attached: true , Departure time: Fr, 14:48
, Block no.: 5 , Block type: LHB , Block size: 4
Arrival no.  : 50125-1 , Platform: 2 , Detached: false , Arrival time: Fr, 9:12
Departure no.: 50245-2 , Platform: 2 , Attached: true , Departure time: Fr, 14:28
, Block no.: 7 , Block type: LHB , Block size: 4
Arrival no.  : 50151-2 , Platform: 2 , Detached: true , Arrival time: Fr, 17:52
Departure no.: 55230-1 , Platform: 2 , Attached: false , Departure time: Sa, 9:38
, Block no.: 11 , Block type: LHB , Block size: 4
Arrival no.  : 50100-2 , Platform: 2 , Detached: false , Arrival time: Sa, 0:52
Departure no.: 50217-1 , Platform: 1 , Attached: false , Departure time: Sa, 5:08
, Block no.: 16 , Block type: LHB , Block size: 4
Arrival no.  : 55144-1 , Platform: 1 , Detached: false , Arrival time: Sa, 15:22
Departure no.: 50218-2 , Platform: 2 , Attached: false , Departure time: Mn, 5:28
, Block no.: 17 , Block type: LHB , Block size: 4
Arrival no.  : 50171-1 , Platform: 2 , Detached: false , Arrival time: Su, 0:32
Departure no.: 50217-2 , Platform: 2 , Attached: false , Departure time: Mn, 5:08
]
VARIABLE: zS2 VALUE = 1
---The following block(s) is/are assigned to a platform track---:
[Block no.: 12 , Block type: LHB , Block size: 4
Arrival no.  : 50101-2 , Platform: 2 , Detached: false , Arrival time: Sa, 1:12
Departure no.: 50216-1 , Platform: 2 , Attached: false , Departure time: Sa, 4:48
, Block no.: 19 , Block type: LHB , Block size: 4
Arrival no.  : 50101-1 , Platform: 2 , Detached: false , Arrival time: Su, 1:12
Departure no.: 50219-1 , Platform: 2 , Attached: false , Departure time: Su, 5:48
, Block no.: 23 , Block type: LHB , Block size: 4
Arrival no.  : 50101-1 , Platform: 2 , Detached: false , Arrival time: Mn, 1:12
Departure no.: 50216-1 , Platform: 2 , Attached: false , Departure time: Mn, 4:48
]

All 24 blocks have been assigned to a track!

Block |  New  | Type | Size | Day & Time |  From/to   |   Track    |          Activity          |    From/to     | Stock
[
0     |   -   | LHB  | 4    | Fr - 07:02 | 55119-2    | P1  /S10   | Arrive at platform - Det.  |    50249-2     | 4,
1     |   -   | LHB  | 4    | Fr - 08:12 | 50122-2    | P2  /S11   | Arrive at platform - Det.  |    50247-2     | 8,
2     |   -   | LHB  | 4    | Fr - 08:32 | 50123-2    | P2  /S10   | Arrive at platform - Det.  |    50248-2     | 12,
3     |   -   | LHB  | 4    | Fr - 08:52 | 50124-2    | P2  /S11   | Arrive at platform - Det.  |    50230-1     | 16,
4     |   -   | LHB  | 4    | Fr - 09:12 | 50125-2    | P2  /S12   | Arrive at platform         |    50246-2     | 20,
5     |   -   | LHB  | 4    | Fr - 09:12 | 50125-1    | P2  /S12   | Arrive at platform         |    50245-2     | 24,
3     |   -   | LHB  | 4    | Fr - 09:28 |    50230-1 | S11 /P2    | Depart from platform       | 50124-2        | 20,
5     |   -   | LHB  | 4    | Fr - 14:28 |    50245-2 | S12 /P2    | Depart from platform - Att. | 50125-1       | 16,
4     |   -   | LHB  | 4    | Fr - 14:48 |    50246-2 | S12 /P2    | Depart from platform - Att. | 50125-2       | 12,
1     |   -   | LHB  | 4    | Fr - 15:08 |    50247-2 | S11 /P2    | Depart from platform - Att. | 50122-2       | 8,
2     |   -   | LHB  | 4    | Fr - 15:28 |    50248-2 | S10 /P2    | Depart from platform - Att. | 50123-2       | 4,
0     |   -   | LHB  | 4    | Fr - 15:48 |    50249-2 | S10 /P2    | Depart from platform - Att. | 55119-2       | 0,
6     |   -   | LHB  | 4    | Fr - 17:32 | 50150-2    | P2  /S10   | Arrive at platform - Det.  |    55231-1     | 4,
7     |   -   | LHB  | 4    | Fr - 17:52 | 50151-2    | P2  /S12   | Arrive at platform - Det.  |    55230-1     | 8,
8     |   -   | LHB  | 4    | Fr - 19:22 | 55156-1    | P1  /S10   | Arrive at platform         |    55229-1     | 12,
9     |   -   | LHB  | 4    | Fr - 19:42 | 55157-1    | P1  /S11   | Arrive at platform         |    50219-1     | 16,
10    |   -   | LHB  | 4    | Sa - 00:32 | 50171-1    | P2  /S11   | Arrive at platform         |    50218-1     | 20,
11    |   -   | LHB  | 4    | Sa - 00:52 | 50100-2    | P2  /S12   | Arrive at platform         |    50217-1     | 24,
12    |   -   | LHB  | 4    | Sa - 01:12 | 50101-2    | P2         | Arrive at platform (stay)  |    50216-1     | 28,
12    |   -   | LHB  | 4    | Sa - 04:48 |    50216-1 | P2         | Depart from platform       | 50101-2        | 24,
11    |   -   | LHB  | 4    | Sa - 05:08 |    50217-1 | S12 /P1    | Depart from platform       | 50100-2        | 20,
10    |   -   | LHB  | 4    | Sa - 05:28 |    50218-1 | S11 /P1    | Depart from platform       | 50171-1        | 16,
9     |   -   | LHB  | 4    | Sa - 05:48 |    50219-1 | S11 /P2    | Depart from platform       | 55157-1        | 12,
13    |   -   | LHB  | 4    | Sa - 05:52 | 50115-2    | P2  /S11   | Arrive at platform - Det.  |    50221-1     | 16,
8     |   -   | LHB  | 4    | Sa - 09:18 |    55229-1 | S10 /P1    | Depart from platform       | 55156-1        | 12,
7     |   -   | LHB  | 4    | Sa - 09:38 |    55230-1 | S12 /P2    | Depart from platform       | 50151-2        | 8,
6     |   -   | LHB  | 4    | Sa - 09:58 |    55231-1 | S10 /P2    | Depart from platform       | 50150-2        | 4,
14    |   -   | LHB  | 4    | Sa - 14:42 | 55142-1    | P1  /S10   | Arrive at platform         |    56019-1     | 8,
15    |   -   | LHB  | 4    | Sa - 15:02 | 55143-1    | P1  /S10   | Arrive at platform         |    50222-1     | 12,
16    |   -   | LHB  | 4    | Sa - 15:22 | 55144-1    | P1  /S12   | Arrive at platform         |    50218-2     | 16,
17    |   -   | LHB  | 4    | Su - 00:32 | 50171-1    | P2  /S12   | Arrive at platform         |    50217-2     | 20,
18    |   -   | LHB  | 4    | Su - 00:52 | 50100-1    | P2  /S11   | Arrive at platform         |    50220-1     | 24,
19    |   -   | LHB  | 4    | Su - 01:12 | 50101-1    | P2         | Arrive at platform (stay)  |    50219-1     | 28,
19    |   -   | LHB  | 4    | Su - 05:48 |    50219-1 | P2         | Depart from platform       | 50101-1        | 24,
18    |   -   | LHB  | 4    | Su - 06:08 |    50220-1 | S11 /P2    | Depart from platform       | 50100-1        | 20,
13    |   -   | LHB  | 4    | Su - 06:28 |    50221-1 | S11 /P2    | Depart from platform       | 50115-2        | 16,
```

```
15    |   -   | LHB  | 4    | Su - 06:48 |     50222-1 | S10 /P2   | Depart from platform       | 55143-1         | 12,
20    |   -   | LHB  | 4    | Su - 06:52 | 50118-2     | P2  /S10  | Arrive at platform - Det.  |    50219-2      | 16,
21    |   -   | LHB  | 4    | Mn - 00:32 | 50171-1     | P2  /S11  | Arrive at platform         |    55221-1      | 20,
22    |   -   | LHB  | 4    | Mn - 00:52 | 50100-1     | P2  /S11  | Arrive at platform         |    55220-1      | 24,
23    |   -   | LHB  | 4    | Mn - 01:12 | 50101-1     | P2        | Arrive at platform (stay)  |    50216-1      | 28,
23    |   -   | LHB  | 4    | Mn - 04:48 |     50216-1 | P2        | Depart from platform       | 50101-1         | 24,
17    |   -   | LHB  | 4    | Mn - 05:08 |     50217-2 | S12 /P2   | Depart from platform       | 50171-1         | 20,
16    |   -   | LHB  | 4    | Mn - 05:28 |     50218-2 | S12 /P2   | Depart from platform       | 55144-1         | 16,
20    |   -   | LHB  | 4    | Mn - 05:48 |     50219-2 | S10 /P2   | Depart from platform       | 50118-2         | 12,
14    |   -   | LHB  | 4    | Mn - 05:58 |     56019-1 | S10 /P1   | Depart from platform       | 55142-1         | 8,
22    |   -   | LHB  | 4    | Mn - 06:18 |     55220-1 | S11 /P2   | Depart from platform       | 50100-1         | 4,
21    |   -   | LHB  | 4    | Mn - 06:38 |     55221-1 | S11 /P2   | Depart from platform       | 50171-1         | 0]
Generate solutions time 2662 msec.
Generate model time 8881 msec.
Write model time 2770 msec.
Solve model time 8467 msec.
Overall solution time 22780 msec.
```

A.4 Farum - Working day (Test - 17 crossings)

```
 ---Starting depot planning for FM---

Block |  New  | Type | Size | Day & Time |  From/to   |   Track   |           Activity           |     From/to     | Stock
[
0     |   -   | LHB  | 4    | Mo - 08:32 | 50123-2    | P2        | Arrive at platform - Det.    |    50230-1      | 4,
1     |   -   | LHB  | 4    | Mo - 08:52 | 50124-2    | P2        | Arrive at platform - Det.    |    50246-2      | 8,
2     |   -   | LHB  | 4    | Mo - 09:12 | 50125-2    | P2        | Arrive at platform           |    50246-2      | 12,
3     |   -   | LHB  | 4    | Mo - 09:12 | 50125-1    | P2        | Arrive at platform           |    50248-2      | 16,
0     |   -   | LHB  | 4    | Mo - 09:28 |    50230-1 | P2        | Depart from platform         | 50123-2         | 12,
1     |   -   | LHB  | 4    | Mo - 14:48 |    50246-2 | P2        | Depart from platform - Att.  | 50124-2         | 8,
3     |   -   | LHB  | 4    | Mo - 15:28 |    50248-2 | P2        | Depart from platform - Att.  | 50125-1         | 4,
2     |   -   | LHB  | 4    | Mo - 15:48 |    50246-2 | P2        | Depart from platform - Att.  | 50125-2         | 0,
4     |   -   | LHB  | 4    | Mo - 16:42 | 55148-2    | P1        | Arrive at platform - Det.    |    50218-2      | 4,
5     |   -   | LHB  | 4    | Mo - 17:02 | 55149-2    | P1        | Arrive at platform - Det.    |    50217-2      | 8,
6     |   -   | LHB  | 4    | Mo - 19:22 | 55156-1    | P1        | Arrive at platform           |    56019-1      | 12,
7     |   -   | LHB  | 4    | Mo - 19:42 | 55157-1    | P1        | Arrive at platform           |    50219-2      | 16,
8     |   -   | LHB  | 4    | Tu - 00:32 | 50171-2    | P2        | Arrive at platform           |    55221-1      | 20,
9     |   -   | LHB  | 4    | Tu - 00:52 | 50100-2    | P2        | Arrive at platform           |    55220-1      | 24,
10    |   -   | LHB  | 4    | Tu - 01:12 | 50101-2    | P2        | Arrive at platform           |    50216-1      | 28,
10    |   -   | LHB  | 4    | Tu - 04:48 |    50216-1 | P2        | Depart from platform         | 50101-2         | 24,
5     |   -   | LHB  | 4    | Tu - 05:08 |    50217-2 | P2        | Depart from platform         | 55149-2         | 20,
4     |   -   | LHB  | 4    | Tu - 05:28 |    50218-2 | P2        | Depart from platform         | 55148-2         | 16,
7     |   -   | LHB  | 4    | Tu - 05:48 |    50219-2 | P2        | Depart from platform         | 55157-1         | 12,
6     |   -   | LHB  | 4    | Tu - 05:58 |    56019-1 | P1        | Depart from platform         | 55156-1         | 8,
9     |   -   | LHB  | 4    | Tu - 06:18 |    55220-1 | P1        | Depart from platform         | 50100-2         | 4,
8     |   -   | LHB  | 4    | Tu - 06:38 |    55221-1 | P1        | Depart from platform         | 50171-2         | 0]

- The number of crossings in the timetable is 17 (the maximum number is 27).

...Running the prototype...

All 11 blocks have been assigned to a track!

Block |  New  | Type | Size | Day & Time |  From/to   |   Track   |           Activity           |     From/to     | Stock
[
0     |   -   | LHB  | 4    | Mo - 08:32 | 50123-2    | P2  /S10  | Arrive at platform - Det.    |    50230-1      | 4,
1     |   -   | LHB  | 4    | Mo - 08:52 | 50124-2    | P2  /S11  | Arrive at platform - Det.    |    50246-2      | 8,
2     |   -   | LHB  | 4    | Mo - 09:12 | 50125-2    | P2  /S12  | Arrive at platform           |    50246-2      | 12,
3     |   -   | LHB  | 4    | Mo - 09:12 | 50125-1    | P2  /S12  | Arrive at platform           |    50248-2      | 16,
0     |   -   | LHB  | 4    | Mo - 09:28 |    50230-1 | S10 /P2   | Depart from platform         | 50123-2         | 12,
1     |   -   | LHB  | 4    | Mo - 14:48 |    50246-2 | S11 /P2   | Depart from platform - Att.  | 50124-2         | 8,
3     |   -   | LHB  | 4    | Mo - 15:28 |    50248-2 | S12 /P2   | Depart from platform - Att.  | 50125-1         | 4,
2     |   -   | LHB  | 4    | Mo - 15:48 |    50246-2 | S12 /P2   | Depart from platform - Att.  | 50125-2         | 0,
4     |   -   | LHB  | 4    | Mo - 16:42 | 55148-2    | P1  /S11  | Arrive at platform - Det.    |    50218-2      | 4,
5     |   -   | LHB  | 4    | Mo - 17:02 | 55149-2    | P1  /S11  | Arrive at platform - Det.    |    50217-2      | 8,
6     |   -   | LHB  | 4    | Mo - 19:22 | 55156-1    | P1  /S12  | Arrive at platform           |    56019-1      | 12,
7     |   -   | LHB  | 4    | Mo - 19:42 | 55157-1    | P1  /S12  | Arrive at platform           |    50219-2      | 16,
8     |   -   | LHB  | 4    | Tu - 00:32 | 50171-2    | P2  /S10  | Arrive at platform           |    55221-1      | 20,
9     |   -   | LHB  | 4    | Tu - 00:52 | 50100-2    | P2  /S10  | Arrive at platform           |    55220-1      | 24,
10    |   -   | LHB  | 4    | Tu - 01:12 | 50101-2    | P2        | Arrive at platform (stay)    |    50216-1      | 28,
10    |   -   | LHB  | 4    | Tu - 04:48 |    50216-1 | P2        | Depart from platform         | 50101-2         | 24,
5     |   -   | LHB  | 4    | Tu - 05:08 |    50217-2 | S11 /P2   | Depart from platform         | 55149-2         | 20,
4     |   -   | LHB  | 4    | Tu - 05:28 |    50218-2 | S11 /P2   | Depart from platform         | 55148-2         | 16,
7     |   -   | LHB  | 4    | Tu - 05:48 |    50219-2 | S12 /P2   | Depart from platform         | 55157-1         | 12,
6     |   -   | LHB  | 4    | Tu - 05:58 |    56019-1 | S12 /P1   | Depart from platform         | 55156-1         | 8,
9     |   -   | LHB  | 4    | Tu - 06:18 |    55220-1 | S10 /P1   | Depart from platform         | 50100-2         | 4,
8     |   -   | LHB  | 4    | Tu - 06:38 |    55221-1 | S10 /P1   | Depart from platform         | 50171-2         | 0]

Generate solutions time 61 msec.
Generate model time 383 msec.
Write model time 49 msec.
Solve model time 121 msec.
Overall solution time 614 msec.
```

A.5 Frederikssund - Working day (2005-1)

---Starting depot planning for FS---

Block	New	Type	Size	Day & Time	From/to	Track	Activity	From/to	Stock
[									
0	-	LHB	4	Mo - 08:43	55223-1	P2	Arrive at platform - Det.	55149-1	4,
1	-	LHB	4	Mo - 09:53	50227-1	P1	Arrive at platform - Det.	55148-1	8,
1	-	LHB	4	Mo - 15:16	55148-1	P2	Depart from platform - Att.	50227-1	4,
0	-	LHB	4	Mo - 15:36	55149-1	P2	Depart from platform - Att.	55223-1	0,
2	-	LHB	4	Mo - 16:13	50246-1	P1	Arrive at platform - Det.	50118-1	4,
3	-	LHB	4	Mo - 16:53	50248-1	P1	Arrive at platform - Det.	50116-1	8,
4	-	LHB	4	Mo - 17:13	50249-1	P1	Arrive at platform - Det.	50120-1	12,
5	-	LHB	4	Mo - 18:23	55252-1	P2	Arrive at platform	55121-1	16,
6	-	LHB	4	Mo - 18:43	55253-1	P2	Arrive at platform	55120-1	20,
7	-	LHB	4	Mo - 19:03	55254-1	P2	Arrive at platform	55124-1	24,
8	-	LHB	4	Mo - 19:23	55255-1	P2	Arrive at platform	55123-1	28,
9	-	LHB	4	Mo - 19:43	55256-1	P2	Arrive at platform	50124-1	32,
10	-	LHB	4	Mo - 20:03	55257-1	P2	Arrive at platform	50123-1	36,
11	-	LHB	4	Tu - 00:53	50200-1	P1	Arrive at platform	50119-1	40,
12	-	LHB	4	Tu - 01:13	50201-1	P1	Arrive at platform	50117-1	44,
3	-	LHB	4	Tu - 04:46	50116-1	P1	Depart from platform	50248-1	40,
12	-	LHB	4	Tu - 05:06	50117-1	P1	Depart from platform	50201-1	36,
2	-	LHB	4	Tu - 05:26	50118-1	P1	Depart from platform	50246-1	32,
11	-	LHB	4	Tu - 05:46	50119-1	P1	Depart from platform	50200-1	28,
13	-	LHB	4	Tu - 05:53	50215-1	P1	Arrive at platform	50122-1	32,
14	-	LHB	4	Tu - 05:53	50215-2	P1	Arrive at platform	55122-1	36,
6	-	LHB	4	Tu - 05:56	55120-1	P2	Depart from platform	55253-1	32,
4	-	LHB	4	Tu - 06:06	50120-1	P1	Depart from platform	50249-1	28,
5	-	LHB	4	Tu - 06:16	55121-1	P2	Depart from platform	55252-1	24,
14	-	LHB	4	Tu - 06:36	55122-1	P2	Depart from platform	50215-2	20,
13	-	LHB	4	Tu - 06:46	50122-1	P1	Depart from platform - Att.	50215-1	16,
8	-	LHB	4	Tu - 06:56	55123-1	P2	Depart from platform	55255-1	12,
10	-	LHB	4	Tu - 07:06	50123-1	P1	Depart from platform - Att.	55257-1	8,
7	-	LHB	4	Tu - 07:16	55124-1	P2	Depart from platform	55254-1	4,
9	-	LHB	4	Tu - 07:26	50124-1	P1	Depart from platform - Att.	55256-1	0]

- The number of crossings in the timetable is 39 (the maximum number is 71).

---Running feasibility check---

1. Finding the number of drivers needed based on the arrivals in the timetable.

- Based on the arrivals of train units in the timetable ONE driver is enough!

2. Checking the capacity needed at the shunt yard.

- The maximum number of units at the shunt yard during the planning period is 44.
- Based on the timetable there is enough capacity at the shunt yard (the capacity is 48 units)!

Check!

3. Checking for infeasiblity in the timetable.

Check!

4. Checking for shunt tracks with insufficient capacity.

Check!

Use symmetry if possible (yes/no)?
y

Set penalty for parking blocks with different subtype on the same shunt track (yes/no)?
y

Set penalties for broken arrivals and departures (yes/no)?
y

Make blocks that are detached at the station cheaper (yes/no)?
y

Create shunt plan (yes/no)?
y

...Solving the parking problem...

All 15 blocks have been assigned to a track!

Block	New	Type	Size	Day & Time	From/to	Track	Activity	From/to	Stock
[									
0	-	LHB	4	Mo - 08:43	55223-1	P2 /S11	Arrive at platform - Det.	55149-1	4,
1	-	LHB	4	Mo - 09:53	50227-1	P1 /S12	Arrive at platform - Det.	55148-1	8,
1	-	LHB	4	Mo - 15:16	55148-1	S12 /P2	Depart from platform - Att.	50227-1	4,

```
0    |  -  | LHB  | 4    | Mo - 15:36 |    55149-1 | S11 /P2   | Depart from platform - Att. | 55223-1        | 0,
2    |  -  | LHB  | 4    | Mo - 16:13 | 50246-1    | P1  /S11  | Arrive at platform - Det.   |    50118-1     | 4,
3    |  -  | LHB  | 4    | Mo - 16:53 | 50248-1    | P1  /S11  | Arrive at platform - Det.   |    50116-1     | 8,
4    |  -  | LHB  | 4    | Mo - 17:13 | 50249-1    | P1  /S21  | Arrive at platform - Det.   |    50120-1     | 12,
5    |  -  | LHB  | 4    | Mo - 18:23 | 55252-1    | P2  /S12  | Arrive at platform          |    55121-1     | 16,
6    |  -  | LHB  | 4    | Mo - 18:43 | 55253-1    | P2  /S12  | Arrive at platform          |    55120-1     | 20,
7    |  -  | LHB  | 4    | Mo - 19:03 | 55254-1    | P2  /S13  | Arrive at platform          |    55124-1     | 24,
8    |  -  | LHB  | 4    | Mo - 19:23 | 55255-1    | P2  /S13  | Arrive at platform          |    55123-1     | 28,
9    |  -  | LHB  | 4    | Mo - 19:43 | 55256-1    | P2  /S14  | Arrive at platform          |    50124-1     | 32,
10   |  -  | LHB  | 4    | Mo - 20:03 | 55257-1    | P2  /S14  | Arrive at platform          |    50123-1     | 36,
11   |  -  | LHB  | 4    | Tu - 00:53 | 50200-1    | P1  /S22  | Arrive at platform          |    50119-1     | 40,
12   |  -  | LHB  | 4    | Tu - 01:13 | 50201-1    | P1  /S22  | Arrive at platform          |    50117-1     | 44,
3    |  -  | LHB  | 4    | Tu - 04:46 |    50116-1 | S11 /P1   | Depart from platform        | 50248-1        | 40,
12   |  -  | LHB  | 4    | Tu - 05:06 |    50117-1 | S22 /P1   | Depart from platform        | 50201-1        | 36,
2    |  -  | LHB  | 4    | Tu - 05:26 |    50118-1 | S11 /P1   | Depart from platform        | 50246-1        | 32,
11   |  -  | LHB  | 4    | Tu - 05:46 |    50119-1 | S22 /P1   | Depart from platform        | 50200-1        | 28,
13   |  -  | LHB  | 4    | Tu - 05:53 | 50215-1    | P1  /S11  | Arrive at platform          |    50122-1     | 32,
14   |  -  | LHB  | 4    | Tu - 05:53 | 50215-2    | P1  /S11  | Arrive at platform          |    55122-1     | 36,
6    |  -  | LHB  | 4    | Tu - 05:56 |    55120-1 | S12 /P2   | Depart from platform        | 55253-1        | 32,
4    |  -  | LHB  | 4    | Tu - 06:06 |    50120-1 | S21 /P1   | Depart from platform        | 50249-1        | 28,
5    |  -  | LHB  | 4    | Tu - 06:16 |    55121-1 | S12 /P2   | Depart from platform        | 55252-1        | 24,
14   |  -  | LHB  | 4    | Tu - 06:36 |    55122-1 | S11 /P2   | Depart from platform        | 50215-2        | 20,
13   |  -  | LHB  | 4    | Tu - 06:46 |    50122-1 | S11 /P1   | Depart from platform - Att. | 50215-1        | 16,
8    |  -  | LHB  | 4    | Tu - 06:56 |    55123-1 | S13 /P2   | Depart from platform        | 55255-1        | 12,
10   |  -  | LHB  | 4    | Tu - 07:06 |    50123-1 | S14 /P1   | Depart from platform - Att. | 55257-1        | 8,
7    |  -  | LHB  | 4    | Tu - 07:16 |    55124-1 | S13 /P2   | Depart from platform        | 55254-1        | 4,
9    |  -  | LHB  | 4    | Tu - 07:26 |    50124-1 | S14 /P1   | Depart from platform - Att. | 55256-1        | 0]

Generate solutions time 117 msec.
Generate model time 537 msec.
Write model time 51 msec.
Solve model time 276 msec.
Overall solution time 981 msec.
```

A.6 Frederikssund - Weekend (2005-1)

```
 ---Starting depot planning for FS---

Block |  New  | Type | Size | Day & Time |  From/to   |   Track    |          Activity          |    From/to     | Stock
[
0     |   -   | LHB  | 4    | Fr - 16:33 | 50247-1    | P1         | Arrive at platform - Det.  |    50131-1     | 4,
1     |   -   | LHB  | 4    | Fr - 16:53 | 50248-1    | P1         | Arrive at platform - Det.  |    50119-1     | 8,
2     |   -   | LHB  | 4    | Fr - 17:13 | 50249-1    | P1         | Arrive at platform - Det.  |    50118-1     | 12,
3     |   -   | LHB  | 4    | Fr - 18:23 | 55252-1    | P2         | Arrive at platform         |    55130-1     | 16,
4     |   -   | LHB  | 4    | Fr - 18:43 | 55253-1    | P2         | Arrive at platform         |    55129-1     | 20,
5     |   -   | LHB  | 4    | Fr - 19:03 | 55254-1    | P2         | Arrive at platform         |    55133-1     | 24,
6     |   -   | LHB  | 4    | Fr - 19:23 | 55255-1    | P2         | Arrive at platform         |    55132-1     | 28,
7     |   -   | LHB  | 4    | Fr - 19:43 | 55256-1    | P2         | Arrive at platform         |    50117-1     | 32,
8     |   -   | LHB  | 4    | Fr - 20:03 | 55257-1    | P2         | Arrive at platform         |    50116-1     | 36,
9     |   -   | LHB  | 4    | Sa - 00:53 | 50200-1    | P1         | Arrive at platform         |    55131-1     | 40,
10    |   -   | LHB  | 4    | Sa - 01:13 | 50201-1    | P1         | Arrive at platform         |    50120-1     | 44,
8     |   -   | LHB  | 4    | Sa - 04:46 |    50116-1 | P1         | Depart from platform       | 55257-1        | 40,
7     |   -   | LHB  | 4    | Sa - 05:06 |    50117-1 | P1         | Depart from platform       | 55256-1        | 36,
2     |   -   | LHB  | 4    | Sa - 05:26 |    50118-1 | P1         | Depart from platform       | 50249-1        | 32,
1     |   -   | LHB  | 4    | Sa - 05:46 |    50119-1 | P1         | Depart from platform       | 50248-1        | 28,
11    |   -   | LHB  | 4    | Sa - 05:53 | 50215-1    | P1         | Arrive at platform         |    50122-1     | 32,
12    |   -   | LHB  | 4    | Sa - 05:53 | 50215-2    | P1         | Arrive at platform         |    50121-1     | 36,
10    |   -   | LHB  | 4    | Sa - 06:06 |    50120-1 | P1         | Depart from platform       | 50201-1        | 32,
4     |   -   | LHB  | 4    | Sa - 08:56 |    55129-1 | P2         | Depart from platform       | 55253-1        | 28,
13    |   -   | LHB  | 4    | Sa - 09:33 | 50226-1    | P1         | Arrive at platform         |    50119-1     | 32,
3     |   -   | LHB  | 4    | Sa - 09:36 |    55130-1 | P2         | Depart from platform       | 55252-1        | 28,
9     |   -   | LHB  | 4    | Sa - 09:36 |    55131-1 | P2         | Depart from platform       | 50200-1        | 24,
0     |   -   | LHB  | 4    | Sa - 09:46 |    50131-1 | P1         | Depart from platform       | 50247-1        | 20,
6     |   -   | LHB  | 4    | Sa - 09:56 |    55132-1 | P2         | Depart from platform       | 55255-1        | 16,
5     |   -   | LHB  | 4    | Sa - 10:16 |    55133-1 | P2         | Depart from platform       | 55254-1        | 12,
14    |   -   | LHB  | 4    | Sa - 14:23 | 55240-1    | P2         | Arrive at platform         |    55121-1     | 16,
15    |   -   | LHB  | 4    | Sa - 14:43 | 55241-1    | P2         | Arrive at platform         |    55120-1     | 20,
16    |   -   | LHB  | 4    | Sa - 15:03 | 55242-1    | P2         | Arrive at platform         |    55124-1     | 24,
17    |   -   | LHB  | 4    | Sa - 15:23 | 55243-1    | P2         | Arrive at platform         |    50123-1     | 28,
18    |   -   | LHB  | 4    | Sa - 15:43 | 55244-1    | P2         | Arrive at platform         |    50119-1     | 32,
19    |   -   | LHB  | 4    | Su - 00:33 | 50271-1    | P1         | Arrive at platform         |    50118-1     | 36,
20    |   -   | LHB  | 4    | Su - 00:53 | 50200-1    | P1         | Arrive at platform         |    50116-1     | 40,
21    |   -   | LHB  | 4    | Su - 01:13 | 50201-1    | P1         | Arrive at platform         |    50120-1     | 44,
13    |   -   | LHB  | 4    | Su - 05:46 |    50119-1 | P1         | Depart from platform       | 50226-1        | 40,
21    |   -   | LHB  | 4    | Su - 06:06 |    50120-1 | P1         | Depart from platform       | 50201-1        | 36,
12    |   -   | LHB  | 4    | Su - 06:26 |    50121-1 | P1         | Depart from platform       | 50215-2        | 32,
11    |   -   | LHB  | 4    | Su - 06:46 |    50122-1 | P1         | Depart from platform       | 50215-1        | 28,
22    |   -   | LHB  | 4    | Su - 06:53 | 50218-1    | P1         | Arrive at platform         |    50124-1     | 32,
23    |   -   | LHB  | 4    | Su - 06:53 | 50218-2    | P1         | Arrive at platform         |    50123-1     | 36,
17    |   -   | LHB  | 4    | Su - 07:06 |    50123-1 | P1         | Depart from platform       | 55243-1        | 32,
24    |   -   | LHB  | 4    | Mn - 00:33 | 50271-1    | P1         | Arrive at platform         |    55123-1     | 36,
25    |   -   | LHB  | 4    | Mn - 00:53 | 50200-1    | P1         | Arrive at platform         |    50117-1     | 40,
26    |   -   | LHB  | 4    | Mn - 01:13 | 50201-1    | P1         | Arrive at platform         |    50120-1     | 44,
20    |   -   | LHB  | 4    | Mn - 04:46 |    50116-1 | P1         | Depart from platform       | 50200-1        | 40,
25    |   -   | LHB  | 4    | Mn - 05:06 |    50117-1 | P1         | Depart from platform       | 50200-1        | 36,
19    |   -   | LHB  | 4    | Mn - 05:26 |    50118-1 | P1         | Depart from platform       | 50271-1        | 32,
18    |   -   | LHB  | 4    | Mn - 05:46 |    50119-1 | P1         | Depart from platform       | 55244-1        | 28,
27    |   -   | LHB  | 4    | Mn - 05:53 | 50215-1    | P1         | Arrive at platform         |    50122-1     | 32,
28    |   -   | LHB  | 4    | Mn - 05:53 | 50215-2    | P1         | Arrive at platform         |    55122-1     | 36,
15    |   -   | LHB  | 4    | Mn - 05:56 |    55120-1 | P2         | Depart from platform       | 55241-1        | 32,
26    |   -   | LHB  | 4    | Mn - 06:06 |    50120-1 | P1         | Depart from platform       | 50201-1        | 28,
14    |   -   | LHB  | 4    | Mn - 06:16 |    55121-1 | P2         | Depart from platform       | 55240-1        | 24,
28    |   -   | LHB  | 4    | Mn - 06:36 |    55122-1 | P2         | Depart from platform       | 50215-2        | 20,
27    |   -   | LHB  | 4    | Mn - 06:46 |    50122-1 | P1         | Depart from platform - Att. | 50215-1       | 16,
24    |   -   | LHB  | 4    | Mn - 06:56 |    55123-1 | P2         | Depart from platform       | 50271-1        | 12,
23    |   -   | LHB  | 4    | Mn - 07:06 |    50123-1 | P1         | Depart from platform - Att. | 50218-2       | 8,
16    |   -   | LHB  | 4    | Mn - 07:16 |    55124-1 | P2         | Depart from platform       | 55242-1        | 4,
22    |   -   | LHB  | 4    | Mn - 07:26 |    50124-1 | P1         | Depart from platform - Att. | 50218-1       | 0]

- The number of crossings in the timetable is 100 (the maximum number is 186).

 ---Running feasibility check---

1. Finding the number of drivers needed based on the arrivals in the timetable.

- Based on the arrivals of train units in the timetable ONE driver is enough!

2. Checking the capacity needed at the shunt yard.

- The maximum number of units at the shunt yard during the planning period is 44.
- Based on the timetable there is enough capacity at the shunt yard (the capacity is 48 units)!

Check!

3. Checking for infeasiblity in the timetable.

Check!
```

```
4. Checking for shunt tracks with insufficient capacity.

Check!

Use symmetry if possible (yes/no)?
y

Set penalty for parking blocks with different subtype on the same shunt track (yes/no)?
y

Set penalties for broken arrivals and departures (yes/no)?
y

Make blocks that are detached at the station cheaper (yes/no)?
y

Create shunt plan (yes/no)?
y

...Solving the parking problem...

All 29 blocks have been assigned to a track!
Block |  New  | Type | Size | Day & Time |  From/to   |   Track   |         Activity          |    From/to     | Stock
[
0     |   -   | LHB  | 4    | Fr - 16:33 | 50247-1    | P1  /S11  | Arrive at platform - Det.  |    50131-1     | 4,
1     |   -   | LHB  | 4    | Fr - 16:53 | 50248-1    | P1  /S21  | Arrive at platform - Det.  |    50119-1     | 8,
2     |   -   | LHB  | 4    | Fr - 17:13 | 50249-1    | P1  /S21  | Arrive at platform - Det.  |    50118-1     | 12,
3     |   -   | LHB  | 4    | Fr - 18:23 | 55252-1    | P2  /S12  | Arrive at platform         |    55130-1     | 16,
4     |   -   | LHB  | 4    | Fr - 18:43 | 55253-1    | P2  /S11  | Arrive at platform         |    55129-1     | 20,
5     |   -   | LHB  | 4    | Fr - 19:03 | 55254-1    | P2  /S13  | Arrive at platform         |    55133-1     | 24,
6     |   -   | LHB  | 4    | Fr - 19:23 | 55255-1    | P2  /S13  | Arrive at platform         |    55132-1     | 28,
7     |   -   | LHB  | 4    | Fr - 19:43 | 55256-1    | P2  /S14  | Arrive at platform         |    50117-1     | 32,
8     |   -   | LHB  | 4    | Fr - 20:03 | 55257-1    | P2  /S14  | Arrive at platform         |    50116-1     | 36,
9     |   -   | LHB  | 4    | Sa - 00:53 | 50200-1    | P1  /S12  | Arrive at platform         |    55131-1     | 40,
10    |   -   | LHB  | 4    | Sa - 01:13 | 50201-1    | P1  /S22  | Arrive at platform         |    50120-1     | 44,
8     |   -   | LHB  | 4    | Sa - 04:46 |    50116-1 | S14 /P1   | Depart from platform       | 55257-1        | 40,
7     |   -   | LHB  | 4    | Sa - 05:06 |    50117-1 | S14 /P1   | Depart from platform       | 55256-1        | 36,
2     |   -   | LHB  | 4    | Sa - 05:26 |    50118-1 | S21 /P1   | Depart from platform       | 50249-1        | 32,
1     |   -   | LHB  | 4    | Sa - 05:46 |    50119-1 | S21 /P1   | Depart from platform       | 50248-1        | 28,
11    |   -   | LHB  | 4    | Sa - 05:53 | 50215-1    | P1  /S21  | Arrive at platform         |    50122-1     | 32,
12    |   -   | LHB  | 4    | Sa - 05:53 | 50215-2    | P1  /S21  | Arrive at platform         |    50121-1     | 36,
10    |   -   | LHB  | 4    | Sa - 06:06 |    50120-1 | S22 /P1   | Depart from platform       | 50201-1        | 32,
4     |   -   | LHB  | 4    | Sa - 08:56 |    55129-1 | S11 /P2   | Depart from platform       | 55253-1        | 28,
13    |   -   | LHB  | 4    | Sa - 09:33 | 50226-1    | P1  /S22  | Arrive at platform         |    50119-1     | 32,
3     |   -   | LHB  | 4    | Sa - 09:36 |    55130-1 | S12 /P2   | Depart from platform       | 55252-1        | 28,
9     |   -   | LHB  | 4    | Sa - 09:36 |    55131-1 | S12 /P2   | Depart from platform       | 50200-1        | 24,
0     |   -   | LHB  | 4    | Sa - 09:46 |    50131-1 | S11 /P1   | Depart from platform       | 50247-1        | 20,
6     |   -   | LHB  | 4    | Sa - 09:56 |    55132-1 | S13 /P2   | Depart from platform       | 55255-1        | 16,
5     |   -   | LHB  | 4    | Sa - 10:16 |    55133-1 | S13 /P2   | Depart from platform       | 55254-1        | 12,
14    |   -   | LHB  | 4    | Sa - 14:23 | 55240-1    | P2  /S14  | Arrive at platform         |    55121-1     | 16,
15    |   -   | LHB  | 4    | Sa - 14:43 | 55241-1    | P2  /S14  | Arrive at platform         |    55120-1     | 20,
16    |   -   | LHB  | 4    | Sa - 15:03 | 55242-1    | P2  /S11  | Arrive at platform         |    55124-1     | 24,
17    |   -   | LHB  | 4    | Sa - 15:23 | 55243-1    | P2  /S11  | Arrive at platform         |    50123-1     | 28,
18    |   -   | LHB  | 4    | Sa - 15:43 | 55244-1    | P2  /S13  | Arrive at platform         |    50119-1     | 32,
19    |   -   | LHB  | 4    | Su - 00:33 | 50271-1    | P1  /S12  | Arrive at platform         |    50118-1     | 36,
20    |   -   | LHB  | 4    | Su - 00:53 | 50200-1    | P1  /S13  | Arrive at platform         |    50116-1     | 40,
21    |   -   | LHB  | 4    | Su - 01:13 | 50201-1    | P1  /S12  | Arrive at platform         |    50120-1     | 44,
13    |   -   | LHB  | 4    | Su - 05:46 |    50119-1 | S22 /P1   | Depart from platform       | 50226-1        | 40,
21    |   -   | LHB  | 4    | Su - 06:06 |    50120-1 | S12 /P1   | Depart from platform       | 50201-1        | 36,
12    |   -   | LHB  | 4    | Su - 06:26 |    50121-1 | S21 /P1   | Depart from platform       | 50215-2        | 32,
11    |   -   | LHB  | 4    | Su - 06:46 |    50122-1 | S21 /P1   | Depart from platform       | 50215-1        | 28,
22    |   -   | LHB  | 4    | Su - 06:53 | 50218-1    | P1  /S21  | Arrive at platform         |    50124-1     | 32,
23    |   -   | LHB  | 4    | Su - 06:53 | 50218-2    | P1  /S21  | Arrive at platform         |    50123-1     | 36,
17    |   -   | LHB  | 4    | Su - 07:06 |    50123-1 | S11 /P1   | Depart from platform       | 55243-1        | 32,
24    |   -   | LHB  | 4    | Mn - 00:33 | 50271-1    | P1  /S11  | Arrive at platform         |    55123-1     | 36,
25    |   -   | LHB  | 4    | Mn - 00:53 | 50200-1    | P1  /S12  | Arrive at platform         |    50117-1     | 40,
26    |   -   | LHB  | 4    | Mn - 01:13 | 50201-1    | P1  /S22  | Arrive at platform         |    50120-1     | 44,
20    |   -   | LHB  | 4    | Mn - 04:46 |    50116-1 | S13 /P1   | Depart from platform       | 50200-1        | 40,
25    |   -   | LHB  | 4    | Mn - 05:06 |    50117-1 | S12 /P1   | Depart from platform       | 50200-1        | 36,
19    |   -   | LHB  | 4    | Mn - 05:26 |    50118-1 | S12 /P1   | Depart from platform       | 50271-1        | 32,
18    |   -   | LHB  | 4    | Mn - 05:46 |    50119-1 | S13 /P1   | Depart from platform       | 55244-1        | 28,
27    |   -   | LHB  | 4    | Mn - 05:53 | 50215-1    | P1  /S13  | Arrive at platform         |    50122-1     | 32,
28    |   -   | LHB  | 4    | Mn - 05:53 | 50215-2    | P1  /S13  | Arrive at platform         |    55122-1     | 36,
15    |   -   | LHB  | 4    | Mn - 05:56 |    55120-1 | S14 /P2   | Depart from platform       | 55241-1        | 32,
26    |   -   | LHB  | 4    | Mn - 06:06 |    50120-1 | S22 /P1   | Depart from platform       | 50201-1        | 28,
14    |   -   | LHB  | 4    | Mn - 06:16 |    55121-1 | S14 /P2   | Depart from platform       | 55240-1        | 24,
28    |   -   | LHB  | 4    | Mn - 06:36 |    55122-1 | S13 /P2   | Depart from platform       | 50215-2        | 20,
27    |   -   | LHB  | 4    | Mn - 06:46 |    50122-1 | S13 /P1   | Depart from platform - Att. | 50215-1       | 16,
24    |   -   | LHB  | 4    | Mn - 06:56 |    55123-1 | S11 /P2   | Depart from platform       | 50271-1        | 12,
23    |   -   | LHB  | 4    | Mn - 07:06 |    50123-1 | S21 /P1   | Depart from platform - Att. | 50218-2       | 8,
16    |   -   | LHB  | 4    | Mn - 07:16 |    55124-1 | S11 /P2   | Depart from platform       | 55242-1        | 4,
22    |   -   | LHB  | 4    | Mn - 07:26 |    50124-1 | S21 /P1   | Depart from platform - Att. | 50218-1       | 0]
Generate solutions time 1188 msec.
Generate model time 2086 msec.
Write model time 375 msec.
Solve model time 5399 msec.
Overall solution time 9048 msec.
```

A.7 Hillerød - Working day (2005-1)

```
 ---Starting depot planning for HI---

Block |  New  | Type | Size | Day & Time |  From/to   |   Track    |          Activity          |     From/to      | Stock
[
0     |   -   | LHB  | 4    | Mo - 08:25 | 41123-2    | P3         | Arrive at platform - Det.  |     41228-1      | 4,
1     |   -   | LHB  | 8    | Mo - 08:45 | 41124-1    | P4         | Arrive at platform         |     41245-1      | 12,
0     |   -   | LHB  | 4    | Mo - 08:56 |    41228-1 | P3         | Depart from platform       | 41123-2          | 8,
2     |   -   | LHB  | 4    | Mo - 09:05 | 41125-2    | P3         | Arrive at platform - Det.  |     41230-1      | 12,
3     |   -   | LHB  | 8    | Mo - 09:25 | 41126-1    | P4         | Arrive at platform         |     41247-1      | 20,
2     |   -   | LHB  | 4    | Mo - 09:36 |    41230-1 | P3         | Depart from platform       | 41125-2          | 16,
1     |   -   | LHB  | 8    | Mo - 14:36 |    41245-1 | P4         | Depart from platform       | 41124-1          | 8,
3     |   -   | LHB  | 8    | Mo - 15:16 |    41247-1 | P3         | Depart from platform       | 41126-1          | 0,
4     |   -   | LHB  | 4    | Mo - 17:05 | 41149-2    | P3         | Arrive at platform - Det.  |     41254-1      | 4,
5     |   -   | LHB  | 4    | Mo - 17:15 | 10149-2    | P1         | Arrive at platform - Det.  |     10222-2      | 8,
6     |   -   | LHB  | 8    | Mo - 17:25 | 41150-1    | P4         | Arrive at platform         |     41221-1      | 16,
7     |   -   | LHB  | 4    | Mo - 17:35 | 10150-2    | P1         | Arrive at platform - Det.  |     10221-2      | 20,
4     |   -   | LHB  | 4    | Mo - 17:36 |    41254-1 | P3         | Depart from platform       | 41149-2          | 16,
8     |   -   | LHB  | 4    | Mo - 17:45 | 41151-2    | P3         | Arrive at platform - Det.  |     41256-1      | 20,
9     |   -   | LHB  | 4    | Mo - 17:55 | 10151-2    | P1         | Arrive at platform - Det.  |     10216-1      | 24,
10    |   -   | LHB  | 8    | Mo - 18:05 | 41152-1    | P4         | Arrive at platform         |     41220-1      | 32,
11    |   -   | LHB  | 4    | Mo - 18:15 | 10152-2    | P1         | Arrive at platform - Det.  |     10223-2      | 36,
8     |   -   | LHB  | 4    | Mo - 18:16 |    41256-1 | P3         | Depart from platform       | 41151-2          | 32,
12    |   -   | LHB  | 4    | Mo - 19:25 | 41156-2    | P3         | Arrive at platform         |     10225-2      | 36,
13    |   -   | LHB  | 4    | Mo - 19:45 | 41157-2    | P3         | Arrive at platform         |     10226-2      | 40,
14    |   -   | LHB  | 4    | Tu - 00:35 | 10171-1    | P1         | Arrive at platform         |     10217-1      | 44,
15    |   -   | LHB  | 4    | Tu - 00:55 | 10100-2    | P1         | Arrive at platform         |     10224-2      | 48,
16    |   -   | LHB  | 4    | Tu - 01:10 | 10901-1    | P4         | Arrive at platform         |     12017-1      | 52,
17    |   -   | LHB  | 4    | Tu - 01:15 | 10101-1    | P1         | Arrive at platform         |     10218-1      | 56,
18    |   -   | LHB  | 4    | Tu - 01:30 | 10902-1    | P4         | Arrive at platform         |     12016-1      | 60,
18    |   -   | LHB  | 4    | Tu - 04:40 |    12016-1 | P4         | Depart from platform       | 10902-1          | 56,
9     |   -   | LHB  | 4    | Tu - 04:46 |    10216-1 | P1         | Depart from platform       | 10151-2          | 52,
14    |   -   | LHB  | 4    | Tu - 04:46 |    10217-1 | P1         | Depart from platform       | 10171-1          | 48,
16    |   -   | LHB  | 4    | Tu - 05:00 |    12017-1 | P4         | Depart from platform       | 10901-1          | 44,
17    |   -   | LHB  | 4    | Tu - 05:26 |    10218-1 | P1         | Depart from platform       | 10101-1          | 40,
10    |   -   | LHB  | 8    | Tu - 06:16 |    41220-1 | P3         | Depart from platform       | 41152-1          | 32,
7     |   -   | LHB  | 4    | Tu - 06:26 |    10221-2 | P1         | Depart from platform - Att. | 10150-2         | 28,
6     |   -   | LHB  | 8    | Tu - 06:36 |    41221-1 | P3         | Depart from platform       | 41150-1          | 20,
5     |   -   | LHB  | 4    | Tu - 06:46 |    10222-2 | P1         | Depart from platform - Att. | 10149-2         | 16,
11    |   -   | LHB  | 4    | Tu - 07:06 |    10223-2 | P1         | Depart from platform - Att. | 10152-2         | 12,
15    |   -   | LHB  | 4    | Tu - 07:26 |    10224-2 | P1         | Depart from platform - Att. | 10100-2         | 8,
12    |   -   | LHB  | 4    | Tu - 07:46 |    10225-2 | P1         | Depart from platform - Att. | 41156-2         | 4,
13    |   -   | LHB  | 4    | Tu - 08:06 |    10226-2 | P1         | Depart from platform - Att. | 41157-2         | 0]

- The number of crossings in the timetable is 41 (the maximum number is 91).

 ---Running feasibility check---

1. Finding the number of drivers needed based on the arrivals in the timetable.

- Based on the arrivals of train units in the timetable TWO drivers are necessary!

2. Checking the capacity needed at the shunt yard.

- The maximum number of units at the shunt yard during the planning period is 60.
- Based on the timetable there is enough capacity at the shunt yard (the capacity is 68 units)!

Check!

3. Checking for infeasiblity in the timetable.

- Block 12 is impossible to place without intermediate shunting movements!
- Block 13 is impossible to place without intermediate shunting movements!
- Accept intermediate shunting movements in order to create a feasible shunt plan (yes/no)?
y
- Create the movements just after arrival? - if not there are placed just before departure (yes/no)
n
Block |  New  | Type | Size | Day & Time |  From/to   |   Track    |          Activity          |     From/to      | Stock
[
0     |   -   | LHB  | 4    | Mo - 08:25 | 41123-2    | P3         | Arrive at platform - Det.  |     41228-1      | 4,
1     |   -   | LHB  | 8    | Mo - 08:45 | 41124-1    | P4         | Arrive at platform         |     41245-1      | 12,
0     |   -   | LHB  | 4    | Mo - 08:56 |    41228-1 | P3         | Depart from platform       | 41123-2          | 8,
2     |   -   | LHB  | 4    | Mo - 09:05 | 41125-2    | P3         | Arrive at platform - Det.  |     41230-1      | 12,
3     |   -   | LHB  | 8    | Mo - 09:25 | 41126-1    | P4         | Arrive at platform         |     41247-1      | 20,
2     |   -   | LHB  | 4    | Mo - 09:36 |    41230-1 | P3         | Depart from platform       | 41125-2          | 16,
1     |   -   | LHB  | 8    | Mo - 14:36 |    41245-1 | P4         | Depart from platform       | 41124-1          | 8,
3     |   -   | LHB  | 8    | Mo - 15:16 |    41247-1 | P3         | Depart from platform       | 41126-1          | 0,
4     |   -   | LHB  | 4    | Mo - 17:05 | 41149-2    | P3         | Arrive at platform - Det.  |     41254-1      | 4,
5     |   -   | LHB  | 4    | Mo - 17:15 | 10149-2    | P1         | Arrive at platform - Det.  |     10222-2      | 8,
6     |   -   | LHB  | 8    | Mo - 17:25 | 41150-1    | P4         | Arrive at platform         |     41221-1      | 16,
7     |   -   | LHB  | 4    | Mo - 17:35 | 10150-2    | P1         | Arrive at platform - Det.  |     10221-2      | 20,
4     |   -   | LHB  | 4    | Mo - 17:36 |    41254-1 | P3         | Depart from platform       | 41149-2          | 16,
8     |   -   | LHB  | 4    | Mo - 17:45 | 41151-2    | P3         | Arrive at platform - Det.  |     41256-1      | 20,
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9     |   -   | LHB  | 4    | Mo - 17:55 | 10151-2     | P1          | Arrive at platform - Det.   |     10216-1      | 24,
10    |   -   | LHB  | 8    | Mo - 18:05 | 41152-1     | P4          | Arrive at platform          |     41220-1      | 32,
11    |   -   | LHB  | 4    | Mo - 18:15 | 10152-2     | P1          | Arrive at platform - Det.   |     10223-2      | 36,
8     |   -   | LHB  | 4    | Mo - 18:16 |     41256-1 | P3          | Depart from platform        | 41151-2          | 32,
12    |   -   | LHB  | 4    | Mo - 19:25 | 41156-2     | P3          | Arrive at platform          |     10225-2      | 36,
13    |   -   | LHB  | 4    | Mo - 19:45 | 41157-2     | P3          | Arrive at platform          |     10226-2      | 40,
14    |   -   | LHB  | 4    | Tu - 00:35 | 10171-1     | P1          | Arrive at platform          |     10217-1      | 44,
15    |   -   | LHB  | 4    | Tu - 00:55 | 10100-2     | P1          | Arrive at platform          |     10224-2      | 48,
16    |   -   | LHB  | 4    | Tu - 01:10 | 10901-1     | P4          | Arrive at platform          |     12017-1      | 52,
17    |   -   | LHB  | 4    | Tu - 01:15 | 10101-1     | P1          | Arrive at platform          |     10218-1      | 56,
18    |   -   | LHB  | 4    | Tu - 01:30 | 10902-1     | P4          | Arrive at platform          |     12016-1      | 60,
18    |   -   | LHB  | 4    | Tu - 04:40 |     12016-1 | P4          | Depart from platform        | 10902-1          | 56,
9     |   -   | LHB  | 4    | Tu - 04:46 |     10216-1 | P1          | Depart from platform        | 10151-2          | 52,
14    |   -   | LHB  | 4    | Tu - 04:46 |     10217-1 | P1          | Depart from platform        | 10171-1          | 48,
16    |   -   | LHB  | 4    | Tu - 05:00 |     12017-1 | P4          | Depart from platform        | 10901-1          | 44,
17    |   -   | LHB  | 4    | Tu - 05:26 |     10218-1 | P1          | Depart from platform        | 10101-1          | 40,
10    |   -   | LHB  | 8    | Tu - 06:16 |     41220-1 | P3          | Depart from platform        | 41152-1          | 32,
7     |   -   | LHB  | 4    | Tu - 06:26 |     10221-2 | P1          | Depart from platform - Att. | 10150-2          | 28,
6     |   -   | LHB  | 8    | Tu - 06:36 |     41221-1 | P3          | Depart from platform        | 41150-1          | 20,
5     |   -   | LHB  | 4    | Tu - 06:46 |     10222-2 | P1          | Depart from platform - Att. | 10149-2          | 16,
11    |   -   | LHB  | 4    | Tu - 07:06 |     10223-2 | P1          | Depart from platform - Att. | 10152-2          | 12,
15    |   -   | LHB  | 4    | Tu - 07:26 |     10224-2 | P1          | Depart from platform - Att. | 10100-2          | 8,
12    | ISM01 | LHB  | 4    | Tu - 07:36 |             |      -      | Intermediate shunting move  | 41156-2/10225-2  | -,
12    |   -   | LHB  | 4    | Tu - 07:46 |     10225-2 | P1          | Depart from platform - Att. | 41156-2          | 4,
13    | ISM02 | LHB  | 4    | Tu - 07:56 |             |      -      | Intermediate shunting move  | 41157-2/10226-2  | -,
13    |   -   | LHB  | 4    | Tu - 08:06 |     10226-2 | P1          | Depart from platform - Att. | 41157-2          | 0]
- Accept the suggested shunting movement(s) (yes/no)?
y

4. Checking for shunt tracks with insufficient capacity.

- The shunt tracks connected to platform 1 have insufficient capacity.
- Accept intermediate shunting movements in order to create a feasible shunt plan (yes/no)?
y
Block |  New  | Type | Size | Day & Time |  From/to    |    Track    |          Activity           |     From/to      | Stock
[
0     |   -   | LHB  | 4    | Mo - 08:25 | 41123-2     | P3          | Arrive at platform - Det.   |     41228-1      | 4,
1     |   -   | LHB  | 8    | Mo - 08:45 | 41124-1     | P4          | Arrive at platform          |     41245-1      | 12,
0     |   -   | LHB  | 4    | Mo - 08:56 |     41228-1 | P3          | Depart from platform        | 41123-2          | 8,
2     |   -   | LHB  | 4    | Mo - 09:05 | 41125-2     | P3          | Arrive at platform - Det.   |     41230-1      | 12,
3     |   -   | LHB  | 8    | Mo - 09:25 | 41126-1     | P4          | Arrive at platform          |     41247-1      | 20,
2     |   -   | LHB  | 4    | Mo - 09:36 |     41230-1 | P3          | Depart from platform        | 41125-2          | 16,
1     |   -   | LHB  | 8    | Mo - 14:36 |     41245-1 | P4          | Depart from platform        | 41124-1          | 8,
3     |   -   | LHB  | 8    | Mo - 15:16 |     41247-1 | P3          | Depart from platform        | 41126-1          | 0,
4     |   -   | LHB  | 4    | Mo - 17:05 | 41149-2     | P3          | Arrive at platform - Det.   |     41254-1      | 4,
5     |   -   | LHB  | 4    | Mo - 17:15 | 10149-2     | P1          | Arrive at platform - Det.   |     10222-2      | 8,
6     |   -   | LHB  | 8    | Mo - 17:25 | 41150-1     | P4          | Arrive at platform          |     41221-1      | 16,
7     |   -   | LHB  | 4    | Mo - 17:35 | 10150-2     | P1          | Arrive at platform - Det.   |     10221-2      | 20,
4     |   -   | LHB  | 4    | Mo - 17:36 |     41254-1 | P3          | Depart from platform        | 41149-2          | 16,
8     |   -   | LHB  | 4    | Mo - 17:45 | 41151-2     | P3          | Arrive at platform - Det.   |     41256-1      | 20,
9     |   -   | LHB  | 4    | Mo - 17:55 | 10151-2     | P1          | Arrive at platform - Det.   |     10216-1      | 24,
10    |   -   | LHB  | 8    | Mo - 18:05 | 41152-1     | P4          | Arrive at platform          |     41220-1      | 32,
11    |   -   | LHB  | 4    | Mo - 18:15 | 10152-2     | P1          | Arrive at platform - Det.   |     10223-2      | 36,
8     |   -   | LHB  | 4    | Mo - 18:16 |     41256-1 | P3          | Depart from platform        | 41151-2          | 32,
12    |   -   | LHB  | 4    | Mo - 19:25 | 41156-2     | P3          | Arrive at platform          |     10225-2      | 36,
13    |   -   | LHB  | 4    | Mo - 19:45 | 41157-2     | P3          | Arrive at platform          |     10226-2      | 40,
11    | ISM11 | LHB  | 4    | Mo - 19:55 |             |      -      | Intermediate shunting move  | 10152-2/10223-2  | -,
5     | ISM21 | LHB  | 4    | Mo - 19:55 |             |      -      | Intermediate shunting move  | 10149-2/10222-2  | -,
7     | ISM31 | LHB  | 4    | Mo - 19:55 |             |      -      | Intermediate shunting move  | 10150-2/10221-2  | -,
14    |   -   | LHB  | 4    | Tu - 00:35 | 10171-1     | P1          | Arrive at platform          |     10217-1      | 44,
15    |   -   | LHB  | 4    | Tu - 00:55 | 10100-2     | P1          | Arrive at platform          |     10224-2      | 48,
16    |   -   | LHB  | 4    | Tu - 01:10 | 10901-1     | P4          | Arrive at platform          |     12017-1      | 52,
17    |   -   | LHB  | 4    | Tu - 01:15 | 10101-1     | P1          | Arrive at platform          |     10218-1      | 56,
18    |   -   | LHB  | 4    | Tu - 01:30 | 10902-1     | P4          | Arrive at platform          |     12016-1      | 60,
18    |   -   | LHB  | 4    | Tu - 04:40 |     12016-1 | P4          | Depart from platform        | 10902-1          | 56,
9     |   -   | LHB  | 4    | Tu - 04:46 |     10216-1 | P1          | Depart from platform        | 10151-2          | 52,
14    |   -   | LHB  | 4    | Tu - 04:46 |     10217-1 | P1          | Depart from platform        | 10171-1          | 48,
16    |   -   | LHB  | 4    | Tu - 05:00 |     12017-1 | P4          | Depart from platform        | 10901-1          | 44,
17    |   -   | LHB  | 4    | Tu - 05:26 |     10218-1 | P1          | Depart from platform        | 10101-1          | 40,
5     | ISM22 | LHB  | 4    | Tu - 06:06 |             |      -      | Intermediate shunting move  | 10149-2/10222-2  | -,
7     | ISM32 | LHB  | 4    | Tu - 06:06 |             |      -      | Intermediate shunting move  | 10150-2/10221-2  | -,
10    |   -   | LHB  | 8    | Tu - 06:16 |     41220-1 | P3          | Depart from platform        | 41152-1          | 32,
7     |   -   | LHB  | 4    | Tu - 06:26 |     10221-2 | P1          | Depart from platform - Att. | 10150-2          | 28,
6     |   -   | LHB  | 8    | Tu - 06:36 |     41221-1 | P3          | Depart from platform        | 41150-1          | 20,
5     |   -   | LHB  | 4    | Tu - 06:46 |     10222-2 | P1          | Depart from platform - Att. | 10149-2          | 16,
11    | ISM12 | LHB  | 4    | Tu - 06:56 |             |      -      | Intermediate shunting move  | 10152-2/10223-2  | -,
11    |   -   | LHB  | 4    | Tu - 07:06 |     10223-2 | P1          | Depart from platform - Att. | 10152-2          | 12,
15    |   -   | LHB  | 4    | Tu - 07:26 |     10224-2 | P1          | Depart from platform - Att. | 10100-2          | 8,
12    | ISM01 | LHB  | 4    | Tu - 07:36 |             |      -      | Intermediate shunting move  | 41156-2/10225-2  | -,
12    |   -   | LHB  | 4    | Tu - 07:46 |     10225-2 | P1          | Depart from platform - Att. | 41156-2          | 4,
13    | ISM02 | LHB  | 4    | Tu - 07:56 |             |      -      | Intermediate shunting move  | 41157-2/10226-2  | -,
13    |   -   | LHB  | 4    | Tu - 08:06 |     10226-2 | P1          | Depart from platform - Att. | 41157-2          | 0]
- Accept the suggested shunting movement(s) (yes/no)?
y

Use symmetry if possible (yes/no) - default is yes?
y
```

```
Set penalty for parking blocks with different subtype on the same shunt track (yes/no) - default is yes?
y

Set penalties for broken arrivals and departures (yes/no) - default is yes?
y

Make blocks that are detached at the station cheaper (yes/no) - default is yes?
y

Create shunt plan (yes/no)?
y
ILOG CPLEX 9.130, licensed to "university-lyngby", options: e m b q
...
Reduced MIP has 31 rows, 4922 columns, and 29665 nonzeros.
...

        Nodes                                         Cuts/
   Node  Left     Objective  IInf  Best Integer     Best Node    ItCnt     Gap         Variable B Parent  Depth

      0     0        5.0000    15                      5.0000      100
*     0+    0                   0    20606.0000        5.0000      100   99.98%
                     5.0000    18    20606.0000    Cliques:  7     127   99.98%
*     0+    0                   0        5.0000        5.0000      127    0.00%

Clique cuts applied:  7
Solution status = Optimal
Solution value = 5

...

All 27 blocks have been assigned to a track!

Block |  New  | Type | Size | Day & Time |  From/to    |   Track    |          Activity          |     From/to      | Stock
[
0     |   -   | LHB  | 4    | Mo - 08:25 | 41123-2     | P3  /S119  | Arrive at platform - Det.   |     41228-1      | 4,
1     |   -   | LHB  | 8    | Mo - 08:45 | 41124-1     | P4  /S6    | Arrive at platform          |     41245-1      | 12,
0     |   -   | LHB  | 4    | Mo - 08:56 |     41228-1 | S119/P3    | Depart from platform        | 41123-2          | 8,
2     |   -   | LHB  | 4    | Mo - 09:05 | 41125-2     | P3  /S119  | Arrive at platform - Det.   |     41230-1      | 12,
3     |   -   | LHB  | 8    | Mo - 09:25 | 41126-1     | P4  /S7    | Arrive at platform          |     41247-1      | 20,
2     |   -   | LHB  | 4    | Mo - 09:36 |     41230-1 | S119/P3    | Depart from platform        | 41125-2          | 16,
1     |   -   | LHB  | 8    | Mo - 14:36 |     41245-1 | S6  /P4    | Depart from platform        | 41124-1          | 8,
3     |   -   | LHB  | 8    | Mo - 15:16 |     41247-1 | S7  /P3    | Depart from platform        | 41126-1          | 0,
4     |   -   | LHB  | 4    | Mo - 17:05 | 41149-2     | P3  /S6    | Arrive at platform - Det.   |     41254-1      | 4,
5     |   -   | LHB  | 4    | Mo - 17:15 | 10149-2     | P1  /S1A   | Arrive at platform - Det.   |     10222-2      | 8,
6     |   -   | LHB  | 8    | Mo - 17:25 | 41150-1     | P4  /S7    | Arrive at platform          |     41221-1      | 16,
7     |   -   | LHB  | 4    | Mo - 17:35 | 10150-2     | P1  /S1A   | Arrive at platform - Det.   |     10221-2      | 20,
4     |   -   | LHB  | 4    | Mo - 17:36 |     41254-1 | S6  /P3    | Depart from platform        | 41149-2          | 16,
8     |   -   | LHB  | 4    | Mo - 17:45 | 41151-2     | P3  /S6    | Arrive at platform - Det.   |     41256-1      | 20,
9     |   -   | LHB  | 4    | Mo - 17:55 | 10151-2     | P1  /S1B   | Arrive at platform - Det.   |     10216-1      | 24,
10    |   -   | LHB  | 8    | Mo - 18:05 | 41152-1     | P4  /S7    | Arrive at platform          |     41220-1      | 32,
11    |   -   | LHB  | 4    | Mo - 18:15 | 10152-2     | P1  /S1B   | Arrive at platform - Det.   |     10223-2      | 36,
8     |   -   | LHB  | 4    | Mo - 18:16 |     41256-1 | S6  /P3    | Depart from platform        | 41151-2          | 32,
12    |   -   | LHB  | 4    | Mo - 19:25 | 41156-2     | P3  /S119  | Arrive at platform          |     10225-2      | 36,
13    |   -   | LHB  | 4    | Mo - 19:45 | 41157-2     | P3  /S6    | Arrive at platform          |     10226-2      | 40,
14    | ISM11 | LHB  | 4    | Mo - 19:55 |             | S1B /S6    | Intermediate shunting move  | 10152-2/10223-2  | -,
15    | ISM21 | LHB  | 4    | Mo - 19:55 |             | S1A /S6    | Intermediate shunting move  | 10149-2/10222-2  | -,
16    | ISM31 | LHB  | 4    | Mo - 19:55 |             | S1A /S7    | Intermediate shunting move  | 10150-2/10221-2  | -,
17    |   -   | LHB  | 4    | Tu - 00:35 | 10171-1     | P1  /S1B   | Arrive at platform          |     10217-1      | 44,
18    |   -   | LHB  | 4    | Tu - 00:55 | 10100-2     | P1  /S1A   | Arrive at platform          |     10224-2      | 48,
19    |   -   | LHB  | 4    | Tu - 01:10 | 10901-1     | P4  /S6    | Arrive at platform          |     12017-1      | 52,
20    |   -   | LHB  | 4    | Tu - 01:15 | 10101-1     | P1  /S1A   | Arrive at platform          |     10218-1      | 56,
21    |   -   | LHB  | 4    | Tu - 01:30 | 10902-1     | P4  /S6    | Arrive at platform          |     12016-1      | 60,
21    |   -   | LHB  | 4    | Tu - 04:40 |     12016-1 | S6  /P4    | Depart from platform        | 10902-1          | 56,
9     |   -   | LHB  | 4    | Tu - 04:46 |     10216-1 | S1B /P1    | Depart from platform        | 10151-2          | 52,
17    |   -   | LHB  | 4    | Tu - 04:46 |     10217-1 | S1B /P1    | Depart from platform        | 10171-1          | 48,
19    |   -   | LHB  | 4    | Tu - 05:00 |     12017-1 | S6  /P4    | Depart from platform        | 10901-1          | 44,
20    |   -   | LHB  | 4    | Tu - 05:26 |     10218-1 | S1A /P1    | Depart from platform        | 10101-1          | 40,
22    | ISM22 | LHB  | 4    | Tu - 06:06 |             | S6  /S1A   | Intermediate shunting move  | 10149-2/10222-2  | -,
23    | ISM32 | LHB  | 4    | Tu - 06:06 |             | S7  /S1B   | Intermediate shunting move  | 10150-2/10221-2  | -,
10    |   -   | LHB  | 8    | Tu - 06:16 |     41220-1 | S7  /P3    | Depart from platform        | 41152-1          | 32,
7     |   -   | LHB  | 4    | Tu - 06:26 |     10221-2 | S1B /P1    | Depart from platform - Att. | 10150-2          | 28,
6     |   -   | LHB  | 8    | Tu - 06:36 |     41221-1 | S7  /P3    | Depart from platform        | 41150-1          | 20,
5     |   -   | LHB  | 4    | Tu - 06:46 |     10222-2 | S1A /P1    | Depart from platform - Att. | 10149-2          | 16,
24    | ISM12 | LHB  | 4    | Tu - 06:56 |             | S6  /S1A   | Intermediate shunting move  | 10152-2/10223-2  | -,
11    |   -   | LHB  | 4    | Tu - 07:06 |     10223-2 | S1A /P1    | Depart from platform - Att. | 10152-2          | 12,
18    |   -   | LHB  | 4    | Tu - 07:26 |     10224-2 | S1A /P1    | Depart from platform - Att. | 10100-2          | 8,
25    | ISM01 | LHB  | 4    | Tu - 07:36 |             | S119/S1B   | Intermediate shunting move  | 41156-2/10225-2  | -,
12    |   -   | LHB  | 4    | Tu - 07:46 |     10225-2 | S1B /P1    | Depart from platform - Att. | 41156-2          | 4,
26    | ISM02 | LHB  | 4    | Tu - 07:56 |             | S6  /S1B   | Intermediate shunting move  | 41157-2/10226-2  | -,
13    |   -   | LHB  | 4    | Tu - 08:06 |     10226-2 | S1B /P1    | Depart from platform - Att. | 41157-2          | 0]

Generate solutions time 789 msec.
Generate model time 994 msec.
Write model time 142 msec.
Solve model time 1213 msec.
Overall solution time 3138 msec.
```

A.8 Hillerød - Weekend (2005-1)

```
---Starting depot planning for HI---

Block |  New  | Type | Size | Day & Time | From/to   |  Track   |           Activity            |    From/to    | Stock
[
0     |   -   | LHB  | 4    | Fr - 08:25 | 41123-2   | P3       | Arrive at platform - Det.   |    41228-1    | 4,
1     |   -   | LHB  | 8    | Fr - 08:45 | 41124-1   | P4       | Arrive at platform          |    41243-1    | 12,
0     |   -   | LHB  | 4    | Fr - 08:56 |   41228-1 | P3       | Depart from platform        | 41123-2       | 8,
2     |   -   | LHB  | 4    | Fr - 09:05 | 41125-2   | P3       | Arrive at platform - Det.   |    41230-1    | 12,
3     |   -   | LHB  | 8    | Fr - 09:25 | 41126-1   | P4       | Arrive at platform          |    41247-1    | 20,
2     |   -   | LHB  | 4    | Fr - 09:36 |   41230-1 | P3       | Depart from platform        | 41125-2       | 16,
1     |   -   | LHB  | 8    | Fr - 13:56 |   41243-1 | P4       | Depart from platform        | 41124-1       | 8,
3     |   -   | LHB  | 8    | Fr - 14:36 |   41247-1 | P3       | Depart from platform        | 41126-1       | 0,
4     |   -   | LHB  | 4    | Fr - 14:55 | 10142-2   | P1       | Arrive at platform - Det.   |    10235-1    | 4,
5     |   -   | LHB  | 4    | Fr - 15:15 | 10143-2   | P1       | Arrive at platform - Det.   |    10225-2    | 8,
6     |   -   | LHB  | 4    | Fr - 15:35 | 10144-2   | P1       | Arrive at platform - Det.   |    10220-1    | 12,
7     |   -   | LHB  | 4    | Fr - 15:55 | 10145-2   | P1       | Arrive at platform - Det.   |    10239-1    | 16,
8     |   -   | LHB  | 4    | Fr - 16:25 | 41147-2   | P3       | Arrive at platform - Det.   |    41252-1    | 20,
9     |   -   | LHB  | 4    | Fr - 16:45 | 41148-1   | P4       | Arrive at platform          |    41233-1    | 24,
10    |   -   | LHB  | 4    | Fr - 16:45 | 41148-2   | P4       | Arrive at platform          |    41232-1    | 28,
8     |   -   | LHB  | 4    | Fr - 16:56 |   41252-1 | P3       | Depart from platform        | 41147-2       | 24,
11    |   -   | LHB  | 4    | Fr - 17:05 | 41149-3   | P3       | Arrive at platform - Det.   |    41254-1    | 28,
12    |   -   | LHB  | 4    | Fr - 17:25 | 41150-1   | P4       | Arrive at platform          |    41230-1    | 32,
13    |   -   | LHB  | 4    | Fr - 17:25 | 41150-2   | P4       | Arrive at platform          |    41231-1    | 36,
11    |   -   | LHB  | 4    | Fr - 17:36 |   41254-1 | P3       | Depart from platform        | 41149-3       | 32,
14    |   -   | LHB  | 4    | Fr - 19:25 | 41156-1   | P3       | Arrive at platform          |    10226-2    | 36,
15    |   -   | LHB  | 4    | Fr - 19:45 | 41157-1   | P3       | Arrive at platform          |    10223-2    | 40,
16    |   -   | LHB  | 4    | Sa - 00:35 | 10171-2   | P1       | Arrive at platform          |    10216-1    | 44,
17    |   -   | LHB  | 4    | Sa - 00:55 | 10100-1   | P1       | Arrive at platform          |    10218-1    | 48,
18    |   -   | LHB  | 4    | Sa - 01:10 | 10901-1   | P4       | Arrive at platform          |    12017-1    | 52,
19    |   -   | LHB  | 4    | Sa - 01:15 | 10101-2   | P1       | Arrive at platform          |    10217-1    | 56,
20    |   -   | LHB  | 4    | Sa - 01:30 | 10902-1   | P4       | Arrive at platform          |    12016-1    | 60,
20    |   -   | LHB  | 4    | Sa - 04:40 |   12016-1 | P4       | Depart from platform        | 10902-1       | 56,
16    |   -   | LHB  | 4    | Sa - 04:46 |   10216-1 | P1       | Depart from platform        | 10171-2       | 52,
18    |   -   | LHB  | 4    | Sa - 05:00 |   12017-1 | P4       | Depart from platform        | 10901-1       | 48,
19    |   -   | LHB  | 4    | Sa - 05:06 |   10217-1 | P1       | Depart from platform        | 10101-2       | 44,
17    |   -   | LHB  | 4    | Sa - 05:26 |   10218-1 | P1       | Depart from platform        | 10100-1       | 40,
13    |   -   | LHB  | 4    | Sa - 09:36 |   41231-1 | P3       | Depart from platform        | 41150-2       | 36,
12    |   -   | LHB  | 4    | Sa - 09:56 |   41230-1 | P3       | Depart from platform        | 41150-1       | 32,
21    |   -   | LHB  | 4    | Sa - 10:05 | 41128-1   | P4       | Arrive at platform          |    41221-2    | 36,
10    |   -   | LHB  | 4    | Sa - 10:16 |   41232-1 | P3       | Depart from platform        | 41148-2       | 32,
22    |   -   | LHB  | 4    | Sa - 10:25 | 41129-1   | P4       | Arrive at platform          |    41221-1    | 36,
9     |   -   | LHB  | 4    | Sa - 10:36 |   41233-1 | P3       | Depart from platform        | 41148-1       | 32,
23    |   -   | LHB  | 4    | Sa - 10:55 | 10130-1   | P1       | Arrive at platform          |    10222-2    | 36,
4     |   -   | LHB  | 4    | Sa - 11:06 |   10235-1 | P1       | Depart from platform        | 10142-2       | 32,
24    |   -   | LHB  | 4    | Sa - 12:15 | 10134-1   | P1       | Arrive at platform          |    10241-1    | 36,
7     |   -   | LHB  | 4    | Sa - 12:26 |   10239-1 | P1       | Depart from platform        | 10145-2       | 32,
25    |   -   | LHB  | 4    | Sa - 12:55 | 10136-1   | P1       | Arrive at platform          |    10221-2    | 36,
24    |   -   | LHB  | 4    | Sa - 13:06 |   10241-1 | P1       | Depart from platform        | 10134-1       | 32,
26    |   -   | LHB  | 4    | Sa - 15:25 | 41144-1   | P3       | Arrive at platform          |    41220-1    | 36,
27    |   -   | LHB  | 4    | Sa - 15:45 | 41145-1   | P3       | Arrive at platform          |    41220-2    | 40,
28    |   -   | LHB  | 4    | Su - 00:35 | 10171-1   | P1       | Arrive at platform          |    10219-1    | 44,
29    |   -   | LHB  | 4    | Su - 00:55 | 10100-1   | P1       | Arrive at platform          |    10603-2    | 48,
30    |   -   | LHB  | 4    | Su - 01:10 | 10901-1   | P4       | Arrive at platform          |    12020-1    | 52,
31    |   -   | LHB  | 4    | Su - 01:15 | 10101-1   | P1       | Arrive at platform          |    10223-2    | 56,
32    |   -   | LHB  | 4    | Su - 01:30 | 10902-1   | P4       | Arrive at platform          |    12019-1    | 60,
32    |   -   | LHB  | 4    | Su - 05:40 |   12019-1 | P4       | Depart from platform        | 10902-1       | 56,
28    |   -   | LHB  | 4    | Su - 05:46 |   10219-1 | P1       | Depart from platform        | 10171-1       | 52,
30    |   -   | LHB  | 4    | Su - 06:00 |   12020-1 | P4       | Depart from platform        | 10901-1       | 48,
6     |   -   | LHB  | 4    | Su - 06:06 |   10220-1 | P1       | Depart from platform        | 10144-2       | 44,
33    |   -   | LHB  | 4    | Su - 06:55 | 10118-1   | P1       | Arrive at platform          |    10216-1    | 48,
31    |   -   | LHB  | 4    | Su - 07:06 |   10223-2 | P1       | Depart from platform        | 10101-1       | 44,
29    |   -   | LHB  | 4    | Mn - 00:26 |   10603-2 | P1       | Depart from platform - Att. | 10100-1       | 40,
34    |   -   | LHB  | 4    | Mn - 00:35 | 10171-1   | P1       | Arrive at platform          |    10224-2    | 44,
35    |   -   | LHB  | 4    | Mn - 00:55 | 10100-1   | P1       | Arrive at platform          |    10218-1    | 48,
36    |   -   | LHB  | 4    | Mn - 01:10 | 10901-1   | P4       | Arrive at platform          |    12017-1    | 52,
37    |   -   | LHB  | 4    | Mn - 01:15 | 10101-1   | P1       | Arrive at platform          |    10217-1    | 56,
38    |   -   | LHB  | 4    | Mn - 01:30 | 10902-1   | P4       | Arrive at platform          |    12016-1    | 60,
38    |   -   | LHB  | 4    | Mn - 04:40 |   12016-1 | P4       | Depart from platform        | 10902-1       | 56,
33    |   -   | LHB  | 4    | Mn - 04:46 |   10216-1 | P1       | Depart from platform        | 10118-1       | 52,
37    |   -   | LHB  | 4    | Mn - 04:46 |   10217-1 | P1       | Depart from platform        | 10101-1       | 48,
36    |   -   | LHB  | 4    | Mn - 05:00 |   12017-1 | P4       | Depart from platform        | 10901-1       | 44,
35    |   -   | LHB  | 4    | Mn - 05:26 |   10218-1 | P1       | Depart from platform        | 10100-1       | 40,
26    |   -   | LHB  | 4    | Mn - 06:16 |   41220-1 | P3       | Depart from platform        | 41144-1       | 36,
27    |   -   | LHB  | 4    | Mn - 06:16 |   41220-2 | P3       | Depart from platform        | 41145-1       | 32,
25    |   -   | LHB  | 4    | Mn - 06:26 |   10221-2 | P1       | Depart from platform - Att. | 10136-1       | 28,
21    |   -   | LHB  | 4    | Mn - 06:36 |   41221-2 | P3       | Depart from platform        | 41128-1       | 24,
22    |   -   | LHB  | 4    | Mn - 06:36 |   41221-1 | P3       | Depart from platform        | 41129-1       | 20,
23    |   -   | LHB  | 4    | Mn - 06:46 |   10222-2 | P1       | Depart from platform - Att. | 10130-1       | 16,
15    |   -   | LHB  | 4    | Mn - 07:06 |   10223-2 | P1       | Depart from platform - Att. | 41157-1       | 12,
34    |   -   | LHB  | 4    | Mn - 07:26 |   10224-2 | P1       | Depart from platform - Att. | 10171-1       | 8,
5     |   -   | LHB  | 4    | Mn - 07:46 |   10225-2 | P1       | Depart from platform - Att. | 10143-2       | 4,
14    |   -   | LHB  | 4    | Mn - 08:06 |   10226-2 | P1       | Depart from platform - Att. | 41156-1       | 0]
```

```
- The number of crossings in the timetable is 69 (the maximum number is 311).

... Running feasibility check ...

- Accept the suggested shunting movement(s) (yes/no)?
y

Use symmetry if possible (yes/no) - default is yes?
y

Set penalty for parking blocks with different subtype on the same shunt track (yes/no) - default is yes?
y

Set penalties for broken arrivals and departures (yes/no) - default is yes?
y

Make blocks that are detached at the station cheaper (yes/no) - default is yes?
y

Create shunt plan (yes/no)?
y
ILOG CPLEX 9.130, licensed to "university-lyngby", options: e m b q
Presolve has eliminated 0 rows and 0 columns...
Presolve has eliminated 0 rows and 4 columns...
Presolve has eliminated 1 rows and 4 columns...
Tried aggregator 1 time.
Presolve has eliminated 1 rows and 4 columns...
MIP Presolve eliminated 1 rows and 4 columns.
Reduced MIP has 55 rows, 1727191 columns, and 16172426 nonzeros.
Presolve time =  139.03 sec.
Clique table members: 53
MIP emphasis: balance optimality and feasibility
Root relaxation solution time = 1409.50 sec.

        Nodes                                         Cuts/
   Node  Left     Objective  IInf  Best Integer     Best Node    ItCnt     Gap         Variable B Parent  Depth

      0     0        5.6667    13                      5.6667     1193
*     0+    0                   0    44606.0000        5.6667     1193   99.99%
                     5.6667    22    44606.0000   Cliques:  6     1282   99.99%
Heuristic still looking
*     0+    0                   0     2805.0000        5.6667     1282   99.80%
*     0+    0                   0        6.0000        5.6667     1282    5.56%
Heuristic complete

Clique cuts applied:  5
Solution status = Optimal
Solution value = 6

... The solution ...

All 51 blocks have been assigned to a track!

Block |  New   | Type | Size | Day & Time |  From/to    |   Track    |          Activity          |    From/to      | Stock
[
0     |   -    | LHB  | 4    | Fr - 08:25 | 41123-2     | P3  /S6    | Arrive at platform - Det.  |    41228-1      | 4,
1     |   -    | LHB  | 8    | Fr - 08:45 | 41124-1     | P4  /S7    | Arrive at platform         |    41243-1      | 12,
0     |   -    | LHB  | 4    | Fr - 08:56 |     41228-1 | S6  /P3    | Depart from platform       | 41123-2         | 8,
2     |   -    | LHB  | 4    | Fr - 09:05 | 41125-2     | P3  /S7    | Arrive at platform - Det.  |    41230-1      | 12,
3     |   -    | LHB  | 8    | Fr - 09:25 | 41126-1     | P4  /S6    | Arrive at platform         |    41247-1      | 20,
2     |   -    | LHB  | 4    | Fr - 09:36 |     41230-1 | S7  /P3    | Depart from platform       | 41125-2         | 16,
1     |   -    | LHB  | 8    | Fr - 13:56 |     41243-1 | S7  /P4    | Depart from platform       | 41124-1         | 8,
3     |   -    | LHB  | 8    | Fr - 14:36 |     41247-1 | S6  /P3    | Depart from platform       | 41126-1         | 0,
4     |   -    | LHB  | 4    | Fr - 14:55 | 10142-2     | P1  /S1A   | Arrive at platform - Det.  |    10235-1      | 4,
5     |   -    | LHB  | 4    | Fr - 15:15 | 10143-2     | P1  /S1A   | Arrive at platform - Det.  |    10225-2      | 8,
6     |   -    | LHB  | 4    | Fr - 15:35 | 10144-2     | P1  /S1B   | Arrive at platform - Det.  |    10220-1      | 12,
7     |   -    | LHB  | 4    | Fr - 15:55 | 10145-2     | P1  /S1B   | Arrive at platform - Det.  |    10239-1      | 16,
8     | ISM11  | LHB  | 4    | Fr - 16:05 |             | S1A /S2    | Intermediate shunting move | 10143-2/10225-2 | -,
9     | ISM21  | LHB  | 4    | Fr - 16:05 |             | S1B /S119  | Intermediate shunting move | 10144-2/10220-1 | -,
10    | ISM31  | LHB  | 4    | Fr - 16:05 |             | S1B /S7    | Intermediate shunting move | 10145-2/10239-1 | -,
11    |   -    | LHB  | 4    | Fr - 16:25 | 41147-2     | P3  /S6    | Arrive at platform - Det.  |    41252-1      | 20,
12    |   -    | LHB  | 4    | Fr - 16:45 | 41148-1     | P4  /S7    | Arrive at platform         |    41233-1      | 24,
13    |   -    | LHB  | 4    | Fr - 16:45 | 41148-2     | P4  /S7    | Arrive at platform         |    41232-1      | 28,
11    |   -    | LHB  | 4    | Fr - 16:56 |     41252-1 | S6  /P3    | Depart from platform       | 41147-2         | 24,
14    |   -    | LHB  | 4    | Fr - 17:05 | 41149-3     | P3  /S6    | Arrive at platform - Det.  |    41254-1      | 28,
15    |   -    | LHB  | 4    | Fr - 17:25 | 41150-1     | P4  /S7    | Arrive at platform         |    41230-1      | 32,
16    |   -    | LHB  | 4    | Fr - 17:25 | 41150-2     | P4  /S7    | Arrive at platform         |    41231-1      | 36,
14    |   -    | LHB  | 4    | Fr - 17:36 |     41254-1 | S6  /P3    | Depart from platform       | 41149-3         | 32,
17    |   -    | LHB  | 4    | Fr - 19:25 | 41156-1     | P3  /S6    | Arrive at platform         |    10226-2      | 36,
18    |   -    | LHB  | 4    | Fr - 19:45 | 41157-1     | P3  /S6    | Arrive at platform         |    10223-2      | 40,
19    |   -    | LHB  | 4    | Sa - 00:35 | 10171-2     | P1  /S1A   | Arrive at platform         |    10216-1      | 44,
20    |   -    | LHB  | 4    | Sa - 00:55 | 10100-1     | P1  /S1B   | Arrive at platform         |    10218-1      | 48,
21    |   -    | LHB  | 4    | Sa - 01:10 | 10901-1     | P4  /S6    | Arrive at platform         |    12017-1      | 52,
22    |   -    | LHB  | 4    | Sa - 01:15 | 10101-2     | P1  /S1B   | Arrive at platform         |    10217-1      | 56,
23    |   -    | LHB  | 4    | Sa - 01:30 | 10902-1     | P4  /S6    | Arrive at platform         |    12016-1      | 60,
23    |   -    | LHB  | 4    | Sa - 04:40 |     12016-1 | S6  /P4    | Depart from platform       | 10902-1         | 56,
```

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19   |   -   | LHB  | 4    | Sa - 04:46 |     10216-1 | S1A /P1    | Depart from platform        | 10171-2           | 52,
21   |   -   | LHB  | 4    | Sa - 05:00 |     12017-1 | S6  /P4    | Depart from platform        | 10901-1           | 48,
22   |   -   | LHB  | 4    | Sa - 05:06 |     10217-1 | S1B /P1    | Depart from platform        | 10101-2           | 44,
20   |   -   | LHB  | 4    | Sa - 05:26 |     10218-1 | S1B /P1    | Depart from platform        | 10100-1           | 40,
16   |   -   | LHB  | 4    | Sa - 09:36 |     41231-1 | S7  /P3    | Depart from platform        | 41150-2           | 36,
15   |   -   | LHB  | 4    | Sa - 09:56 |     41230-1 | S7  /P3    | Depart from platform        | 41150-1           | 32,
24   |   -   | LHB  | 4    | Sa - 10:05 | 41128-1     | P4  /S6    | Arrive at platform          |    41221-2        | 36,
13   |   -   | LHB  | 4    | Sa - 10:16 |     41232-1 | S7  /P3    | Depart from platform        | 41148-2           | 32,
25   |   -   | LHB  | 4    | Sa - 10:25 | 41129-1     | P4  /S6    | Arrive at platform          |    41221-1        | 36,
12   |   -   | LHB  | 4    | Sa - 10:36 |     41233-1 | S7  /P3    | Depart from platform        | 41148-1           | 32,
26   |   -   | LHB  | 4    | Sa - 10:55 | 10130-1     | P1  /S1B   | Arrive at platform          |    10222-2        | 36,
4    |   -   | LHB  | 4    | Sa - 11:06 |     10235-1 | S1A /P1    | Depart from platform        | 10142-2           | 32,
27   | ISM41 | LHB  | 4    | Sa - 11:16 |             | S1B /S6    | Intermediate shunting move  | 10130-1/10222-2 | -,
28   | ISM32 | LHB  | 4    | Sa - 12:05 |             | S7  /S1B   | Intermediate shunting move  | 10145-2/10239-1 | -,
29   |   -   | LHB  | 4    | Sa - 12:15 | 10134-1     | P1  /S1A   | Arrive at platform          |    10241-1        | 36,
7    |   -   | LHB  | 4    | Sa - 12:26 |     10239-1 | S1B /P1    | Depart from platform        | 10145-2           | 32,
30   |   -   | LHB  | 4    | Sa - 12:55 | 10136-1     | P1  /S1B   | Arrive at platform          |    10221-2        | 36,
29   |   -   | LHB  | 4    | Sa - 13:06 |     10241-1 | S1A /P1    | Depart from platform        | 10134-1           | 32,
31   | ISM51 | LHB  | 4    | Sa - 13:16 |             | S1B /S2    | Intermediate shunting move  | 10136-1/10221-2 | -,
32   |   -   | LHB  | 4    | Sa - 15:25 | 41144-1     | P3  /S7    | Arrive at platform          |    41220-1        | 36,
33   |   -   | LHB  | 4    | Sa - 15:45 | 41145-1     | P3  /S7    | Arrive at platform          |    41220-2        | 40,
34   |   -   | LHB  | 4    | Su - 00:35 | 10171-1     | P1  /S1A   | Arrive at platform          |    10219-1        | 44,
35   |   -   | LHB  | 4    | Su - 00:55 | 10100-1     | P1  /S1B   | Arrive at platform          |    10603-2        | 48,
36   |   -   | LHB  | 4    | Su - 01:10 | 10901-1     | P4  /S7    | Arrive at platform          |    12020-1        | 52,
37   |   -   | LHB  | 4    | Su - 01:15 | 10101-1     | P1  /S1B   | Arrive at platform          |    10223-2        | 56,
38   |   -   | LHB  | 4    | Su - 01:30 | 10902-1     | P4  /S7    | Arrive at platform          |    12019-1        | 60,
38   |   -   | LHB  | 4    | Su - 05:40 |     12019-1 | S7  /P4    | Depart from platform        | 10902-1           | 56,
34   |   -   | LHB  | 4    | Su - 05:46 |     10219-1 | S1A /P1    | Depart from platform        | 10171-1           | 52,
39   | ISM22 | LHB  | 4    | Su - 05:56 |             | S119/S1A   | Intermediate shunting move  | 10144-2/10220-1 | -,
36   |   -   | LHB  | 4    | Su - 06:00 |     12020-1 | S7  /P4    | Depart from platform        | 10901-1           | 48,
6    |   -   | LHB  | 4    | Su - 06:06 |     10220-1 | S1A /P1    | Depart from platform        | 10144-2           | 44,
40   |   -   | LHB  | 4    | Su - 06:55 | 10118-1     | P1  /S1A   | Arrive at platform          |    10216-1        | 48,
37   |   -   | LHB  | 4    | Su - 07:06 |     10223-2 | S1B /P1    | Depart from platform        | 10101-1           | 44,
35   |   -   | LHB  | 4    | Mn - 00:26 |     10603-2 | S1B /P1    | Depart from platform - Att. | 10100-1           | 40,
41   |   -   | LHB  | 4    | Mn - 00:35 | 10171-1     | P1  /S1B   | Arrive at platform          |    10224-2        | 44,
42   |   -   | LHB  | 4    | Mn - 00:55 | 10100-1     | P1  /S1B   | Arrive at platform          |    10218-1        | 48,
43   |   -   | LHB  | 4    | Mn - 01:10 | 10901-1     | P4  /S7    | Arrive at platform          |    12017-1        | 52,
44   |   -   | LHB  | 4    | Mn - 01:15 | 10101-1     | P1  /S1A   | Arrive at platform          |    10217-1        | 56,
45   |   -   | LHB  | 4    | Mn - 01:30 | 10902-1     | P4  /S7    | Arrive at platform          |    12016-1        | 60,
45   |   -   | LHB  | 4    | Mn - 04:40 |     12016-1 | S7  /P4    | Depart from platform        | 10902-1           | 56,
40   |   -   | LHB  | 4    | Mn - 04:46 |     10216-1 | S1A /P1    | Depart from platform        | 10118-1           | 52,
44   |   -   | LHB  | 4    | Mn - 04:46 |     10217-1 | S1A /P1    | Depart from platform        | 10101-1           | 48,
43   |   -   | LHB  | 4    | Mn - 05:00 |     12017-1 | S7  /P4    | Depart from platform        | 10901-1           | 44,
42   |   -   | LHB  | 4    | Mn - 05:26 |     10218-1 | S1B /P1    | Depart from platform        | 10100-1           | 40,
46   | ISM42 | LHB  | 4    | Mn - 06:06 |             | S6  /S1A   | Intermediate shunting move  | 10130-1/10222-2 | -,
47   | ISM52 | LHB  | 4    | Mn - 06:06 |             | S2  /S1A   | Intermediate shunting move  | 10136-1/10221-2 | -,
32   |   -   | LHB  | 4    | Mn - 06:16 |     41220-1 | S7  /P3    | Depart from platform        | 41144-1           | 36,
33   |   -   | LHB  | 4    | Mn - 06:16 |     41220-2 | S7  /P3    | Depart from platform        | 41145-1           | 32,
30   |   -   | LHB  | 4    | Mn - 06:26 |     10221-2 | S1A /P1    | Depart from platform - Att. | 10136-1           | 28,
24   |   -   | LHB  | 4    | Mn - 06:36 |     41221-2 | S6  /P3    | Depart from platform        | 41128-1           | 24,
25   |   -   | LHB  | 4    | Mn - 06:36 |     41221-1 | S6  /P3    | Depart from platform        | 41129-1           | 20,
26   |   -   | LHB  | 4    | Mn - 06:46 |     10222-2 | S1A /P1    | Depart from platform - Att. | 10130-1           | 16,
48   | ISM02 | LHB  | 4    | Mn - 06:56 |             | S6  /S1A   | Intermediate shunting move  | 41157-1/10223-2 | -,
18   |   -   | LHB  | 4    | Mn - 07:06 |     10223-2 | S1A /P1    | Depart from platform - Att. | 41157-1           | 12,
41   |   -   | LHB  | 4    | Mn - 07:26 |     10224-2 | S1B /P1    | Depart from platform - Att. | 10171-1           | 8,
49   | ISM12 | LHB  | 4    | Mn - 07:36 |             | S2  /S1B   | Intermediate shunting move  | 10143-2/10225-2 | -,
5    |   -   | LHB  | 4    | Mn - 07:46 |     10225-2 | S1B /P1    | Depart from platform - Att. | 10143-2           | 4,
50   | ISM01 | LHB  | 4    | Mn - 07:56 |             | S6  /S1B   | Intermediate shunting move  | 41156-1/10226-2 | -,
17   |   -   | LHB  | 4    | Mn - 08:06 |     10226-2 | S1B /P1    | Depart from platform - Att. | 41156-1           | 0]

Generate solutions time 120237 msec.
Generate model time 1859500 msec.
Write model time 81227 msec.
Solve model time 2642456 msec.
Overall solution time 4703420 msec.
```

A.9 Hillerød - Working day (Test - 49 crossings)

```
 ---Starting depot planning for HI---

Block |  New  | Type | Size | Day & Time |  From/to   |   Track    |          Activity          |     From/to     | Stock
[
0     |   -   | LHB  | 4    | Mo - 08:25 | 41123-2    | P3         | Arrive at platform - Det.  |   41228-1       | 4,
1     |   -   | LHB  | 8    | Mo - 08:45 | 41124-1    | P4         | Arrive at platform         |   41245-1       | 12,
0     |   -   | LHB  | 4    | Mo - 08:56 |    41228-1 | P3         | Depart from platform       | 41123-2         | 8,
2     |   -   | LHB  | 4    | Mo - 09:05 | 41125-2    | P3         | Arrive at platform - Det.  |   41230-1       | 12,
3     |   -   | LHB  | 8    | Mo - 09:25 | 41126-1    | P4         | Arrive at platform         |   41247-1       | 20,
2     |   -   | LHB  | 4    | Mo - 09:36 |    41230-1 | P3         | Depart from platform       | 41125-2         | 16,
1     |   -   | LHB  | 8    | Mo - 14:36 |    41245-1 | P4         | Depart from platform       | 41124-1         | 8,
3     |   -   | LHB  | 8    | Mo - 15:16 |    41247-1 | P3         | Depart from platform       | 41126-1         | 0,
4     |   -   | LHB  | 4    | Mo - 17:05 | 41149-2    | P3         | Arrive at platform - Det.  |   41254-1       | 4,
5     |   -   | LHB  | 4    | Mo - 17:15 | 10149-2    | P1         | Arrive at platform - Det.  |   10218-1       | 8,
6     |   -   | LHB  | 8    | Mo - 17:25 | 41150-1    | P4         | Arrive at platform         |   41221-1       | 16,
7     |   -   | LHB  | 4    | Mo - 17:35 | 10150-2    | P1         | Arrive at platform - Det.  |   10216-1       | 20,
4     |   -   | LHB  | 4    | Mo - 17:36 |    41254-1 | P3         | Depart from platform       | 41149-2         | 16,
8     |   -   | LHB  | 4    | Mo - 17:45 | 41151-2    | P3         | Arrive at platform - Det.  |   41256-1       | 20,
9     |   -   | LHB  | 4    | Mo - 17:55 | 10151-2    | P1         | Arrive at platform - Det.  |   10221-2       | 24,
10    |   -   | LHB  | 8    | Mo - 18:05 | 41152-1    | P4         | Arrive at platform         |   41220-1       | 32,
11    |   -   | LHB  | 4    | Mo - 18:15 | 10152-2    | P1         | Arrive at platform - Det.  |   10223-2       | 36,
8     |   -   | LHB  | 4    | Mo - 18:16 |    41256-1 | P3         | Depart from platform       | 41151-2         | 32,
12    |   -   | LHB  | 4    | Mo - 19:25 | 41156-2    | P3         | Arrive at platform         |   10225-2       | 36,
13    |   -   | LHB  | 4    | Mo - 19:45 | 41157-2    | P3         | Arrive at platform         |   10226-2       | 40,
14    |   -   | LHB  | 4    | Tu - 00:35 | 10171-1    | P1         | Arrive at platform         |   10217-1       | 44,
15    |   -   | LHB  | 4    | Tu - 00:55 | 10100-2    | P1         | Arrive at platform         |   10224-2       | 48,
16    |   -   | LHB  | 4    | Tu - 01:10 | 10901-1    | P4         | Arrive at platform         |   12017-1       | 52,
17    |   -   | LHB  | 4    | Tu - 01:15 | 10101-1    | P1         | Arrive at platform         |   10222-2       | 56,
18    |   -   | LHB  | 4    | Tu - 01:30 | 10902-1    | P4         | Arrive at platform         |   12016-1       | 60,
18    |   -   | LHB  | 4    | Tu - 04:40 |    12016-1 | P4         | Depart from platform       | 10902-1         | 56,
7     |   -   | LHB  | 4    | Tu - 04:46 |    10216-1 | P1         | Depart from platform       | 10150-2         | 52,
14    |   -   | LHB  | 4    | Tu - 04:46 |    10217-1 | P1         | Depart from platform       | 10171-1         | 48,
16    |   -   | LHB  | 4    | Tu - 05:00 |    12017-1 | P4         | Depart from platform       | 10901-1         | 44,
5     |   -   | LHB  | 4    | Tu - 05:26 |    10218-1 | P1         | Depart from platform       | 10149-2         | 40,
10    |   -   | LHB  | 8    | Tu - 06:16 |    41220-1 | P3         | Depart from platform       | 41152-1         | 32,
9     |   -   | LHB  | 4    | Tu - 06:26 |    10221-2 | P1         | Depart from platform - Att. | 10151-2        | 28,
6     |   -   | LHB  | 8    | Tu - 06:36 |    41221-1 | P3         | Depart from platform       | 41150-1         | 20,
17    |   -   | LHB  | 4    | Tu - 06:46 |    10222-2 | P1         | Depart from platform - Att. | 10101-1        | 16,
11    |   -   | LHB  | 4    | Tu - 07:06 |    10223-2 | P1         | Depart from platform - Att. | 10152-2        | 12,
15    |   -   | LHB  | 4    | Tu - 07:26 |    10224-2 | P1         | Depart from platform - Att. | 10100-2        | 8,
12    |   -   | LHB  | 4    | Tu - 07:46 |    10225-2 | P1         | Depart from platform - Att. | 41156-2        | 4,
13    |   -   | LHB  | 4    | Tu - 08:06 |    10226-2 | P1         | Depart from platform - Att. | 41157-2        | 0]

- The number of crossings in the timetable is 49 (the maximum number is 91).

... Running the prototype ...

All 27 blocks have been assigned to a track!

Block |  New  | Type | Size | Day & Time |  From/to   |   Track    |          Activity          |     From/to     | Stock
[
0     |   -   | LHB  | 4    | Mo - 08:25 | 41123-2    | P3  /S6    | Arrive at platform - Det.  |   41228-1       | 4,
1     |   -   | LHB  | 8    | Mo - 08:45 | 41124-1    | P4  /S7    | Arrive at platform         |   41245-1       | 12,
0     |   -   | LHB  | 4    | Mo - 08:56 |    41228-1 | S6  /P3    | Depart from platform       | 41123-2         | 8,
2     |   -   | LHB  | 4    | Mo - 09:05 | 41125-2    | P3  /S7    | Arrive at platform - Det.  |   41230-1       | 12,
3     |   -   | LHB  | 8    | Mo - 09:25 | 41126-1    | P4  /S6    | Arrive at platform         |   41247-1       | 20,
2     |   -   | LHB  | 4    | Mo - 09:36 |    41230-1 | S7  /P3    | Depart from platform       | 41125-2         | 16,
1     |   -   | LHB  | 8    | Mo - 14:36 |    41245-1 | S7  /P4    | Depart from platform       | 41124-1         | 8,
3     |   -   | LHB  | 8    | Mo - 15:16 |    41247-1 | S6  /P3    | Depart from platform       | 41126-1         | 0,
4     |   -   | LHB  | 4    | Mo - 17:05 | 41149-2    | P3  /S7    | Arrive at platform - Det.  |   41254-1       | 4,
5     |   -   | LHB  | 4    | Mo - 17:15 | 10149-2    | P1  /S1A   | Arrive at platform - Det.  |   10218-1       | 8,
6     |   -   | LHB  | 8    | Mo - 17:25 | 41150-1    | P4  /S6    | Arrive at platform         |   41221-1       | 16,
7     |   -   | LHB  | 4    | Mo - 17:35 | 10150-2    | P1  /S1B   | Arrive at platform - Det.  |   10216-1       | 20,
4     |   -   | LHB  | 4    | Mo - 17:36 |    41254-1 | S7  /P3    | Depart from platform       | 41149-2         | 16,
8     |   -   | LHB  | 4    | Mo - 17:45 | 41151-2    | P3  /S7    | Arrive at platform - Det.  |   41256-1       | 20,
9     |   -   | LHB  | 4    | Mo - 17:55 | 10151-2    | P1  /S1B   | Arrive at platform - Det.  |   10221-2       | 24,
10    |   -   | LHB  | 8    | Mo - 18:05 | 41152-1    | P4  /S6    | Arrive at platform         |   41220-1       | 32,
11    |   -   | LHB  | 4    | Mo - 18:15 | 10152-2    | P1  /S1A   | Arrive at platform - Det.  |   10223-2       | 36,
8     |   -   | LHB  | 4    | Mo - 18:16 |    41256-1 | S7  /P3    | Depart from platform       | 41151-2         | 32,
12    |   -   | LHB  | 4    | Mo - 19:25 | 41156-2    | P3  /S119  | Arrive at platform         |   10225-2       | 36,
13    |   -   | LHB  | 4    | Mo - 19:45 | 41157-2    | P3  /S7    | Arrive at platform         |   10226-2       | 40,
14    | ISM11 | LHB  | 4    | Mo - 19:55 |            | S1A /S7    | Intermediate shunting move | 10152-2/10223-2 | -,
15    | ISM21 | LHB  | 4    | Mo - 19:55 |            | S1B /S7    | Intermediate shunting move | 10151-2/10221-2 | -,
16    | ISM31 | LHB  | 4    | Mo - 19:55 |            | S1A /S6    | Intermediate shunting move | 10149-2/10218-1 | -,
17    |   -   | LHB  | 4    | Tu - 00:35 | 10171-1    | P1  /S1B   | Arrive at platform         |   10217-1       | 44,
18    |   -   | LHB  | 4    | Tu - 00:55 | 10100-2    | P1  /S1A   | Arrive at platform         |   10224-2       | 48,
19    |   -   | LHB  | 4    | Tu - 01:10 | 10901-1    | P4  /S7    | Arrive at platform         |   12017-1       | 52,
20    |   -   | LHB  | 4    | Tu - 01:15 | 10101-1    | P1  /S1A   | Arrive at platform         |   10222-2       | 56,
21    |   -   | LHB  | 4    | Tu - 01:30 | 10902-1    | P4  /S7    | Arrive at platform         |   12016-1       | 60,
21    |   -   | LHB  | 4    | Tu - 04:40 |    12016-1 | S7  /P4    | Depart from platform       | 10902-1         | 56,
7     |   -   | LHB  | 4    | Tu - 04:46 |    10216-1 | S1B /P1    | Depart from platform       | 10150-2         | 52,
17    |   -   | LHB  | 4    | Tu - 04:46 |    10217-1 | S1B /P1    | Depart from platform       | 10171-1         | 48,
```

```
19    |   -   | LHB  | 4    | Tu - 05:00 |    12017-1 | S7  /P4   | Depart from platform        | 10901-1         | 44,
22    | ISM32 | LHB  | 4    | Tu - 05:16 |            | S6  /S1B  | Intermediate shunting move  | 10149-2/10218-1 | -,
5     |   -   | LHB  | 4    | Tu - 05:26 |    10218-1 | S1B /P1   | Depart from platform        | 10149-2         | 40,
23    | ISM22 | LHB  | 4    | Tu - 06:06 |            | S7  /S1B  | Intermediate shunting move  | 10151-2/10221-2 | -,
10    |   -   | LHB  | 8    | Tu - 06:16 |    41220-1 | S6  /P3   | Depart from platform        | 41152-1         | 32,
9     |   -   | LHB  | 4    | Tu - 06:26 |    10221-2 | S1B /P1   | Depart from platform - Att. | 10151-2         | 28,
6     |   -   | LHB  | 8    | Tu - 06:36 |    41221-1 | S6  /P3   | Depart from platform        | 41150-1         | 20,
20    |   -   | LHB  | 4    | Tu - 06:46 |    10222-2 | S1A /P1   | Depart from platform - Att. | 10101-1         | 16,
24    | ISM12 | LHB  | 4    | Tu - 06:56 |            | S7  /S1B  | Intermediate shunting move  | 10152-2/10223-2 | -,
11    |   -   | LHB  | 4    | Tu - 07:06 |    10223-2 | S1B /P1   | Depart from platform - Att. | 10152-2         | 12,
18    |   -   | LHB  | 4    | Tu - 07:26 |    10224-2 | S1A /P1   | Depart from platform - Att. | 10100-2         | 8,
25    | ISM01 | LHB  | 4    | Tu - 07:36 |            | S119/S1B  | Intermediate shunting move  | 41156-2/10225-2 | -,
12    |   -   | LHB  | 4    | Tu - 07:46 |    10225-2 | S1B /P1   | Depart from platform - Att. | 41156-2         | 4,
26    | ISM02 | LHB  | 4    | Tu - 07:56 |            | S7  /S1A  | Intermediate shunting move  | 41157-2/10226-2 | -,
13    |   -   | LHB  | 4    | Tu - 08:06 |    10226-2 | S1A /P1   | Depart from platform - Att. | 41157-2         | 0]

Generate solutions time 951 msec.
Generate model time 1327 msec.
Write model time 176 msec.
Solve model time 1112 msec.
Overall solution time 3566 msec.
```

A.10 Klampenborg - Working day (2005-1)

```
 ---Starting depot planning for KL---

Block |  New  | Type | Size | Day & Time |  From/to   |   Track   |          Activity          |    From/to     | Stock
[
0     |   -   | ASEA | 4    | Tu - 00:31 | 75901-1    | P7        | Arrive at platform         |    71016-1     | 4,
1     |   -   | ASEA | 4    | Tu - 00:41 | 70901-1    | P7        | Arrive at platform         |    71015-1     | 8,
2     |   -   | ASEA | 4    | Tu - 00:51 | 75902-1    | P7        | Arrive at platform         |    76017-1     | 12,
3     |   -   | ASEA | 4    | Tu - 01:01 | 70902-1    | P7        | Arrive at platform         |    76016-1     | 16,
4     |   -   | ASEA | 4    | Tu - 01:11 | 75903-1    | P7        | Arrive at platform         |    76015-1     | 20,
5     |   -   | ASEA | 4    | Tu - 01:21 | 70903-1    | P5        | Arrive at platform         |    71014-1     | 24,
5     |   -   | ASEA | 4    | Tu - 04:42 |    71014-1 | P5        | Depart from platform       | 70903-1        | 20,
4     |   -   | ASEA | 4    | Tu - 04:52 |    76015-1 | P7        | Depart from platform       | 75903-1        | 16,
1     |   -   | ASEA | 4    | Tu - 05:02 |    71015-1 | P7        | Depart from platform       | 70901-1        | 12,
3     |   -   | ASEA | 4    | Tu - 05:12 |    76016-1 | P7        | Depart from platform       | 70902-1        | 8,
0     |   -   | ASEA | 4    | Tu - 05:22 |    71016-1 | P7        | Depart from platform       | 75901-1        | 4,
2     |   -   | ASEA | 4    | Tu - 05:32 |    76017-1 | P7        | Depart from platform       | 75902-1        | 0]

- The number of crossings in the timetable is 3 (the maximum number is 15).

 ---Running feasibility check---

1. Finding the number of drivers needed based on the arrivals in the timetable.

- Based on the arrivals of train units in the timetable TWO drivers are necessary!

2. Checking the capacity needed at the shunt yard.

- The maximum number of units at the shunt yard during the planning period is 24.
- There is not enough capacity at the shunt yard (the capacity is only 20 units)!
- Allow the use of platforms as depot tracks at night (yes/no)?
y
- Write the block you allow to park at the platforms at night (e.g 3)?
5
- Is it possible to park the block at the platform from arrival to departure (yes/no)?
y
Block |  New  | Type | Size | Day & Time |  From/to   |   Track   |          Activity          |    From/to     | Stock
[
0     |   -   | ASEA | 4    | Tu - 00:31 | 75901-1    | P7        | Arrive at platform         |    71016-1     | 4,
1     |   -   | ASEA | 4    | Tu - 00:41 | 70901-1    | P7        | Arrive at platform         |    71015-1     | 8,
2     |   -   | ASEA | 4    | Tu - 00:51 | 75902-1    | P7        | Arrive at platform         |    76017-1     | 12,
3     |   -   | ASEA | 4    | Tu - 01:01 | 70902-1    | P7        | Arrive at platform         |    76016-1     | 16,
4     |   -   | ASEA | 4    | Tu - 01:11 | 75903-1    | P7        | Arrive at platform         |    76015-1     | 20,
5     |   -   | ASEA | 4    | Tu - 01:21 | 70903-1    | P5        | Arrive at platform (stay)  |    71014-1     | 24,
5     |   -   | ASEA | 4    | Tu - 04:42 |    71014-1 | P5        | Depart from platform       | 70903-1        | 20,
4     |   -   | ASEA | 4    | Tu - 04:52 |    76015-1 | P7        | Depart from platform       | 75903-1        | 16,
1     |   -   | ASEA | 4    | Tu - 05:02 |    71015-1 | P7        | Depart from platform       | 70901-1        | 12,
3     |   -   | ASEA | 4    | Tu - 05:12 |    76016-1 | P7        | Depart from platform       | 70902-1        | 8,
0     |   -   | ASEA | 4    | Tu - 05:22 |    71016-1 | P7        | Depart from platform       | 75901-1        | 4,
2     |   -   | ASEA | 4    | Tu - 05:32 |    76017-1 | P7        | Depart from platform       | 75902-1        | 0]
- Park more blocks at the platform at night (the capacity at the shunt yard is 20) (yes/no)?
n

3. Checking for infeasiblity in the timetable.

Check!

4. Checking for shunt tracks with insufficient capacity.

- The shunt tracks connected to platform 5 have insufficient capacity.
- Accept intermediate shunting movements in order to create a feasible shunt plan (yes/no)?
n

Use symmetry if possible (yes/no) - default is yes?
y

Set penalty for parking blocks with different subtype on the same shunt track (yes/no) - default is yes?
y

Set penalties for broken arrivals and departures (yes/no) - default is yes?
y

Make blocks that are detached at the station cheaper (yes/no) - default is yes?
y

Create shunt plan (yes/no)?
y
ILOG CPLEX 9.130, licensed to "university-lyngby", options: e m b q
Tried aggregator 1 time.
MIP Presolve eliminated 0 rows and 2 columns.
Aggregator did 2 substitutions.
Reduced MIP has 7 rows, 22 columns, and 46 nonzeros.
Presolve time =    0.00 sec.
```

```
Clique table members: 6
MIP emphasis: balance optimality and feasibility
Root relaxation solution time =    0.00 sec.

        Nodes                                         Cuts/
   Node  Left     Objective  IInf  Best Integer     Best Node    ItCnt     Gap         Variable B Parent  Depth

      0     0      503.0000     6                    503.0000       10
*     0+    0                   0     2503.0000      503.0000       10   79.90%
*     0+    0                   0      503.0000      503.0000       10    0.00%
Solution status = Optimal
Solution value = 503
VARIABLE: xB.0,S8 VALUE = 1
[Block no.: 0 , Block type: ASEA , Block size: 4
Arrival no.  : 75901-1 , Platform: 7 , Detached: false , Arrival time: Tu, 0:31
Departure no.: 71016-1 , Platform: 7 , Attached: false , Departure time: Tu, 5:22
]
VARIABLE: xB.1.4,S9 VALUE = 1
[Block no.: 1 , Block type: ASEA , Block size: 4
Arrival no.  : 70901-1 , Platform: 7 , Detached: false , Arrival time: Tu, 0:41
Departure no.: 71015-1 , Platform: 7 , Attached: false , Departure time: Tu, 5:02
, Block no.: 4 , Block type: ASEA , Block size: 4
Arrival no.  : 75903-1 , Platform: 7 , Detached: false , Arrival time: Tu, 1:11
Departure no.: 76015-1 , Platform: 7 , Attached: false , Departure time: Tu, 4:52
]
VARIABLE: xB.2.3,S10 VALUE = 1
[Block no.: 2 , Block type: ASEA , Block size: 4
Arrival no.  : 75902-1 , Platform: 7 , Detached: false , Arrival time: Tu, 0:51
Departure no.: 76017-1 , Platform: 7 , Attached: false , Departure time: Tu, 5:32
, Block no.: 3 , Block type: ASEA , Block size: 4
Arrival no.  : 70902-1 , Platform: 7 , Detached: false , Arrival time: Tu, 1:01
Departure no.: 76016-1 , Platform: 7 , Attached: false , Departure time: Tu, 5:12
]
VARIABLE: zS5 VALUE = 1
---The following block(s) is/are assigned to a platform track---:
[Block no.: 5 , Block type: ASEA , Block size: 4
Arrival no.  : 70903-1 , Platform: 5 , Detached: false , Arrival time: Tu, 1:21
Departure no.: 71014-1 , Platform: 5 , Attached: false , Departure time: Tu, 4:42
]

All 6 blocks have been assigned to a track!

Block |  New  | Type | Size | Day & Time |  From/to   |   Track   |          Activity          |     From/to     | Stock
[
0     |   -   | ASEA | 4    | Tu - 00:31 | 75901-1    | P7  /S8   | Arrive at platform         |    71016-1      | 4,
1     |   -   | ASEA | 4    | Tu - 00:41 | 70901-1    | P7  /S9   | Arrive at platform         |    71015-1      | 8,
2     |   -   | ASEA | 4    | Tu - 00:51 | 75902-1    | P7  /S10  | Arrive at platform         |    76017-1      | 12,
3     |   -   | ASEA | 4    | Tu - 01:01 | 70902-1    | P7  /S10  | Arrive at platform         |    76016-1      | 16,
4     |   -   | ASEA | 4    | Tu - 01:11 | 75903-1    | P7  /S9   | Arrive at platform         |    76015-1      | 20,
5     |   -   | ASEA | 4    | Tu - 01:21 | 70903-1    | P5        | Arrive at platform (stay)  |    71014-1      | 24,
5     |   -   | ASEA | 4    | Tu - 04:42 |    71014-1 | P5        | Depart from platform       | 70903-1         | 20,
4     |   -   | ASEA | 4    | Tu - 04:52 |    76015-1 | S9  /P7   | Depart from platform       | 75903-1         | 16,
1     |   -   | ASEA | 4    | Tu - 05:02 |    71015-1 | S9  /P7   | Depart from platform       | 70901-1         | 12,
3     |   -   | ASEA | 4    | Tu - 05:12 |    76016-1 | S10 /P7   | Depart from platform       | 70902-1         | 8,
0     |   -   | ASEA | 4    | Tu - 05:22 |    71016-1 | S8  /P7   | Depart from platform       | 75901-1         | 4,
2     |   -   | ASEA | 4    | Tu - 05:32 |    76017-1 | S10 /P7   | Depart from platform       | 75902-1         | 0]

Generate solutions time 112 msec.
Generate model time 342 msec.
Write model time 16 msec.
Solve model time 128 msec.
Overall solution time 598 msec.
```

A.11 Klampenborg - Weekend (2005-1)

```
 ---Starting depot planning for KL---

Block |  New  | Type | Size | Day & Time |  From/to    |   Track    |          Activity          |    From/to     | Stock
[
0     |   -   | ASEA | 4    | Su - 00:31 | 75901-1    | P7         | Arrive at platform         |    71019-1     | 4,
1     |   -   | ASEA | 4    | Su - 00:41 | 70901-1    | P7         | Arrive at platform         |    71018-1     | 8,
2     |   -   | ASEA | 4    | Su - 00:51 | 75902-1    | P7         | Arrive at platform         |    76020-1     | 12,
3     |   -   | ASEA | 4    | Su - 01:01 | 70902-1    | P7         | Arrive at platform         |    76019-1     | 16,
4     |   -   | ASEA | 4    | Su - 01:11 | 75903-1    | P7         | Arrive at platform         |    76018-1     | 20,
5     |   -   | ASEA | 4    | Su - 01:21 | 70903-1    | P5         | Arrive at platform         |    71017-1     | 24,
5     |   -   | ASEA | 4    | Su - 05:42 |    71017-1 | P5         | Depart from platform       | 70903-1        | 20,
4     |   -   | ASEA | 4    | Su - 05:52 |    76018-1 | P7         | Depart from platform       | 75903-1        | 16,
1     |   -   | ASEA | 4    | Su - 06:02 |    71018-1 | P7         | Depart from platform       | 70901-1        | 12,
3     |   -   | ASEA | 4    | Su - 06:12 |    76019-1 | P7         | Depart from platform       | 70902-1        | 8,
0     |   -   | ASEA | 4    | Su - 06:22 |    71019-1 | P7         | Depart from platform       | 75901-1        | 4,
2     |   -   | ASEA | 4    | Su - 06:32 |    76020-1 | P7         | Depart from platform       | 75902-1        | 0,
6     |   -   | ASEA | 4    | Mn - 00:31 | 75901-1    | P7         | Arrive at platform         |    76016-1     | 4,
7     |   -   | ASEA | 4    | Mn - 00:41 | 70901-1    | P7         | Arrive at platform         |    71015-1     | 8,
8     |   -   | ASEA | 4    | Mn - 00:51 | 75902-1    | P7         | Arrive at platform         |    76017-1     | 12,
9     |   -   | ASEA | 4    | Mn - 01:01 | 70902-1    | P7         | Arrive at platform         |    71016-1     | 16,
10    |   -   | ASEA | 4    | Mn - 01:11 | 75903-1    | P5         | Arrive at platform         |    71014-1     | 20,
11    |   -   | ASEA | 4    | Mn - 01:21 | 70903-1    | P7         | Arrive at platform         |    76015-1     | 24,
10    |   -   | ASEA | 4    | Mn - 04:42 |    71014-1 | P5         | Depart from platform       | 75903-1        | 20,
11    |   -   | ASEA | 4    | Mn - 04:52 |    76015-1 | P7         | Depart from platform       | 70903-1        | 16,
7     |   -   | ASEA | 4    | Mn - 05:02 |    71015-1 | P7         | Depart from platform       | 70901-1        | 12,
6     |   -   | ASEA | 4    | Mn - 05:12 |    76016-1 | P7         | Depart from platform       | 75901-1        | 8,
9     |   -   | ASEA | 4    | Mn - 05:22 |    71016-1 | P7         | Depart from platform       | 70902-1        | 4,
8     |   -   | ASEA | 4    | Mn - 05:32 |    76017-1 | P7         | Depart from platform       | 75902-1        | 0]

- The number of crossings in the timetable is 8 (the maximum number is 30).

 ---Running feasibility check---

1. Finding the number of drivers needed based on the arrivals in the timetable.

- Based on the arrivals of train units in the timetable TWO drivers are necessary!

2. Checking the capacity needed at the shunt yard.

- The maximum number of units at the shunt yard during the planning period is 24.
- There is not enough capacity at the shunt yard (the capacity is only 20 units)!
- Allow the use of platforms as depot tracks at night (yes/no)?
y
- Write the block you allow to park at the platforms at night (e.g 3)?
5
- Is it possible to park the block at the platform from arrival to departure (yes/no)?
y
Block |  New  | Type | Size | Day & Time |  From/to    |   Track    |          Activity          |    From/to     | Stock
[
0     |   -   | ASEA | 4    | Su - 00:31 | 75901-1    | P7         | Arrive at platform         |    71019-1     | 4,
1     |   -   | ASEA | 4    | Su - 00:41 | 70901-1    | P7         | Arrive at platform         |    71018-1     | 8,
2     |   -   | ASEA | 4    | Su - 00:51 | 75902-1    | P7         | Arrive at platform         |    76020-1     | 12,
3     |   -   | ASEA | 4    | Su - 01:01 | 70902-1    | P7         | Arrive at platform         |    76019-1     | 16,
4     |   -   | ASEA | 4    | Su - 01:11 | 75903-1    | P7         | Arrive at platform         |    76018-1     | 20,
5     |   -   | ASEA | 4    | Su - 01:21 | 70903-1    | P5         | Arrive at platform (stay)  |    71017-1     | 24,
5     |   -   | ASEA | 4    | Su - 05:42 |    71017-1 | P5         | Depart from platform       | 70903-1        | 20,
4     |   -   | ASEA | 4    | Su - 05:52 |    76018-1 | P7         | Depart from platform       | 75903-1        | 16,
1     |   -   | ASEA | 4    | Su - 06:02 |    71018-1 | P7         | Depart from platform       | 70901-1        | 12,
3     |   -   | ASEA | 4    | Su - 06:12 |    76019-1 | P7         | Depart from platform       | 70902-1        | 8,
0     |   -   | ASEA | 4    | Su - 06:22 |    71019-1 | P7         | Depart from platform       | 75901-1        | 4,
2     |   -   | ASEA | 4    | Su - 06:32 |    76020-1 | P7         | Depart from platform       | 75902-1        | 0,
6     |   -   | ASEA | 4    | Mn - 00:31 | 75901-1    | P7         | Arrive at platform         |    76016-1     | 4,
7     |   -   | ASEA | 4    | Mn - 00:41 | 70901-1    | P7         | Arrive at platform         |    71015-1     | 8,
8     |   -   | ASEA | 4    | Mn - 00:51 | 75902-1    | P7         | Arrive at platform         |    76017-1     | 12,
9     |   -   | ASEA | 4    | Mn - 01:01 | 70902-1    | P7         | Arrive at platform         |    71016-1     | 16,
10    |   -   | ASEA | 4    | Mn - 01:11 | 75903-1    | P5         | Arrive at platform         |    71014-1     | 20,
11    |   -   | ASEA | 4    | Mn - 01:21 | 70903-1    | P7         | Arrive at platform         |    76015-1     | 24,
10    |   -   | ASEA | 4    | Mn - 04:42 |    71014-1 | P5         | Depart from platform       | 75903-1        | 20,
11    |   -   | ASEA | 4    | Mn - 04:52 |    76015-1 | P7         | Depart from platform       | 70903-1        | 16,
7     |   -   | ASEA | 4    | Mn - 05:02 |    71015-1 | P7         | Depart from platform       | 70901-1        | 12,
6     |   -   | ASEA | 4    | Mn - 05:12 |    76016-1 | P7         | Depart from platform       | 75901-1        | 8,
9     |   -   | ASEA | 4    | Mn - 05:22 |    71016-1 | P7         | Depart from platform       | 70902-1        | 4,
8     |   -   | ASEA | 4    | Mn - 05:32 |    76017-1 | P7         | Depart from platform       | 75902-1        | 0]
- Park more blocks at the platform at night (the capacity at the shunt yard is 20) (yes/no)?
y
- Write the block you allow to park at the platforms at night (e.g 3)?
10
- Is it possible to park the block at the platform from arrival to departure (yes/no)?
y
Block |  New  | Type | Size | Day & Time |  From/to    |   Track    |          Activity          |    From/to     | Stock
[
0     |   -   | ASEA | 4    | Su - 00:31 | 75901-1    | P7         | Arrive at platform         |    71019-1     | 4,
```

```
1     |   -   | ASEA | 4    | Su - 00:41 | 70901-1    | P7        | Arrive at platform         |    71018-1      | 8,
2     |   -   | ASEA | 4    | Su - 00:51 | 75902-1    | P7        | Arrive at platform         |    76020-1      | 12,
3     |   -   | ASEA | 4    | Su - 01:01 | 70902-1    | P7        | Arrive at platform         |    76019-1      | 16,
4     |   -   | ASEA | 4    | Su - 01:11 | 75903-1    | P7        | Arrive at platform         |    76018-1      | 20,
5     |   -   | ASEA | 4    | Su - 01:21 | 70903-1    | P5        | Arrive at platform (stay)  |    71017-1      | 24,
5     |   -   | ASEA | 4    | Su - 05:42 |    71017-1 | P5        | Depart from platform       | 70903-1         | 20,
4     |   -   | ASEA | 4    | Su - 05:52 |    76018-1 | P7        | Depart from platform       | 75903-1         | 16,
1     |   -   | ASEA | 4    | Su - 06:02 |    71018-1 | P7        | Depart from platform       | 70901-1         | 12,
3     |   -   | ASEA | 4    | Su - 06:12 |    76019-1 | P7        | Depart from platform       | 70902-1         | 8,
0     |   -   | ASEA | 4    | Su - 06:22 |    71019-1 | P7        | Depart from platform       | 75901-1         | 4,
2     |   -   | ASEA | 4    | Su - 06:32 |    76020-1 | P7        | Depart from platform       | 75902-1         | 0,
6     |   -   | ASEA | 4    | Mn - 00:31 | 75901-1    | P7        | Arrive at platform         |    76016-1      | 4,
7     |   -   | ASEA | 4    | Mn - 00:41 | 70901-1    | P7        | Arrive at platform         |    71015-1      | 8,
8     |   -   | ASEA | 4    | Mn - 00:51 | 75902-1    | P7        | Arrive at platform         |    76017-1      | 12,
9     |   -   | ASEA | 4    | Mn - 01:01 | 70902-1    | P7        | Arrive at platform         |    71016-1      | 16,
10    |   -   | ASEA | 4    | Mn - 01:11 | 75903-1    | P5        | Arrive at platform (stay)  |    71014-1      | 20,
11    |   -   | ASEA | 4    | Mn - 01:21 | 70903-1    | P7        | Arrive at platform         |    76015-1      | 24,
10    |   -   | ASEA | 4    | Mn - 04:42 |    71014-1 | P5        | Depart from platform       | 75903-1         | 20,
11    |   -   | ASEA | 4    | Mn - 04:52 |    76015-1 | P7        | Depart from platform       | 70903-1         | 16,
7     |   -   | ASEA | 4    | Mn - 05:02 |    71015-1 | P7        | Depart from platform       | 70901-1         | 12,
6     |   -   | ASEA | 4    | Mn - 05:12 |    76016-1 | P7        | Depart from platform       | 75901-1         | 8,
9     |   -   | ASEA | 4    | Mn - 05:22 |    71016-1 | P7        | Depart from platform       | 70902-1         | 4,
8     |   -   | ASEA | 4    | Mn - 05:32 |    76017-1 | P7        | Depart from platform       | 75902-1         | 0]
- Park more blocks at the platform at night (the capacity at the shunt yard is 20) (yes/no)?
n

3. Checking for infeasiblity in the timetable.

Check!

4. Checking for shunt tracks with insufficient capacity.

- The shunt tracks connected to platform 5 have insufficient capacity.
- Accept intermediate shunting movements in order to create a feasible shunt plan (yes/no)?
n

Use symmetry if possible (yes/no) - default is yes?
y

Set penalty for parking blocks with different subtype on the same shunt track (yes/no) - default is yes?
y

Set penalties for broken arrivals and departures (yes/no) - default is yes?
y

Make blocks that are detached at the station cheaper (yes/no) - default is yes?
y

Create shunt plan (yes/no)?
y
ILOG CPLEX 9.130, licensed to "university-lyngby", options: e m b q
Tried aggregator 1 time.
MIP Presolve eliminated 0 rows and 2 columns.
Aggregator did 3 substitutions.
Reduced MIP has 12 rows, 200 columns, and 709 nonzeros.
Presolve time =    0.01 sec.
Clique table members: 11
MIP emphasis: balance optimality and feasibility
Root relaxation solution time =    0.01 sec.

        Nodes                                         Cuts/
   Node  Left     Objective  IInf  Best Integer     Best Node    ItCnt     Gap         Variable B Parent  Depth

      0     0      503.0000     9                   503.0000       28
*     0+    0                   0     7503.0000     503.0000       28   93.30%
*     0+    0                   0     2503.0000     503.0000       28   79.90%
                   503.0000     8     2503.0000   Cliques:  5      33   79.90%
*     0+    0                   0      503.0000     503.0000       33    0.00%

Clique cuts applied:  2
Solution status = Optimal
Solution value = 503
VARIABLE: xB.4.11,S8 VALUE = 1
[Block no.: 4 , Block type: ASEA , Block size: 4
Arrival no.  : 75903-1 , Platform: 7 , Detached: false , Arrival time: Su, 1:11
Departure no.: 76018-1 , Platform: 7 , Attached: false , Departure time: Su, 5:52
, Block no.: 11 , Block type: ASEA , Block size: 4
Arrival no.  : 70903-1 , Platform: 7 , Detached: false , Arrival time: Mn, 1:21
Departure no.: 76015-1 , Platform: 7 , Attached: false , Departure time: Mn, 4:52
]
VARIABLE: xB.0.1.8.9,S9 VALUE = 1
[Block no.: 0 , Block type: ASEA , Block size: 4
Arrival no.  : 75901-1 , Platform: 7 , Detached: false , Arrival time: Su, 0:31
Departure no.: 71019-1 , Platform: 7 , Attached: false , Departure time: Su, 6:22
, Block no.: 1 , Block type: ASEA , Block size: 4
Arrival no.  : 70901-1 , Platform: 7 , Detached: false , Arrival time: Su, 0:41
Departure no.: 71018-1 , Platform: 7 , Attached: false , Departure time: Su, 6:02
```

```
, Block no.: 8 , Block type: ASEA , Block size: 4
Arrival no.  : 75902-1 , Platform: 7 , Detached: false , Arrival time: Mn, 0:51
Departure no.: 76017-1 , Platform: 7 , Attached: false , Departure time: Mn, 5:32
, Block no.: 9 , Block type: ASEA , Block size: 4
Arrival no.  : 70902-1 , Platform: 7 , Detached: false , Arrival time: Mn, 1:01
Departure no.: 71016-1 , Platform: 7 , Attached: false , Departure time: Mn, 5:22
]
VARIABLE: xB.2.3.6.7,S10 VALUE = 1
[Block no.: 2 , Block type: ASEA , Block size: 4
Arrival no.  : 75902-1 , Platform: 7 , Detached: false , Arrival time: Su, 0:51
Departure no.: 76020-1 , Platform: 7 , Attached: false , Departure time: Su, 6:32
, Block no.: 3 , Block type: ASEA , Block size: 4
Arrival no.  : 70902-1 , Platform: 7 , Detached: false , Arrival time: Su, 1:01
Departure no.: 76019-1 , Platform: 7 , Attached: false , Departure time: Su, 6:12
, Block no.: 6 , Block type: ASEA , Block size: 4
Arrival no.  : 75901-1 , Platform: 7 , Detached: false , Arrival time: Mn, 0:31
Departure no.: 76016-1 , Platform: 7 , Attached: false , Departure time: Mn, 5:12
, Block no.: 7 , Block type: ASEA , Block size: 4
Arrival no.  : 70901-1 , Platform: 7 , Detached: false , Arrival time: Mn, 0:41
Departure no.: 71015-1 , Platform: 7 , Attached: false , Departure time: Mn, 5:02
]
VARIABLE: zS5 VALUE = 1
---The following block(s) is/are assigned to a platform track---:
[Block no.: 5 , Block type: ASEA , Block size: 4
Arrival no.  : 70903-1 , Platform: 5 , Detached: false , Arrival time: Su, 1:21
Departure no.: 71017-1 , Platform: 5 , Attached: false , Departure time: Su, 5:42
, Block no.: 10 , Block type: ASEA , Block size: 4
Arrival no.  : 75903-1 , Platform: 5 , Detached: false , Arrival time: Mn, 1:11
Departure no.: 71014-1 , Platform: 5 , Attached: false , Departure time: Mn, 4:42
]

All 12 blocks have been assigned to a track!

Block |  New  | Type | Size | Day & Time |  From/to    |   Track    |          Activity          |     From/to     | Stock
[
0     |   -   | ASEA | 4    | Su - 00:31 | 75901-1     | P7  /S9    | Arrive at platform         |     71019-1     | 4,
1     |   -   | ASEA | 4    | Su - 00:41 | 70901-1     | P7  /S9    | Arrive at platform         |     71018-1     | 8,
2     |   -   | ASEA | 4    | Su - 00:51 | 75902-1     | P7  /S10   | Arrive at platform         |     76020-1     | 12,
3     |   -   | ASEA | 4    | Su - 01:01 | 70902-1     | P7  /S10   | Arrive at platform         |     76019-1     | 16,
4     |   -   | ASEA | 4    | Su - 01:11 | 75903-1     | P7  /S8    | Arrive at platform         |     76018-1     | 20,
5     |   -   | ASEA | 4    | Su - 01:21 | 70903-1     | P5         | Arrive at platform (stay)  |     71017-1     | 24,
5     |   -   | ASEA | 4    | Su - 05:42 |     71017-1 | P5         | Depart from platform       | 70903-1         | 20,
4     |   -   | ASEA | 4    | Su - 05:52 |     76018-1 | S8  /P7    | Depart from platform       | 75903-1         | 16,
1     |   -   | ASEA | 4    | Su - 06:02 |     71018-1 | S9  /P7    | Depart from platform       | 70901-1         | 12,
3     |   -   | ASEA | 4    | Su - 06:12 |     76019-1 | S10 /P7    | Depart from platform       | 70902-1         | 8,
0     |   -   | ASEA | 4    | Su - 06:22 |     71019-1 | S9  /P7    | Depart from platform       | 75901-1         | 4,
2     |   -   | ASEA | 4    | Su - 06:32 |     76020-1 | S10 /P7    | Depart from platform       | 75902-1         | 0,
6     |   -   | ASEA | 4    | Mn - 00:31 | 75901-1     | P7  /S10   | Arrive at platform         |     76016-1     | 4,
7     |   -   | ASEA | 4    | Mn - 00:41 | 70901-1     | P7  /S10   | Arrive at platform         |     71015-1     | 8,
8     |   -   | ASEA | 4    | Mn - 00:51 | 75902-1     | P7  /S9    | Arrive at platform         |     76017-1     | 12,
9     |   -   | ASEA | 4    | Mn - 01:01 | 70902-1     | P7  /S9    | Arrive at platform         |     71016-1     | 16,
10    |   -   | ASEA | 4    | Mn - 01:11 | 75903-1     | P5         | Arrive at platform (stay)  |     71014-1     | 20,
11    |   -   | ASEA | 4    | Mn - 01:21 | 70903-1     | P7  /S8    | Arrive at platform         |     76015-1     | 24,
10    |   -   | ASEA | 4    | Mn - 04:42 |     71014-1 | P5         | Depart from platform       | 75903-1         | 20,
11    |   -   | ASEA | 4    | Mn - 04:52 |     76015-1 | S8  /P7    | Depart from platform       | 70903-1         | 16,
7     |   -   | ASEA | 4    | Mn - 05:02 |     71015-1 | S10 /P7    | Depart from platform       | 70901-1         | 12,
6     |   -   | ASEA | 4    | Mn - 05:12 |     76016-1 | S10 /P7    | Depart from platform       | 75901-1         | 8,
9     |   -   | ASEA | 4    | Mn - 05:22 |     71016-1 | S9  /P7    | Depart from platform       | 70902-1         | 4,
8     |   -   | ASEA | 4    | Mn - 05:32 |     76017-1 | S9  /P7    | Depart from platform       | 75902-1         | 0]

Generate solutions time 107 msec.
Generate model time 327 msec.
Write model time 25 msec.
Solve model time 198 msec.
Overall solution time 657 msec.
```

A.12 Køge - Working day (2005-1)

```
 ---Starting depot planning for KJ---

Block |  New  | Type | Size | Day & Time |  From/to   |   Track   |           Activity           |     From/to     | Stock
[
0     |   -   | LHB  | 4    | Mo - 08:32 | 41223-1    | P7        | Arrive at platform - Det.    |    41146-1      | 4,
1     |   -   | LHB  | 4    | Mo - 08:42 | 15224-1    | P6        | Arrive at platform - Det.    |    15148-1      | 8,
2     |   -   | LHB  | 4    | Mo - 08:52 | 41224-1    | P7        | Arrive at platform - Det.    |    41147-1      | 12,
3     |   -   | LHB  | 4    | Mo - 09:02 | 15225-1    | P6        | Arrive at platform - Det.    |    15147-1      | 16,
4     |   -   | LHB  | 4    | Mo - 09:12 | 41225-1    | P7        | Arrive at platform - Det.    |    41148-1      | 20,
5     |   -   | LHB  | 4    | Mo - 09:22 | 15226-1    | P6        | Arrive at platform - Det.    |    16958-1      | 24,
6     |   -   | LHB  | 4    | Mo - 09:32 | 41226-1    | P7        | Arrive at platform - Det.    |    41149-1      | 28,
7     |   -   | LHB  | 4    | Mo - 09:42 | 15227-1    | P6        | Arrive at platform - Det.    |    41145-1      | 32,
7     |   -   | LHB  | 4    | Mo - 14:28 |    41145-1 | P7        | Depart from platform - Att. | 15227-1         | 28,
0     |   -   | LHB  | 4    | Mo - 14:48 |    41146-1 | P7        | Depart from platform - Att. | 41223-1         | 24,
2     |   -   | LHB  | 4    | Mo - 15:08 |    41147-1 | P7        | Depart from platform - Att. | 41224-1         | 20,
3     |   -   | LHB  | 4    | Mo - 15:18 |    15147-1 | P6        | Depart from platform - Att. | 15225-1         | 16,
4     |   -   | LHB  | 4    | Mo - 15:28 |    41148-1 | P7        | Depart from platform - Att. | 41225-1         | 12,
1     |   -   | LHB  | 4    | Mo - 15:38 |    15148-1 | P6        | Depart from platform - Att. | 15224-1         | 8,
6     |   -   | LHB  | 4    | Mo - 15:48 |    41149-1 | P7        | Depart from platform - Att. | 41226-1         | 4,
8     |   -   | LHB  | 4    | Mo - 16:52 | 41248-1    | P7        | Arrive at platform - Det.    |    40116-1      | 8,
9     |   -   | LHB  | 4    | Mo - 17:02 | 15249-1    | P6        | Arrive at platform - Det.    |    45125-1      | 12,
10    |   -   | LHB  | 4    | Mo - 17:12 | 41249-1    | P7        | Arrive at platform - Det.    |    40117-1      | 16,
11    |   -   | LHB  | 4    | Mo - 17:22 | 15250-1    | P6        | Arrive at platform - Det.    |    45124-1      | 20,
12    |   -   | LHB  | 4    | Mo - 17:32 | 41250-1    | P7        | Arrive at platform - Det.    |    40117-2      | 24,
13    |   -   | LHB  | 4    | Mo - 17:52 | 41251-1    | P7        | Arrive at platform - Det.    |    41119-1      | 28,
14    |   -   | LHB  | 4    | Mo - 18:12 | 41252-1    | P7        | Arrive at platform - Det.    |    41119-2      | 32,
5     |   -   | LHB  | 4    | Mo - 18:51 |    16958-1 | P6        | Depart from platform - Att. | 15226-1         | 28,
15    |   -   | LHB  | 4    | Mo - 19:22 | 15256-2    | P6        | Arrive at platform           |    15119-1      | 32,
16    |   -   | LHB  | 4    | Mo - 19:42 | 15257-2    | P6        | Arrive at platform           |    15119-2      | 36,
17    |   -   | LHB  | 4    | Tu - 00:32 | 40271-2    | P7        | Arrive at platform           |    40116-2      | 40,
18    |   -   | LHB  | 4    | Tu - 00:52 | 40200-2    | P7        | Arrive at platform           |    45123-1      | 44,
19    |   -   | LHB  | 4    | Tu - 01:12 | 40201-1    | P7        | Arrive at platform           |    41118-2      | 48,
8     |   -   | LHB  | 4    | Tu - 04:48 |    40116-1 | P7        | Depart from platform         | 41248-1         | 44,
17    |   -   | LHB  | 4    | Tu - 04:48 |    40116-2 | P7        | Depart from platform         | 40271-2         | 40,
10    |   -   | LHB  | 4    | Tu - 05:08 |    40117-1 | P7        | Depart from platform         | 41249-1         | 36,
12    |   -   | LHB  | 4    | Tu - 05:08 |    40117-2 | P7        | Depart from platform         | 41250-1         | 32,
19    |   -   | LHB  | 4    | Tu - 05:28 |    41118-2 | P7        | Depart from platform         | 40201-1         | 28,
13    |   -   | LHB  | 4    | Tu - 05:48 |    41119-1 | P7        | Depart from platform         | 41251-1         | 24,
14    |   -   | LHB  | 4    | Tu - 05:48 |    41119-2 | P7        | Depart from platform         | 41252-1         | 20,
15    |   -   | LHB  | 4    | Tu - 05:58 |    15119-1 | P6        | Depart from platform         | 15256-2         | 16,
16    |   -   | LHB  | 4    | Tu - 05:58 |    15119-2 | P6        | Depart from platform         | 15257-2         | 12,
20    |   -   | LHB  | 4    | Tu - 06:02 | 16016-1    | P6        | Arrive at platform - Det.    |    41121-1      | 16,
21    |   -   | LHB  | 4    | Tu - 06:22 | 16017-1    | P6        | Arrive at platform - Det.    |    45122-1      | 20,
20    |   -   | LHB  | 4    | Tu - 06:28 |    41121-1 | P7        | Depart from platform - Att. | 16016-1         | 16,
21    |   -   | LHB  | 4    | Tu - 06:45 |    45122-1 | P6        | Depart from platform         | 16017-1         | 12,
18    |   -   | LHB  | 4    | Tu - 07:05 |    45123-1 | P6        | Depart from platform         | 40200-2         | 8,
11    |   -   | LHB  | 4    | Tu - 07:25 |    45124-1 | P6        | Depart from platform         | 15250-1         | 4,
9     |   -   | LHB  | 4    | Tu - 07:45 |    45125-1 | P6        | Depart from platform         | 15249-1         | 0]

- The number of crossings in the timetable is 62 (the maximum number is 108).

 ---Running feasibility check---

1. Finding the number of drivers needed based on the arrivals in the timetable.

- Based on the arrivals of train units in the timetable TWO drivers are necessary!

2. Checking the capacity needed at the shunt yard.

- The maximum number of units at the shunt yard during the planning period is 48.
- There is not enough capacity at the shunt yard (the capacity is only 40 units)!
- Allow the use of platforms as depot tracks at night (yes/no)?
y
- Write the block you allow to park at the platforms at night (e.g 3)?
15
- Is it possible to park the block at the platform from arrival to departure (yes/no)?
n
- Write the day and time for the move to the platform (e.g Tu,23:45)?
Tu,00:30
Block |  New  | Type | Size | Day & Time |  From/to   |   Track   |           Activity           |     From/to     | Stock
[
0     |   -   | LHB  | 4    | Mo - 08:32 | 41223-1    | P7        | Arrive at platform - Det.    |    41146-1      | 4,
1     |   -   | LHB  | 4    | Mo - 08:42 | 15224-1    | P6        | Arrive at platform - Det.    |    15148-1      | 8,
2     |   -   | LHB  | 4    | Mo - 08:52 | 41224-1    | P7        | Arrive at platform - Det.    |    41147-1      | 12,
3     |   -   | LHB  | 4    | Mo - 09:02 | 15225-1    | P6        | Arrive at platform - Det.    |    15147-1      | 16,
4     |   -   | LHB  | 4    | Mo - 09:12 | 41225-1    | P7        | Arrive at platform - Det.    |    41148-1      | 20,
5     |   -   | LHB  | 4    | Mo - 09:22 | 15226-1    | P6        | Arrive at platform - Det.    |    16958-1      | 24,
6     |   -   | LHB  | 4    | Mo - 09:32 | 41226-1    | P7        | Arrive at platform - Det.    |    41149-1      | 28,
7     |   -   | LHB  | 4    | Mo - 09:42 | 15227-1    | P6        | Arrive at platform - Det.    |    41145-1      | 32,
7     |   -   | LHB  | 4    | Mo - 14:28 |    41145-1 | P7        | Depart from platform - Att. | 15227-1         | 28,
0     |   -   | LHB  | 4    | Mo - 14:48 |    41146-1 | P7        | Depart from platform - Att. | 41223-1         | 24,
2     |   -   | LHB  | 4    | Mo - 15:08 |    41147-1 | P7        | Depart from platform - Att. | 41224-1         | 20,
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3     |  -  | LHB  | 4   | Mo - 15:18 |    15147-1 | P6       | Depart from platform - Att. | 15225-1         | 16,
4     |  -  | LHB  | 4   | Mo - 15:28 |    41148-1 | P7       | Depart from platform - Att. | 41225-1         | 12,
1     |  -  | LHB  | 4   | Mo - 15:38 |    15148-1 | P6       | Depart from platform - Att. | 15224-1         | 8,
6     |  -  | LHB  | 4   | Mo - 15:48 |    41149-1 | P7       | Depart from platform - Att. | 41226-1         | 4,
8     |  -  | LHB  | 4   | Mo - 16:52 | 41248-1    | P7       | Arrive at platform - Det.   |    40116-1      | 8,
9     |  -  | LHB  | 4   | Mo - 17:02 | 15249-1    | P6       | Arrive at platform - Det.   |    45125-1      | 12,
10    |  -  | LHB  | 4   | Mo - 17:12 | 41249-1    | P7       | Arrive at platform - Det.   |    40117-1      | 16,
11    |  -  | LHB  | 4   | Mo - 17:22 | 15250-1    | P6       | Arrive at platform - Det.   |    45124-1      | 20,
12    |  -  | LHB  | 4   | Mo - 17:32 | 41250-1    | P7       | Arrive at platform - Det.   |    40117-2      | 24,
13    |  -  | LHB  | 4   | Mo - 17:52 | 41251-1    | P7       | Arrive at platform - Det.   |    41119-1      | 28,
14    |  -  | LHB  | 4   | Mo - 18:12 | 41252-1    | P7       | Arrive at platform - Det.   |    41119-2      | 32,
5     |  -  | LHB  | 4   | Mo - 18:51 |    16958-1 | P6       | Depart from platform - Att. | 15226-1         | 28,
15    |  -  | LHB  | 4   | Mo - 19:22 | 15256-2    | P6       | Arrive at platform          |    15119-1      | 32,
16    |  -  | LHB  | 4   | Mo - 19:42 | 15257-2    | P6       | Arrive at platform          |    15119-2      | 36,
15    | NGT-1 | LHB | 4  | Tu - 00:30 |            |     /P6  | Move to platform            | 15256-2/15119-1 | -,
17    |  -  | LHB  | 4   | Tu - 00:32 | 40271-2    | P7       | Arrive at platform          |    40116-2      | 36,
18    |  -  | LHB  | 4   | Tu - 00:52 | 40200-2    | P7       | Arrive at platform          |    45123-1      | 40,
19    |  -  | LHB  | 4   | Tu - 01:12 | 40201-1    | P7       | Arrive at platform          |    41118-2      | 44,
8     |  -  | LHB  | 4   | Tu - 04:48 |    40116-1 | P7       | Depart from platform        | 41248-1         | 40,
17    |  -  | LHB  | 4   | Tu - 04:48 |    40116-2 | P7       | Depart from platform        | 40271-2         | 36,
10    |  -  | LHB  | 4   | Tu - 05:08 |    40117-1 | P7       | Depart from platform        | 41249-1         | 32,
12    |  -  | LHB  | 4   | Tu - 05:08 |    40117-2 | P7       | Depart from platform        | 41250-1         | 28,
19    |  -  | LHB  | 4   | Tu - 05:28 |    41118-2 | P7       | Depart from platform        | 40201-1         | 24,
13    |  -  | LHB  | 4   | Tu - 05:48 |    41119-1 | P7       | Depart from platform        | 41251-1         | 20,
14    |  -  | LHB  | 4   | Tu - 05:48 |    41119-2 | P7       | Depart from platform        | 41252-1         | 16,
15    |  -  | LHB  | 4   | Tu - 05:58 |    15119-1 | P6       | Depart from platform        | 15256-2         | 16,
16    |  -  | LHB  | 4   | Tu - 05:58 |    15119-2 | P6       | Depart from platform        | 15257-2         | 12,
20    |  -  | LHB  | 4   | Tu - 06:02 | 16016-1    | P6       | Arrive at platform - Det.   |    41121-1      | 16,
21    |  -  | LHB  | 4   | Tu - 06:22 | 16017-1    | P6       | Arrive at platform - Det.   |    45122-1      | 20,
20    |  -  | LHB  | 4   | Tu - 06:28 |    41121-1 | P7       | Depart from platform - Att. | 16016-1         | 16,
21    |  -  | LHB  | 4   | Tu - 06:45 |    45122-1 | P6       | Depart from platform        | 16017-1         | 12,
18    |  -  | LHB  | 4   | Tu - 07:05 |    45123-1 | P6       | Depart from platform        | 40200-2         | 8,
11    |  -  | LHB  | 4   | Tu - 07:25 |    45124-1 | P6       | Depart from platform        | 15250-1         | 4,
9     |  -  | LHB  | 4   | Tu - 07:45 |    45125-1 | P6       | Depart from platform        | 15249-1         | 0]
- Park more blocks at the platform at night (the capacity at the shunt yard is 40) (yes/no)?
y
- Write the block you allow to park at the platforms at night (e.g 3)?
16
- Is it possible to park the block at the platform from arrival to departure (yes/no)?
n
- Write the day and time for the move to the platform (e.g Tu,23:45)?
Tu,00:30
Block |  New  | Type | Size | Day & Time |  From/to   |  Track   |          Activity           |     From/to     | Stock
[
0     |  -  | LHB  | 4   | Mo - 08:32 | 41223-1    | P7       | Arrive at platform - Det.   |    41146-1      | 4,
1     |  -  | LHB  | 4   | Mo - 08:42 | 15224-1    | P6       | Arrive at platform - Det.   |    15148-1      | 8,
2     |  -  | LHB  | 4   | Mo - 08:52 | 41224-1    | P7       | Arrive at platform - Det.   |    41147-1      | 12,
3     |  -  | LHB  | 4   | Mo - 09:02 | 15225-1    | P6       | Arrive at platform - Det.   |    15147-1      | 16,
4     |  -  | LHB  | 4   | Mo - 09:12 | 41225-1    | P7       | Arrive at platform - Det.   |    41148-1      | 20,
5     |  -  | LHB  | 4   | Mo - 09:22 | 15226-1    | P6       | Arrive at platform - Det.   |    16958-1      | 24,
6     |  -  | LHB  | 4   | Mo - 09:32 | 41226-1    | P7       | Arrive at platform - Det.   |    41149-1      | 28,
7     |  -  | LHB  | 4   | Mo - 09:42 | 15227-1    | P6       | Arrive at platform - Det.   |    41145-1      | 32,
7     |  -  | LHB  | 4   | Mo - 14:28 |    41145-1 | P7       | Depart from platform - Att. | 15227-1         | 28,
0     |  -  | LHB  | 4   | Mo - 14:48 |    41146-1 | P7       | Depart from platform - Att. | 41223-1         | 24,
2     |  -  | LHB  | 4   | Mo - 15:08 |    41147-1 | P7       | Depart from platform - Att. | 41224-1         | 20,
3     |  -  | LHB  | 4   | Mo - 15:18 |    15147-1 | P6       | Depart from platform - Att. | 15225-1         | 16,
4     |  -  | LHB  | 4   | Mo - 15:28 |    41148-1 | P7       | Depart from platform - Att. | 41225-1         | 12,
1     |  -  | LHB  | 4   | Mo - 15:38 |    15148-1 | P6       | Depart from platform - Att. | 15224-1         | 8,
6     |  -  | LHB  | 4   | Mo - 15:48 |    41149-1 | P7       | Depart from platform - Att. | 41226-1         | 4,
8     |  -  | LHB  | 4   | Mo - 16:52 | 41248-1    | P7       | Arrive at platform - Det.   |    40116-1      | 8,
9     |  -  | LHB  | 4   | Mo - 17:02 | 15249-1    | P6       | Arrive at platform - Det.   |    45125-1      | 12,
10    |  -  | LHB  | 4   | Mo - 17:12 | 41249-1    | P7       | Arrive at platform - Det.   |    40117-1      | 16,
11    |  -  | LHB  | 4   | Mo - 17:22 | 15250-1    | P6       | Arrive at platform - Det.   |    45124-1      | 20,
12    |  -  | LHB  | 4   | Mo - 17:32 | 41250-1    | P7       | Arrive at platform - Det.   |    40117-2      | 24,
13    |  -  | LHB  | 4   | Mo - 17:52 | 41251-1    | P7       | Arrive at platform - Det.   |    41119-1      | 28,
14    |  -  | LHB  | 4   | Mo - 18:12 | 41252-1    | P7       | Arrive at platform - Det.   |    41119-2      | 32,
5     |  -  | LHB  | 4   | Mo - 18:51 |    16958-1 | P6       | Depart from platform - Att. | 15226-1         | 28,
15    |  -  | LHB  | 4   | Mo - 19:22 | 15256-2    | P6       | Arrive at platform          |    15119-1      | 32,
16    |  -  | LHB  | 4   | Mo - 19:42 | 15257-2    | P6       | Arrive at platform          |    15119-2      | 36,
15    | NGT-1 | LHB | 4  | Tu - 00:30 |            |     /P6  | Move to platform            | 15256-2/15119-1 | -,
16    | NGT-2 | LHB | 4  | Tu - 00:30 |            |     /P6  | Move to platform            | 15257-2/15119-2 | -,
17    |  -  | LHB  | 4   | Tu - 00:32 | 40271-2    | P7       | Arrive at platform          |    40116-2      | 32,
18    |  -  | LHB  | 4   | Tu - 00:52 | 40200-2    | P7       | Arrive at platform          |    45123-1      | 36,
19    |  -  | LHB  | 4   | Tu - 01:12 | 40201-1    | P7       | Arrive at platform          |    41118-2      | 40,
8     |  -  | LHB  | 4   | Tu - 04:48 |    40116-1 | P7       | Depart from platform        | 41248-1         | 36,
17    |  -  | LHB  | 4   | Tu - 04:48 |    40116-2 | P7       | Depart from platform        | 40271-2         | 32,
10    |  -  | LHB  | 4   | Tu - 05:08 |    40117-1 | P7       | Depart from platform        | 41249-1         | 28,
12    |  -  | LHB  | 4   | Tu - 05:08 |    40117-2 | P7       | Depart from platform        | 41250-1         | 24,
19    |  -  | LHB  | 4   | Tu - 05:28 |    41118-2 | P7       | Depart from platform        | 40201-1         | 20,
13    |  -  | LHB  | 4   | Tu - 05:48 |    41119-1 | P7       | Depart from platform        | 41251-1         | 16,
14    |  -  | LHB  | 4   | Tu - 05:48 |    41119-2 | P7       | Depart from platform        | 41252-1         | 12,
15    |  -  | LHB  | 4   | Tu - 05:58 |    15119-1 | P6       | Depart from platform        | 15256-2         | 12,
16    |  -  | LHB  | 4   | Tu - 05:58 |    15119-2 | P6       | Depart from platform        | 15257-2         | 12,
20    |  -  | LHB  | 4   | Tu - 06:02 | 16016-1    | P6       | Arrive at platform - Det.   |    41121-1      | 16,
21    |  -  | LHB  | 4   | Tu - 06:22 | 16017-1    | P6       | Arrive at platform - Det.   |    45122-1      | 20,
20    |  -  | LHB  | 4   | Tu - 06:28 |    41121-1 | P7       | Depart from platform - Att. | 16016-1         | 16,
21    |  -  | LHB  | 4   | Tu - 06:45 |    45122-1 | P6       | Depart from platform        | 16017-1         | 12,
```

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18    |  -   | LHB  | 4    | Tu - 07:05 |    45123-1 | P6        | Depart from platform        | 40200-2        | 8,
11    |  -   | LHB  | 4    | Tu - 07:25 |    45124-1 | P6        | Depart from platform        | 15250-1        | 4,
9     |  -   | LHB  | 4    | Tu - 07:45 |    45125-1 | P6        | Depart from platform        | 15249-1        | 0]
- Park more blocks at the platform at night (the capacity at the shunt yard is 40) (yes/no)?
n

3. Checking for infeasiblity in the timetable.

Check!

4. Checking for shunt tracks with insufficient capacity.

Check!

Use symmetry if possible (yes/no) - default is yes?
y

Set penalty for parking blocks with different subtype on the same shunt track (yes/no) - default is yes?
y

Set penalties for broken arrivals and departures (yes/no) - default is yes?
y

Make blocks that are detached at the station cheaper (yes/no) - default is yes?
y

Create shunt plan (yes/no)?
y

... Solving the problem ...

All 24 blocks have been assigned to a track!

Block |  New  | Type | Size | Day & Time |  From/to   |   Track   |          Activity           |     From/to     | Stock
[
0     |  -   | LHB  | 4    | Mo - 08:32 | 41223-1    | P7  /S71  | Arrive at platform - Det.   |    41146-1      | 4,
1     |  -   | LHB  | 4    | Mo - 08:42 | 15224-1    | P6  /S72  | Arrive at platform - Det.   |    15148-1      | 8,
2     |  -   | LHB  | 4    | Mo - 08:52 | 41224-1    | P7  /S72  | Arrive at platform - Det.   |    41147-1      | 12,
3     |  -   | LHB  | 4    | Mo - 09:02 | 15225-1    | P6  /S73  | Arrive at platform - Det.   |    15147-1      | 16,
4     |  -   | LHB  | 4    | Mo - 09:12 | 41225-1    | P7  /S74  | Arrive at platform - Det.   |    41148-1      | 20,
5     |  -   | LHB  | 4    | Mo - 09:22 | 15226-1    | P6  /S75  | Arrive at platform - Det.   |    16958-1      | 24,
6     |  -   | LHB  | 4    | Mo - 09:32 | 41226-1    | P7  /S75  | Arrive at platform - Det.   |    41149-1      | 28,
7     |  -   | LHB  | 4    | Mo - 09:42 | 15227-1    | P6  /S71  | Arrive at platform - Det.   |    41145-1      | 32,
7     |  -   | LHB  | 4    | Mo - 14:28 |    41145-1 | S71 /P7   | Depart from platform - Att. | 15227-1         | 28,
0     |  -   | LHB  | 4    | Mo - 14:48 |    41146-1 | S71 /P7   | Depart from platform - Att. | 41223-1         | 24,
2     |  -   | LHB  | 4    | Mo - 15:08 |    41147-1 | S72 /P7   | Depart from platform - Att. | 41224-1         | 20,
3     |  -   | LHB  | 4    | Mo - 15:18 |    15147-1 | S73 /P6   | Depart from platform - Att. | 15225-1         | 16,
4     |  -   | LHB  | 4    | Mo - 15:28 |    41148-1 | S74 /P7   | Depart from platform - Att. | 41225-1         | 12,
1     |  -   | LHB  | 4    | Mo - 15:38 |    15148-1 | S72 /P6   | Depart from platform - Att. | 15224-1         | 8,
6     |  -   | LHB  | 4    | Mo - 15:48 |    41149-1 | S75 /P7   | Depart from platform - Att. | 41226-1         | 4,
8     |  -   | LHB  | 4    | Mo - 16:52 | 41248-1    | P7  /S71  | Arrive at platform - Det.   |    40116-1      | 8,
9     |  -   | LHB  | 4    | Mo - 17:02 | 15249-1    | P6  /S73  | Arrive at platform - Det.   |    45125-1      | 12,
10    |  -   | LHB  | 4    | Mo - 17:12 | 41249-1    | P7  /S74  | Arrive at platform - Det.   |    40117-1      | 16,
11    |  -   | LHB  | 4    | Mo - 17:22 | 15250-1    | P6  /S73  | Arrive at platform - Det.   |    45124-1      | 20,
12    |  -   | LHB  | 4    | Mo - 17:32 | 41250-1    | P7  /S74  | Arrive at platform - Det.   |    40117-2      | 24,
13    |  -   | LHB  | 4    | Mo - 17:52 | 41251-1    | P7  /S72  | Arrive at platform - Det.   |    41119-1      | 28,
14    |  -   | LHB  | 4    | Mo - 18:12 | 41252-1    | P7  /S72  | Arrive at platform - Det.   |    41119-2      | 32,
5     |  -   | LHB  | 4    | Mo - 18:51 |    16958-1 | S75 /P6   | Depart from platform - Att. | 15226-1         | 28,
15    |  -   | LHB  | 4    | Mo - 19:22 | 15256-2    | P6  /S75  | Arrive at platform          |    15119-1      | 32,
16    |  -   | LHB  | 4    | Mo - 19:42 | 15257-2    | P6  /S75  | Arrive at platform          |    15119-2      | 36,
17    | NGT-1 | LHB  | 4    | Tu - 00:30 |            | S75 /P6   | Move to platform            | 15256-2/15119-1 | -,
18    | NGT-2 | LHB  | 4    | Tu - 00:30 |            | S75 /P6   | Move to platform            | 15257-2/15119-2 | -,
19    |  -   | LHB  | 4    | Tu - 00:32 | 40271-2    | P7  /S71  | Arrive at platform          |    40116-2      | 32,
20    |  -   | LHB  | 4    | Tu - 00:52 | 40200-2    | P7  /S75  | Arrive at platform          |    45123-1      | 36,
21    |  -   | LHB  | 4    | Tu - 01:12 | 40201-1    | P7  /S75  | Arrive at platform          |    41118-2      | 40,
8     |  -   | LHB  | 4    | Tu - 04:48 |    40116-1 | S71 /P7   | Depart from platform        | 41248-1         | 36,
19    |  -   | LHB  | 4    | Tu - 04:48 |    40116-2 | S71 /P7   | Depart from platform        | 40271-2         | 32,
10    |  -   | LHB  | 4    | Tu - 05:08 |    40117-1 | S74 /P7   | Depart from platform        | 41249-1         | 28,
12    |  -   | LHB  | 4    | Tu - 05:08 |    40117-2 | S74 /P7   | Depart from platform        | 41250-1         | 24,
21    |  -   | LHB  | 4    | Tu - 05:28 |    41118-2 | S75 /P7   | Depart from platform        | 40201-1         | 20,
13    |  -   | LHB  | 4    | Tu - 05:48 |    41119-1 | S72 /P7   | Depart from platform        | 41251-1         | 16,
14    |  -   | LHB  | 4    | Tu - 05:48 |    41119-2 | S72 /P7   | Depart from platform        | 41252-1         | 12,
15    |  -   | LHB  | 4    | Tu - 05:58 |    15119-1 | P6  /P6   | Depart from platform        | 15256-2         | 12,
16    |  -   | LHB  | 4    | Tu - 05:58 |    15119-2 | P6  /P6   | Depart from platform        | 15257-2         | 12,
22    |  -   | LHB  | 4    | Tu - 06:02 | 16016-1    | P6  /S72  | Arrive at platform - Det.   |    41121-1      | 16,
23    |  -   | LHB  | 4    | Tu - 06:22 | 16017-1    | P6  /S74  | Arrive at platform - Det.   |    45122-1      | 20,
22    |  -   | LHB  | 4    | Tu - 06:28 |    41121-1 | S72 /P7   | Depart from platform - Att. | 16016-1         | 16,
23    |  -   | LHB  | 4    | Tu - 06:45 |    45122-1 | S74 /P6   | Depart from platform        | 16017-1         | 12,
20    |  -   | LHB  | 4    | Tu - 07:05 |    45123-1 | S75 /P6   | Depart from platform        | 40200-2         | 8,
11    |  -   | LHB  | 4    | Tu - 07:25 |    45124-1 | S73 /P6   | Depart from platform        | 15250-1         | 4,
9     |  -   | LHB  | 4    | Tu - 07:45 |    45125-1 | S73 /P6   | Depart from platform        | 15249-1         | 0]

Generate solutions time 702 msec.
Generate model time 1115 msec.
Write model time 195 msec.
Solve model time 524 msec.
Overall solution time 2536 msec.
```

A.13 Køge - Weekend (2005-1)

```
 ---Starting depot planning for KJ---

Block |  New  | Type | Size | Day & Time |  From/to   |   Track   |          Activity           |    From/to    | Stock
[
0     |   -   | LHB  | 4    | Fr - 08:32 | 41223-1    | P7        | Arrive at platform - Det.   |    41146-1    | 4,
1     |   -   | LHB  | 4    | Fr - 08:42 | 15224-1    | P6        | Arrive at platform - Det.   |    15146-1    | 8,
2     |   -   | LHB  | 4    | Fr - 08:52 | 41224-1    | P7        | Arrive at platform - Det.   |    41147-1    | 12,
3     |   -   | LHB  | 4    | Fr - 09:02 | 15225-1    | P6        | Arrive at platform - Det.   |    15145-1    | 16,
4     |   -   | LHB  | 4    | Fr - 09:12 | 41225-1    | P7        | Arrive at platform - Det.   |    41144-1    | 20,
5     |   -   | LHB  | 4    | Fr - 09:22 | 15226-1    | P6        | Arrive at platform - Det.   |    16958-1    | 24,
6     |   -   | LHB  | 4    | Fr - 09:32 | 41226-1    | P7        | Arrive at platform - Det.   |    41143-1    | 28,
7     |   -   | LHB  | 4    | Fr - 09:42 | 15227-1    | P6        | Arrive at platform - Det.   |    41145-1    | 32,
6     |   -   | LHB  | 4    | Fr - 13:48 |    41143-1 | P7        | Depart from platform - Att. | 41226-1       | 28,
4     |   -   | LHB  | 4    | Fr - 14:08 |    41144-1 | P7        | Depart from platform - Att. | 41225-1       | 24,
7     |   -   | LHB  | 4    | Fr - 14:28 |    41145-1 | P7        | Depart from platform - Att. | 15227-1       | 20,
3     |   -   | LHB  | 4    | Fr - 14:38 |    15145-1 | P6        | Depart from platform - Att. | 15225-1       | 16,
0     |   -   | LHB  | 4    | Fr - 14:48 |    41146-1 | P7        | Depart from platform - Att. | 41223-1       | 12,
1     |   -   | LHB  | 4    | Fr - 14:58 |    15146-1 | P6        | Depart from platform - Att. | 15224-1       | 8,
2     |   -   | LHB  | 4    | Fr - 15:08 |    41147-1 | P7        | Depart from platform - Att. | 41224-1       | 4,
8     |   -   | LHB  | 4    | Fr - 16:12 | 41246-1    | P7        | Arrive at platform - Det.   |    15135-1    | 8,
9     |   -   | LHB  | 4    | Fr - 16:22 | 15247-1    | P6        | Arrive at platform - Det.   |    40119-1    | 12,
10    |   -   | LHB  | 4    | Fr - 16:32 | 41247-1    | P7        | Arrive at platform - Det.   |    15134-1    | 16,
11    |   -   | LHB  | 4    | Fr - 16:42 | 15248-1    | P6        | Arrive at platform - Det.   |    40116-1    | 20,
12    |   -   | LHB  | 4    | Fr - 16:52 | 41248-1    | P7        | Arrive at platform - Det.   |    15133-1    | 24,
13    |   -   | LHB  | 4    | Fr - 17:12 | 41249-1    | P7        | Arrive at platform - Det.   |    15131-1    | 28,
14    |   -   | LHB  | 4    | Fr - 17:32 | 41250-1    | P7        | Arrive at platform - Det.   |    40120-1    | 32,
5     |   -   | LHB  | 4    | Fr - 18:51 |    16958-1 | P6        | Depart from platform - Att. | 15226-1       | 28,
15    |   -   | LHB  | 4    | Fr - 19:22 | 15256-2    | P6        | Arrive at platform          |    45123-1    | 32,
16    |   -   | LHB  | 4    | Fr - 19:42 | 15257-2    | P6        | Arrive at platform          |    41118-2    | 36,
17    |   -   | LHB  | 4    | Sa - 00:32 | 40271-2    | P7        | Arrive at platform          |    15132-1    | 40,
18    |   -   | LHB  | 4    | Sa - 00:52 | 40200-2    | P7        | Arrive at platform          |    40118-1    | 44,
19    |   -   | LHB  | 4    | Sa - 01:12 | 40201-2    | P7        | Arrive at platform          |    40117-1    | 48,
11    |   -   | LHB  | 4    | Sa - 04:48 |    40116-1 | P7        | Depart from platform        | 15248-1       | 44,
19    |   -   | LHB  | 4    | Sa - 05:08 |    40117-1 | P7        | Depart from platform        | 40201-2       | 40,
18    |   -   | LHB  | 4    | Sa - 05:28 |    40118-1 | P7        | Depart from platform        | 40200-2       | 36,
9     |   -   | LHB  | 4    | Sa - 05:48 |    40119-1 | P7        | Depart from platform        | 15247-1       | 32,
20    |   -   | LHB  | 8    | Sa - 05:52 | 40215-1    | P6        | Arrive at platform          |    15119-1    | 40,
14    |   -   | LHB  | 4    | Sa - 06:08 |    40120-1 | P7        | Depart from platform        | 41250-1       | 36,
13    |   -   | LHB  | 4    | Sa - 09:58 |    15131-1 | P6        | Depart from platform        | 41249-1       | 32,
17    |   -   | LHB  | 4    | Sa - 10:18 |    15132-1 | P6        | Depart from platform        | 40271-2       | 28,
12    |   -   | LHB  | 4    | Sa - 10:38 |    15133-1 | P6        | Depart from platform        | 41248-1       | 24,
10    |   -   | LHB  | 4    | Sa - 10:58 |    15134-1 | P6        | Depart from platform        | 41247-1       | 20,
8     |   -   | LHB  | 4    | Sa - 11:18 |    15135-1 | P6        | Depart from platform        | 41246-1       | 16,
21    |   -   | LHB  | 4    | Sa - 15:22 | 15244-1    | P6        | Arrive at platform          |    40122-1    | 20,
22    |   -   | LHB  | 4    | Sa - 15:42 | 15245-1    | P6        | Arrive at platform          |    40121-1    | 24,
23    |   -   | LHB  | 4    | Sa - 16:02 | 15246-1    | P6        | Arrive at platform          |    40124-1    | 28,
24    |   -   | LHB  | 4    | Sa - 16:22 | 15247-1    | P6        | Arrive at platform          |    40123-1    | 32,
25    |   -   | LHB  | 4    | Sa - 16:42 | 15248-1    | P6        | Arrive at platform          |    41119-1    | 36,
26    |   -   | LHB  | 4    | Su - 00:32 | 40271-1    | P7        | Arrive at platform          |    40125-1    | 40,
27    |   -   | LHB  | 4    | Su - 00:52 | 40200-1    | P7        | Arrive at platform          |    40120-1    | 44,
28    |   -   | LHB  | 4    | Su - 01:12 | 40201-1    | P7        | Arrive at platform          |    40119-1    | 48,
28    |   -   | LHB  | 4    | Su - 05:48 |    40119-1 | P7        | Depart from platform        | 40201-1       | 44,
27    |   -   | LHB  | 4    | Su - 06:08 |    40120-1 | P7        | Depart from platform        | 40200-1       | 40,
22    |   -   | LHB  | 4    | Su - 06:28 |    40121-1 | P7        | Depart from platform        | 15245-1       | 36,
21    |   -   | LHB  | 4    | Su - 06:48 |    40122-1 | P7        | Depart from platform        | 15244-1       | 32,
29    |   -   | LHB  | 8    | Su - 06:52 | 40218-1    | P6        | Arrive at platform          |    40117-0    | 40,
24    |   -   | LHB  | 4    | Su - 07:08 |    40123-1 | P7        | Depart from platform        | 15247-1       | 36,
30    |   -   | LHB  | 4    | Su - 07:12 | 40219-1    | P6        | Arrive at platform          |    40116-1    | 40,
23    |   -   | LHB  | 4    | Su - 07:28 |    40124-1 | P7        | Depart from platform        | 15246-1       | 36,
31    |   -   | LHB  | 4    | Su - 07:32 | 40220-1    | P6        | Arrive at platform          |    40116-2    | 40,
26    |   -   | LHB  | 4    | Su - 07:48 |    40125-1 | P7        | Depart from platform        | 40271-1       | 36,
32    |   -   | LHB  | 4    | Mn - 00:32 | 40271-1    | P7        | Arrive at platform          |    41119-2    | 40,
33    |   -   | LHB  | 4    | Mn - 00:52 | 40200-1    | P7        | Arrive at platform          |    45125-1    | 44,
34    |   -   | LHB  | 4    | Mn - 01:12 | 40201-1    | P7        | Arrive at platform          |    45124-1    | 48,
30    |   -   | LHB  | 4    | Mn - 04:48 |    40116-1 | P7        | Depart from platform        | 40219-1       | 44,
31    |   -   | LHB  | 4    | Mn - 04:48 |    40116-2 | P7        | Depart from platform        | 40220-1       | 40,
29    |   -   | LHB  | 8    | Mn - 05:08 |    40117-0 | P7        | Depart from platform        | 40218-1       | 32,
16    |   -   | LHB  | 4    | Mn - 05:28 |    41118-2 | P7        | Depart from platform        | 15257-2       | 28,
25    |   -   | LHB  | 4    | Mn - 05:48 |    41119-1 | P7        | Depart from platform        | 15248-1       | 24,
32    |   -   | LHB  | 4    | Mn - 05:48 |    41119-2 | P7        | Depart from platform        | 40271-1       | 20,
20    |   -   | LHB  | 8    | Mn - 05:58 |    15119-1 | P6        | Depart from platform        | 40215-1       | 12,
35    |   -   | LHB  | 4    | Mn - 06:02 | 16016-1    | P6        | Arrive at platform - Det.   |    41121-1    | 16,
36    |   -   | LHB  | 4    | Mn - 06:22 | 16017-1    | P6        | Arrive at platform - Det.   |    45122-1    | 20,
35    |   -   | LHB  | 4    | Mn - 06:28 |    41121-1 | P7        | Depart from platform - Att. | 16016-1       | 16,
36    |   -   | LHB  | 4    | Mn - 06:45 |    45122-1 | P6        | Depart from platform        | 16017-1       | 12,
15    |   -   | LHB  | 4    | Mn - 07:05 |    45123-1 | P6        | Depart from platform        | 15256-2       | 8,
34    |   -   | LHB  | 4    | Mn - 07:25 |    45124-1 | P6        | Depart from platform        | 40201-1       | 4,
33    |   -   | LHB  | 4    | Mn - 07:45 |    45125-1 | P6        | Depart from platform        | 40200-1       | 0]

- The number of crossings in the timetable is 93 (the maximum number is 213).

 ---Running feasibility check---
```

```
1. Finding the number of drivers needed based on the arrivals in the timetable.

- Based on the arrivals of train units in the timetable TWO drivers are necessary!

2. Checking the capacity needed at the shunt yard.

- The maximum number of units at the shunt yard during the planning period is 48.
- There is not enough capacity at the shunt yard (the capacity is only 40 units)!
- Allow the use of platforms as depot tracks at night (yes/no)?
n

3. Checking for infeasiblity in the timetable.

Check!

4. Checking for shunt tracks with insufficient capacity.

Check!

Use symmetry if possible (yes/no) - default is yes?
y

Set penalty for parking blocks with different subtype on the same shunt track (yes/no) - default is yes?
y

Set penalties for broken arrivals and departures (yes/no) - default is yes?
y

Make blocks that are detached at the station cheaper (yes/no) - default is yes?
y

Create shunt plan (yes/no)?
y
ILOG CPLEX 9.130, licensed to "university-lyngby", options: e m b q
Presolve has eliminated 0 rows and 2 columns...
Presolve has eliminated 1 rows and 2 columns...
Aggregator has done 0 substitutions...
Tried aggregator 1 time.
Presolve has eliminated 1 rows and 2 columns...
MIP Presolve eliminated 1 rows and 2 columns.
Reduced MIP has 38 rows, 529083 columns, and 3957786 nonzeros.
Presolve time =   47.12 sec.
Clique table members: 37
MIP emphasis: balance optimality and feasibility
Root relaxation solution time =   69.53 sec.

        Nodes                                        Cuts/
   Node  Left     Objective  IInf  Best Integer     Best Node    ItCnt     Gap         Variable B Parent  Depth

      0     0     2005.0000    28                   2005.0000      265
*     0+    0                   0    30805.0000     2005.0000      265   93.49%
*     0+    0                   0     2005.0000     2005.0000      265    0.00%
Solution status = Optimal
Solution value = 2005

... The track assingments used ...

VARIABLE: y15 VALUE = 1
The following block could not be assigned to any track:
Block no.: 15 , Block type: LHB , Block size: 4
Arrival no.  : 15256-2 , Platform: 6 , Detached: false , Arrival time: Fr, 19:22
Departure no.: 45123-1 , Platform: 6 , Attached: false , Departure time: Mn, 7:05

VARIABLE: y16 VALUE = 1
The following block could not be assigned to any track:
Block no.: 16 , Block type: LHB , Block size: 4
Arrival no.  : 15257-2 , Platform: 6 , Detached: false , Arrival time: Fr, 19:42
Departure no.: 41118-2 , Platform: 7 , Attached: false , Departure time: Mn, 5:28


35 blocks have been assigned to a track
2 blocks could NOT be assigned to a track!

Block |  New  | Type | Size | Day & Time |  From/to   |   Track    |          Activity          |     From/to     | Stock
[
0     |   -   | LHB  | 4    | Fr - 08:32 | 41223-1    | P7  /S71  | Arrive at platform - Det.  |    41146-1      | 4,
1     |   -   | LHB  | 4    | Fr - 08:42 | 15224-1    | P6  /S72  | Arrive at platform - Det.  |    15146-1      | 8,
2     |   -   | LHB  | 4    | Fr - 08:52 | 41224-1    | P7  /S73  | Arrive at platform - Det.  |    41147-1      | 12,
3     |   -   | LHB  | 4    | Fr - 09:02 | 15225-1    | P6  /S74  | Arrive at platform - Det.  |    15145-1      | 16,
4     |   -   | LHB  | 4    | Fr - 09:12 | 41225-1    | P7  /S71  | Arrive at platform - Det.  |    41144-1      | 20,
5     |   -   | LHB  | 4    | Fr - 09:22 | 15226-1    | P6  /S75  | Arrive at platform - Det.  |    16958-1      | 24,
6     |   -   | LHB  | 4    | Fr - 09:32 | 41226-1    | P7  /S74  | Arrive at platform - Det.  |    41143-1      | 28,
7     |   -   | LHB  | 4    | Fr - 09:42 | 15227-1    | P6  /S75  | Arrive at platform - Det.  |    41145-1      | 32,
6     |   -   | LHB  | 4    | Fr - 13:48 |    41143-1 | S74 /P7   | Depart from platform - Att. | 41226-1        | 28,
4     |   -   | LHB  | 4    | Fr - 14:08 |    41144-1 | S71 /P7   | Depart from platform - Att. | 41225-1        | 24,
7     |   -   | LHB  | 4    | Fr - 14:28 |    41145-1 | S75 /P7   | Depart from platform - Att. | 15227-1        | 20,
```

```
3     |  -  | LHB  | 4   | Fr - 14:38 |     15145-1 | S74 /P6   | Depart from platform - Att. | 15225-1        | 16,
0     |  -  | LHB  | 4   | Fr - 14:48 |     41146-1 | S71 /P7   | Depart from platform - Att. | 41223-1        | 12,
1     |  -  | LHB  | 4   | Fr - 14:58 |     15146-1 | S72 /P6   | Depart from platform - Att. | 15224-1        | 8,
2     |  -  | LHB  | 4   | Fr - 15:08 |     41147-1 | S73 /P7   | Depart from platform - Att. | 41224-1        | 4,
8     |  -  | LHB  | 4   | Fr - 16:12 | 41246-1     | P7  /S73  | Arrive at platform - Det.   |    15135-1     | 8,
9     |  -  | LHB  | 4   | Fr - 16:22 | 15247-1     | P6  /S72  | Arrive at platform - Det.   |    40119-1     | 12,
10    |  -  | LHB  | 4   | Fr - 16:32 | 41247-1     | P7  /S74  | Arrive at platform - Det.   |    15134-1     | 16,
11    |  -  | LHB  | 4   | Fr - 16:42 | 15248-1     | P6  /S72  | Arrive at platform - Det.   |    40116-1     | 20,
12    |  -  | LHB  | 4   | Fr - 16:52 | 41248-1     | P7  /S74  | Arrive at platform - Det.   |    15133-1     | 24,
13    |  -  | LHB  | 4   | Fr - 17:12 | 41249-1     | P7  /S71  | Arrive at platform - Det.   |    15131-1     | 28,
14    |  -  | LHB  | 4   | Fr - 17:32 | 41250-1     | P7  /S71  | Arrive at platform - Det.   |    40120-1     | 32,
5     |  -  | LHB  | 4   | Fr - 18:51 |     16958-1 | S75 /P6   | Depart from platform - Att. | 15226-1        | 28,
15    |  -  | LHB  | 4   | Fr - 19:22 | 15256-2     | P6  /??   | Arrive at platform          |    45123-1     | 32,
16    |  -  | LHB  | 4   | Fr - 19:42 | 15257-2     | P6  /??   | Arrive at platform          |    41118-2     | 36,
17    |  -  | LHB  | 4   | Sa - 00:32 | 40271-2     | P7  /S73  | Arrive at platform          |    15132-1     | 40,
18    |  -  | LHB  | 4   | Sa - 00:52 | 40200-2     | P7  /S75  | Arrive at platform          |    40118-1     | 44,
19    |  -  | LHB  | 4   | Sa - 01:12 | 40201-2     | P7  /S75  | Arrive at platform          |    40117-1     | 48,
11    |  -  | LHB  | 4   | Sa - 04:48 |     40116-1 | S72 /P7   | Depart from platform        | 15248-1        | 44,
19    |  -  | LHB  | 4   | Sa - 05:08 |     40117-1 | S75 /P7   | Depart from platform        | 40201-2        | 40,
18    |  -  | LHB  | 4   | Sa - 05:28 |     40118-1 | S75 /P7   | Depart from platform        | 40200-2        | 36,
9     |  -  | LHB  | 4   | Sa - 05:48 |     40119-1 | S72 /P7   | Depart from platform        | 15247-1        | 32,
20    |  -  | LHB  | 8   | Sa - 05:52 | 40215-1     | P6  /S75  | Arrive at platform          |    15119-1     | 40,
14    |  -  | LHB  | 4   | Sa - 06:08 |     40120-1 | S71 /P7   | Depart from platform        | 41250-1        | 36,
13    |  -  | LHB  | 4   | Sa - 09:58 |     15131-1 | S71 /P6   | Depart from platform        | 41249-1        | 32,
17    |  -  | LHB  | 4   | Sa - 10:18 |     15132-1 | S73 /P6   | Depart from platform        | 40271-2        | 28,
12    |  -  | LHB  | 4   | Sa - 10:38 |     15133-1 | S74 /P6   | Depart from platform        | 41248-1        | 24,
10    |  -  | LHB  | 4   | Sa - 10:58 |     15134-1 | S74 /P6   | Depart from platform        | 41247-1        | 20,
8     |  -  | LHB  | 4   | Sa - 11:18 |     15135-1 | S73 /P6   | Depart from platform        | 41246-1        | 16,
21    |  -  | LHB  | 4   | Sa - 15:22 | 15244-1     | P6  /S73  | Arrive at platform          |    40122-1     | 20,
22    |  -  | LHB  | 4   | Sa - 15:42 | 15245-1     | P6  /S73  | Arrive at platform          |    40121-1     | 24,
23    |  -  | LHB  | 4   | Sa - 16:02 | 15246-1     | P6  /S71  | Arrive at platform          |    40124-1     | 28,
24    |  -  | LHB  | 4   | Sa - 16:22 | 15247-1     | P6  /S71  | Arrive at platform          |    40123-1     | 32,
25    |  -  | LHB  | 4   | Sa - 16:42 | 15248-1     | P6  /S72  | Arrive at platform          |    41119-1     | 36,
26    |  -  | LHB  | 4   | Su - 00:32 | 40271-1     | P7  /S72  | Arrive at platform          |    40125-1     | 40,
27    |  -  | LHB  | 4   | Su - 00:52 | 40200-1     | P7  /S74  | Arrive at platform          |    40120-1     | 44,
28    |  -  | LHB  | 4   | Su - 01:12 | 40201-1     | P7  /S74  | Arrive at platform          |    40119-1     | 48,
28    |  -  | LHB  | 4   | Su - 05:48 |     40119-1 | S74 /P7   | Depart from platform        | 40201-1        | 44,
27    |  -  | LHB  | 4   | Su - 06:08 |     40120-1 | S74 /P7   | Depart from platform        | 40200-1        | 40,
22    |  -  | LHB  | 4   | Su - 06:28 |     40121-1 | S73 /P7   | Depart from platform        | 15245-1        | 36,
21    |  -  | LHB  | 4   | Su - 06:48 |     40122-1 | S73 /P7   | Depart from platform        | 15244-1        | 32,
29    |  -  | LHB  | 8   | Su - 06:52 | 40218-1     | P6  /S74  | Arrive at platform          |    40117-0     | 40,
24    |  -  | LHB  | 4   | Su - 07:08 |     40123-1 | S71 /P7   | Depart from platform        | 15247-1        | 36,
30    |  -  | LHB  | 4   | Su - 07:12 | 40219-1     | P6  /S73  | Arrive at platform          |    40116-1     | 40,
23    |  -  | LHB  | 4   | Su - 07:28 |     40124-1 | S71 /P7   | Depart from platform        | 15246-1        | 36,
31    |  -  | LHB  | 4   | Su - 07:32 | 40220-1     | P6  /S73  | Arrive at platform          |    40116-2     | 40,
26    |  -  | LHB  | 4   | Su - 07:48 |     40125-1 | S72 /P7   | Depart from platform        | 40271-1        | 36,
32    |  -  | LHB  | 4   | Mn - 00:32 | 40271-1     | P7  /S72  | Arrive at platform          |    41119-2     | 40,
33    |  -  | LHB  | 4   | Mn - 00:52 | 40200-1     | P7  /S71  | Arrive at platform          |    45125-1     | 44,
34    |  -  | LHB  | 4   | Mn - 01:12 | 40201-1     | P7  /S71  | Arrive at platform          |    45124-1     | 48,
30    |  -  | LHB  | 4   | Mn - 04:48 |     40116-1 | S73 /P7   | Depart from platform        | 40219-1        | 44,
31    |  -  | LHB  | 4   | Mn - 04:48 |     40116-2 | S73 /P7   | Depart from platform        | 40220-1        | 40,
29    |  -  | LHB  | 8   | Mn - 05:08 |     40117-0 | S74 /P7   | Depart from platform        | 40218-1        | 32,
16    |  -  | LHB  | 4   | Mn - 05:28 |     41118-2 | ??  /P7   | Depart from platform        | 15257-2        | 28,
25    |  -  | LHB  | 4   | Mn - 05:48 |     41119-1 | S72 /P7   | Depart from platform        | 15248-1        | 24,
32    |  -  | LHB  | 4   | Mn - 05:48 |     41119-2 | S72 /P7   | Depart from platform        | 40271-1        | 20,
20    |  -  | LHB  | 8   | Mn - 05:58 |     15119-1 | S75 /P6   | Depart from platform        | 40215-1        | 12,
35    |  -  | LHB  | 4   | Mn - 06:02 | 16016-1     | P6  /S75  | Arrive at platform - Det.   |    41121-1     | 16,
36    |  -  | LHB  | 4   | Mn - 06:22 | 16017-1     | P6  /S74  | Arrive at platform - Det.   |    45122-1     | 20,
35    |  -  | LHB  | 4   | Mn - 06:28 |     41121-1 | S75 /P7   | Depart from platform - Att. | 16016-1        | 16,
36    |  -  | LHB  | 4   | Mn - 06:45 |     45122-1 | S74 /P6   | Depart from platform        | 16017-1        | 12,
15    |  -  | LHB  | 4   | Mn - 07:05 |     45123-1 | ??  /P6   | Depart from platform        | 15256-2        | 8,
34    |  -  | LHB  | 4   | Mn - 07:25 |     45124-1 | S71 /P6   | Depart from platform        | 40201-1        | 4,
33    |  -  | LHB  | 4   | Mn - 07:45 |     45125-1 | S71 /P6   | Depart from platform        | 40200-1        | 0]

Generate solutions time 22777 msec.
Generate model time 102341 msec.
Write model time 17211 msec.
Solve model time 154366 msec.
Overall solution time 296695 msec.
```