CHALMERS

UNIVERSITY OF TECHNOLOGY

Evaluating Discrete Event Simulation for Rail Port Operations

A case study made in the Port of Gothenburg using AutoMod Path Mover System

Master's thesis in Product and Production development

Fredrik Tallroth

Jonas Rappu

Evaluating Discrete Event Simulation software for railport operations

Master's thesis in Product and Production development

Fredrik Tallroth
Jonas Rappu

CHALMERS

UNIVERSITY OF TECHNOLOGY

Department of Product and Production development
Division of Product and Production development
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2016

Evaluating Discrete Event Simulation software for rail port operations
A case study made in the Port of Gothenburg using Automod's Path Mover System
FREDRIK TALLROTH
JONAS RAPPU

Abstract

The main purpose of this thesis is to evaluate the DES software AutoMod's Path Mover System, which is usually used for simulation of production systems, in its ability to simulate the train operations in a rail port. Production system theory and methodology has been used throughout this thesis. To evaluate the Path Mover System, it will be used in a case study made for the Port of Gothenburg where all freight train operations in the port will be simulated. A validated model of the ports train operations was created and thus the Path Mover System is concluded to be able to simulate rail port train operations. However, there are some improvements that could be made to the system to make the model building easier and less time consuming.

Acknowledgements

Contents

Contents

1

Introduction

1.1 Project Background

The Port of Gothenburg is handling approximately 30% of Sweden's foreign trade and is using the port to ship and receive goods, which typically comes in freight containers. The transportation of freight containers between the port, distribution terminals and end customers are done by freight trains and trucks. Port of Gothenburg has the need to increase the capacity of their cargo transportation to handle an increasing demand, and they are looking to improve the railway system. The port is owned by Port of Gothenburg but they rent it out to several companies. The companies that utilize the tracks around the port for transportation, other then to and from the port, include Volvo cars, Preem and ST1. These companies would also be affected by future changes of the railroad and could stand to benefit from increased capacity of the railway.

To evaluate which future improvements that will benefit the Port of Gothenburg the most, the port needs some evaluation tool. Discrete event simulation (DES) is an appropriate tool to investigate improvement suggestions [1]. DES is heavily used in production systems because of the benefit that it brings. Some of the benefits is that simulation allows a company to experiment with different improvements without disrupting the real world system [2] [1]. As well as identifying several problems such as poor design and bottlenecks. Carson [2] also explain that a simulation model is a good visual tool for explaining and illustrating suggested changes of a system. By applying the benefits that simulation gives a production system to a logistic system, Port of Gothenburg is looking to use a simulation model for the purpose of creating a current state model as well as investigating future improvement suggestions. Train simulation have been used in other places then the port area such as metropolitan [3] and the mining industry [4].

A company that works with DES is ÅF. Port of Gothenburg and ÅF collaborated and decided to create a simulation in the software AutoMod [5]. The software was chosen because ÅF have a lot of expertise and experience with it. To simulate trains in AutoMod its needed to use the Path Mover System, which handles vehicles that travels along a path. The problem with Path Mover System is that its not specified for rail port activity. A research about the possibility to use Path Mover System was needed.

1.2   Concept and Purpose

The purpose of this project is to use a production evaluation tool called Discrete Event Simulation (DES). By applying theory and methods often used in production systems, the thesis aim to evaluate AutoMod's [5] Path Mover System ability to simulate the freight train traffic of a rail port. To do this, this project will first define what components that are needed to simulate the train traffic in a rail port and then evaluate the Path Mover System's ability to create and control these components. The software will be used in a case study in the Port of Gothenburg to be able to evaluate it. The case consist of a simulation project ordered by the port, and by using the Path Mover System for the case the systems ability to model such rail operations will be attainable. The case study aims to answer two questions.

1. Is it possible use a production approach in Discrete Event Simulation to create a validated simulation model of the freight train traffic in a rail port using AutoMod's Path Mover System?
2. What functions are missing in Path Mover System to make it work in both production system and logistic systems? Were the logistic system is rail port activity

By using the Path Mover System for a case with high complexity regarding vehicle movement, this thesis aims to find some strengths and weaknesses of the system so it can be better estimated how well the Path Mover System would perform in simulating a certain real system, regardless if it is a production system or a logistic system.

The case purpose is to apply a production approach to DES and create a simulation model of the railroad system in and around the Port of Gothenburg regarding the throughput of goods traveling on freight trains and the arrival time differences. The simulation model is created for two purposes for the Port of Gothenburg. The first purpose is to stress test the system and seek to find the maximum capacity of the system. The second purpose is to simulate and evaluate proposed changes to the system. The two changes are to invest in more diesel engines and to electrify the rail at certain parts of the system so it can be used by electric engines rather than just diesel engines.

1.3   Clarification of the Problem

This thesis is produced for a degree in production engineering. Thus, methodology and knowledge used primarily for production systems will be used in the case study, which is of a logistic system. This may lead to problems arising during the case being seen from an unconventional viewpoint from a logistic perspective.

The project will:
Answer if the Path Mover System can be used to create a validated model for rail port operations.

- If the answer is yes, it will also deliver:
  - Experiment models for future improvements.
  - A simulation model showing the throughput of goods traveling on the freight train tracks and their arrival time differences.

1.4   Delimitations

The simulation model will be limited to only include train operations. During times where trains are ongoing other operations, such as loading or unloading, the train will simply do nothing in the model for the time that operation takes.

The thesis members will not take into consideration the economic aspect for improvement suggestions. That will be for the Port of Gothenburg to decide.

1.5   Case Description

The case was brought forward by Port of Gothenburg. They have the need to evaluate the capacity for the freight train traffic in the port as well as some future improvement suggestions. In this section, the system and the different analysis's that are to be made are briefly described. The case study will include the rails, rail yards and terminals that are shown in figure 1.1.

To understand the basics of the freight train system in the Port of Gothenburg, all operations a train will go through in the system will be described in the order they happen.
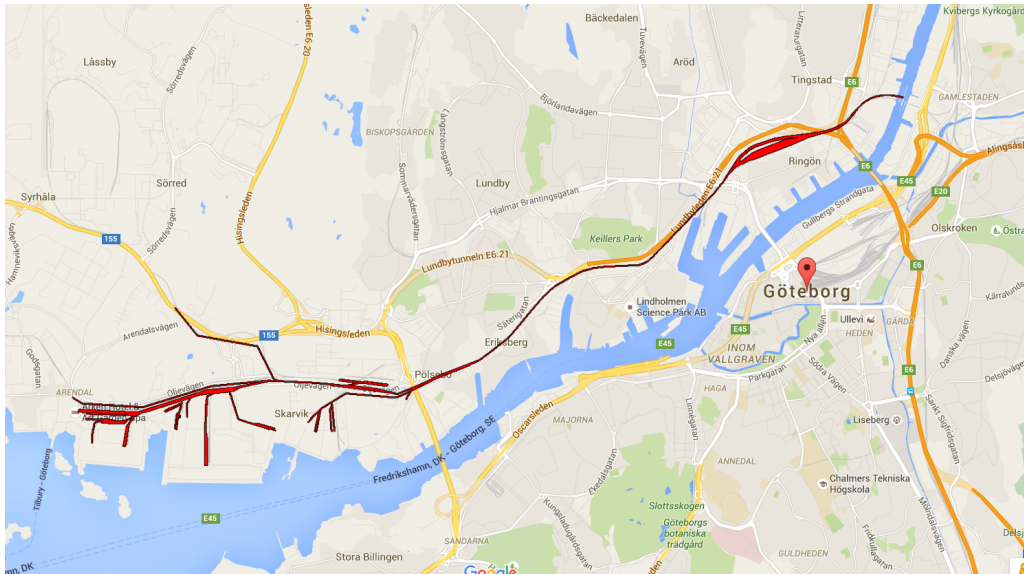
Figure 1.1: The rail way tracks, yards and terminals included in the case.

1.5.1 Arrival

When the train arrives to Port of Gothenburg, it is connected to an electric engine and is driven to one of three arrival tracks, see figure 1.2. At the track, the electric engine decouples from the train and travels to park in the system, see figure 1.3. The train waits at the arrival track until a diesel engine is attached to the train and starts slotting it to a terminal where the train can be loaded or unloaded. Once the diesel engine is attached, an arrival inspection is performed by one of the two operators that handle the slotting operations for the diesel engine. During the inspection, the diesel engine is pumping up the pneumatic break system with air. Once the break system has a high enough pressure and the inspection is done, the train can begin to move again.
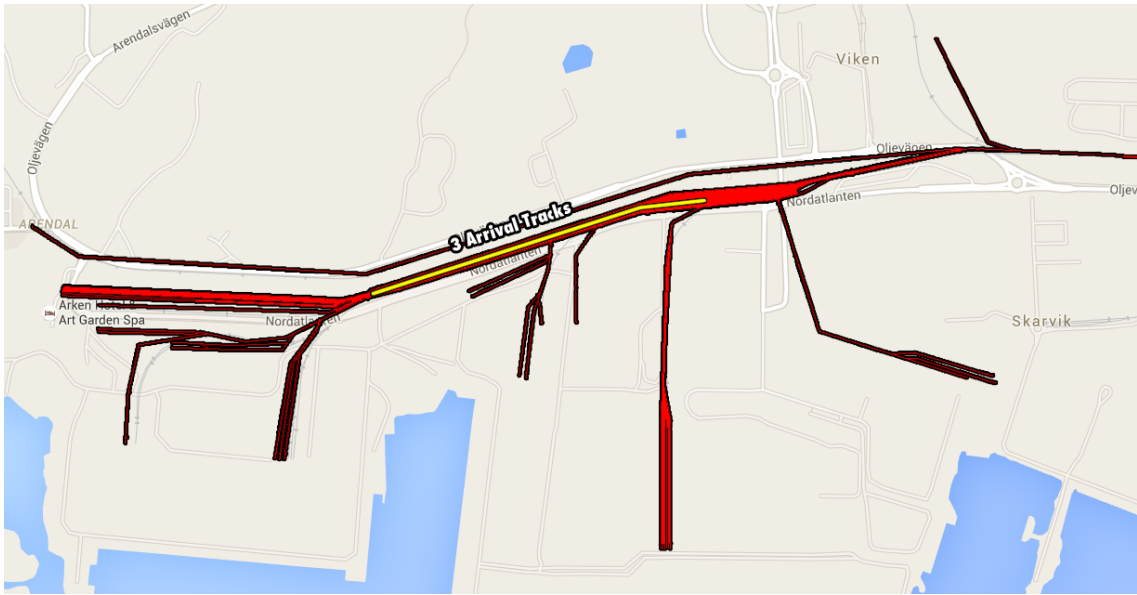
Figure 1.2: The three arrival tracks available are marked with yellow.
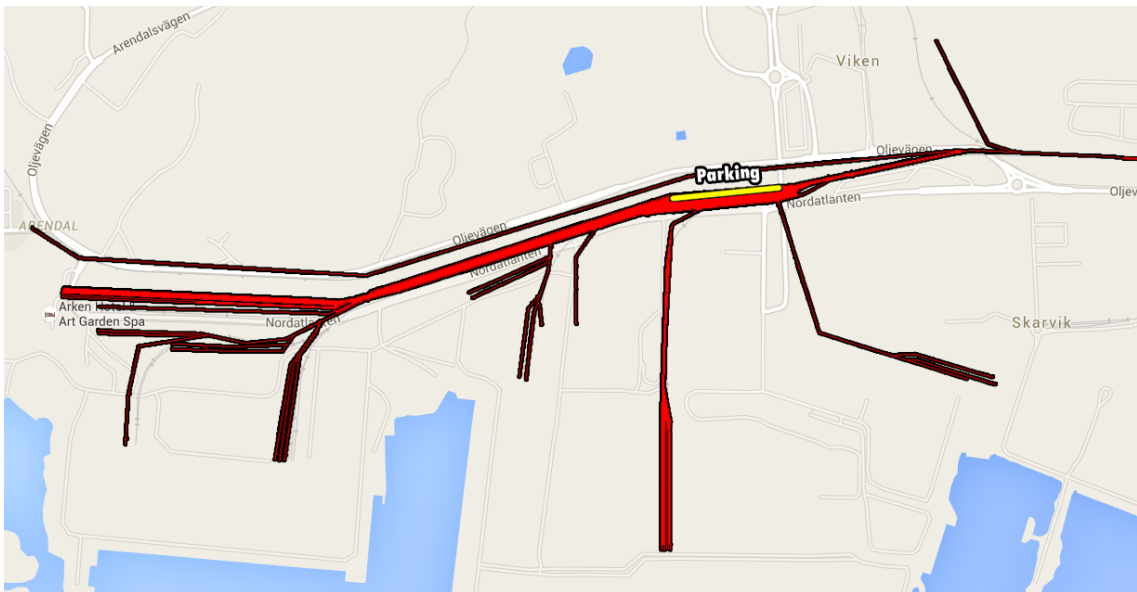
Figure 1.3: The yellow marks were the electric engines park after they detached from the carts

1.5.2 Slotting to Terminal

Before the train moves in the system, the diesel driver makes sure there are no other train traveling on the same tracks. This is done by calling a traffic operator at the Swedish Traffic Administration that oversees all train operations in the area. The driver gets permission from the traffic operator, the train moves through the system to the right terminal to perform the loading and unloading operations. See figure 1.4 to see what terminals are available in the system. The train sometimes divides it self up between terminal 71, 65 and 61 but most commonly each train is loaded/unloaded in only one terminal.
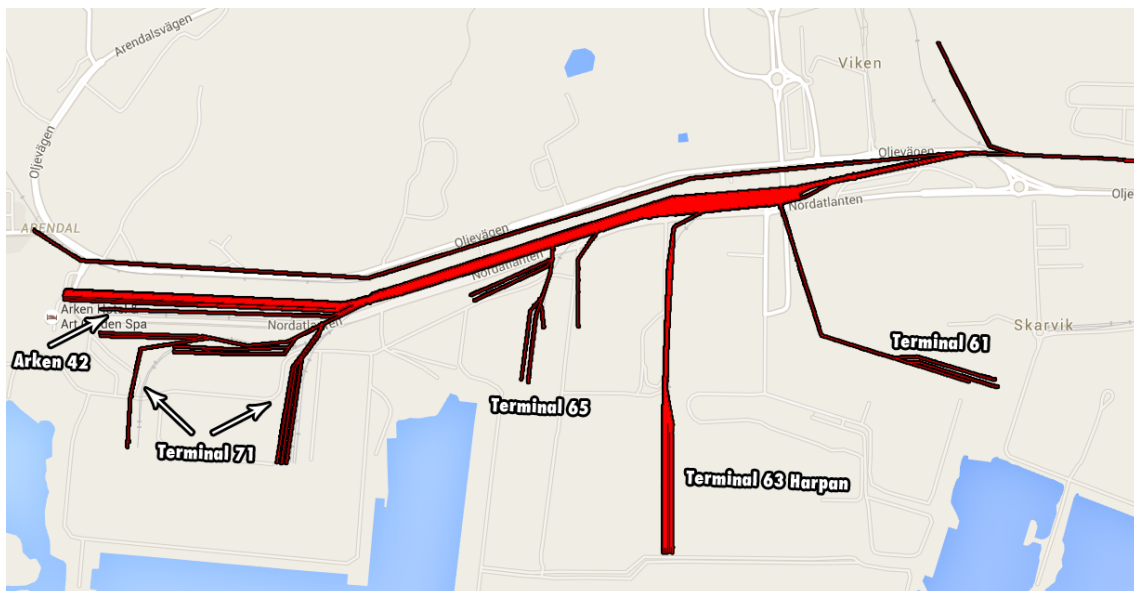
Figure 1.4: The terminals used for loading/unloading the trains.

1.5.3 Slotting to Departure Tracks

When the loading/unloading operations for the train have been completed the train waits for a diesel engine to slot the train to a departure track, see figure 1.5. When the diesel engine is attached, the break system is pumped to the right pressure. Traffic controller is called and the train starts to travel when permission is granted. When the train reaches the departure track, one of the diesel operators perform a departure inspection of the train before decoupling and moving to the next operation on their schedule.
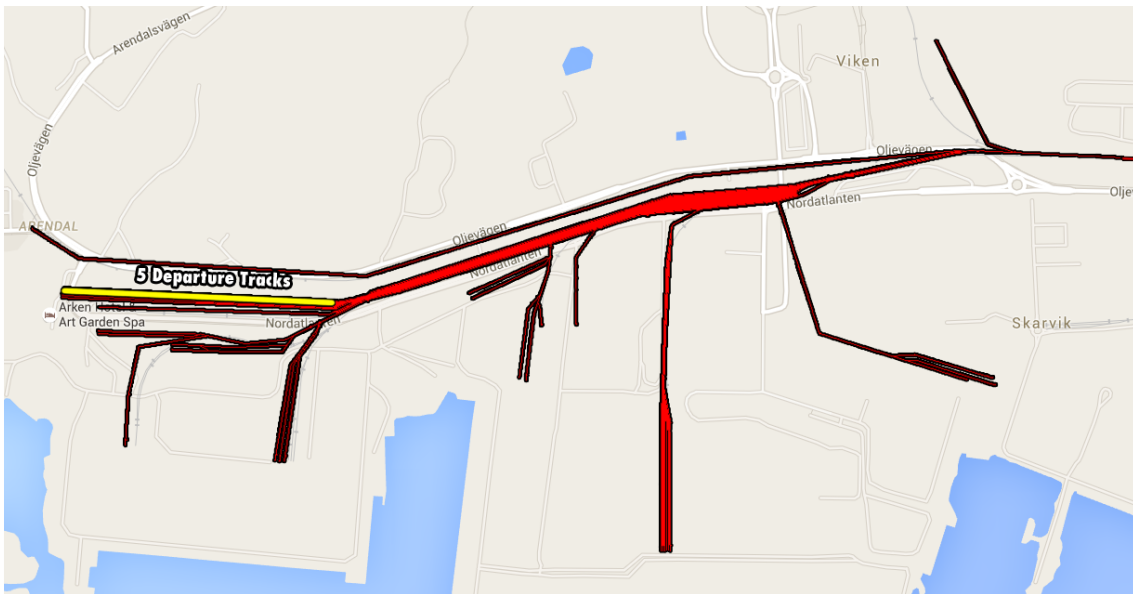
Figure 1.5: The five available departure tracks are marked in yellow.

1.5.4 Departure

When the train is released in the departure track it waits for an electric engine to connect to the train for departure from the system. Once the electric engine is connected and the break system is pumped up, the train operator will call the traffic controller and depart from the system when permission is granted.

1.5.5 Analysis and Experimentation

The Port of Gothenburg wants to know what the capacity of their current system for freight train system is. As well as what effects that could be expected from certain changes to the system.

1.5.5.1 Evaluation of System Capacity

There are certain times every day where trains arrive more frequently. During these periods, the system is pushed to operate at a higher capacity. The Port of Gothenburg want to see the results from a simulation of their system where more trains may arrive at these periods of time to see at what capacity the system can run in its current state.

1.5.5.2 Evaluation of Future Improvement Suggestions

As a higher demand on the freight train system is imminent, the Port of Gothenburg has some suggestions on how to improve the system in the future. In this case, two of these suggestions are to be evaluated.

The first suggestion is to add more diesel engines to the system. The time the trains spends waiting for a diesel engine might be reduced and thus the throughput

time will also be reduced. However, more diesel engines in the system is likely to increase booking conflicts in the system. As diesel engines often use the same tracks for many operations, the time spent waiting for other diesel to perform their tasks and get out of the way may increase with more diesel engines in operation.

The second improvement suggestion is to electrify the terminal in the port that has the most traffic. This terminal currently handles the loading operations of 60% of the trains that arrive to the port. By electrifying these tracks, the need for diesel engines to slot these trains to that terminal would be eliminated since the electric engines could perform these operations on their own. There would also be no need to take the train to a departure track after the terminal operations are done, since the electric engine is already attached and can leave the system. The Port of Gothenburg would like to see how the throughput time and capacity changes for the system when this change is implemented.

2

Theory

This chapter will include theory about what discrete event simulation is and what the usage of it is. The chapter will describe the software to be used in the case as well as some brief information about what other simulation software available that might be used for a similar project.

2.1 Simulation

The definition of simulation according to Shannon [6] is "The process of designing a model of a real system and conducting experiments with this model for the purpose either of understanding the behavior of the system or of evaluating various strategies (within the limits imposed by a criterion or set of criteria) for the operation of the system.". The thesis simulation will both be for understanding the behavior of the system and for conducting experiments to find improvements. Simulation is a great problem-solving tool that can be applied to a lot of real life issues [1]. This thesis simulation will be in discrete-event simulation which will be described later in the report.

An example of when to use simulation could be in a production line. The company in charge of the productions wants to increase their output but they are not sure in either to invest in new machines, to re-schedule the planning or to hire more workers. Instead of disrupting the existing production with a e.g. new machine and trying it out to see if it works they could instead collect the necessary data and create a simulation of the production. When the simulation works and produces validated results satisfactorily to the existing production, they can start experimenting with the simulation model by trying out a lot of different solutions and see what yields the best results. Since the simulation can simulate a production for 50 days in a matter of minutes it is easy to see which investments pays of.

2.1.1 Discrete Event Simulation

Discrete-event is when each event in a simulation occurs at a chosen instant in time and changes a state in the system [23]. Another way of simulating would be continuous. Instead of event-based it is activity-based which means that a state gets changed/updated at a chosen time slice [9]. A discrete-event simulation usually have the following components (which will be described later in the report) entities, activities and events, resources, global variables, a random number generator, a

calendar, system state variables and statistics collectors [7].

2.1.1.1   Entities

Entities is the element that makes things happen in the simulation, it causes the changes in the model [7]. All of the entities in the model have attributes that describes the entity. A entity in this thesis can be the containers on the trains that will have a attribute that tell us where it came from, where it is heading, size, weight etc. This means that a simulation can have a lot of entities. Entities can also represent the flow of information such as orders, phone calls and so on.

2.1.1.2   Activities and Events

The activities in the simulation is the processes and logic [7]. Ingalls also explains that the events are conditions that causes the changes of the state in the system. To explain it further he says "An entity interacts with activities. Entities interacting with activities create events." To apply this, an example could be that our container entity interacts with a logic activity, which means that the container had the information that made a logic state variable tell the entity to take the left train track in an intersection where it could go left or right. So the entity attribute information tells the activity logic what to choose and this causes an event. As described above a activity could be a type of logic but it could also be delay and queues [7]. Those are the three major types. Ingall explains that the delay type is used when an entity is delayed for a definite period of time and the queue type is when the entities have to wait for an unspecified period of time.

2.1.1.3   Resources

Resources in simulations is anything with a constrained or restricted capacity [7]. An example could be the train, workers on the train, the rail intersections or loading tracks.

2.1.1.4   Global Variables

A global variable is a variable that anything in the model can access and use/update at all times [7]. This variable can track things such as number of trains on the tracks, order size, throughput and more.

2.1.1.5   Random Number Generator

Production lines or logistics usually have machinery fail and sometimes break, and when that happens it needs to be fixed. The time until it fail and the fixing time is not always the exact same time since it could be different people doing it, distance to the failure etc. So in DES you use Random Number Generator that generates a random number between 0 and 1 [7]. You then use that number with a chosen distribution formula e.g. uniformly distribution. Let's say the repair time is around 5 hours, then the simulation can generate a time that have a high percentage to

land on 5 hours but can range between 4-6 hours. This shows the user how the simulation handles different times.

2.1.1.6 The Calendar

The Calendar is a list of events that are scheduled to occur in the future [7], e.g. the arrival time of a certain train to a certain location in the model.

2.1.1.7 System State Variables

One of the most common system state variables is the current time in the simulation [7] which can be used to control the arrival of trains in a model by comparing it to an attribute for arrival time. Other simulations can have other system state variables as well.

2.1.1.8 Statistics Collectors

In the simulation it's important to get statistics on certain things to see how well the simulation behaves. There is three different types and those are counts, time-persistent and tallies [7]. Counts can be used as to count number of trains passed a certain point. Time-persistent can be used to see the utilization of a resource. Tally is used to see how long something have been at a certain part of the simulation or in the simulation, e.g. the total time on a certain railway track.

2.1.2 Discrete Event Simulation in Production Systems

Manufacturing was one of the first areas where discrete event process simulation was used [10]. For example, DES has been used in production to perform bottle neck detection [11], to optimize highly flexible production lines, to validate production layouts and to plan resource scheduling in a production system [10].

2.1.3 AutoMod and Path Mover System

AutoMod's Path Mover System is used to build simulation models where vehicles are moving along a set of guided paths to transfer loads. The system has, for example, been used to simulate forklift and shuttle trolley traffic [12], tractors in port operation [13], automated rail guided vehicles in logistics systems [14] and for Unit Load Devices in airport operations [15]. The Path Mover System uses four different components to build a model: Guided paths for vehicles to travel upon, transfers where different paths are connected, control points where loads can be loaded or unloaded and vehicles which travel on the paths and can be loaded or unloaded [16]. Each component has some attributes, such as top speed and loading time for vehicles, that governs the behavior of the model.

2.2 Simulating Trains

Simulation software has previously been used for both long distance train operations [17] [18] [19] and rail yard operations [18]. The Swedish traffic administration has used the software Railsys for creating schedules over certain heavy trafficed rail lines [17]. Since punctuality is seen as one of the main quality indicators for rail systems, it is important to be able to create robust time tables [19]. Railsys is also used for evaluating rail signaling systems [19]. Wang [18] divides the components necessary for a train rail simulation into the five categories Main inputs, Scenarios, Simulation, Operating strategies and Output. Main inputs include the network to be simuleted, block design and speed code, train schedule, rolling stock and passenger demand. Scenarios are put into the model to see how the system reacts to certain incidents that may occur in a rail system. The simulation describes how the system behaves regarding such elements as vehicle movements, interactions and station operations. Operation strategies include different strategies to handle certain operations so that the different strategies may be evaluated and the outputs are the measured results of the simulation [18].

Other simulation software, such as Yardsim, are used to simulate rail yard operations, such as humping [20]. Humping is the process of disassembling trains and to assemble them into new sets before the trains travel to their next destination [21]. Lin [20] describes the components that rail yard simulation software must be able to create and control. The components include the ones described by Wang [18] with the additions of yard inventory, yard resources, train consist and trip plan. Thus, for a successful rail yard simulation it is necessary to have information about the final destination of every car that is entering or is in the rail yard as well as information about what resources are available to perform the operations in the rail yard [20].

2.3 Data Collection

The data phase during a Discrete Event Simulation (DES)-project is generally time consuming. There are studies that show that the data phase take up 10-40% of project time, with an average of 31% [22]. It is thus of value to use a methodology that reduces the time for data management. A lot of the research aimed to reduce the time for data management have been focused on automating the collection of input data management, for example by using a corporate business system as input for a simulation model [22].

Robinson and Bathia [23] classifies data into three different categories, see table 2.1. Category A is data that is already available, be it from a corporate system or collected at an earlier occasion. Category B is data that is not available and thus requires some effort to collect. Category C is data that is not available and also not collectible [23].

Table 2.1: Classification of Data [23]

Category A	Available
Category B	Not available but collectible
Category C	Not available and not collectible

2.4 Validation and Verification

Model verification is defined by Sargent [24] as "ensuring that the computer program of the computerized model and its implementation are correct". Model validation is defined in the same paper as "substantiation that a computerized model within its domain of applicability possesses a satisfactory range of accuracy consistent with the intended application of the model". These definitions of verification and validation are the ones that will be used within this thesis paper. When determining the validity of a model, it should be determined with regard to the purpose of the model [24].

Due to the high cost of determining if the model is absolutely valid in the domain, tests are usually done to determine the model as sufficiently valid for its purpose. Figure 2.1 shows the relationship of model confidence to the cost of validation and the value of the model for the end user [24].
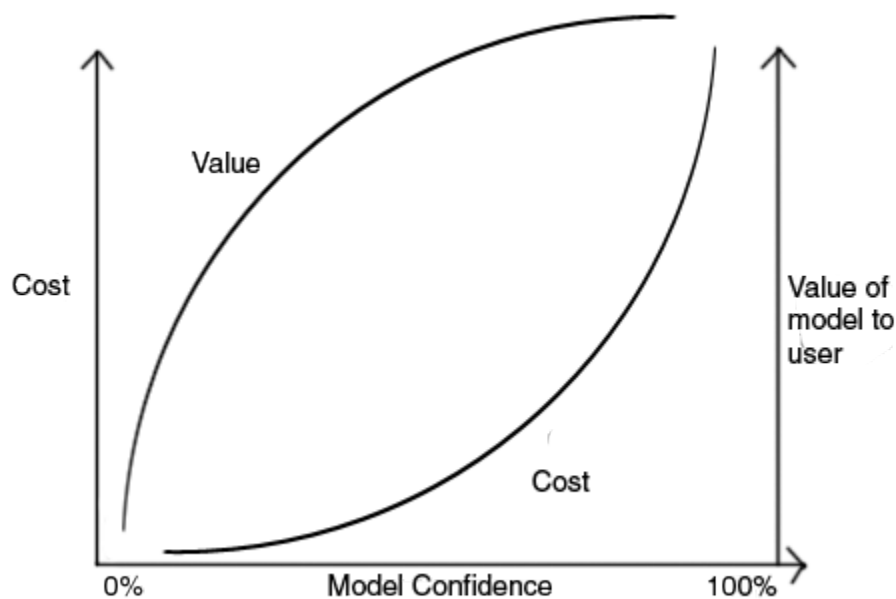
Figure 2.1: Relationship of model confidence that is based of Sargents figure [24].

2.5 Train Logistics

Railway logistics is often used as a part of intermodal transport. Intermodal transport is defined in Rushton [25] as "the movement of goods in one and the same

loading unit or vehicle, which uses successively several modes of transport without handling of the goods themselves in changing modes."

The strengths of the railway include high speed over distances of 80 to 500 km, highest capacity of cargo transfer among land-based cargo systems and energy efficient travel [25]. The railway is also seen as a green way of transportation among the general public and it has the lowest amount of CO2-equivalent/tonnes/km of all land transportation systems in use today [25] [?]. The railway system is the land based system that is the least affected by bad weather [25].

There are of course some weaknesses of railroad transportation. For example, the infrastructure of the railway is fixed and thereby inflexible. It is thus sensitive to changes in areas surrounding it. Since the cargo in a intermodal system requires the cargo to be trans-shipped during its transportation, the railway system is not efficient if the transportation on railway is to short to gain back the value for the cost of trans-shipment [25].

3
Methods

To be able to answer the question "If Path Mover System can be used to create a validated model for rail port operations?" certain methods will be needed. The methods will be used to create the case from the Port of Gothenburg and the result gained from the case models will, if validated, answer the above question.

Tools, techniques and methods are needed to create the case and the following chapter will explain how the thesis members solved this. The chapter goes through the importance of starting the project correctly to increase the quality as well as how to collect the data for the case and what computer model parts that is needed for the simulation. How to verify and validate the case is important, because an incorrect case would answer the question incorrectly, thus it will be explained. A part of the case was to create experiments for the Port of Gothenburg hence a section to describe how to best conclude with the experiments.

3.1   Evaluating the Path Mover System

Even though the purpose of this thesis is to see whether the Path Mover System can be used to simulate rail port train operations or not, it also of importance to evaluate the systems strengths and weaknesses in this regard so the system can be compared with other software.

3.1.1   Necessary Components for the Simulation of Rail Port Train Operations

By combining existing literature of components needed for similar train operations with a detailed description of the operations that take place in the port, the necessary components for a simulation of rail port train operations will be defined. The detailed description of port operations will be created through interviews with management at Port of Gothenburg as well as with management and operators at the company that performs all diesel engine operations in the port.

By defining the different components it will be possible to evaluate the Path Mover System in regard of each component to find the strengths and weaknesses of the Path Mover System's ability to simulate these kinds of train operations.

3.2 Simulation Project

Throughout the project, a modified version of Banks model for a simulation project, see figure C.1, will be used [1]. The model offers structure and guidance to the project. The difference of this modified version and the original is that the data collection is done during the time that the model is being built and validated rather then collecting all data before the building of the model begins. This modification is used by ÅF during their simulation projects. The start of this project is dedicated to formulate the problem at hand. This is done during meetings with some of the most important stakeholders of the project, mainly representatives from the Port of Gothenburg and ÅF, and the project members. As suggested by Carson [2], these meetings serves to formulate the problem and objectives of the project so that a level of detail of the future model can be set.
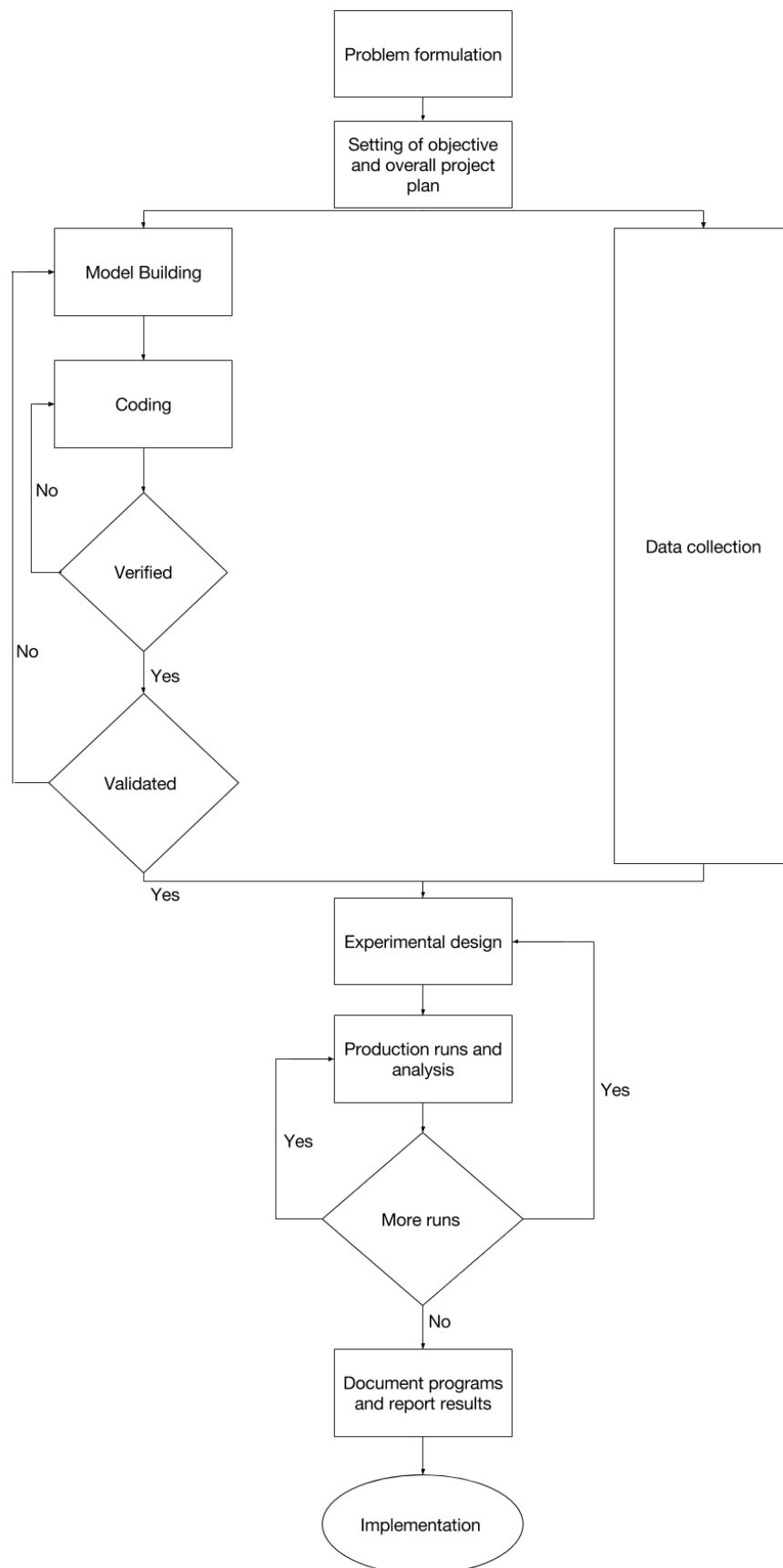
Figure 3.1: Modified Banks model for a simulation project

3.2.1 Conceptual Model and Assumption Document

The building of the final model is made by doing a conceptual model, collecting data and then programming the computer model. Throughout the process, verification and validation tests are made until a valid final model is built, in accordance to Banks [1].

The conceptual model consists of some logical or mathematical expressions that describe the real world system [1] [24]. Thus, to build a conceptual model it is necessary to gain knowledge about the system. Where certain elements of the system are hard to observe some assumptions are made as well as a plan for data to be collected to validate these assumptions [2]. The conceptual model should be easy to understand for all project members [2].

In this project, the conceptual model will consist of description of operations, maps of the systems infrastructure, description of traffic control operations, velocities of different vehicles and train schedules. The conceptual model can be seen in Appendix C.1.

3.2.2 Data Collection

At the start of the project, the process of data collection will begin. Both quantitative and qualitative data will be collected. The qualitative data will be gathered through meetings and interviews with employees of Port of Gothenburg to gain understanding of how the railway system surrounding the port operates. Once a basic understanding of the system is acquired, a plan for what quantitative data needed to construct the simulation model is to be made. The quantitative data will be based on the current timetable (arrival and departure times) that the Swedish Transport Administration and Gothenburg Port creates together yearly.

Azadeh [26] describes a case where the time for the cargo trains are collected from existing documentations and that the timetable is set by different uses of methods depending on the areas. A company should follow the set timetable as close as possible and that creating a good timetable usually means optimization of an old one and repeating the process until satisfied [3]. This is usually done by simulation [3]. You can then add disturbances to see how they will affect the simulation and see how robust the time table is. The time table should also consider the schedules of other operations that are dependent on the trains, such as loading operations [27]. The timetable should be checked for quality since a lot of time tables are constructed manually that the company believe is good enough and might be needed to be updated and modified says Brannlund [28]. The time table that will be used in this project is created by the Swedish Transportation Administration and is done one and a half year ahead in time [29], an example of a timetable can be seen in the appendix B.3. The timetable can be modified based on forecasts that gets optimized later on but that train timetable can be disrupted by maintenance, accidents etc, and might render the current timetable unusable, then people must quickly make a working one usually with a tight deadline [30]. These possible disturbances

will cause inaccuracies in the model as an unedited timetable will be used for this project. Interviews will be held with train and port operators and management with the goal to find how accurate these timetables usually are.

If the needed data does not exist, an effort to extract the data through documents or doing it on site must be put in [2]. The data should then be validated by the company to ensure good quality. Carson [2] writes that the simulator should make sure that the data is at least plausible by auditing different part of the data. Sometimes it is necessary to cleanse data to make it accurate. He explains that sometimes data, that is for distribution, can be hard to simulate with statistical distribution. Then the actual customer orders can be used as input for the distribution part of the simulation model. To get some variation several different samples from order files can be used.

For this project, a schedule for the port operations during a 24 hour period will be used. By performing interviews with Baneservice, that are responsible for carrying out the port operations, and Port of Gothenburg the schedule will be modified to create a schedule that well describes a typical day of operations. This schedule will then be repeated for every day throughout a simulation run.

Some data that was not collected through interviews and schedules was collected by a previously performed simulation project [31] that the port was a part in and was also validated by the Port of Gothenburg. This data included some physical data of the trains, such as velocity and acceleration as well as information about how certain processes were performed. On site data collection will also be carried out by interviewing train operators and riding along in the train engines as operations are performed to improve understanding about the operations.

3.2.3 Computer Model

In this project, the computer model will be used using AutoMod's Path Mover System that was described in the theory chapter. The characteristics of the Path Mover System is lacking when it comes to simulating rail way operations, since the system was designed to simulate AGV's (Automated guided vehicles) [16]. The different components of the Path Mover System can easily relate to different parts of a railway system. Guide paths can relate to the rail itself, transfers where paths join together can relate to railroad switches, control points to loading and unloading points on the track and vehicles to the engine and freight wagons. Where the system is lacking is where vehicles of more than one segment is to be handled. The solution to the problems encountered while performing operations with sizable vehicles such as trains are described in this chapter.

3.2.3.1 Track Creation

Instead of drawing all the tracks in AutoMod (which is hard and takes a lot of time) the CAD software AutoCAD is to be used [32]. Port of Gothenburg will provide an AutoCAD file for most of the tracks except a few missing areas. To draw the

missing areas, imported air plane photos was used and put into AutoCAD. When all the tracks are completed they are exported into a Path Mover System.

Using this method can result in a Path Mover System with an unnecessary amount of paths. If this is the case, the CAD-file is modified to keep the amount of paths down, resulting in faster build times for the model. The modification is carried out by replacing curves with some straight lines and straightening out some tracks so they might be represented by one single line. To ensure this new Path Mover System is still valid, some measurements of the travel time between certain points of the models are done before and after modification.

3.2.3.2 Movement

In the model for this project, the trains will be moved into the system in accordance to available schedules for the port operations. When the train is moved into the system, it is composed by a vehicle where the locomotive and each carriage is a segment of its own. A load is placed on the train to guide the train through the system. The load contains all the data that is needed to guide the train through the model, such as scheduled times and destinations for different operations.

3.2.3.3 Zone booking

According to the Swedish Transport Administration, trains are booking certain track segments on its way to its destination. Since paths in AutoMod has no capacity attribute, this booking was simulated using AutoMod blocks that are placed on the paths in the model. When a train is to move between two locations, it gathers all the blocks in its path to the destination, and books the zone between each block. As a zone is exited, the booking of the zone is canceled. Before a train can travel, it has to see if all zones on its path is clear and then book them. Figure 3.2 shows how the booking is carried out.
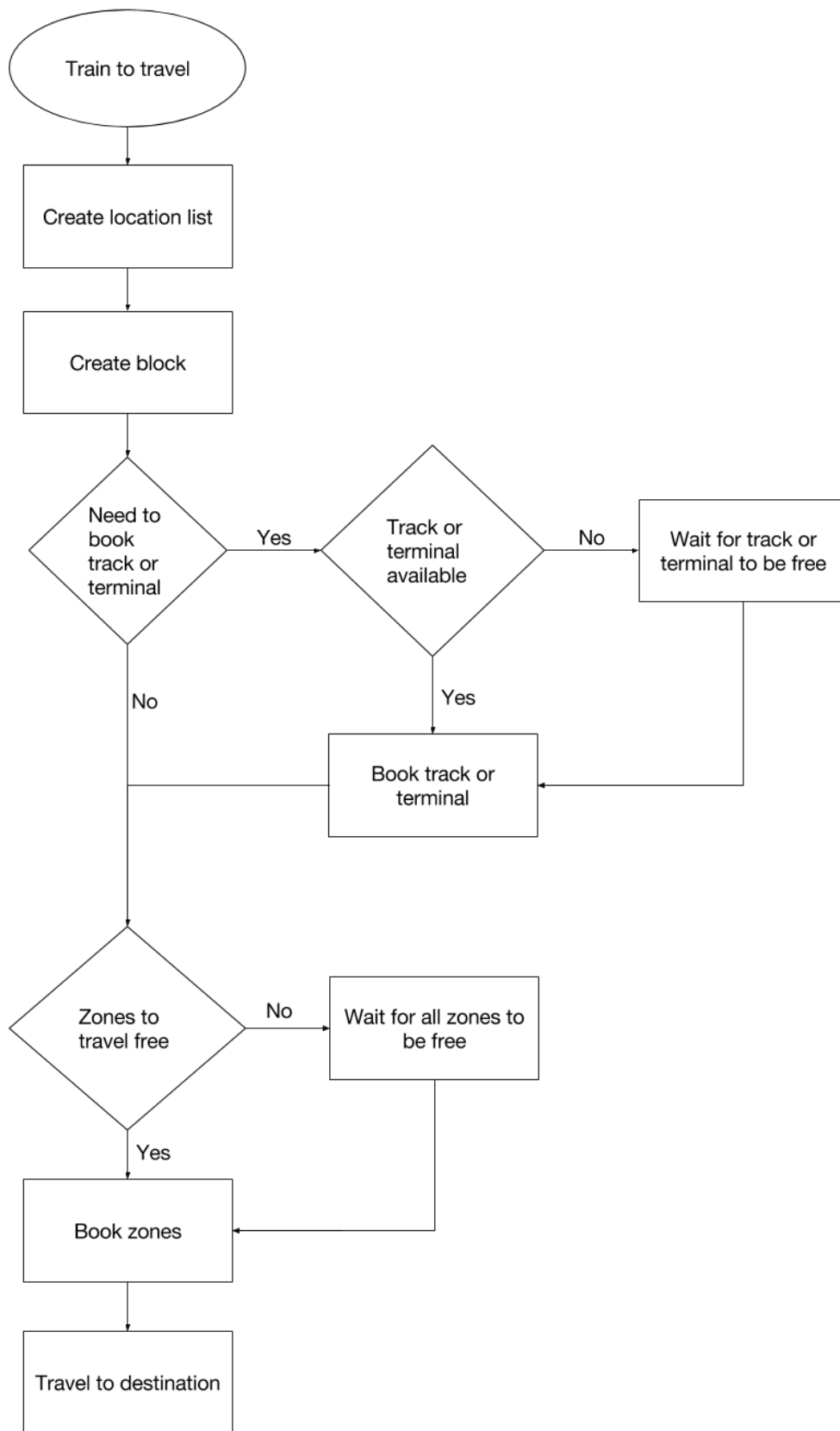
Figure 3.2: The method used for booking tracks and zones before traveling

The operators at Swedish Transport Administration books all the tracks towards its destination with the exception of tracks being used at certain areas [33]. In the simulation model for the system, this is relevant when the train is traveling from Kville terminal to GSH (Gothenburg Scandia Hamnen). In this case the train would face delays if it were to wait until some operation at GSH to finish before it starts traveling. To avoid this, arriving trains first looks to book the zones to Pölsebo terminal, and after arriving at Pölsebo the train seeks to book and travel the rest of the way to GSH.

In addition to the booking of zones, which is done as the train is traveling, the trains will also be able to book certain tracks. These tracks are 3 tracks at Kville, the 3 arriving tracks, the 5 departure tracks, 3 tracks in harpan and one track for each other terminal. The reason is that a train might be going to a certain track or terminal, but it will not book the zones there until some operation other then moving is done. To make sure there is a track available at the trains destination when it is time to travel, it is booked as soon as the operation starts. An example of this is when a diesel engine gets a job to slot a train to a terminal. In this case, the diesel engine first books a track at the terminal, travels to and connects to the train, perform arriving inspection and then books the zones and starts to travel. Thus, another diesel engine cannot start a job at the same terminal while the inspection is being done and conflicts are avoided.

3.2.3.4 Acceleration and Velocity

The train have different velocity and acceleration depending on were it is in the model. To change between values transfer blocks (as above) were used, but instead between each speed zone. Data collection showed that three speed zones exists: 10 km/h at industrial tracks, for example in terminals, 20 km/h at rail yards and 40 km/h at all other tracks. When the train goes through a transfer block it will see from what speed zone it came from and what zone it's entering and changes the acceleration and velocity accordingly.

3.2.3.5 Carriage Release

As part of the operations in the port, the engines decouples and couples with the train a couple times while the train is in GSH. The Path Mover System in AutoMod does not allow for segments to to be decoupled from a vehicle, it is only possible to remove the segments or attach them to another vehicle. To enable the decoupling of carriages, this model will use dummy trains where the train might stand with no engine attached.

When an engine arrives with a train to a track for decoupling, the load that drives the train will first remove all carriage segments from the train. It will then clone a load from itself to a process for dummy driver loads. By cloning a load instead of creating one, all data that is available about the train will also be available for the dummy train. This load will use the information it inherited from the original load to call in a dummy train to the track, board the train and build the train. The

engine may now continue with other operations while the train is waiting on the track. When the train is to be coupled to an engine again, the engine driver will save all the data needed from the dummy load before sending it to die, which will also result in the dummy train being moved to a queue. The engine then adds the carriage segments and is now ready to travel with the train attached.

3.2.3.6 Turning on a Track

During the slotting operations in the port, the train often has to turn on a track as it travels through the system to reach a certain track or terminal. The turning of a vehicle with many segments creates certain problems in AutoMod's Path Mover System. When the load that is driving the train is pushing the carriages rather then pulling them as the train approaches a rail switch, the leading carriages will sometimes starts choose the wrong path in the switch. To avoid this, the driver load must be pulling the trains. To achieve this after a train has turned on a track, there are two versions of every train. One that is led by an engine, and one that is led by the last carriage of the train. In a turning operation, the driver switches the trains and boards the other, enabling the load to pull the train in the other direction as well.

3.2.3.7 Animation

AutoMod can import CAD models instead of using the original boxes that appear when creating entities. Instead of creating CAD models you can import with the software AutoSimulations Creation Editor (ACE) which is an embedded tool within AutoMod. In ACE you can create your own models or use the existing library, the latter was used thus imported models for the train engine and the cart were inserted. The usage of improved models instead of the boxes is to increase the credibility of the model for other people such as the customer. It is easier to grasp what happens when a actual train move around instead of rectangular boxes.

3.2.4 Model Verification and Validation

3.2.4.1 Verification

Verification is done continuously throughout the model-building process. As the code and systems have been defined for a certain process, it is verified by comparing how the model behaves against the conceptual model. This is done by observing the model as it runs, certain variables and attributes are monitored to see that the model works as intended. In cases where the models behavior is divergent, the code is debugged and fixed until the process is verified.

When the computer model is completed and verified against the conceptual model, the process of validating the model will take place.

3.2.4.2 Model Validation

Sargent [24] describes several validation techniques, a selection of them are presented here.

- *Animation:* Animated graphics are used to show the model's behaviour.

- *Degenerate Tests:* Test if the model behaves as expected by setting some internal parameters and looking at the outcome.

- *Event Validity:* Determine whether certain events occur as frequently in the model as in the real system.

- *Extreme Condition Tests:* Test the model under extreme conditions and see if the outcomes are plausible.

- *Face Validity:* A system expert compares the behaviour of the model to the system.

- *Internal Validity:* Several simulation runs are made throughout the model to see that the results are satisfactory random.

- *Operational Graphics:* Use graphics of certain measures, for examples size of queues, to see of if model behaves as expected.

- *Traces:* Trace certain model entities to see that they move through the system as planned.

- *Turing Tests:* A system expert compares the output of the model to the output of the real system to see if they are distinguishable.

In the project, trace validation will be used to see if all the tracks were working after the export from AutoCAD, this will be done by sending load entities to all the possible end tracks and see if they end up there.

Face Validity technique will be used by having management from Port of Gothenburg validating the base model simulation. To do this, a manager with good knowledge of the system will observe how the trains moves in the model and if the gathered data seems plausible.

Animation will be used to animate locomotive and carts as vehicles move in the simulation. By having animations in the model, it will be easier to see how different parts of the model interacts with each other.

3.2.4.3 Verification and Validation Paradigms

Sargent [24] presents two paradigms that shows how verification and validation fits into the model building process. The first paradigm is a simpler paradigm and, according to Sargent, better illuminates how verification and validation is worked with during the building of the model. The paradigm is displayed in Figure 3.3 and is the one that will be used within this project.
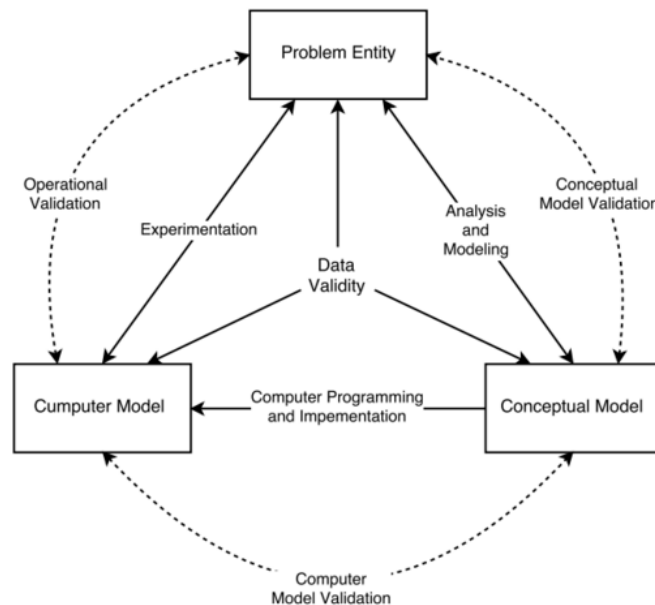

Figure 3.3: Simple Paradigm for verification and validation [24].

In Figure 3.3 concept model validation is defined as "determining that the theories and assumptions underlying the conceptual model are correct and that the model representation of the problem entity is "reasonable" for the intended purpose of the model" [24]. Computerized model verification is defined as "assuring that the computer programming and implementation of the conceptual model is correct" [24]. Operational validation is defined as "determining that the model's output behavior has sufficient accuracy for the model's intended purpose over the domain of the model's intended applicability" [24]. Data validity is defined as "ensuring that the data necessary for model building, model evaluation and testing, and conducting the model experiments to solve the problem are adequate and correct" [24]. Using the paradigm presented in Figure 3.3 is an iterative process that produces several versions of the model until the computerized model is validated as sufficient for its proposed use and domain.

3.2.5 Experimentation

When the base model is verified and validated it can start to be used for the purpose it was intended for. The project plan is used to decide what different alterations and settings that should be used to conduct the needed experiments to reach a conclusion for the project [2]. In the case of this project, the purposes of the model is

to perform a stress test to evaluate the top capacity of the system, and to see what changes to the systems throughput could be expected when adding diesel engines or electrifying certain tracks in the system.

When it comes to testing the capacity for the system, there must first exist a criteria that, when fulfilled, shows the system is no longer performing at a minimum required level. Two parameters will be interesting to look at in this case. The first is the total number of trains to pass through the system. If more trains are added to the schedule in different time periods, and the queue to enter the system can be observed to be growing over time while the number of trains that are processed by the system daily remains close to constant, the system will be working at max capacity. The second parameter is to observe how the trains delays into the systems are affected as more trains are added to the schedule. Big delays in this system might mean that some containers will arrive after the boats they were supposed to be transferred to have departed. A minimum allowed average delay could be decided upon with the Port of Gothenburg, that when fulfilled would deem the system as under performing.

Evaluating changes to the system is a little bit more complicated since it will be necessary to do some changes to the model. The project is following Banks Model [1], so all these different alterations of the model are included in the conceptual model, and the model can be built from the start to make sure these changes can be implemented. The first possible change is to be able to alter the number of diesel engines in the system. In the model, all diesel engines will use the same processes and to alter the number of diesel engines is done by changing a variable that controls how many diesel drivers are created.

Electrifying the tracks down to the Harpan terminal is more complicated since it will require the electric engines to perform some new tasks that are normally done by the diesel engines. An extra process for the electric drivers will be written that carries out the operations necessary for the electric engine to slot the train down to the terminal and then leave the system. Before running the simulation, a variable is set that decides if the electric driver should be sent to this new process or if it should continue on the processes of the base model.

3.2.6   Run Control and User Interface

To control the different parameters that decides the number of trains to be sent into the system, the number of diesel engines to be used and whether the Harpan terminal is electrified or not a user interface is to be used. The user interface is built in Microsoft Excel by ÅF. The simulator can write input to the model in the Excel interface that writes the input data to a text file that can be read by AutoMod. The interface is also used to read output data that AutoMod writes to text files during the simulation runs.

3.2.7 Analysis and Reporting

Sometimes the output of the simulation model can give indications to problems with the model but not pointing to the problem [2]. The analyst then need to use the model and the output to create hypotheses of what the problem might be. Later the analyst use other measurements to help you pinpoint to the cause to prove your hypothesis.

Reporting is usually done by showing the analysis and experimentation with presentations and written reports [2]. The final report should include the assumption document with the eventual changes that happened.

3.3 Time Plan

A Gantt chart will be used and updated during the thesis work. The Gantt chart will contain the project deliveries and when the members will work on them and at the same time, try to reflect the thesis project methodology. See the Gantt charts in appendix B.1 and B.2.

The time plan was heavily set back due to longer time gathering data and problems during the coding phase of AutoMod that had a lot bugs and glitches that had to be circumvented. This added up to 3 extra weeks of data gathering and base model building.

4

Results

To be able to answer the case question "If Path Mover System can be used to create a validated model for rail port operations?", results from the base model simulation and experiment model was needed to present to the company. The data must be validated by the company to be able to fully answer the case question correctly. The result will also include the improvement suggestion to increase the amount of trains in the port by stress testing it.

The case study was done to find what components are necessary to simulate train operations in a rail port and to evaluate the Path Mover System's ability to create and control such components. These results follows the results of the case and the validation by the Port of Gothenburg.

4.1 Base Model

Two different kind of data can be extracted from the base model. The first is the Average arrival delay and the second is the average throughput time.

4.1.1 Average Arrival Delay

The key data that will be collected is the delay until a train reached the arrival tracks and the throughput time for the trains. To compare the data that will be shown, in the experiment chapters below, its needed to see what the data is in the current base model, without experiment changes. The simulation runs for three days and its steady state, the following day is called "day 1". The current state for day 1 can be seen in figure 4.1 and for day 1 to 5 can be seen in figure 4.3.

The delay is negative because its extracted from the simulation by taking the arrival time and subtracting it with the delayed arrival time, which is larger.
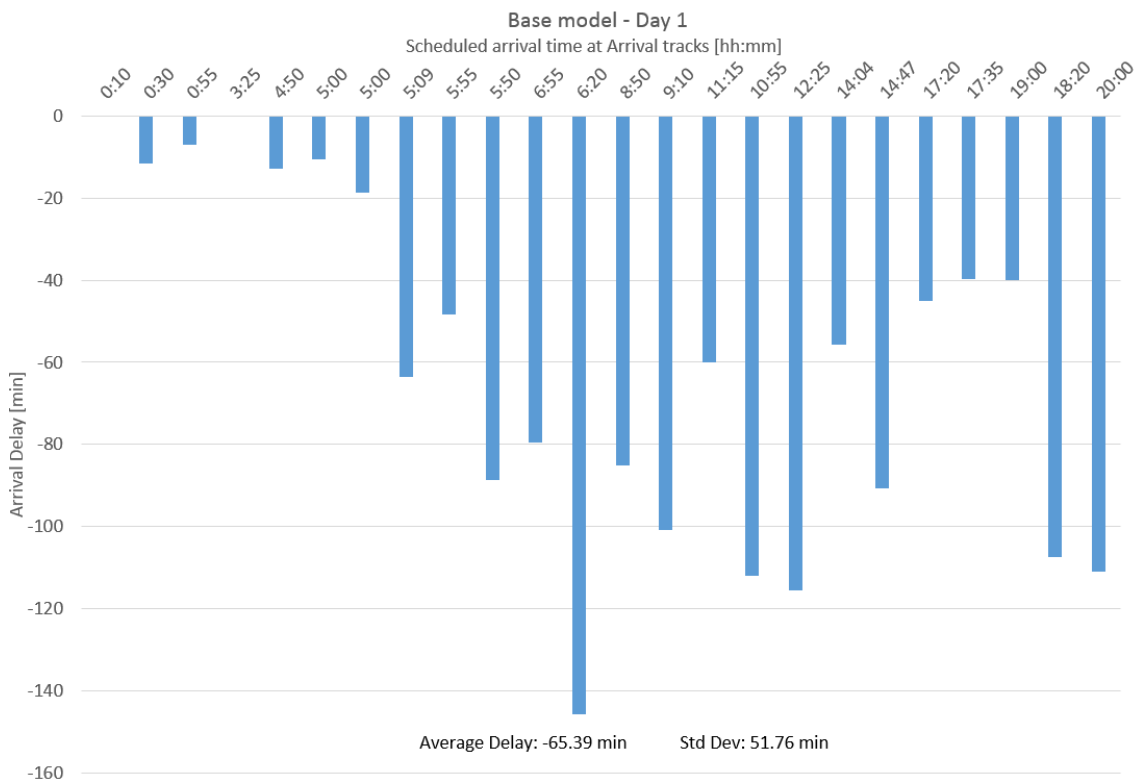
Figure 4.1: The x-axis shows when the trains should arrive at the arrival tracks (see figure 4.2 for were they are located), and the y-axis show how delayed they are when they arrive. The graph show that the port is busy during the 5:00 to 6:20 hours, then the model slowly works down the delays only to be pushed up again in the late hours. Below the graph the average delay can be read as well as the standard deviation.
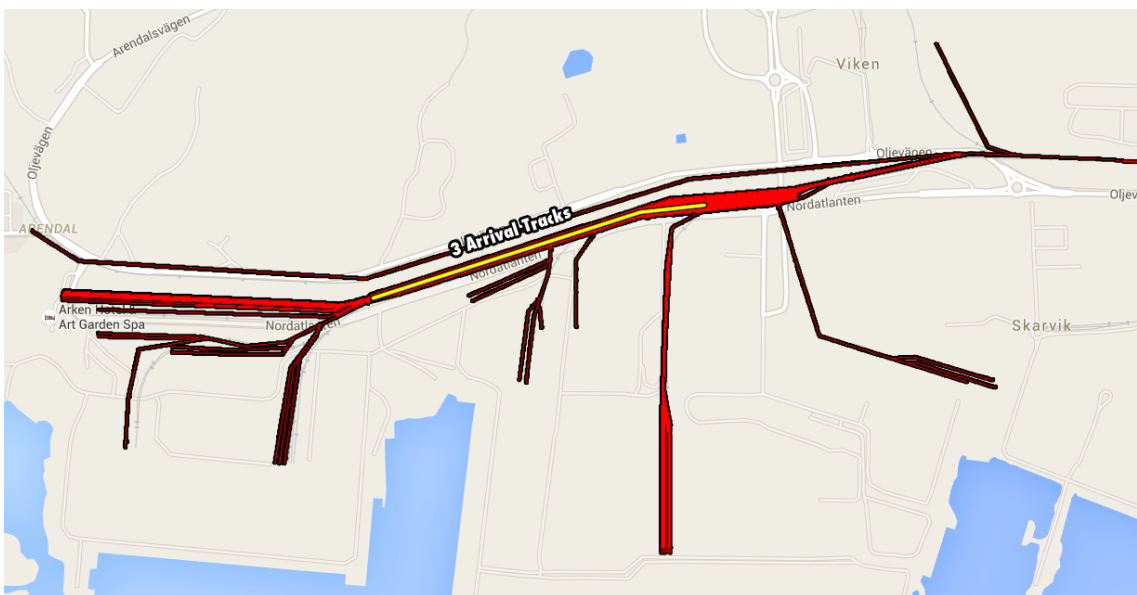

Figure 4.2: The three arrival tracks available are marked with yellow.

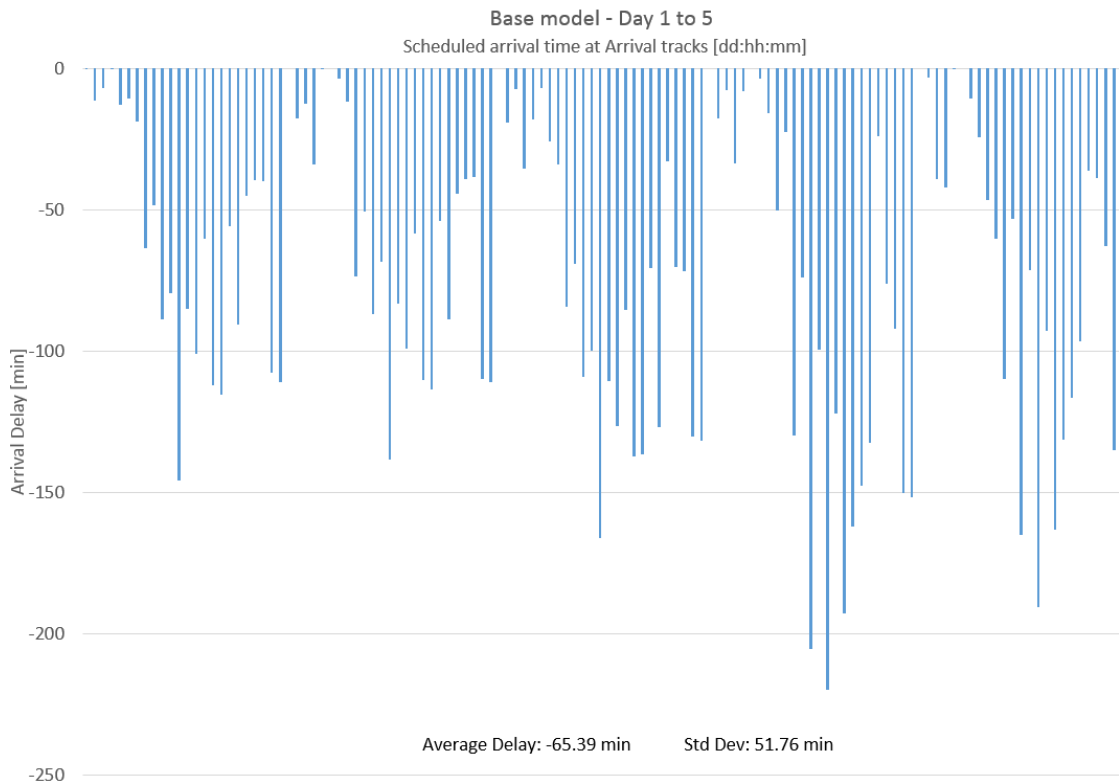The results for the base model over five days can be seen in figure 4.3.

Figure 4.3: The x-axis shows the same thing as before but it instead repeats for 5 days, and each section represent a day in the model. The model spikes during the peek hours each day but recovers during the night. Some spikes are higher (day 4) due to an unfavorable train combination that can occur.

4.1.2 Average Throughput Time

There are two different definitions for the throughput time, one for when harpan is electrified and one for when it is not. When harpan is electrified, the throughput time is measured as the time between when the electric engine decouples after arriving to the arrival tracks until the time when the full train starts its zone booking procedure before departure from harpan.

When harpan is not electrified, the throughput time is defined as the time from when the electric engine decouples from the train at the arrival tracks until the time that the diesel operators are done with the departure inspection for that train at the departure tracks.

4.2 Stress Testing

The model and experiment data will only look at the 24 trains traveling to the port and the other 8 will affect the model as disturbances. The key data that will be collected is the delay until a train reached the arrival tracks and the throughput time for the trains.

4.2.1 Increasing Diesel

To be able to handle the increase of trains certain amount of extra diesel engines were added to the model. In the tables below you can see how the arrival and throughput times change depending on the amount of extra trains as well as different amount of diesel engines. The amount of trains that enters was tested by increasing with 1 until satisfied with the amount of data. This ended up with the tables and graphs containing 4, 8 and 12 extra trains.

Table 4.1 shows how the delay changes when increasing the number of diesel engines, during certain amount of extra trains. The table is based on the graphs, which can be seen in Appendix A.

Table 4.1: Delay difference for different combination of extra trains and diesel engines. Were the base model is at the top of the table

Extra trains [#]	Diesel engines [#]	Delay [min]	Compared to base model [%]
0	2	-65	0 %
0	3	-23	-64 %
0	4	-18	-72 %
4	2	-379	+583 %
4	3	-72	+101 %
4	4	-58	-11 %
8	3	-294	+452 %
8	4	-167	+257 %
12	3	-341	+524 %

The table show that increasing extra trains causes increases in arrival delay, but that it can be decreased by increasing the amount of diesel engines. The Port of Gothenburg can look at the table and then decide what combination is best for them.

Table 4.2 shows how the throughput times changes when increasing the number of diesel engines, during certain amount of extra trains.

Table 4.2: The avarage throughput times for harpan train.

Extra trains [#]	Diesel Engines [#]	Throughput time [min]	Difference vs. base model [%]
0	2	240	0%
4	2	244	2%
8	2	253	5%
12	2	264	10%
0	3	192	-20%
4	3	201	-16%
8	3	183	-24%
12	3	223	-7%
0	4	192	-20%
4	4	204	-15%
8	4	193	-20%

It is interesting to note from table 4.2 that the throughput times difference is a lot less than the differences in arrival times. The fact that the trains are buffering up before the arrival tracks but are then able to move through the system at the same pace, even when traffic increases, points to the arrival tracks being the bottleneck of the system.

4.2.2 Electrifying Harpan

At the time the trains have to switch engine from electric to diesel to be able to travel to the Harpan terminal. This takes time and can be avoided by providing electricity down to Harpan. This was simulated and the tables below shows how the arrival time and throughput changes depending on the amount of trains added.

Table 4.3 shows how the delay changes when increasing the number of trains when the Harpan terminal is electrified. The table is based on the graphs, which can be seen in Appendix A.

Table 4.3: Delay difference for different amount of extra trains when Harpan terminal is electrified. The base model that is compared against is -63 min delay with 2 diesel engines and no electric Harpan

Extra train [#]	Diesel engines [#]	Delay [min]	Compared to base model [%]
0	2	-27	-58 % (Base = -65 min)
4	2	-53	-86 % (Base = -379 min)
8	2	-114	(Base = Can't handle)
12	2	-250	(Base = Can't handle)

The table show that increasing extra trains causes increases in arrival delay. Just by electrifying harpan it becomes 57% less delay and continues to be lesser until 8 extra trains is reached. The Port of Gothenburg can look at the table and then decide what combination is best for them.

Table 4.4 shows how the throughput times changes when increasing the number of trains when the Harpan terminal is electrified.

Table 4.4: Throughput time for harpan trains when harpan is electrified

Extra trains [#]	Diesel Engines [#]	Throughput time [min]	Difference vs. electrified [%]
0	2	156	-34 %
4	2	164	-33 %
8	2	152	-40 %
12	2	184	-30 %

It is again shown in table 4.4 that the throughput time for the trains changes very little as more trains are added compared to the changes in arrival times. This shows that even when harpan is electrified the arrival tracks are still the bottleneck of the system.

4.3   Validation by the Port of Gothenburg

The data from the base and experiment model was presented to the company at a meeting with the responsible people at Port of Gothenburg. The operations in the simulation was presented and the simulation acted in similar ways to the port, thus validating it. The arrival delay and throughput data was shown and became validated as reasonable, and the stress testing experiment will be looked upon and might be used for future improvement suggestions in the port.

Therefor, the question "If Path Mover System can be used to create a validated model for rail port operations?" is answered and the answer is yes. The simulation operations, delay and throughput is similar to the current state of the Port of Gothenburg.

4.4 Components in DES for Rail Port Operations

The components found to be necessary to create a DES model for rail port operations are similar to those described for rail yard operations by Lin [20] and where found as described in 3.1.1. In figure 4.4 the components, which will be described below, can be seen.
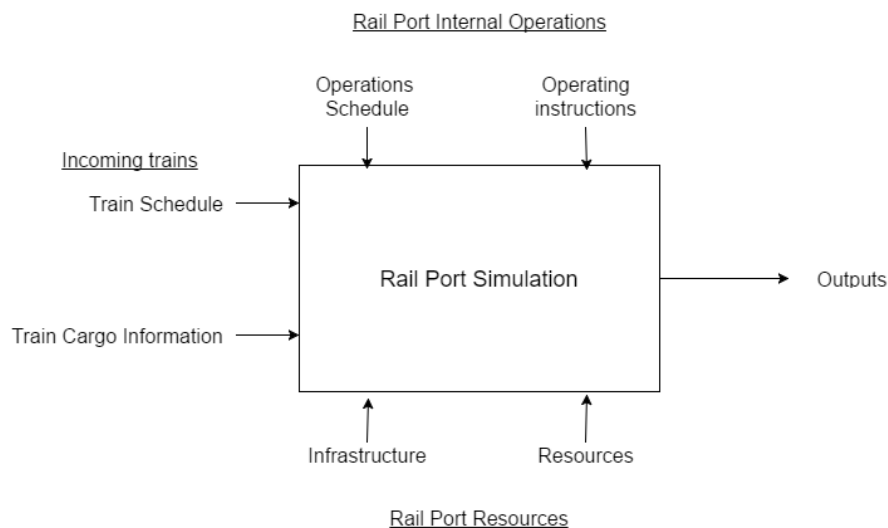

Figure 4.4: The components necessary for conducting a simulation of rail port operation.

4.4.1 Incoming Trains

The components included in this category contains information about the trains that enter the system. For the model to be able to produce valid result it is necessary for it to have access to a schedule for the incoming trains.

It is also necessary to have access to the cargo of every train that is scheduled to enter the system. The model needs information about what terminal or track the different trains are to be slotted to.

4.4.2 Rail Port Internal Operations

The components under this section are needed to describe the internal operations of the port. The model needs to include instructions of every operation that is carried out in the port as well as information about when each operation is carried out.

4.4.3 Rail Port Resources

To carry out the internal operations of the rail port, there must of course be resources to handle the tasks available. The rail port resources include the infrastructure of the system as well as resources such as diesel engines and operators.

4.5 Suitability of Path Mover System for Modeling Rail Port Operations

In this section, it will be described how suitable AutoMod's Path Mover System is for modeling rail port operations by evaluating its ability to handle the components described in the above section. The system proved to quite able to create a validated model, although the system could be improved in the category of rail port internal operations.

4.5.1 Incoming Trains

AutoMod and Path Mover are able to control these components of the simulation well by reading the necessary data from a text file. By using an excel UI with data sheets of the trains schedules and cargo information to create input text files for AutoMod to read, it is possible to produce trains according to the given information.

4.5.2 Rail Port Internal Operations

The operations of the rail yard are coded in AutoMod processes and can be validated by using animation and face validation techniques. The operations in the model can also be validated by collecting data of certain operation times in the model, travel times between certain points in the model and the models ability to follow the schedule.

There where some challenges in creating certain operations such as carriage release and turning on a track, but these problems could be solved to create a functioning model as described in the methods chapter.

4.5.3 Rail Port Resources

Valid rail infrastructure can be created using paths, transfers and control points in the Path Mover System. All the trains that use the rails can be defined and created as a set of vehicle segments in the Path Mover System.

5

Discussion

This thesis has concluded that AutoMod's Path Mover System can be used to model the train operations in a rail port. There are however some problems that has to be solved and certain operations or maneuvers are more complicated to program than should be necessary. Even though the system can create valid models for rail port operations that does not mean that the software is the best suitable for the job. These topics, among others will be discussed in this chapter.

5.1 Improvement Suggestions for the Path Mover System

Since Path Mover System has proven itself to be able to build a validated model for rail port operations, there is nothing that needs to be added for it to be used for this purpose. However, there are some aspects of the system that may be improved to make the model building process easier and less time consuming.

One functionality that would make the model building easier would be to have multi-segment vehicle move reliably through the system no matter where the driving load is located on the vehicle. Currently, a multi-segment vehicle will sometimes choose the wrong wrong path in an intersection or have some segments move through each other as the train is turning on a path, if the driving load is not in the leading segment. These problems can be solved once the programmer is aware of them, but they still increases the time spent on building the model.

Another functionality would be to enable the trains to choose route in another way than just choosing the shortest one. The paths in AutoMod has an attribute called navigation factor that can be set only when creating the path. This navigation factor is multiplied with the paths length and this value is used when a vehicle is searching for the shortest way to its destination. This is a way to control the paths a vehicle chooses, but the vehicle will choose the same route every time. To get a vehicle to choose a different route than the one with shortest distance to a control point, to circumvent another parked vehicle for example, there must be some control points set out on the longer path and the vehicle must be guided through these control points. This includes a different challenge since the vehicle will decelerate and stop after every move command. This can be fixed by creating station claimed and released functions to set the deceleration and acceleration to big values to make the stop as short as possible and then reset the values for acceleration and

deceleration after the control point. If the Path Mover System allowed for a path to be claimed so that a vehicle would start looking for another route these maneuvers would be a lot easier to control.

5.2 Recommendations for the Port of Gothenburg

When working with the thesis we observed several parts that we believe could improve the port operations. These observations does not have data backed by it and should be seen as a example of future suggestions that the Port of Gothenburg can research further.

5.2.1 Bottleneck at Arrival Tracks

Today the arrival tracks consist of 3 tracks were arriving trains can leave their carts before changing/turning the engine. We can see in the result by increasing the amount of diesel engines, the delay decreases. This will work for low amount of trains, however if more then 3 trains arrive at the same time, the fourth trains and those after will be +30 min late. This is due to the inspection time that each trains need when switching engine, and the inspection time is 30 minuets. So even if the port optimizing in a way that there is no delay, low throughput, no disturbances they will always have a bottleneck at the 3 arrival tracks.

If they build more arrival tracks or somehow remakes the logistics so that the arrival tracks are avoided, the next bottlneck will land on the Departure tracks. There are 5 tracks there at the moment, and they have the same problem with a 30 minuets inspection time.

The Port of Gothenburg should look into this if they want to increase the capacity of the port. One way to fix this can be read in chapter 5.2.2.

5.2.2 Easier Accessibility to Harpan terminal

When a train departs from the arrival tracks and moves towards the Harpan terminal its forced to drive towards Pölsebo, blocking the track for all the trains driving from/to Kville rail yard and later back down to Harpan terminal. See figure 5.1 for over head view of the operation.
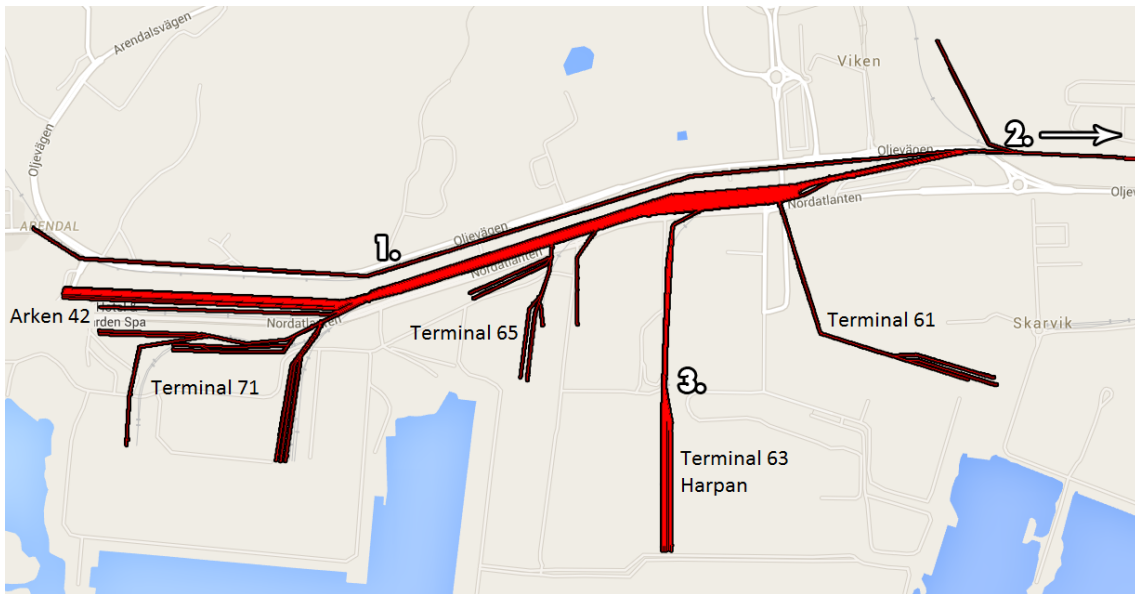
Figure 5.1: The train starts at 1. drive towards 2. and backs down to 3.

A good solution would be to skip the arrival tracks entirely by electrifying the Harpan terminal and adding extra track at the top of the Harpan terminal, so you can access it from the left side as well.

So the new operation would be: 1. Enter the port, drive down track 6 (the yellow track in figure 5.2) and then back down into the Harpan Terminal
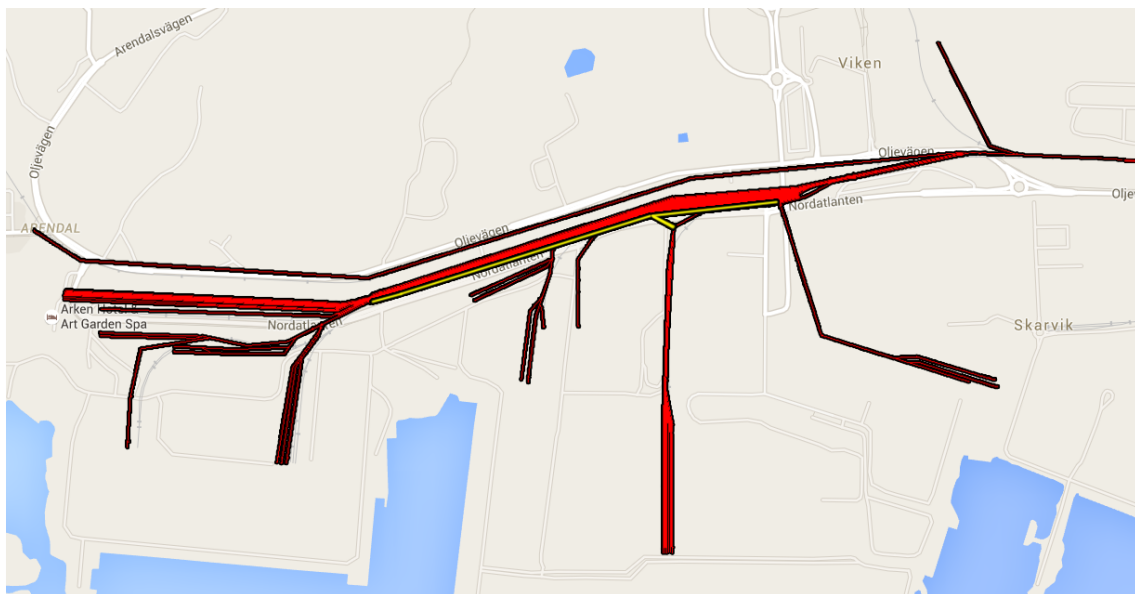

Figure 5.2: A suggestion to access Harpan terminal from the left side

5.2.3   Reduce Inspection Time

As mentioned in the bottleneck chapter above, the inspection time of the train means that every train that switches between engines need to do a 30 min inspection. Since

it is 30 min for each train this means that a lot of time i wasted on the train standing still.

We believe that the Port of Gothenburg could save a lot of time by trying to improve the inspection operation so it can be lowered.

5.3   Different Software

As mentioned in the theory chapter, there are other simulation software that is developed to simulate train traffic and rail yard operations that are similar to the operations done in a rail port. To use one of these softwares would be likely to produce results faster and thereby cheaper then when using AutoMod's Path Mover System. This means that by using a software more specialized for the task would probably have been beneficial for this case.

However, would the Port of Gothenburg wish to expand upon the model later to include operations that are not train related, such as forklift traffic and loading operations for freight ships, this would be quite possible for AutoMod. A specialized software would probably struggle to simulate operations other then the ones it was developed to simulate.

Why did we choose to do the simulation in AutoMod? The company that hired us to do the master thesis, ÅF, is also a retailer for AutoMod and do a lot of projects in that software. So we chose AutoMod to have expertise close when needed. Both members in the project have experience with the AutoMod software in earlier courses when we did a similar project.

Even though all the facts pointed us to use AutoMod we at least tried different software such as Anylogic [34]. The software really have potential for transportation flow but the time we needed to put into learning the program was instead put on data gathering and later simulation in AutoMod. So we decided later to use AutoMod because of the arguments in the previous section.

5.4   Electrification VS Diesel

The two experiments, electrification to Harpan or increasing diesel engines, are both giving the port of Gothenburg the possibility to increase the number of trains in the model. We explained in the result the pros and cons utility wise and cost wise but never the environmental wise. If the source of the electricity is from a good green source it is clearly the better choice instead of purchasing another diesel engine, which needs refilling once a week. An electric train engine in Sweden have a 60% less climate impact compared to a diesel engine as well as other benefits according to the data base Ecoinvent [35] regarding transport, freight train and diesel/electrical processes. The greener the source of the electricity the less environmental impact will be. So that can be a standing point that Port of Gothenburg can try to convince

the Swedish Transportation Administration to improve.

5.5   Data Collection

The rail port is used by a lot of different companies so gathering data from them all have been hard and collecting data that don't contradict each other, almost impossible. First we used the time schedule from the Swedish Transportation Administration [29] to see how many trains move around daily and also how fast they move between stations. We used that information and then interviewed the management at Baneservice [36] to see if he agrees with the number of trains going to different parts of the port. The number of trains in Scandia port is correct and is based on time schedules and interviews but other parts such as Torslanda and Arendal etc. is based on the same interviews and what the average train number is daily. Since that number was very low and impacts the model slightly we accepted it as data. We also notice that Scandia ports own schedule does not always match the schedule from Swedish Transportation Administration the causes could be simplifications to remove certain elements that did not affect them or just plainly mistakes, when asked the port was not sure.

Our interview techniques could have been better and probably more prepared to decrease the amount of meetings that was needed to get the necessary information. So if we had taken a few hours/days to prepare our material we could have saved time. But we do not think that the quality of the data from our interviews is bad because of it, just inefficiently gathered.

The data gathered about the length of the trains, weight and accelerations was collected from a existing project [31] and we were first unsure about the credibility of the data but through interviews we got the same results thus validating the pre-existed project.

5.6   Production Engineering Mentality for a Logistics Problem

The case that was used in this thesis regarded a logistic system, but it was worked with by two production engineering students. This means that the logistic problems that would arise during the case work would be met with the mentality and tools connected to production systems. It is of interest to discuss how this production mentality and methods may have influenced the work and the case results.

When we viewed the port rail system with it's operations we saw it as a production system. We quickly realized that as long as the infrastructure remained the same, the travel times between certain parts of the port, where certain operations where carried out, would always be the same. Thus, optimizing the throughput of the system is about limiting the times when the trains are standing still.

During our 2 years in a production engineering masters program, we are trained to always be on the lookout for bottlenecks and wasteful activities. There are certain signs of a bottleneck that we will always be on a lookout for. During the experimentation part of the case work, we noticed that for each scenario the throughput time changed little while the delay increased considerably as more trains where put into the system. This points to the arriving tracks being the bottleneck of the system, as all trains move through the system in the same time once they get through the arriving tracks. Thus, changes that decrease the time a train spends on the arrival track are intuitively most likely to have the biggest impact on the systems total capacity when it comes to number of trains per day.

In this case, the knowledge we had from our studies of production systems enabled us to find the systems bottleneck and where change initiatives are most likely to have a significant impact on the system.

5.7 DES in Production Systems VS Rail Port Train Operations

Before starting this thesis, both thesis workers had some experience using AutoMod for creating DES models for production systems. The knowledge we had of DES from production systems proved to be enough for us to perform the case simulation problem. The only big challenges in the building of the computer model where the ones that arouse from the limits of Path Mover System described above.

As long as the used software is able to create and control the components needed for building the model, the principles of building the model is the same. As an example of this in our model, trains waited in order list for zones to become free just as loads would wait in an order list for a resource to become free in a model of a production system. We believe that a production system simulator with compatible software for the task would be able to create a valid model of any system similar to one in the case study of this thesis.

5.8 Impact of the Simulation on the Real World

How will it help anyone to simulate a "small" part of Gothenburg when things outside our simulation affect it greatly? An outside effect could be Norway having the train workforce on strike or a container boat not arriving on time. So even if our simulation solution is perfect it will never be able to simulate all of the disturbances outside of the simulation affecting the simulation. One solution could be to expand the simulation to the entire Gothenburg region. Our model could be the starting point in Gothenburg and if the argument, that the simulation wont represent the real world because of the outside disturbances, is being used you can answer that this is the start and you can just expand to make it more like the real world.

6
Conclusion

A valid model was produced using the AutoMod Path Mover System and the data that is valuable to the costumer was produced by the model. This means that the thesis are able to conclude that the system is able to simulate rail port operations.

The current state model simulation of the port was built, with an included experiment model. The experiment model was created to research if it was possible to increase the amount of trains in the port. The result was that an increase can be done by investing in either extra diesel train engines and/or making a terminal available for electric train engines. These investment could increase the amount of trains depending on the investment size. Both investments have pros and cons, but the delimitations that was made involves not doing investment calculations. The thesis members believe that the Port of Gothenburg will make the best decision with our provided data however.

To be able to answer if the Path Mover System is working, for Port of Gothenburg, they had to approve that the models and experiment is validated. The company validated the models in small increments, by attending several meeting showing how the model works and runs as well as being shown throughput and disturbances. The model behaved satisfactorily thus showing that the Path Mover System in AutoMod can be used for rail port activity.

Recommended future work is to create an extended model of a rail port to include more detailed loading operations, fork lift traffic and loading operations for freight trains.

6. Conclusion

Bibliography

[1] Banks, J. (1999, December). Introduction to simulation. In *Proceedings of the 31st conference on Winter simulation: Simulation—a bridge to the future-Volume 1* (pp. 7-13). ACM. Chicago

[2] Carson II, J. S. (2004). Introduction to modeling and simulation. Proceedings - Winter Simulation Conference, 1, 9-16.

[3] Nunez, F., Reyes, F., Grube, P., & Cipriano, A. (2010).Simulating railway and metropolitan rail networks: From planning to on-line control. PISCATAWAY: IEEE. doi:10.1109/MITS.2010.939923

[4] Knights, Peter F., and Eduardo JL Bonates. (1999). "Applications of discrete mine simulation modeling in South America." International Journal of Surface Mining, Reclamation and Environment 13.2 : 69-72.APA

[5] http://www.appliedmaterials.com/global-services/automation-software/automod, May 2016

[6] Review of "systems simulation: The art and science, by robert E. shannon", prentice-hall, 1975. (1976). ACM SIGSIM Simulation Digest, 7(3), 3-3. doi:10.1145/1102746.1102759

[7] Ingalls, R. G. (2011). Introduction to simulation. Paper presented at the 1374-1388. doi:10.1109/WSC.2011.6147858

[8] Robinson, S., & Bhatia, V. (1995, December). Secrets of successful simulation projects. In Proceedings of the 27th conference on Winter simulation (pp. 61-67). IEEE Computer Society.

[9] Bahouth, A., Crites, S., Matloff, N.,& Williamson, T. (2007). Revisiting the issue of performance enhancement of discrete event simulation software. Paper presented at the 114-122. doi:10.1109/ANSS.2007.36

[10] Bangsow, S. (2012). Use cases of discrete event simulation. Berlin: Springer.

[11] Wan Laailatul Hanim Mat Desa, Kamaruddin, S., Mohd Kamal Mohd Nawawi, & Khalid, R. (2013). Evaluating the performance of a multipart production system using discrete event simulation (DES). International Proceedings of Economics Development and Research, 63, 64.

[12] Sang, B., & Liu, Y. (2015, August). Simulation modeling of shuttle racking system based on automod. In Advanced Mechatronic Systems (ICAMechS), 2015 International Conference on (pp. 90-95). IEEE.

[13] Lau, Y. K. H., & Lee, M. Y. N. (2007). Simulation study of port container terminal quay side traffic. In AsiaSim 2007 (pp. 227-236). Springer Berlin Heidelberg.

[14] Liu, Y., Li, S., Li, J., & Shen, J. (2010, November). Operation Policy Research of Double Rail-Guided Vehicle Based on Simulation. In E-Product E-

Service and E-Entertainment (ICEEE), 2010 International Conference on(pp. 1-4). IEEE.

[15] HOW, L. C. (2005). A simulation model of an air cargo import terminal(Doctoral dissertation).

[16] Banks, J. (2000). Getting started with AutoMod. Brooks Automation. Autosimulation Division.

[17] Sipilä, H. (2011). Calibration of Simulation on the Southern Main Line in Sweden. In Railway Engineering (pp. 1-12). Stockholm: Railway Engineering.

[18] Wang, Z. & Koutsopoulos, H. (2011). Calibration of urban rail simulation models: A methodology using SPSA algorithm. In Winter Simulation Conference (pp. 3699-3709).

[19] Nunez, F., Reyes, F., Grube, P., & Cipriano, A. (2010). Simulating Railway and Metropolitan Rail Networks: From Planning to On-line Control. IEEE Intelligent Transportation Systems Magazine, 2(4), 18-30. http://dx.doi.org/10.1109/mits.2010.939923

[20] Lin, E. & Cheng, C. (2016). Simulation and analysis of railroad hump yards in north america. In Winter simulation conference (pp. 3710-3718).

[21] Yagar, S., Saccomanno, F., & Shi, Q. (1983). An efficient sequencing model for humping in a rail yard. Transportation Research Part A: General, 17(4), 251-262. http://dx.doi.org/10.1016/0191-2607(83)90089-4

[22] Skoogh, A., & Johansson, B. (2008, December). A methodology for input data management in discrete event simulation projects. In Proceedings of the 40th Conference on Winter Simulation (pp. 1727-1735). Winter Simulation Conference.

[23] Robinson, S. (2004). Simulation: The practice of model development and use. Chichester: Wiley

[24] Sargent, R. G. (2005, December). Verification and validation of simulation models. In Proceedings of the 37th conference on Winter simulation (pp. 130-143). winter simulation conference. Chicago

[25] Rushton, Alan Croucher, Phil Baker, Peter. (2010). Handbook of Logistics and Distribution Management (4th Edition). Kogan Page Publishers.

[26] Azadeh, A., Faghihroohi, S., & Izadbakhsh, H. R. (2012). Optimisation of train scheduling in complex railways with imprecise and ambiguous input data by an improved integrated model. International Journal of Services and Operations Management, 13(3), 310-328. doi:10.1504/IJSOM.2012.049707

[27] Nageshwaraniyer, S. S., Son, Y., & Dessureault, S. (2013). Simulation-based optimal planning for material handling networks in mining. Simulation, 89(3), 330-345. doi:10.1177/0037549712464278

[28] Brannlund, U., Lindberg, P. O., Nou, A., & Nilsson, J. -. (1998). Railway timetabling using lagrangian relaxation.Transportation Science, 32(4), 358-369. doi:10.1287/trsc.32.4.358

[29] Swedish Transport Administration (2016, February). Yearly Train Plans. Retrieved from http://www.trafikverket.se/for-dig-i-branschen/jarnvag/tagplan-att-skapa-tidtabeller-for-tag/Tagplan-2016/dagliga-grafer-2016/

[30] Lusby, R. M., Larsen, J., Ehrgott, M., & Ryan, D. (2011). Railway track allocation: Models and methods. OR Spectrum, 33(4), 843-883. doi:10.1007/s00291-009-0189-0

[31] Brigelius, L., Simulett AB, (2012). Track schedule and simulation of train trafic in the port of Gothenburg

[32] http://www.autodesk.com/education/free-software/autocad , Mars 2016

[33] Manager, Swedish Transport Administration, April 2016

[34] http://www.anylogic.com/, Mars 2016

[35] Ecoinvent (2016): Data base for "Transport, Freight train, Diesel" and "Transport, freight train, electricity" processes

[36] Management, Baneservice, Mars 2016

[37] Management, Port Development, Port of Gothenburg, February 2016

[38] Logistic Management, General Manager Rail Planning, Port of Gothenburg, February 2016

A

Appendix 1 - Graphs

The model handles 32 trains each day. Were 24 is traveling to the port and the other 8 travels to neighboring places. Our model and experiment data will only look at the 24 trains traveling to the port and the other 8 will affect the model as disturbances.

A.1 Base model data

The key data that will be collected is the delay until a train reached the arrival tracks and the throughput time for the trains. To compare the data that will be shown in the experiment chapters below its needed to see how the data is in the current base model without experiment changes. The current state for day 1 can be seen in graph A.1 and for day 1 to 5 can be seen in graph A.3.
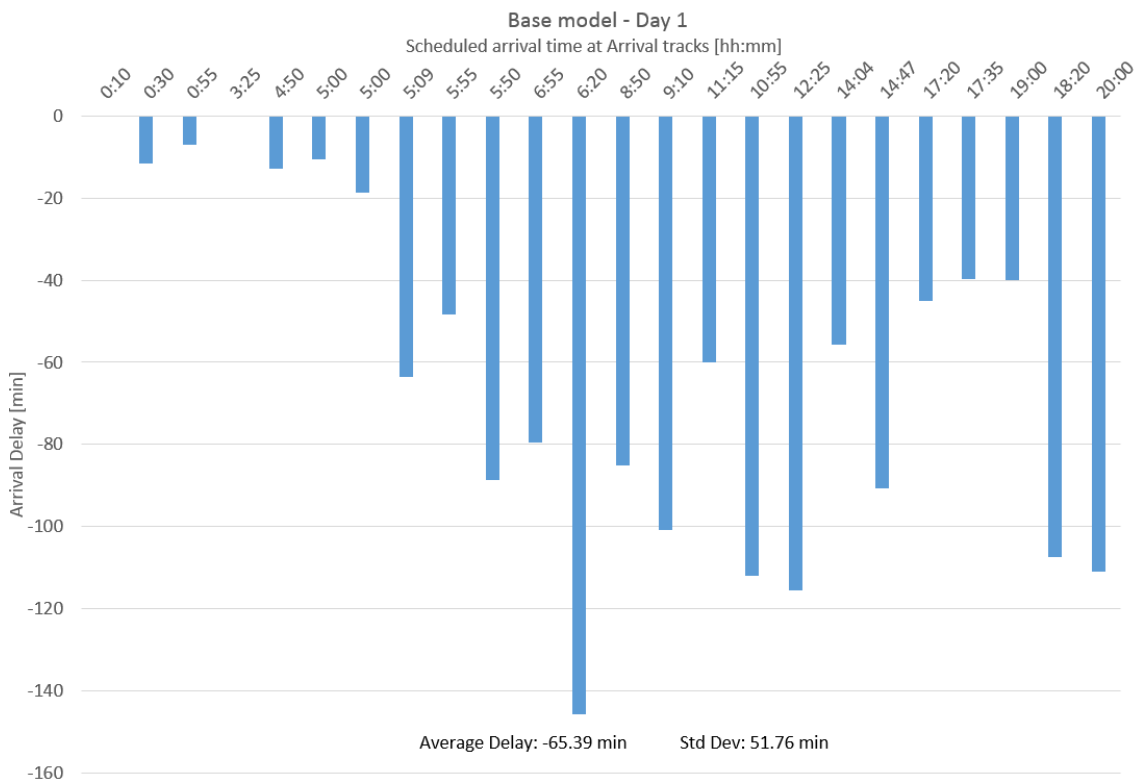
Figure A.1: The x-axis shows when the trains should arrive at the arrival tracks (see figure A.2 for were they are located), and the y-axis show how delayed they are when they arrive. The graph show that the port is busy during the 5:00 to 6:20 hours, then the model slowly works down the delays only to be pushed up again in the late hours. Below the graph the average delay can be read as well as the standard deviation.
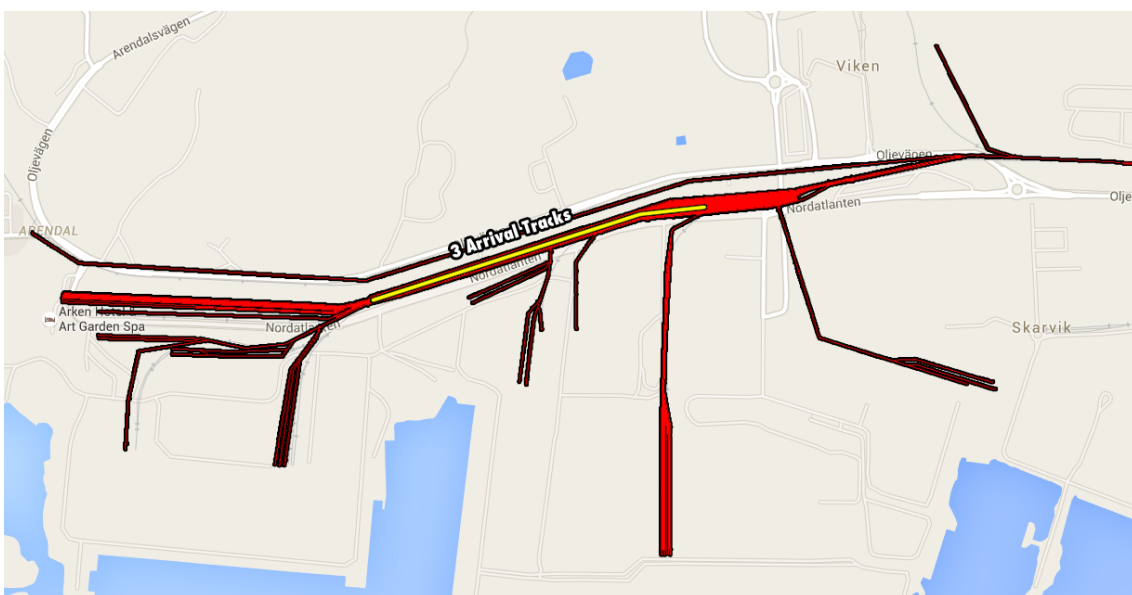
Figure A.2: The three arrival tracks available are marked with yellow.

If we show the base model but let it continue for 5 days, the following graph can be created (see graph A.3)
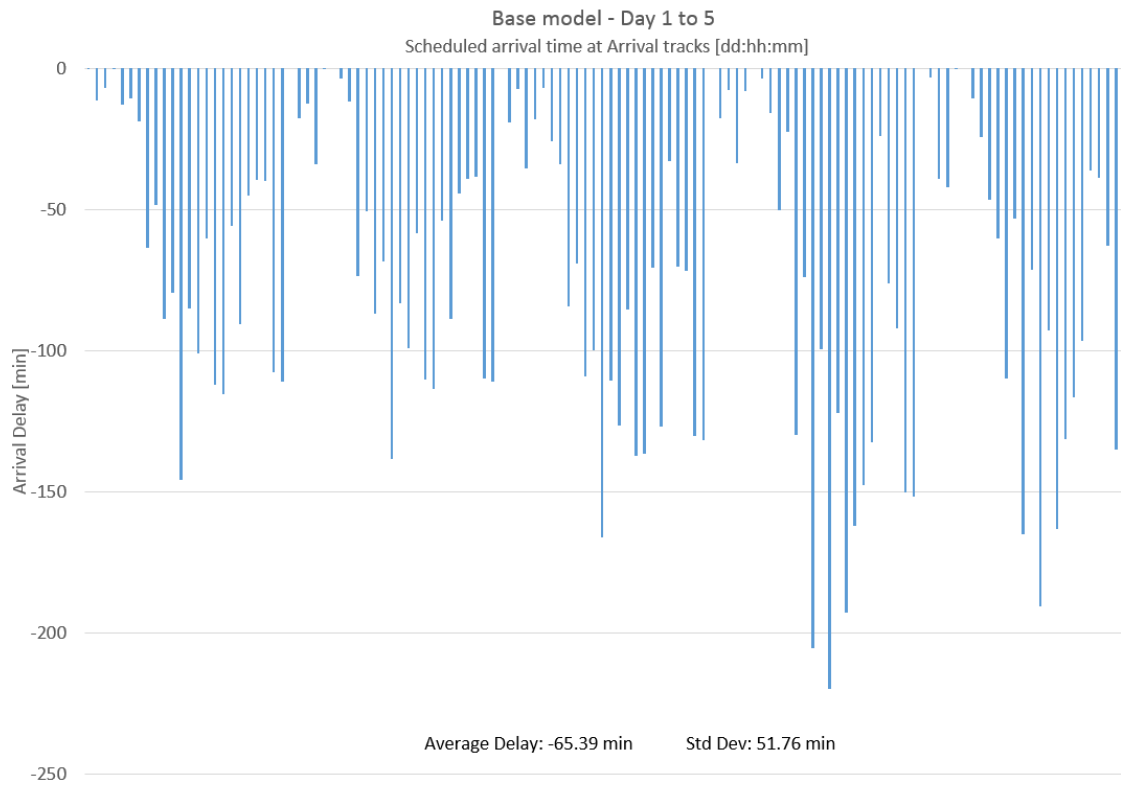
Figure A.3: The x-axis shows the same thing as before but it instead repeats for 5 days, and each section represent a day in the model. The model spikes during the peek hours each day but recovers during the night. Some spikes are higher (day 4) due to an unfavorable train combination that can occur.

A.2 Stress testing

The Port of Gothenburg are interested in increasing the amount of trains going into and out of the port. To be able to see how many trains the port can handle, extra trains are sent in during the busiest time of the day. If the model can handle it at the worst case scenario it can handle the rest of the day without problem. Before the model receives the extra trains, its needed to see how the base model handles three and four diesel compared to the todays two diesel setup. These base model results will then later be compared to the extra train experiment graphs.
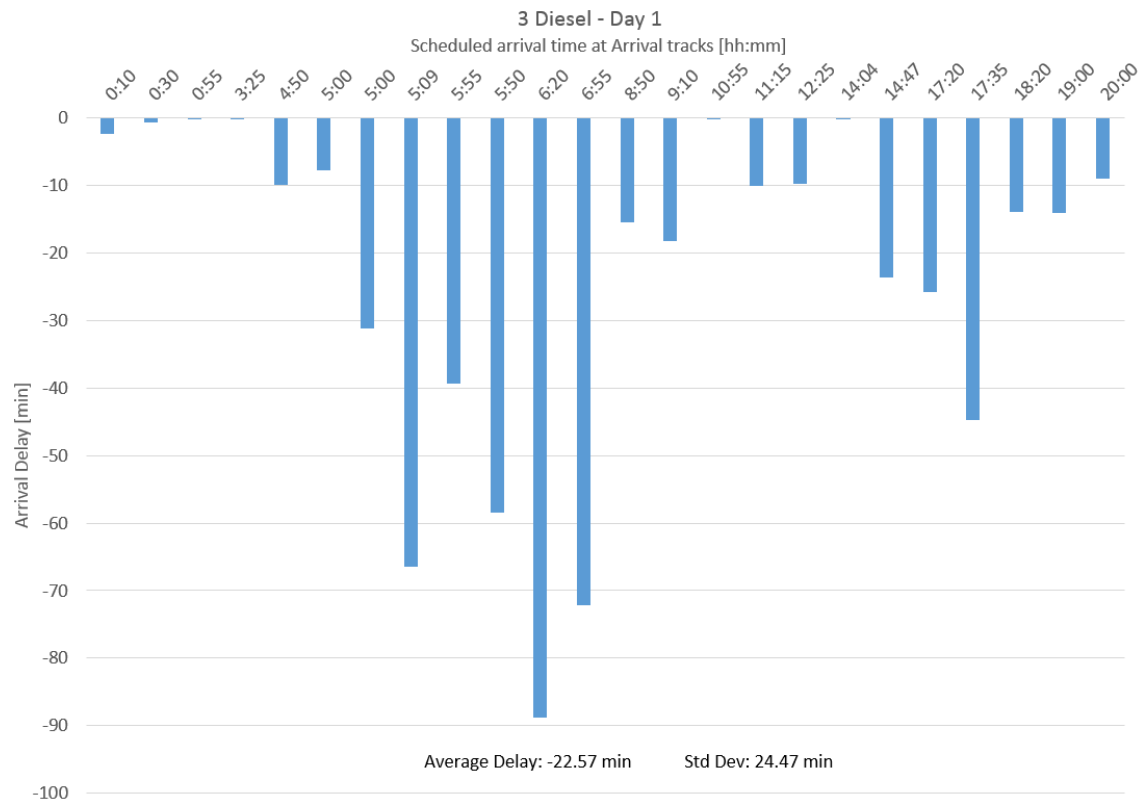
Figure A.4: The graph is a better version of base model with three diesel engines, this can be seen in the Average Delay and Standard Deviation result (base model had Delay: -65.39 min and Std Dev: 51.76 min). The same delay spikes occur roughly at the same time but not as sever as in the base model.
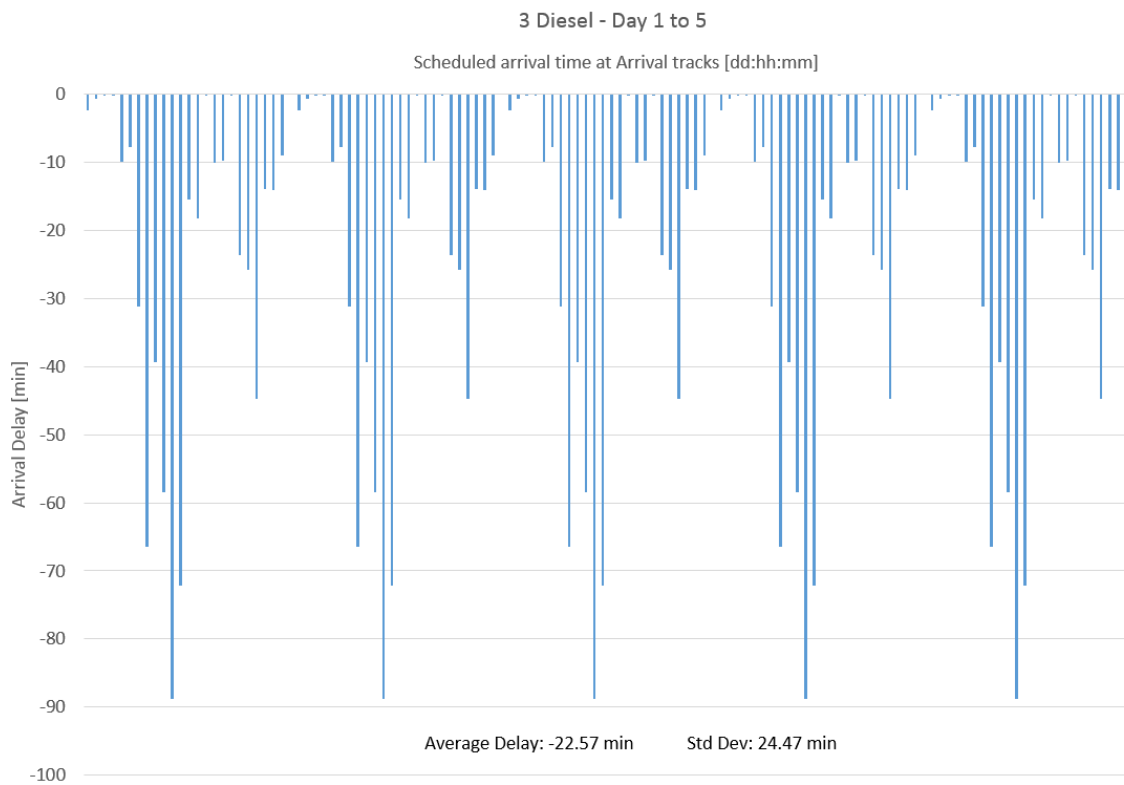
Figure A.5: The graph show that the delay occur at the same time each day and that the model works away the delay during the night.
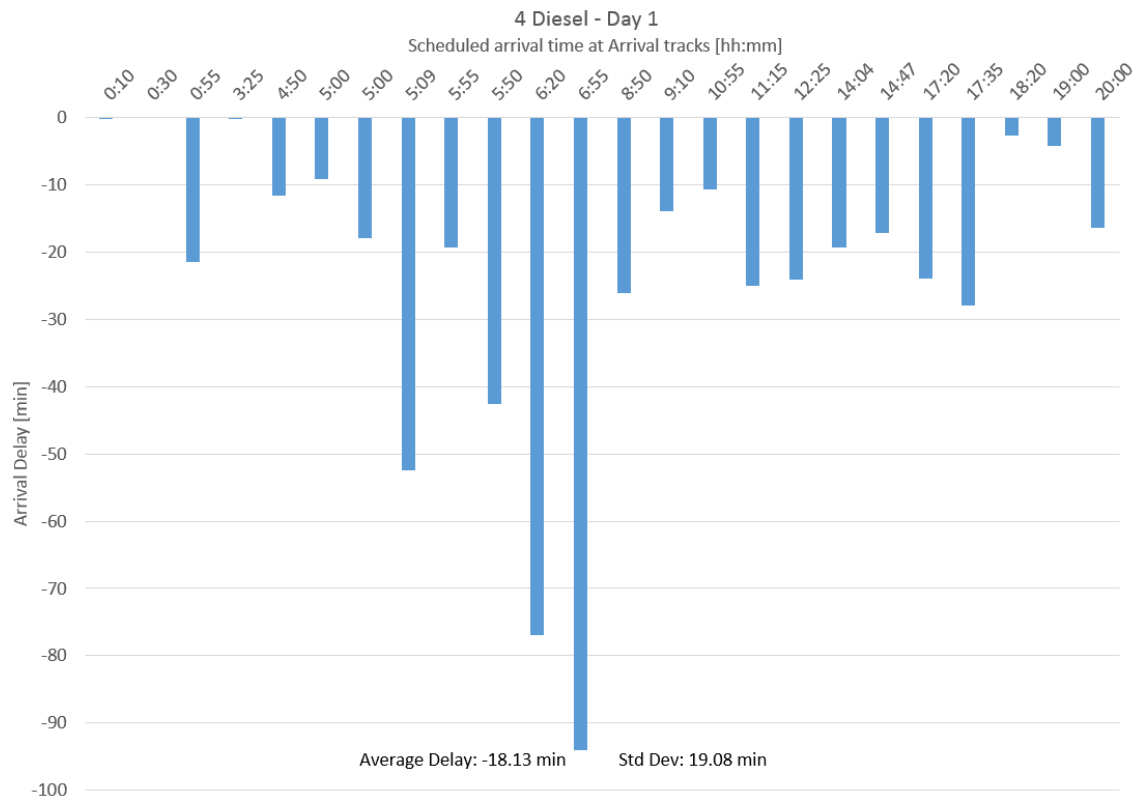
Figure A.6: The decrease in delay is not as big from three to four diesel engines as compared to two to three engines.

The extra trains will be sent in at 05:00-07:00 and/or 14:00-17:00, these times were set since the schedule is busy, as can be seen in the time schedule (see figure A.7).

#	Customer	Name	Arrival time
1	Hector Rail	Italientaget	5:00
2	CFLcargo	Dalapendeln	0:10
3	Tagab	Vanern	0:30
4	Hector Rail	Gavlepilen X	0:55
5	Hector Rail	Gavlepilen	3:25
6	Green Cargo	Biltag	4:50
7	Green Cargo	Baseport slot 1	5:00
8	Green Cargo	Vagnslast 1	5:09
9	Green Cargo	Baseport slot 2	5:50
10	Green Cargo	Gullbergsvass	5:55
11	Green Cargo	Hallsberg	6:20
12	Green Cargo	Baseport slot 3	6:55
13	Green Cargo	Baseport slot 4	19:00
14	Green Cargo	Vagnlast 2	8:50
15	Green Cargo	Savenas	9:10
16	Tagfrakt	Falkoping	10:55
17	Green Cargo	Steelbridge	11:15
18	Green Cargo	Savenas X	12:25
19	TMRail	TMRail	14:04
20	Green Cargo	Gullbergsvass X	14:47
21	Green Cargo	Baseport slot 7	17:20
22	CFLcargo	Vaggeryd	17:35
23	Tagfrakt	orebro	18:20
24	Green Cargo	Hogland	20:00

Figure A.7: The train schedule were the peek hours are between the red lines

The model will now have to many trains for the currently two diesel engines to handle which can be seen in the graphs. The data shows that the trains get delayed and misses the arrival time by several minutes and also increases the throughput for the train in different terminals.

A.2.1 Increasing number of Diesel engines

To be able to handle the increase of trains certain amount of extra diesel engines were added to the model. In the graphs below you can see how the arrival times change depending on the amount of extra trains as well as different amount of diesel

engines. The amount of trains we send in was tested by increasing with 1 until satisfied with the amount of data. This ended up with the graphs showing 4, 8 and 12 extra trains. Some graphs with certain combinations of trains and diesel wont be shown because the graphs would look repeating. The graphs shown however will be able to show to most interesting results. The following graphs will always start with showing a steady state simulation day, and sometimes (if interesting/important) a graph showing day 1 to 5 will follow. The graphs that follows will then either increase in extra trains or extra diesel engines.
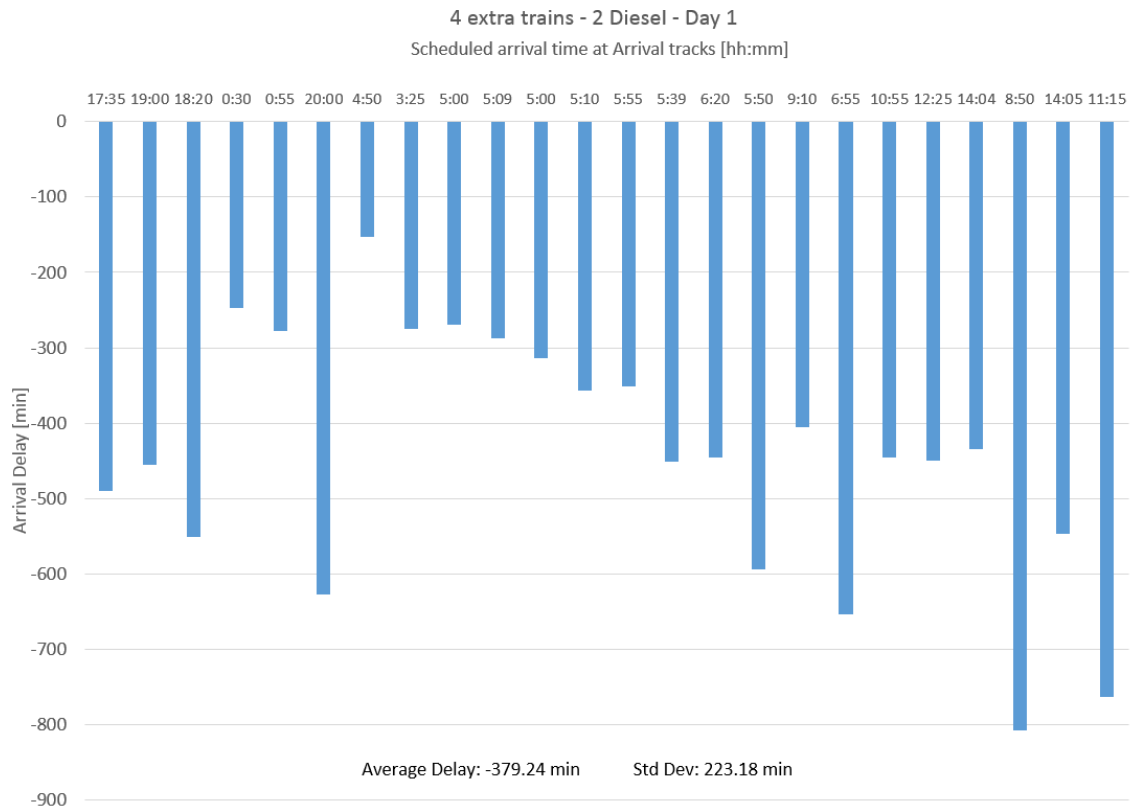
Figure A.8: Two important things can be notict here. First, there is a lot of late trains arriving from the previous days early in the morning. This happens because of the continuously late trains that the model cant work down during the night (as the base model did). The second important thing is the Average Delay and the Std Dev that is high (compared to base model, Delay: -65.39 min and Std Dev: 51.76 min).
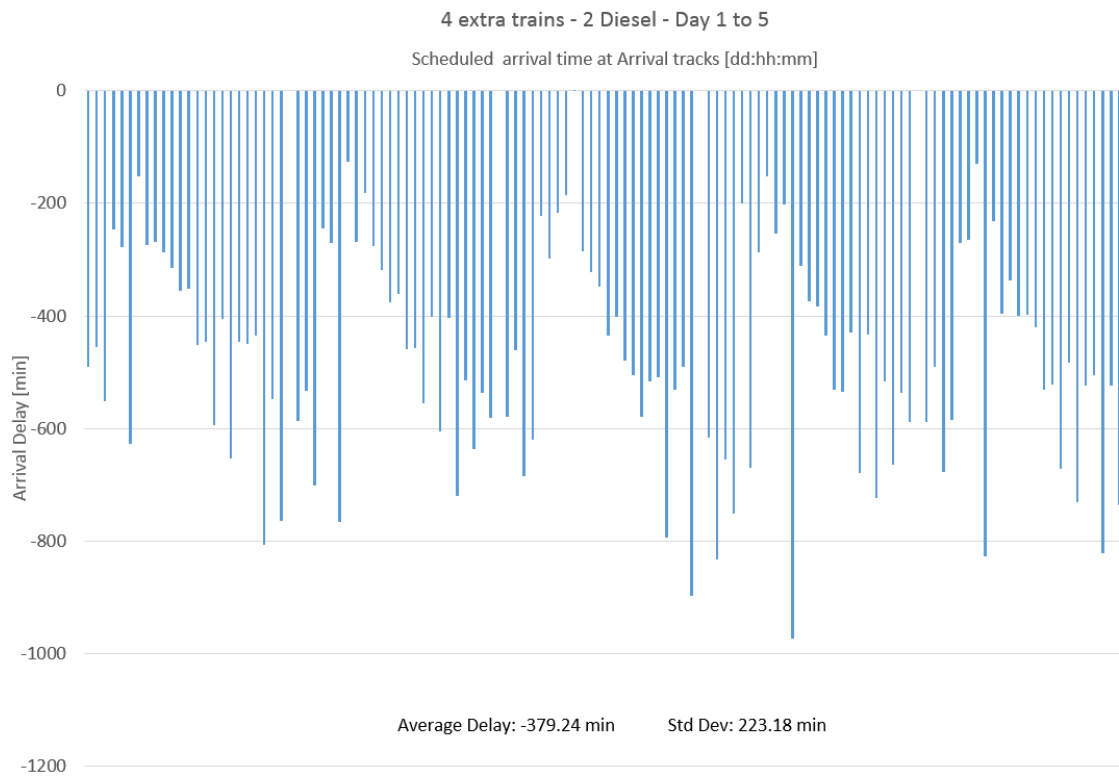
Figure A.9: Each day is harder to see in this graph due to the high arrival delay
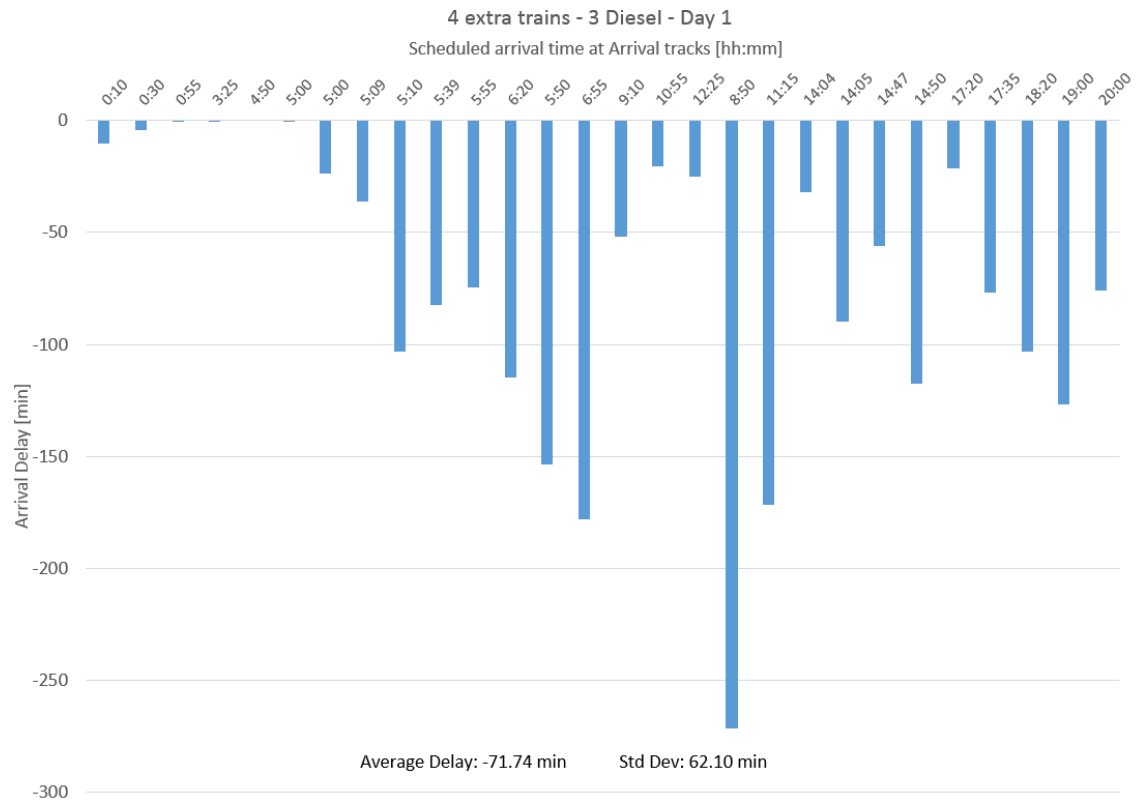
Figure A.10: The model gains a additional diesel engine to handle the extra trains. The delay decreases from -379.24 min to -71.74 min and is now close to the delay from the base model delay of -65.39 min
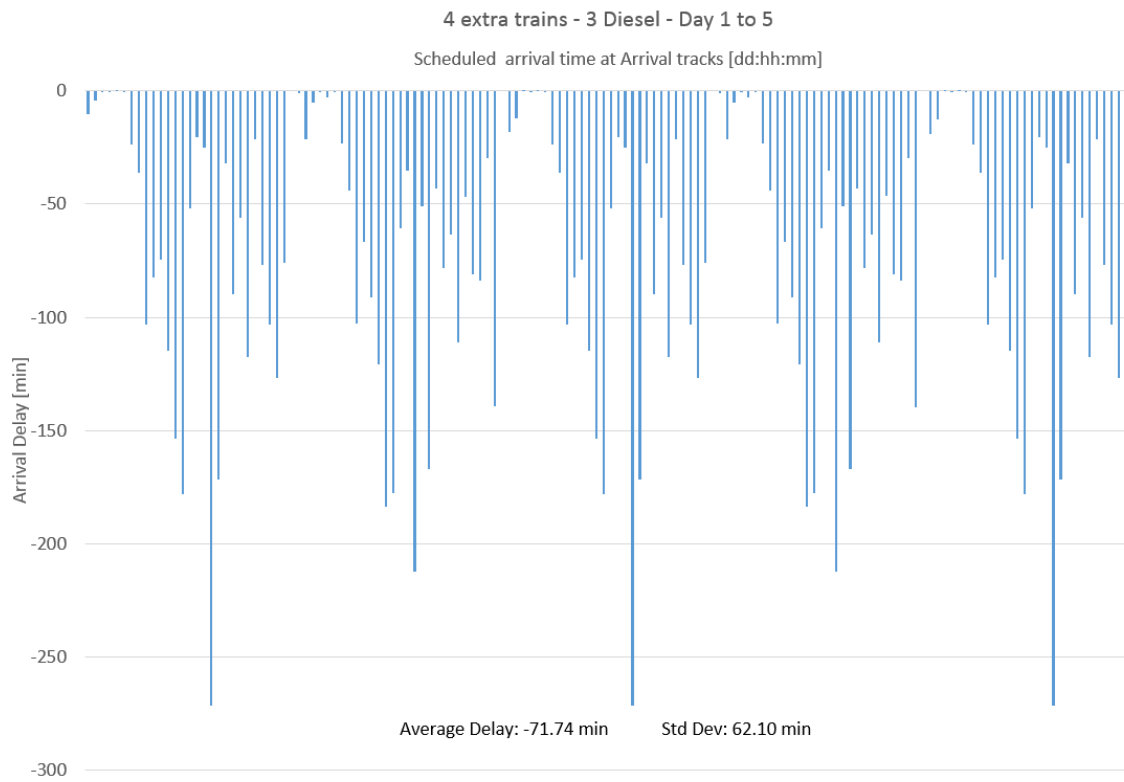
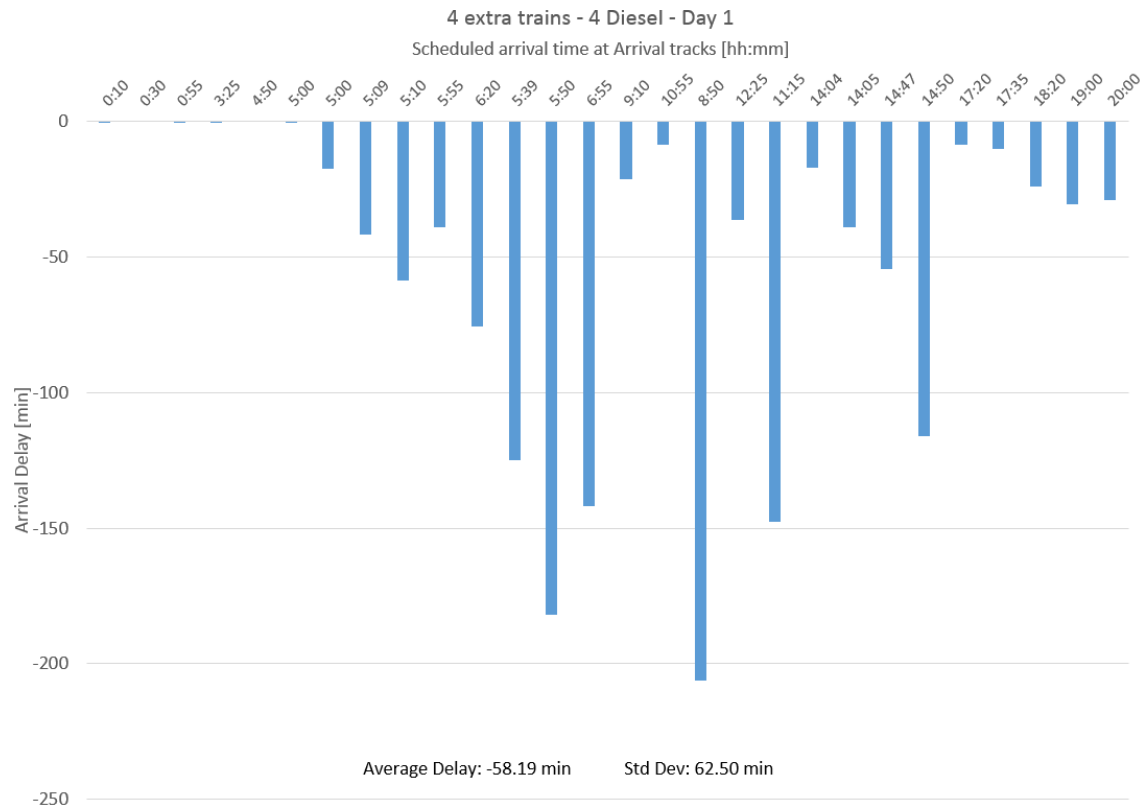**Figure A.11:** The model now work away the delay during the night as it does in the base model

Figure A.12: The model gains an additional diesel engine. The delay decrease goes from -71.74 min to -58.19 min and is now lower then the base model delay of -65.39 min.
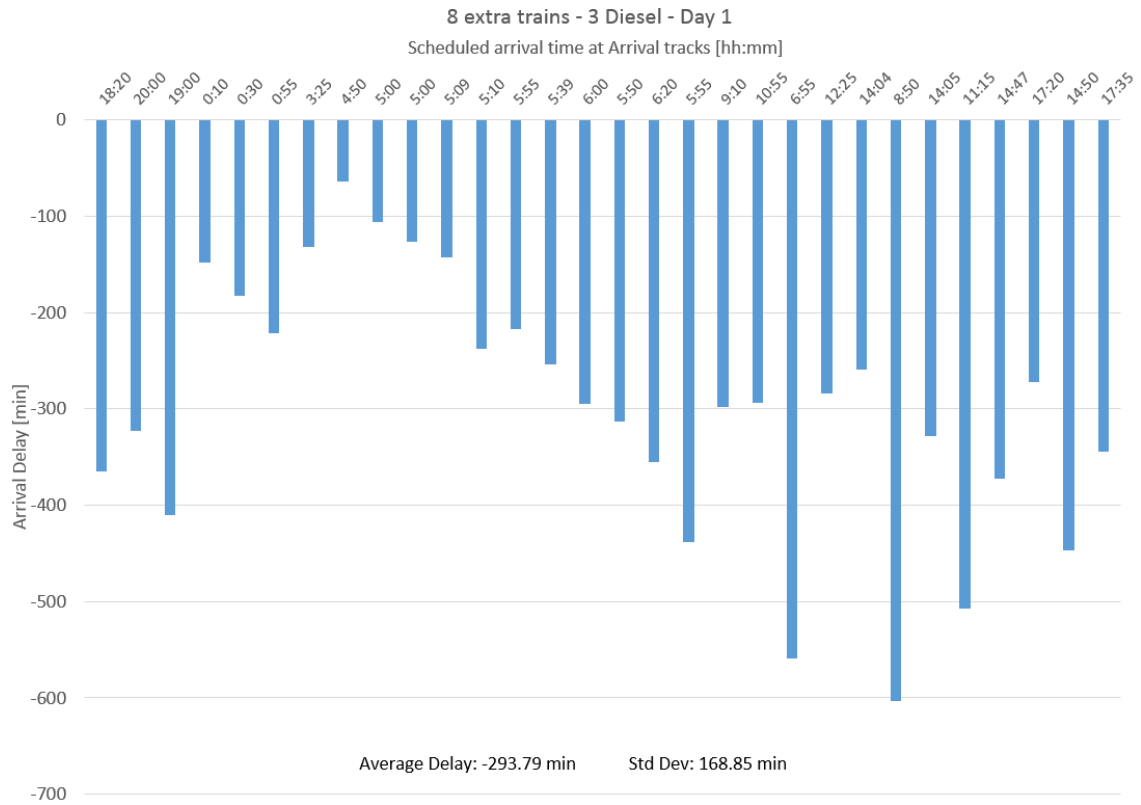
Figure A.13: The amount of trains increase up to 8 and the model reacts with increasing the delay severely. It looks much alike in comparison to figure A.8. Another diesel will be needed to decrease the delay
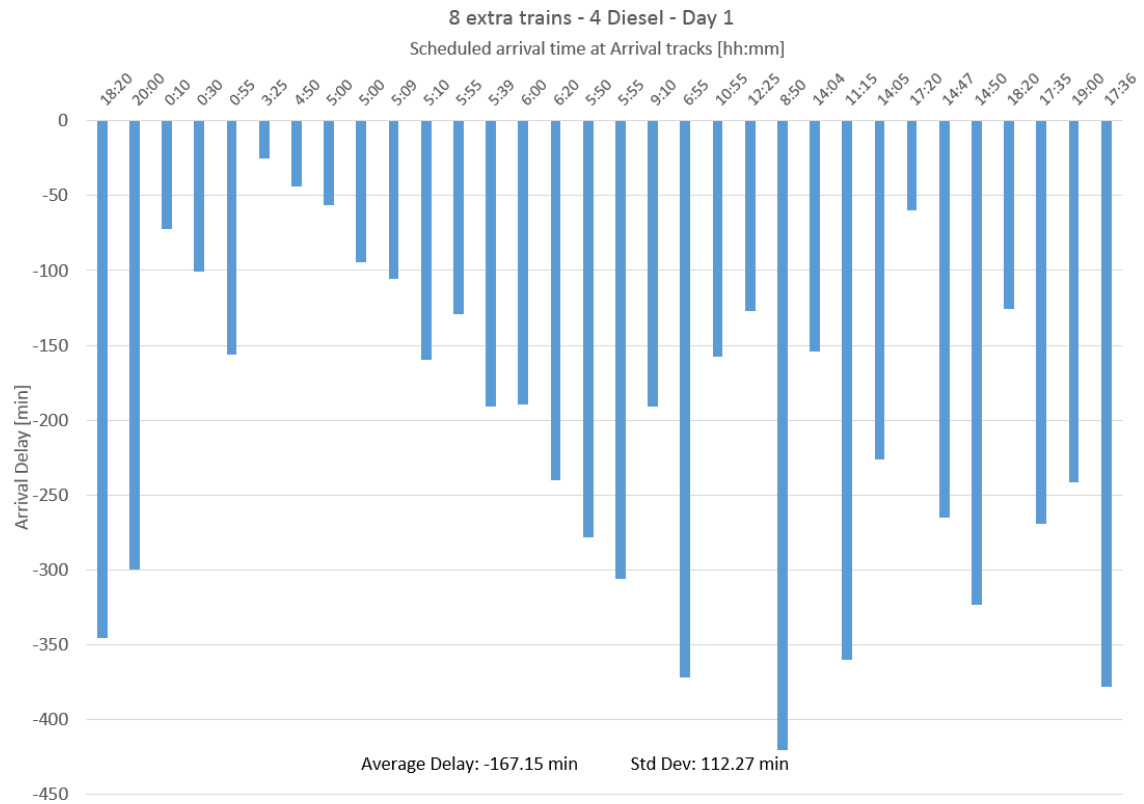
Figure A.14: An additional diesel is added. The model reacts by decreasing from -293.79 min to -167.15 min but is still far away from the base models delay of -65.39 min
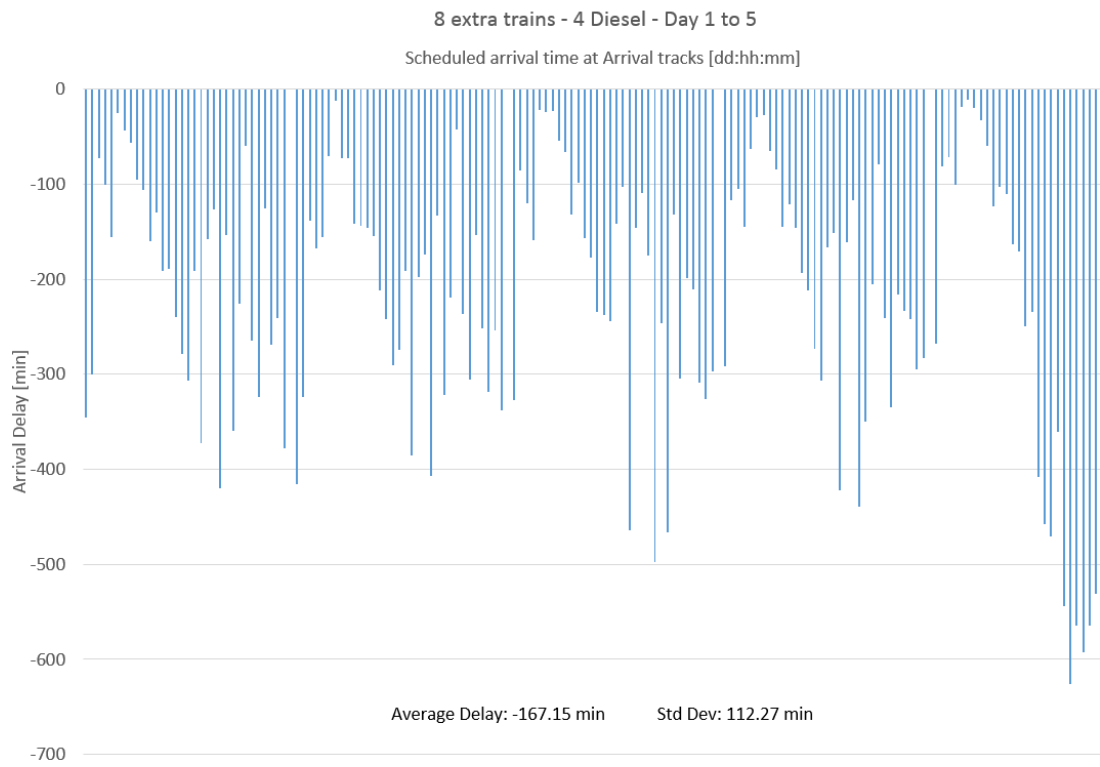
Figure A.15: The 5 days look stable with the a large spike on the last day.
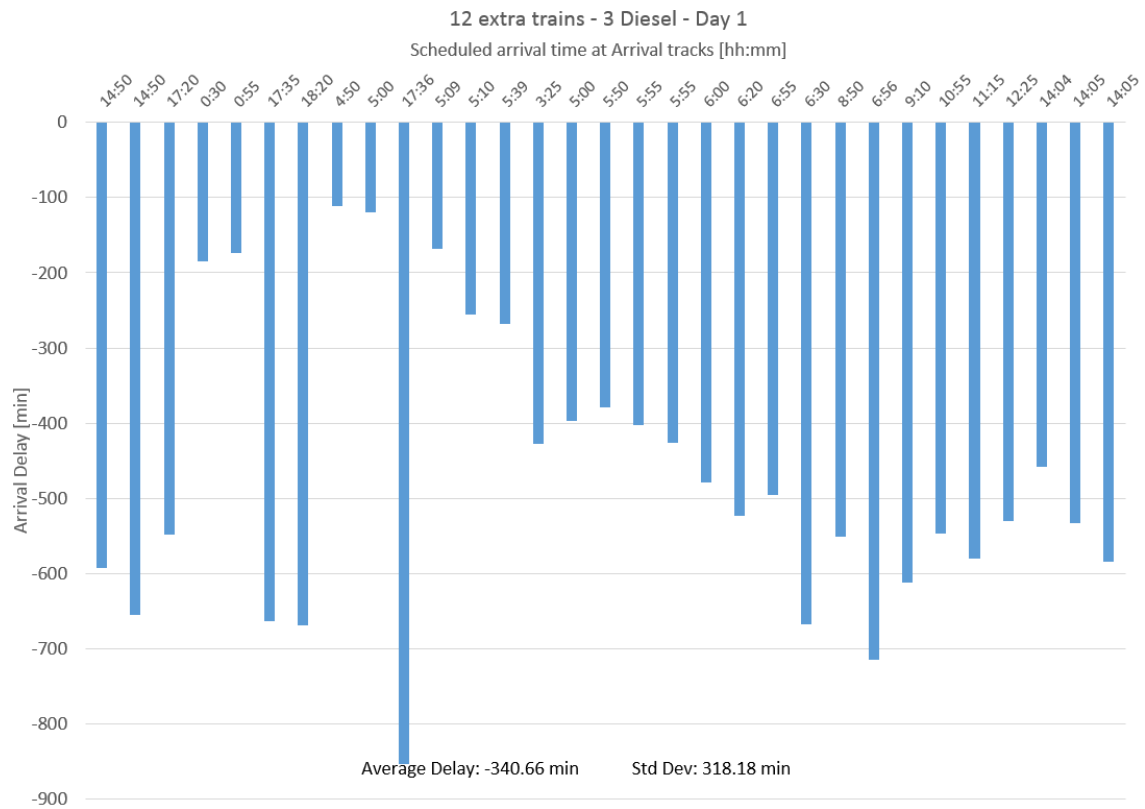
Figure A.16: The amount of trains increase up to 12 and the model reacts with increasing the delay severely and looks like figure A.13. As before the high delay forces some trains to enter in the following day.
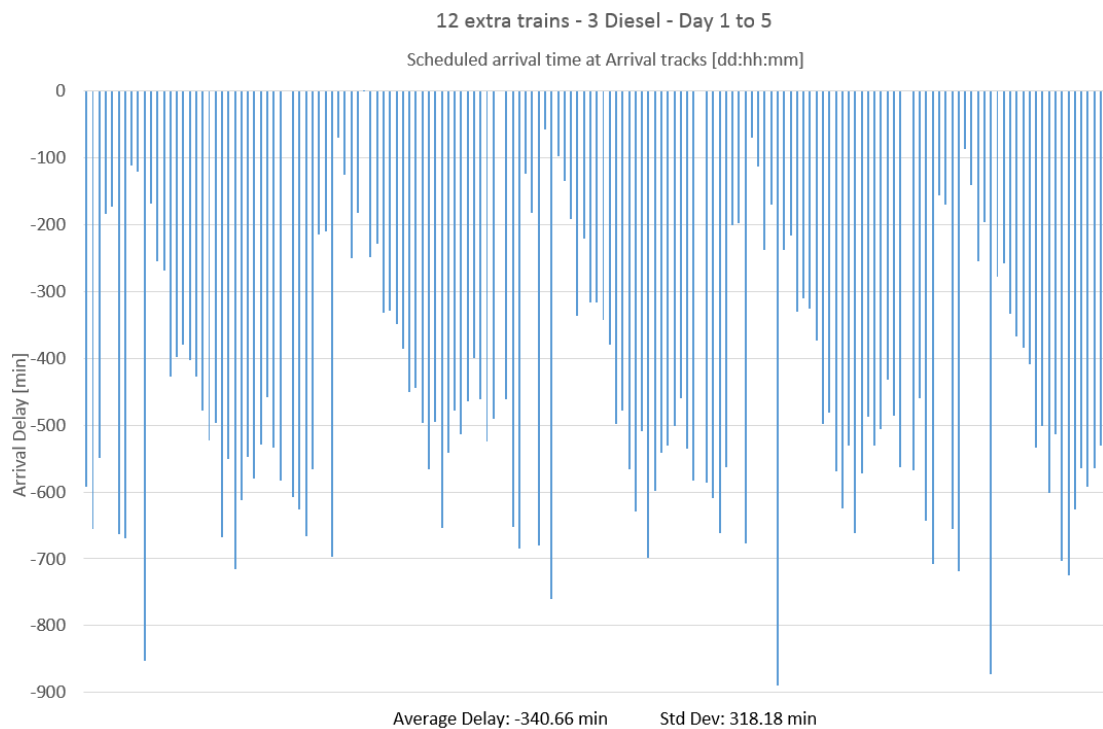
Figure A.17: The graph show a steady rise and decline between each day, but the delay is still a lot higher then the base model.

A.2.2   Electrify Harpan

At the time the trains have to switch engine from electric to diesel to be able to travel to the Harpan terminal. This takes time and can be avoided by providing electricity down to Harpan. This was simulated and the graphs below shows how the arrival time and throughput changes depending on the amount of trains added. The way of showing the graphs will follow the way as in the previous chapters with the exception of changes being only in the amount of extra trains.
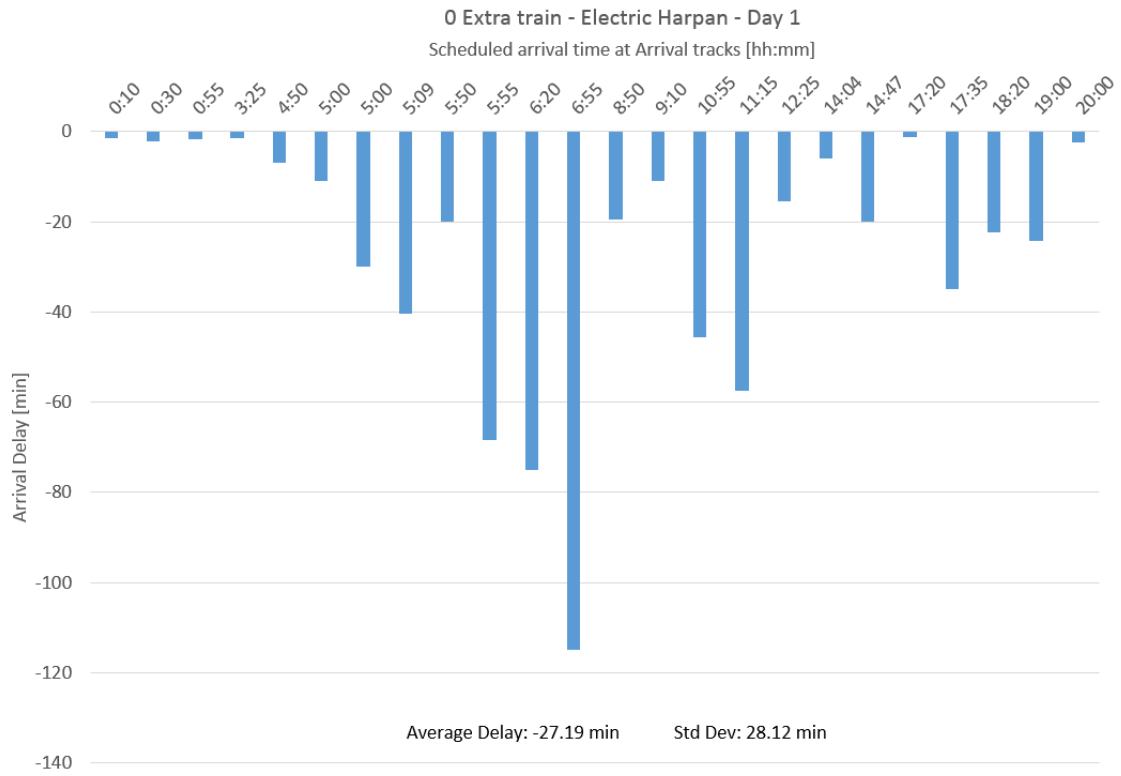
Figure A.18: The average delay is almost half of base models -65.93 min delay.
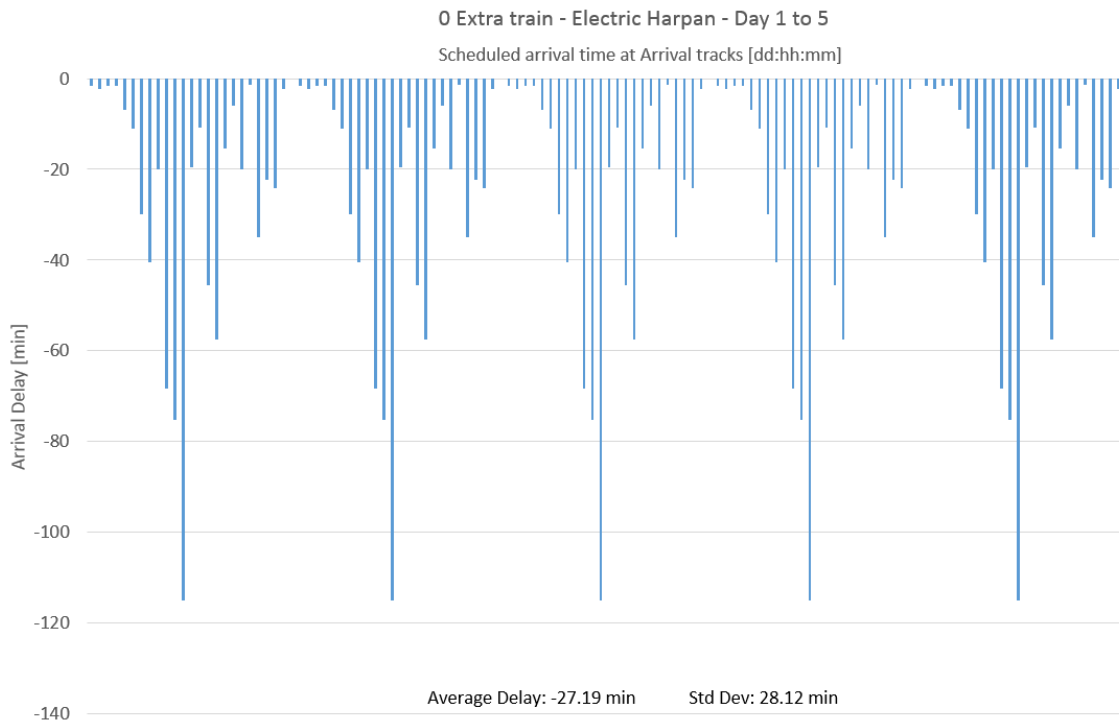

Figure A.19: Clearly shows that the model works down the delay during the nights
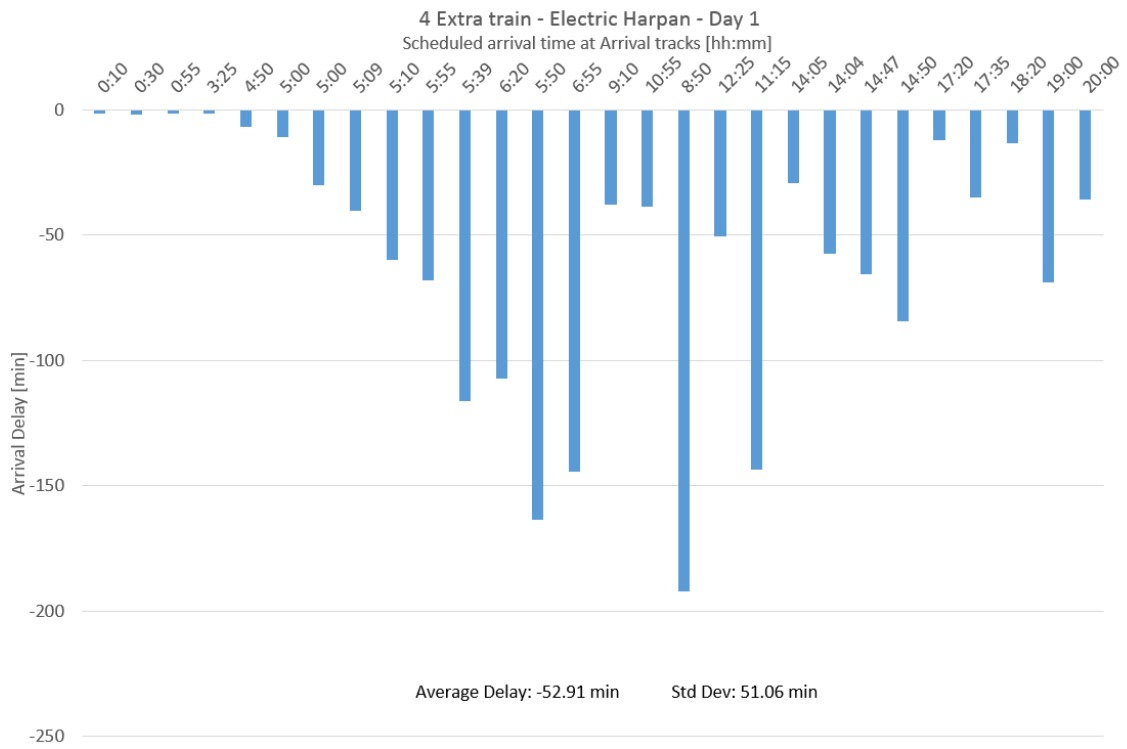
Figure A.20: 4 extra trains are added and this increases the delay from -27.19 min to -52.91 min but is still lower then base models delay of -65.39 min
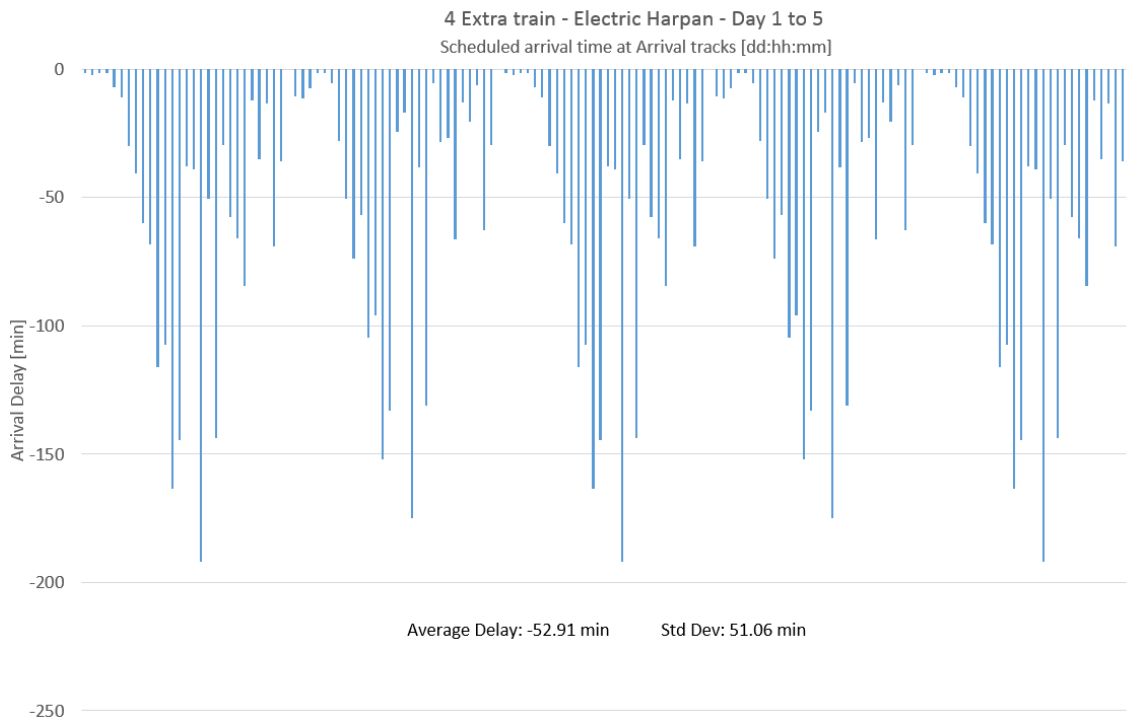

Figure A.21: Similar to A.19 that it works away the delay during the night
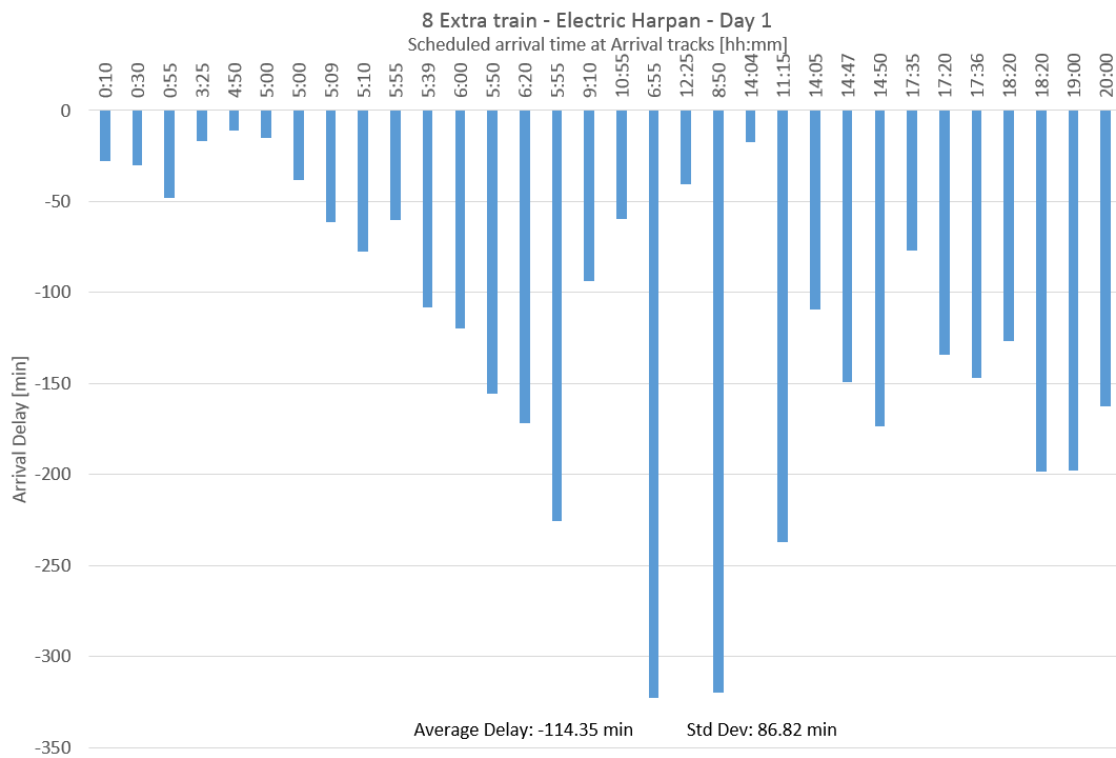
Figure A.22: 8 extra trains are added and this increases the delay from -52.91 min to -114.35 and is now higher then base models delay of -65.39 min
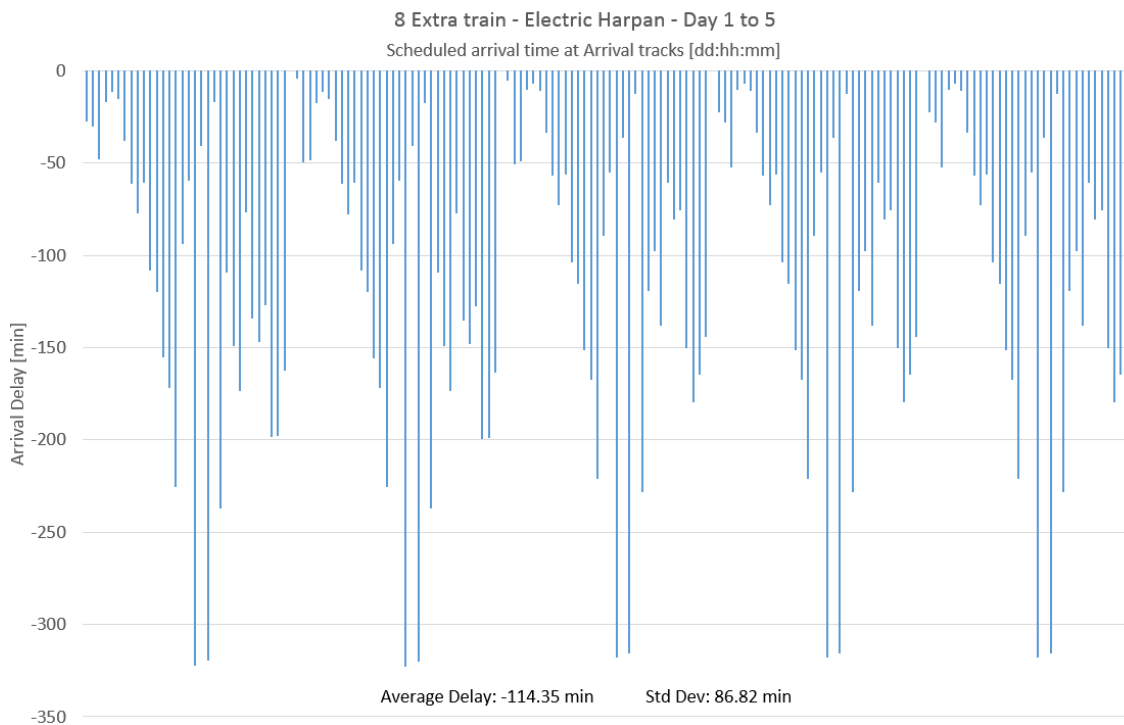

Figure A.23: The graph is starting to have high delays during the night as well which will in turn affect the next day, but it is at the moment under control.

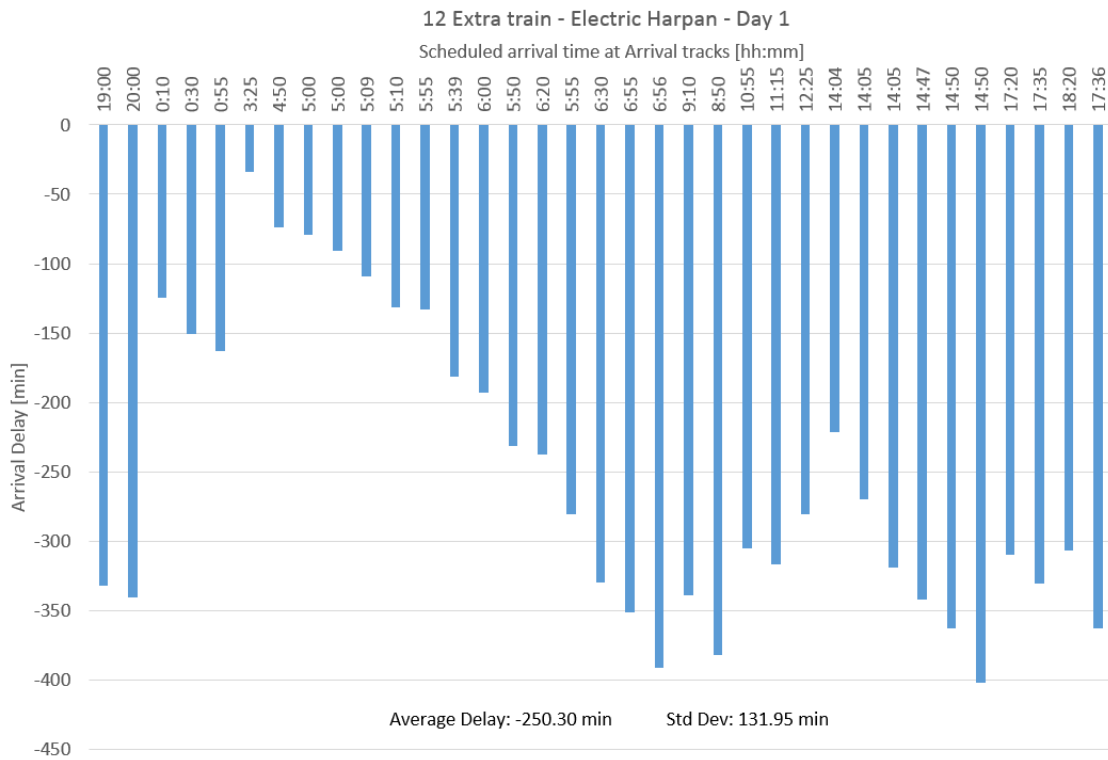**Figure A.24:** 12 extra trains are added and this increases the delay from -114.35 to -250.30 and is still higher then base models delay of -65.39 min. Some of the previous days trains are now arriving during the current day as can be see in the graph. This escalates the delay severely hence the jump from -114 min to -250 min
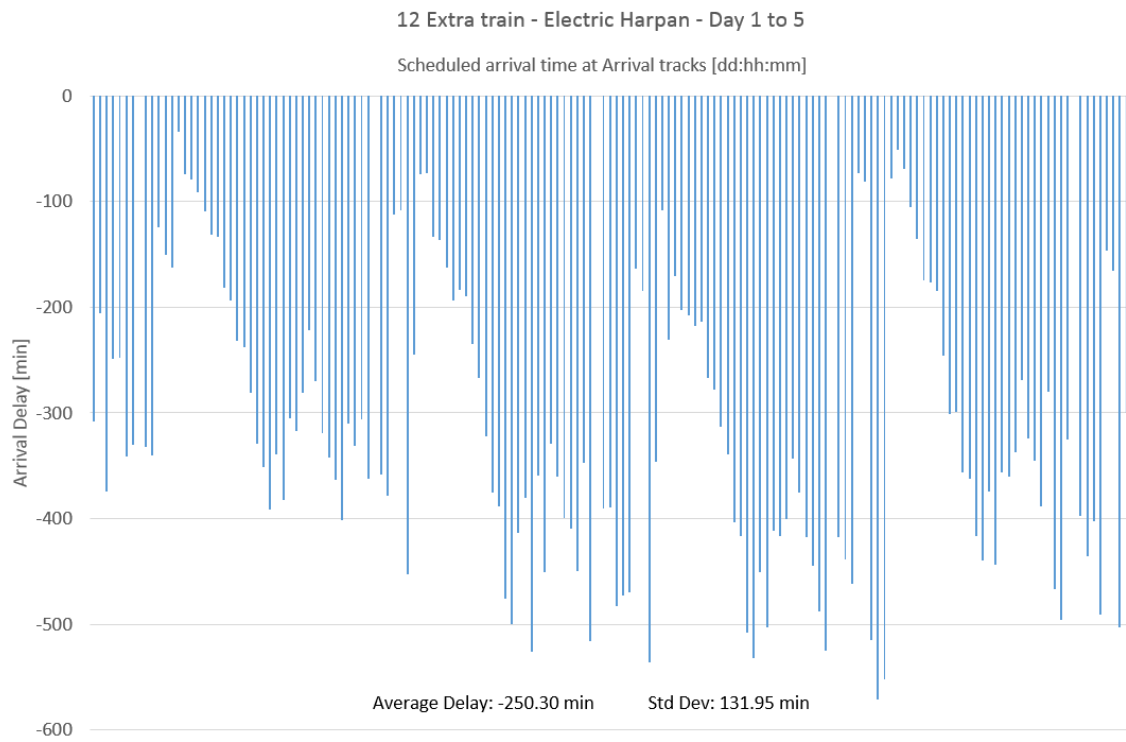
Figure A.25: The model is not able to work down the delay during the nights

B

Appendix 2

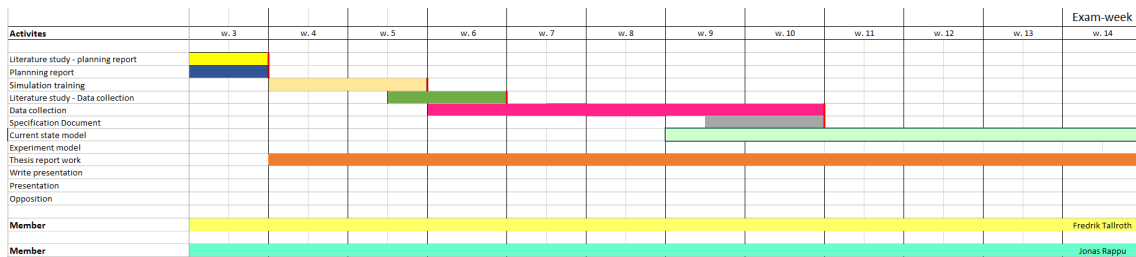## B.1   Time plan

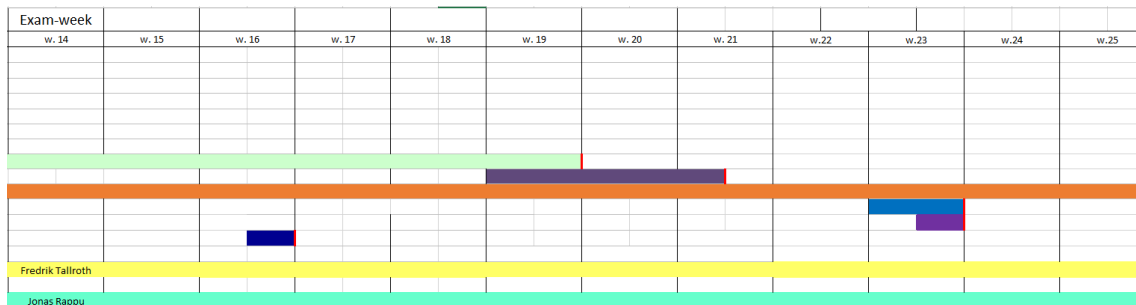**Figure B.1:** First part of the Gantt chart

Figure B.2: second part of the Gantt chart

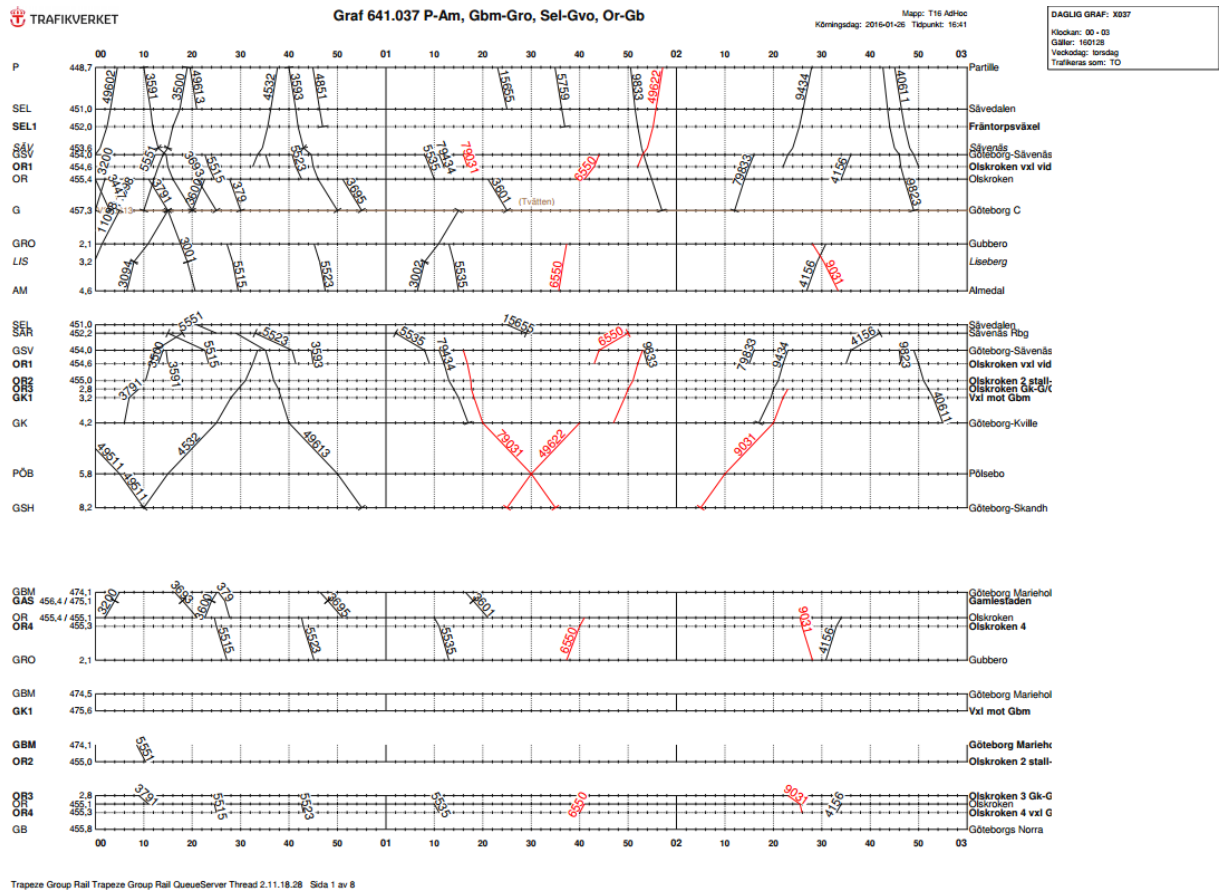## B.2 Train traffic timetable

Figure B.3: Example of a timetable between 00:00 and 03:00 [29]

C

Appendix 3 - Results

C.1 Conceptual model

The conceptual model worked as a translation document between the project members and the customer so the customer could agree or disagree with some information instead of going through our own notes that could be hard to understand for outsiders. Everything important in the model should be in the conceptual model

C.1.1 Data

This Data has been gathered with the help of employees at Gothenburg Port and Baneservice.

C.1.1.1 Train arrivals and departures

The information regarding trains that travels on the tracks from Kville train station to Gothenburg Skandia port (GSH) are collected by interviews [36] and is divided as following:

- 24 trains to GSH according to the schedual from Swedish Transportation Administration 2016-03-16
- 3 to Arendal daily.
- 2 to Torslanda daily.
- 1 to Preem/ST1 daily
- 3 to Energy port daily.

In the base model all container trains will include 32 carts with each being 20 meters long. Each loaded cart will assume to weigh 90 ton. This information is gathered from a pre-existed project [31].
Baneservice uses two diesel locomotive engines [36] and each diesel engine is manned by a driver and a switching operators. When switching tracks the switching operator is located at the end of the train to help the driver while backing. At the same time the operators communicate with the help of radios.

C.1.1.2 Operations in GSH

The operations carried out by Baneservice is listed below. The times given are the times used by Baneservice while making their schedules. The operations might be

faster or slower depending on disturbances. After a train arrives, Baneservice performs the following operations:

- Arrival inspection – 30 min
- Slotting – 20 min
- Loading/unloading – 1 Hour
- Slotting – 20 min
- Departure inspection and break test – 30 min

In the model, inspections will be implemented as the diesel engine and driver are waiting for the given time. During the loading phase, the train will be standing in the terminal for its scheduled time. When the train is loaded, a signal will be sent that the train is ready and loaded.

The slotting operation starts with the engine pumping air into the train's brake system, this takes around 5 minutes according to an earlier simulation project at Gothenburg Port. Next, the engine driver calls Trafikverket och asks for a path to be set to the trains terminal. The driver then follows the signals to the terminal. In the terminals, all Shunting are made manually by the Shunting operator. The engine operator's follows a schedule. If disturbances, e.g late/early arrivals, occurs, the schedule might change during the day. These changes are coordinated by a coordinator at Baneservice that oversees the operations.

C.1.1.3   Speed limits and acceleration

The different tracks have speed limits as follows:

- Within rail yards: 20 km/h
- At track between Kville and GSH: 40 km/h
- At industry tracks: 10 km/h

In the model, the engines will have the following accelerations to get the the speed limit.
(Calculated from $F = ma$, were F is from the engine information table C.1. F is from when $v = 10m/s$ and 5 m/s).

- 40 km/h
    - Electric engine unloaded: 1.925 m/s^2
    - Electric engine loaded: 0.080 m/s^2
- 20 km/h
    - Electric engine unloaded: 2.041 m/s^2
    - Electric engine loaded: 0.0851 m/s^2
- 10 km/h
    - Electric engine unloaded: 2.375 m/s^2
    - Electric engine loaded: 0.098 m/s^2

Table C.1: Engine information [31]

Unit	VO (m/s)	Tractive effort (kN)	Unit	VO (m/s)	Tractive effort (kN)
Electric Engine	5	245	Diesel	5	330
Electric Engine	10	231	Diesel	10	300
Electric Engine	15	206	Diesel	15	240
Electric Engine	20	181	Diesel	20	181
Electric Engine	25	140	Diesel	25	140
Electric Engine	30	115	Diesel	30	115
Electric Engine	35	93	Diesel	35	93
Electric Engine	50	93	Diesel	50	93

C.1.1.4   Track ability

The ability of the tracks in GSH is based on interviews Baneservice and Management at Port of Gothenburg

- Track 6 is used to slot trains into the different terminals
- Track 13 and 15 are used for parking of electric engines
- Track 1-4 is where arriving trains wait after arrival. Track 1 or 2 is left clear so that trains can depart at all times. Track 1 and 2 are divided into two parts (1A, 1B, 2A and 2B) so that 2 trains can wait on each of these tracks.
- Track 31-35 are where trains wait before departure.
- Kajspår 61 is used to park the diesel engines. The engines are also filled up with diesel here.
- Kajspår 63 is what is called "Harpan". This terminal has 6 tracks. Since the trains are longer than these tracks, the train is divided onto two of the tracks during the loading phase. Other "kajspår" are terminals.
- Kajspår 66 is sometimes referred to as kajspår 71.
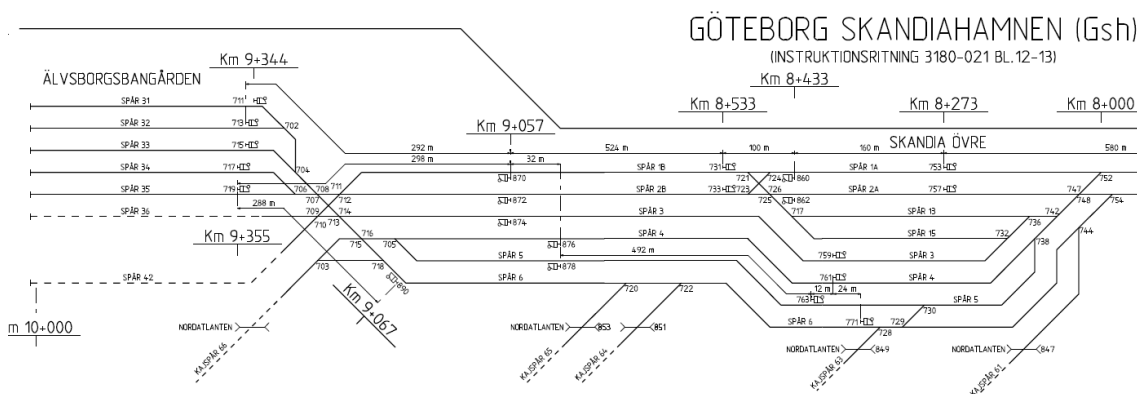- Other tracks will be used as needed by the trains to navigate through the port

Figure C.1: Picture of Scandia port [29].

C.1.2 Train controls

The model will be built to mimic the real control systems as close as possible. To move with any engine or train, the driver must first contact 'trafikverket' and request a path to the target location. Once that is done, the path to be travelled is booked by the train, and no other trains can access any rail on that path. Each track is unblocked when the last segment of the train leaves the track.

The driver gets a destination. The driver saves all the blocks that are on the way to that destination in a blocklist. The driver books all these blocks and zones. The zones still has to be booked as they are unbooked as each zone is released. The unbooking of zones is done in the block released function.

The function "F_getLocationList" will be called with the train name and current job. The function returns a list of control points that the train will travel to in order to reach its final destination.

C.1.2.1 Arriving driver procedure

If the end destination is in Scandia port then
1. Choose track at kville
2. Travel to end of that track
3. Travel to cp before pölsebo
4. Choose track at Pölsebo
5. Travel to end of that track
6. Choose arrival track for parking
7. Travel to that track
8. Detach electric engine
9. Travel to electric engine parking

If destination is not Scandia then
1. Choose track at kville
2. Travel to end of that track
3. Travel to cp before pölsebo
4. Choose track at Pölsebo
5. Travel to end of that track
6. Choose track towards chosen location
7. Travel to end of that track
8. Put on queue until departure

C.1.2.2 Slotting TO terminal driver procedure

1. Attach diesel engine
2. Arrival Inspection
3. Travel to turning CP
4. Travel to terminal
   (a) If needed split the train

    (b) Travel to second track in terminal

5. Detach Engine
6. Wait for new job

C.1.2.3   Slotting FROM terminal driver procedure

1. Attach diesel engine
2. Pump up breaks
3. Choose departure track
4. Travel to turning point
5. Travel to departure track
6. Departure inspection and break test
7. Detach engine
8. Look for new job

C.1.2.4   Train departure driver procedure

1. Choose arriving track to travel through
2. Travel to end of that track
3. Travel to before pölsebo
4. Choose track at pölsebo
5. Travel to end of that track
6. Travel to exit point

C.1.3   Interface

C.1.3.1   Input

- Train Schedule
- Train data (Length and type of each train)
- Physical variables (speed, accelerations, weights etc)
- Disturbances and failures, breakdowns etc
- Operation cycle times (inspection, loading/unloading, fika-break, etc)
- Model control inputs
  - Electric going to harpan ON/OFF
  - Number of diesel engines in operation
  - Number of extra trains to be included in schedule

C.1.3.2   Output

- Number of trains processed
- Average time from train arriving to GSH to train departing.
- Difference between train arrival time and trains scheduled arrival time

C.1.4   Structure and standards for coding

To make sure that the model will be easy to understand for other users than the authors of the model, certain standards will be followed as to how the code is structured.

C.1.4.1   Entity names

All naming of variables, attributes entities etc that are not covered here are to be named according to AutoMod standards, for example a process is named as P_processName.

Variables have the prefix VX, where X is the variable type. Attributes use the same system with the prefix AX. The types are abbreviated as follows.

String	S
Integer	I
Real number	R
File pointer	Fptr
Load pointer	Lptr

Path mover entities shall be named as follows

Path mover path	pathX, X1, 2, 3, ...
Path Mover Control Point	CP_controlPointName
Vehicle segment	VehSeg_segmentName
Vehicle	Veh_vehicleName

C.1.4.2   Green text and indentations

All code shall be coded with green text to such an extent that someone who only has access to this document and the code can understand how the model works. Processes, functions, sub functions, etc shall always be thoroughly described by green text.

Indentations shall be used to enhance the readability of any code.

C.1.5   Performance measurements

What to measure is decided from interviews with management at Port of Gothenburg [38] [37]. Amount of trains being processed (and carts) Average time cycle in Skandia port (arrival to departure)

XXX