CREW MANAGEMENT WITHIN SOUTH AFRICAN FREIGHT RAIL

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A research report submitted to the Faculty of Engineering and the Built Environment, University of the Witwatersrand, Johannesburg, in partial fulfilment of the requirements for the degree of Master of Science in Engineering.

Johannesburg, 2015

DECLARATION

I declare that this research report is my own unaided work. It is being submitted for the Degree of Master of Science to the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination to any other University.

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Rohini Shookan

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ABSTRACT

Optimisation of resource allocation is a common problem in any operational environment. This research project aims to investigate an alternative method of matching train drivers or crew to trains. Traditionally, crew are matched to trains based on defined train schedules, however this research project tested the impact of a heuristic that matches crew to trains based on random train departures. The impact is measured on the number of successful train crew combinations and the number of loads delivered.

Transnet Freight Rail Natal corridor will be used to understand rail operations and crew scheduling to develop a simulation model that increases crew coverage for random train departures. Currently, trains do not depart on schedule and there is significant variability between the train plan and the actual train departures. This is due to many factors that include, but are not limited to infrastructure and rolling stock failures, resulting in misalignment between actual train arrival/departure times and the crew schedules. The impact of such misalignments could lead to any of the following, overtime incurred by crew, trains wait for relief crew to arrive or train cancellations.

A simulation model is used to test a proposed future situation in which crew are matched to trains without the use of a schedule or train plan, as previous researchers have done. The model was developed with an embedded heuristic to improve crew coverage over 24 hours. The simulation illustrated an improvement in the number of successful train crew combinations and the number of loads delivered, while reducing variability of crew waiting times and overtime. These findings could contribute to efficiency improvements for the train system and increase asset utilisation.

DEDICATION

To my family who supported me through a difficult period and to a very special person who contributed greatly to the person I am today.

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The author would like to acknowledge the technical support and training provided by the Anylogic technical team.

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CTC	- Central Train Control
DBN	- Durban
ERP	- Enterprise Resource Planning
FIFO	- First in, First out
ITP	- Integrated Train Plan
KPI	- Key Performance Indicator
MTV	- Reference for a name of a station
NCS	- Newcastle
SOC	- State-owned Company
TFR	- Transnet Freight Rail

1 INTRODUCTION

1.1 Background to the Problem

This research project aimed to develop a simulation model to test whether a personnel scheduling method for freight rail is workable. In order to understand train operations and crew secluding within freight rail the Natal Corridor between Newcastle (NCS) and Durban (DBN) was used as a case study. Data and information on current operations on the Natal Corridor was sourced to assist with the development of the simulation model.

Research published on Transnet Freight Rail (TFR) or operations of South African freight rail was not located; hence, internal company documents were used to provide background information and context. Internal company documents include reports commissioned from consulting firms. TFR is one of the biggest players in the South African logistics chain and provides a competitive business service to the country as a state-owned company (SOC). It is a strategic tool used to provide network infrastructure to ensure security of supply in supporting the growth of the South African general economic activity (Transnet, 2012).

TFR transports freight via rail, for domestic and export consumption. It is an effective method to transport high volumes of commodities and goods over long distances. Pre-1990, there was a period of suspended investment. The maintenance regime was reactive, which resulted in reduced reliability of the infrastructure and rolling stock. In 2005, TFR started on a journey to deliver freight reliably by focusing on improving strategic, organisational and operational aspects of the business (Transnet, 2012).

Operational improvements focused on enhancement of train movement planning, asset balancing and increasing the mechanical reliability of rolling stock and infrastructure to run a scheduled railway. Balance refers to optimising asset availability by ensuring that the assets are in the appropriate positions in the system. This would enable optimum arrival and departure rates without a bunching of assets in one location or a shortage in another. The mechanical reliability of assets was addressed in two ways. The first was to implement proactive maintenance of assets and infrastructure and the second was to plan and execute the movement of trains around planned maintenance areas on the railway lines. This would reduce the number of train delays in the system. The aim was to run a scheduled railway whereby trains would arrive and depart according to a published schedule. The objective was to generate the maximum revenue through the optimisation of TFR's existing asset base before increasing the capacity through expansion projects (Transnet, 2012).

TFR commissioned work from consulting companies to conduct diagnostics on the system and define initiatives to implement a scheduled railway. The required outcome of the diagnostics was to identify and prioritise initiatives to run a scheduled railway. The basic elements of a train system excluding the loading and off-loading sites are detailed in Figure 1.1.

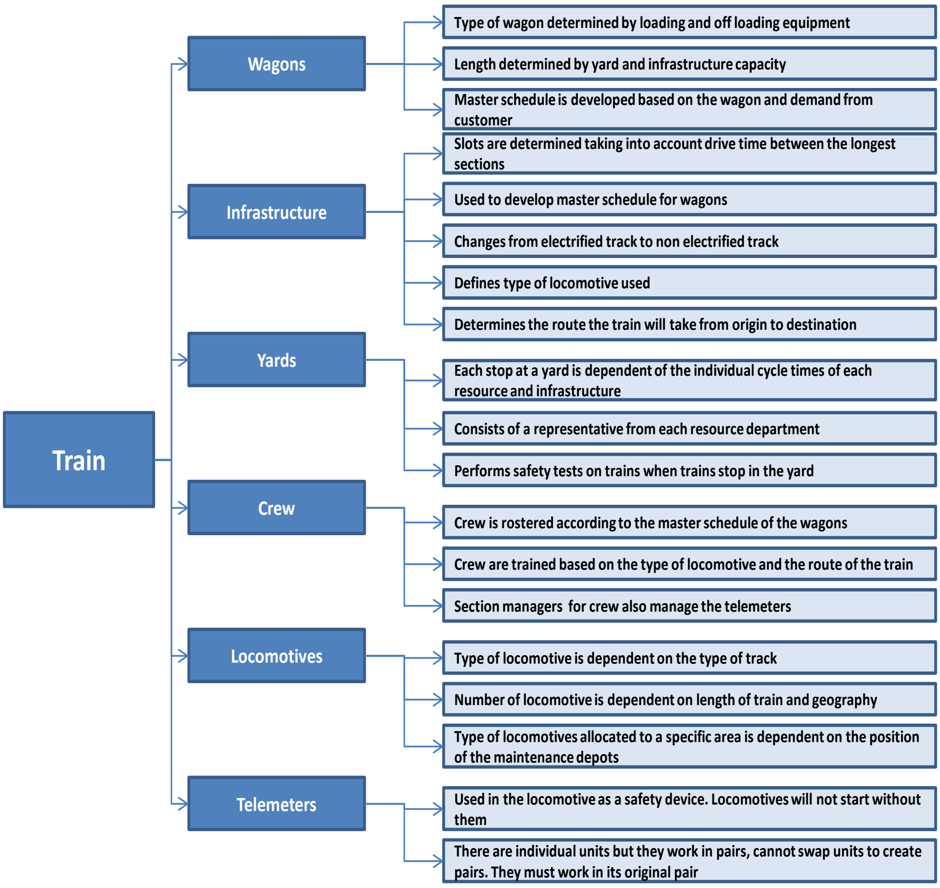

Figure 1.1 Elements of a train system

It is a complex and interdependent system whereby each element (as indicated in Figure 1.1) influences the system and train cycle time. Information contained in this section pertains to the company and is based on findings across multiple corridors.

Because of the reduced reliability of the assets (as mentioned above) including the infrastructure, trains are prevented from operating according to a schedule. TFR must take the time to clear the affected site to repair or replace the asset. The time taken to do this affects all trains in the system. Trains in other parts of the system have to be parked or staged in yards to avoid a traffic jam on a section of the system.

The diagnostic exercise enabled the consulting team to design interventions to improve reliability of the system in an attempt to run trains using a schedule. These interventions had limited success because improvement in the reliability of the rolling stock and infrastructure was difficult to achieve. These assets needed to be replaced. Key insights from diagnostics conducted by Letsema Business Consulting and McKinsey and Company indicate that it is currently not possible for TFR to run a scheduled railway (Letsema, 2008; 2009a; 2009b). The misalignment between planning to run a scheduled railway and running an unscheduled railway has major negative implications for resource allocation. The misalignment between the train plan and resource allocation with respect to train drivers/crew is discussed throughout this document. Some of the factors that contribute to TFR not being able to run a scheduled railway are grouped into the following categories; planning, train movement or execution, and resources (Letsema, 2008; 2009a; 2009b).

1.1.1 Planning

Planning the movement of trains is a complex process. The plan was mostly used to establish the quantum of saleable capacity to the customer and for monitoring and reporting purposes on volumes delivered. The actual volumes railed would be compared to the planned volumes in arrears. The process starts with the customer’s estimated annual tonnage. The annual tonnage is the volume customers intend to transport via rail, e.g. coal. The railway is a time-shared resource that is divided into time slots. The time slots are defined based on the amount of time a train takes to drive through the longest section between two train yards. Train yards are points in the train system that is used to change resources, conduct safety checks and change routes. Once the tonnage is confirmed, the number of required train slots is calculated and assigned to the respective commodity. The requirement for resources such as wagons, locomotives and crew are calculated and assigned to transport the commodity. The plan is refined over different time horizons to ensure that it is realistic. The long-, medium- and short-term plans that are put in place are further described below:

- *Long-term plan (over multiple years):* An Integrated Train Plan (ITP) or service design is created to transport commodities between origin and destination points. Customers are charged per ton based on the assets and infrastructure assigned to transport the commodity. The ITP therefore consists of committed train slots per commodity (Transnet, 2006);
- *Medium-term plan (Annual):* The long-term ITP is amended based on the adjusted annual customer demand. For increased demand, additional trains need to be added to the ITP. For decreased demand, trains are rendered inactive on the ITP. (Transnet, 2006); and
- *Short-term plan (Weekly):* The annual demand is reduced to the customer's weekly demand based on the service design. Through weekly engagements with the customer, the customer's actual demand for the week is then validated against the service design. The total number of trains on a weekly basis can be adjusted based on cancellations and other deviations that may affect the ITP or plan (Transnet, 2006).

The processes to develop a weekly plan, i.e. to first develop a long-term plan and then to refine it over different time horizons is reasonable (Letsema, 2009b). However, there are three key challenges experienced with the planning process.

First, the ITP is not created considering the arrival and departure rates per yard, which results in inaccurate yard processing capacity. The train arrival and departure rates refer to the time intervals that trains either arrive at or depart from a yard. At times, trains arrive at the same time resulting in trains waiting in a queue to enter the yard. Yard capacity can either be under- or overestimated. In the case of TFR yard capacity is more often overestimated thus increasing delays in train cycle times. The train cycle times are understood to be the total time taken by a set of wagons to travel from the origin point to the destination for off-loading and back to the origin point for reloading. The yard processing capacity is determined by the number of staging lines available and the number of hours it takes to process a train; the fewer the lines or the longer the train processing time per train, the lower the capacity. Staging lines are used to park wagons while en route to its destination. The capacity of a staging line is determined by the amount of time it is occupied by a train while it is being processed. Train processing comprises activities that include, but are not limited to safety checks.

Second, the train plan is the sum of all of the time taken to move the individual trains from their origin to their destination and back again, without considering integration with train plans of other commodities entering the same yard. These result in yards becoming blocked and increasing delays in train cycle times.

Third, weekly plans are created with the assumption that assets are reset to their positions of origin as per the ITP; however, the locomotives and wagons are physically located at different points along the route between the origin and destination points as defined on the train plan. Trains do not operate according to schedule when departing from the loading or off-loading points while accumulating time delays as they get closer to their destination points (Letsema, 2009b).

To the knowledge of the author, none of the abovementioned has been addressed in the past. However, there are plans in place to create a software package to automate the design of train plans considering some of the abovementioned challenges.

1.1.2 Train movement or execution

Once the plan is finalised, it then needs to be executed. The execution stage is divided into two major steps, yard processing and trains travelling between yards or en route to the next yard:

- *Yard processing*: Depending where in the system a set of wagons is positioned, the processing steps differ. These activities influence the amount of time a train spends in the yard. The last step is to crew a train or to match a train driver to a train. This step will be the focus of this research.

- Various types of yard processing activities take place (Transnet, 2006). For example:

  - Major yard processing activities occur in yards while en route between origin (loading) and destination (off-loading) points. They include but are not limited to locomotive change over, safety inspections and crew changes (Transnet, 2006). In a yard where loading and off-loading of wagons take place, a standard number of wagons are coupled together (e.g. 50). These activities i.e. loading, off-loading and coupling of wagons are classified as major yard processing activities because of the time and complexity involved (Transnet, 2006).

  - Minor yard processing activities occur in yards while en route between origin (loading) and destination (off-loading) points. These may include crew changes (Transnet, 2006).

- *Travelling en route:* Trains travel on the rail line between yards, and these train movements are controlled and co-ordinated using a signalling system. The Central Train Control (CTC) department monitors and manages the system to ensure that there are no collisions or accidents while en route. They notify the drivers whether they can enter or must stop before entering a section of the railway line by changing the signal colour to green or red respectively (Transnet, 2006).

During the implementation or execution of the train plan, further challenges are experienced. First, the ITP is misaligned with the actual asset positions causing difficulty in the implementation of the plan and the assignment of resources. Second, the poor integration and visibility of the position of the empty or loaded wagons between the origin and destination points inhibits the ability to effectively reprioritise and reschedule trains across the supply chain. This is due to poor monitoring and tracking of the asset positions (Letsema, 2008, 2009b).

1.1.3 Resources

Resources are broadly defined to not only include the physical asset base e.g. locomotives, infrastructure and railway lines used to execute a train plan, it also includes the personnel. Prior to 1990, there was a period of suspended capital investment where little to no investment was made in the procurement of new assets for replacement purposes or preventative maintenance schemes. At the time there was no need for expansion as there was sufficient capacity available. This led to two issues that negatively influence the implementation of the train plan. These are listed below:

- *Reliability of assets and infrastructure*: Frequent breakdown incidents of the aged assets and the infrastructure. This increases delays on train cycle times and reduces asset availability (Letsema, 2008; 2009a; 2009b); and
- *Capacity*: There is insufficient capacity to deliver customer volumes, create buffer capacity at the planning phase and cater for deviations in the system during execution (Transnet, 2006).

The reliability and capacity challenges due to the physical assets and infrastructure has had a negative ‘knock on’ effect on the capacity scheduling of personnel.

A pilot study was conducted at Transnet in 2011 to investigate reasons why train crews were not meeting expectations. The resource manager was based in Steelpoort yard at the time and is the person interviewed for this research project. The pilot study interview, detailed in Appendix A, took place on 23 August 2011; and the transcript of the interview for this study took place on 29 November 2013 and is attached as Appendix B.

The resource manager was requested to provide an explanation of the current crew scheduling methods. There are two methods, namely The Diagram and First in First out (FIFO) method. Both methods assume that the train will arrive and depart on time as per the schedule. There is, however, no policy document or procedure within TFR to determine where to implement either of the crew scheduling methods. The available crew capacity is calculated over a month for both crew scheduling methods. The capacity considers the shift structure whereby each crew member will be available for three consecutive day shifts, three consecutive night shifts and three days off, with a mandatory rest period of 12 hours between shifts. The capacity is validated against the number of trains planned to arrive and depart from the yard for that month. If there is a shortfall, the requirement for standby crew is forecasted (Appendix A, Appendix B).

With respect to the diagram method, once the overall capacity is confirmed, the crew roster is created. The crew roster is created for the month by assigning individual crew members to specific trains based on when they are available. Their availability is determined by forecasting the crew shift cycles for day shift, night shift and days off. There have been instances of no coverage in terms of crew availability because crew scheduling and rosters have been created based on the ITP. The yards are either over or under-capacitated on the day because planned trains may not arrive on time and will instead arrive a day later which would increase the demand for crew for the next day (Appendix A, Appendix B, Letsema, 2008, 2009a, 2009b).

In respect of the FIFO method, the crew roster is created for a period of a week. A forecast is created to establish when each crew member will arrive back in the yard after returning from a trip. A queue will then be created based on the principle that if a crew member arrives from a trip first in the yard, they will be the first to depart on a train during their next shift. This creates a lot of complexity because of the mandatory rest period of 12 hours for a normal shift and 16 hours if the crew worked overtime. There have been instances where there has been no coverage in terms of crew availability as all standby crew would have been used. This crew scheduling and rostering method attempts to address key issues associated with the variability in the system by rostering crew closer to the time that trains actually arrive and depart (Appendix A, Appendix B, Letsema, 2008, 2009a, 2009b).

During the interview, the resource manager was requested to provide detail on the crew behaviour in respect to their presence, behavioural aspects such as willingness to work and their competence.

The crew presence refers to whether the crew are available on time in the yard as per their shift schedule. Crew presence excludes factors such as scheduled leave, training, and sick leave. The data used to calculate daily and weekly crew capacity is recorded and maintained. The aspect of crew presence that is not recorded is whether or not the crew arrived in the yard on time as per their shift schedule. One of the reasons why this data is not recorded is because if the crew is late, stand by crew is used, and the original crew are used to drive other trains.

The behaviour of train drivers is affected by their willingness to work. There are instances whereby train drivers become unwilling to work and fabricate reasons on why they cannot work. One example of this is when a train driver logs a fault on the locomotive when, in fact, it is functioning. The impact of logging a fault like this is that Transnet is obligated to take the time to investigate the fault for safety reasons and remedy it. By the time this process is completed and the finding is that there was no fault the drivers shift has ended. The data on driver behaviour however, is not recorded to identify problems and resolve them accordingly. One of the reasons for not recording the data as indicated by the resource manager is that the company was undergoing a restructuring exercise and the staffing position required to capture the data had not been finalised in the organisational structure. He indicated that there was an intention to start recording the data as it would improve crew performance in the system and contribute to the reliability of the train arrival and departure times.

Driver competence is tracked by TFR, who record all incidents related to a driver's competence. This internal report details the incident, the root cause and the disciplinary action taken against the train driver. These incidents can happen in the yard or while driving en-route to another yard.

Crew presence, their willingness to work and their competence, are known to delay train arrivals and departures. The three factors are not quantified in terms of cycle time losses, deviation from schedule or other applicable measures.

There is a longer-term plan to increase crew capacity nationally. The long term plan considers that it takes two years to train one crew member, as well as, employee attrition rates and promotions. However presently, management decisions to mitigate the risk, associated with crew presence and crew behaviour, that reduces crew presence are the same as when trains arrive and depart late from a yard. These decisions are further discussed in Section 4.2.2.

An insight from the diagnostics conducted by the consultants (reference the consultants) was that trains did not run according to plan. Random train arrivals and departures resulted in a lack of crew coverage, that is, there were no crews available to run trains that were not scheduled to depart according to the ITP (Appendix A).

Some background to crew management in TFR was discussed in an interview with the resource manager (Appendix B). The resource manager provided background into how crew management and scheduling within TFR is governed by the rules of working conditions contained in documents named the Variation Agreement (Transnet Freight Rail, 2011) and the Main Agreement (Transnet, 2008). The purpose of these documents is to ensure fair labour practices are applied during the development of crew schedules and rosters.

The principles contained in these documents are:

- The overall availability of personnel, considering training, annual leave, sick leave, etc. is considered when scheduling crew;
- The shifts, normal working hours and overtime are defined;
- Appropriate compensation be applied based on the working and service requirements; and
- The treatment of the respective train movements are applied consistently with respect to work requirements (Transnet, 2008; Transnet Freight Rail, 2011).

Currently, TFR uses the rules contained in these documents (Transnet Freight Rail, 2011; Transnet, 2008) to schedule crew. It is important to ensure fair labour practices are applied during the development of crew schedules. With the exception of personnel characteristics relevant to developing the simulation model, the rules contained in the Variation Agreement (Transnet Freight Rail, 2011) and the Main Agreement (Transnet, 2008) are excluded from this research as the scope of the problem does not include the influence of labour regulations. Personnel characteristics relevant to the simulation model are discussed in Section 4.2.2.

In summary, this section provides a background to the company and describes the basic approach used to operate TFR as a scheduled railway. It further discusses the reasons that prevent it from operating a scheduled railway. The main constraint is that presently TFR does not operate a scheduled railway. This research project investigates whether a personnel scheduling method to crew trains in an unscheduled railway is workable.

In Chapter 5 further background is provided with specific relevance to the NCS-DBN corridor.

1.2 Statement of the Problem

The train delays directly impact on the number of loads delivered. One contributing factor is the misalignment of the train's actual movements and the crew schedule. This is because a train's actual movements do not follow the schedule as defined in the ITP. The crew schedule is based on the ITP, hence the misalignment. Improvements in crew scheduling can reduce overtime and train delays. This will lead to an increase in loads delivered per day and ultimately asset utilisation.

Assuming that all the rules contained in the Variation Agreement (Transnet Freight Rail, 2011) and the Main Agreement (Transnet, 2008) were applied, the ITP would be used to calculate the crew capacity per yard, i.e. the number of crew needed. The calculation of crew capacity was further complicated through the allocation of drivers because of specialised skills. Between 2005 and 2009, crews specialised in a locomotive type and a route (train movements between two yards). Crew capacity was therefore calculated per route and locomotive type. This created constraints that led to reduced crew capacity.

In an effort to improve crew scheduling, TFR benchmarked their operations against other international railways. During this exercise, they realised that when crew were specialised to drive specific routes and locomotive types, it reduced the company's flexibility to use crew to drive different locomotive types thus reducing capacity. The crewing department lost the flexibility to respond to immediate demands for different locomotive types on the same route. Therefore, in an effort to increase crew capacity and availability for different locomotive types, TFR embarked on a process to multi-skill train drivers on multiple locomotive types. This created a homogenous set of skills per route. This reduced train rescheduling and cancellations due to the non-availability of train drivers as detailed in the interview with the resource manager in Appendix B.

Albeit a marked improvement in reducing train delays as crew availability increased, the crew department had not found a solution to scheduling crew more efficiently for the random train departures. Crew, who waited too long, ran out of time when trains were delayed as the crew's available time cannot be inventoried, resulting in reduced capacity. With all the improvement initiatives made by TFR, two key challenges remain:

[1] High overtime wage bills as crew are forced to work beyond their maximum 12-hour shifts.

[2] Train delays or cancellations as there is insufficient crew coverage in a train yard because the schedule is based on the ITP, which does not cater for the random train departures (See interview with the resource manager in Appendix B).

A better understanding of crew scheduling for an unscheduled railway was required.

Crew scheduling is a subfield of personnel scheduling (Ernest et al., 2001). Ernest et al. (2001) define crew scheduling as a phased approach where the first phase is "the construction of duties in such a way that the timetable is covered adequately". The second phase is described as "duties generated during the crew scheduling phase are sequenced together to form a roster for each crew" (Ernest, et al., 2001:212).

Past work focused on the objective of minimising personnel cost while adequately covering a timetable. In the annotated bibliography of Ernest et al. (2004), it is stated that Ernest et al. (2004) and other researchers used this approach. The outcomes indicated an improvement in covering the schedule and a reduction in cost. Depending on the environment and the assumptions made, research that makes use of a timetable as a base to develop crew schedules is, however, not relevant for this research project. The inherent assumption in using a timetable is that the railway company operates a scheduled railway system. This research project focuses on a base assumption that the railway operates an unscheduled railway system. Hence, further investigation into crew scheduling for unscheduled railways was required.

Kroon et al. (2008) acknowledged that real time railway operations are subject to stochastic disturbances and, therefore, a timetable should be able to accommodate these disturbances. The approach used was to create process and buffer times between pairs of consecutive trains. Results indicated that average delays could be reduced by adjusting the timetable (Kroon, et al., 2008). Kroon, et al., (2008) seemed to be the first to acknowledge that railway operations are subject to stochastic disturbances. However, they continued to work on the assumption that there was a train timetable from which to work.

Research has been conducted on unscheduled railways. Godwin et al. (2008) conducted a study to determine tactical locomotive fleet sizing for a rail system that does not have a schedule. They focused on the locomotive assignment problem of assigning a set of locomotives to operate freight trains at minimum cost.

Thus, the problem can be defined as increased cycle times, where any reduction in cycle times will increase asset utilisation and volume throughput. They found that the misalignment of unscheduled train departures and scheduling crew based on scheduled train departures, although not investigated or quantified, resulted in low asset utilisation and a lower volume throughput.

1.3 Purpose of the Study

The purpose of this study was to develop a simulation model to assess if a method to crew trains without a schedule is workable.

1.4 Critical Research Question

The central question for this study, assuming that the crews' available time cannot be inventoried, was to ascertain if increasing crew coverage (number of crew) in a yard would increase the number of successful train crew combinations. The secondary question was to determine what the cost implications of the coverage constraint are.

1.5 The Objective of the Study

The objectives of the research were to:

- Investigate train movements and the current crew operations within TFR;
- Outline all relevant research already performed on personnel scheduling within railways;
- Establish that the current train movements in TFR are random using scatter plot diagrams;
- Develop a conceptual model of how the future state crew scheduling methodology should operate based on random train movements;
- Translate the conceptual model into a computerised simulation model to simulate the future state crew scheduling methodology based on random train movements;
- Validate the input parameters of computerised simulation model using historical data from TFR against data gathered from the simulation model when the simulation model is run; and
- Document the process followed, the simulation model, analysis and findings.

This research project tested, in part, the impact of a heuristic to improve train crew combinations using the simulation model. A heuristic, as discussed in Godwin et al. (2008) is a series of 'if … then …' statements that implement the defined rules embedded in the logic. This was done in the context of freight rail operations.

1.6 Research Method

A simplified, adapted three-stage methodology was used to develop a computerised simulation model of the proposed system as illustrated in Figure 1.2.

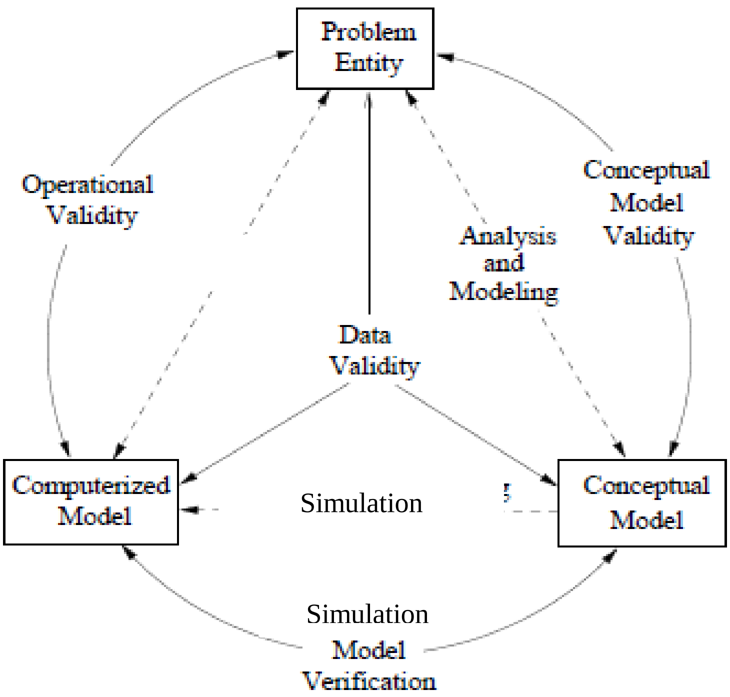

Figure 1.2 Simplified adapted model of the modelling process

(Sargent, 2013)

For the purposes of this research project the problem entity was an idea or proposed system theory. The conceptual model was the graphical representation that mimics the problem entity developed for this study. The computerised model was the conceptual model implemented on a computer (Sargent, 2013).

The simulation software package, AnyLogic, was used to simulate the proposed system theory. Using a simulation model allowed the testing of the impact of a future state crew scheduling method by matching:

- Random train departures; and
- Crew using a crew scheduling heuristic to improve crew coverage (AnyLogic, 2012).

In the current crew scheduling method and in the simulation model, trains arrive randomly at a yard exhibiting an exponential distribution. The simulation generated crew that came on duty at defined intervals whether trains were available to depart or not. The objective was to increase crew availability in the yard throughout the day. When a train had completed its yard processing activities, the train combined with available crew and departed from the yard. However, if crew were not available a train needed to wait for crew to come on duty or use standby crew.

A simulation methodological approach was used to gain insight into a proposed future situation because a real life experiment is not permissible under the contractual agreements that govern the operations. In most instances when simulation is used the ease of implementation in real life is very low due to the expense and constraints (Van der Aalst & Voorhoeve, 2008).

1.7 Assumptions and Limitations

The following assumptions defined the scope of the research project:

- It did not include identification of any improvement opportunities on train planning/scheduling, operations or yard processing. It focused on the last activity performed during yard processing which was how to improve crew coverage for successful train crew combinations with random train departures in a yard.

- Crew coverage in a yard was defined from the time an individual crew member signed on for duty. This means that coverage was based on whether the ITP had crew members assigned to it.
- Due to the complexity of an integrated rail system, the model developed aimed to simulate train movement and crew scheduling between two yards. The model can be applied to other yard combinations by changing the input parameters to simulate the physical characteristics of the system.
- The data provided by TFR was assumed to be an accurate reflection of reality. However, there may have been some limitations within the data, as follows:
    - Root causes of delays and their respective contribution to cycle time losses were not documented.
    - The crew's contributions to cycle time losses were not documented.
    - There were data capturing errors that have been removed,
    - Times when crews signed on for duty were not documented.
    - Trains that were driven by crew incurring overtime, replaced or staged the train en route were not captured.
    - The train schedule did not include buffer time.
- If deviations, such as rolling stock failures or infrastructure failures, took place while the train was en route between two yards, the crew on the train needed to be relieved when they ran out of shift time. The management of crew relief while the train is en route between two yards was out of the scope of the project.
- The simulation model was developed based on a proposed future situation. The proposed future situation was based on an unscheduled railway. The computerised model cannot be validated using the real world situation and therefore it could not determine if the simulation was a close approximation of the current situation in

terms of crew scheduling. The validation of the model is further discussed in Chapter 5.

1.8 Chapter Outline

1.8.1 Chapter 1: Introduction

The introduction presents a case for this research project. The development of a simulation model using an alternative method to schedule crew for freight trains, is the subject matter under investigation. This chapter provides a background to the problem, the purpose of the research, the objectives, the central research question, the research method and the assumptions/limitations that assisted with defining the scope of the project.

1.8.2 Chapter 2: Review of related literature

The literature review discusses various aspects of general personnel scheduling, providing a history of contributions made by various researchers since the 1950s. The literature review indicates that all personnel scheduling methodologies applied were based on a principle that aimed to maximise coverage of a train schedule while minimising cost of personnel. Based on the literature review conducted no research could be found on crew or personnel scheduling for an unscheduled railway. Research conducted by Godwin et al. (2008) to determine tactical locomotive fleet sizing for a rail system that does not have a schedule, forms a basis for this research project.

1.8.3 Chapter 3: Research method

The research method chosen was to simulate the proposed situation. This chapter discusses the process followed for repeatability and validity purposes. It covers the following topics; sources of data, sampling procedures, description of the procedures, methods and instruments of gathering data, details of interviews, documentation and statistical treatments of data.

1.8.4 Chapter 4: Model development

This chapter discusses the scope of the model. The heuristic embedded in the simulation model was developed in two phases. The first phase is the initialisation to establish train movements and second is crew scheduling. The model was based on a heuristic that incorporates train and crew operations to schedule crew to meet the needs of random train departures. The simulation model's fidelity, functional characteristics, verification, validation and expert opinions are addressed in this chapter.

1.8.5 Chapter 5: Data analysis and results

This chapter discusses the outputs of the simulation compared with the current situation. A sample of 17 days data from the current situation was used as the baseline against which to compare the results of the simulation. Summary data tables were used to compare the current and potential future situation based on the number of trains, volume of commodities, cost of crew and revenue.

1.8.6 Chapter 6: Discussion

This chapter discusses performance of the simulation against three key performance indicators, listed as follows:

[1] Number of successful train crew combinations.
[2] Number of loads delivered.
[3] Number of crew used per day.

Comparisons were made based on the current situation to identify what influence the heuristic may have had on train and crew operations.

1.8.7 Chapter 7: Conclusions

The conclusion summarises the procedure followed, the major findings and recommendations for further research.

2 REVIEW OF RELATED LITERATURE

The purpose of this chapter is to identify and outline personnel scheduling concepts that are relevant to freight rail networks and unscheduled railways. This is achieved by providing a background of personnel scheduling since the 1950s when it became important to identify how productivity could be improved. Various research studies are identified and discussed at a high level. These have been applied across numerous industries such as nursing and airline crewing. Personnel scheduling was investigated in general. In discussion, the past research on personnel scheduling was systematically reduced to relevant aspects that are applied within this research project. Bear in mind that the relevant aspects in respect of the personnel scheduling within the freight rail industry are the technical features of solution methods themselves, solution methods and the incorporation of uncertainty. This literature review does not delve into the mechanics of each technical feature or solution method because each solution has different constraints, scope and assumptions.

Further contributions to research within the freight railway industry, specifically, relevant to this research project and how it was applied are subsequently discussed.

Figure 2.1 illustrates the structure of this chapter.

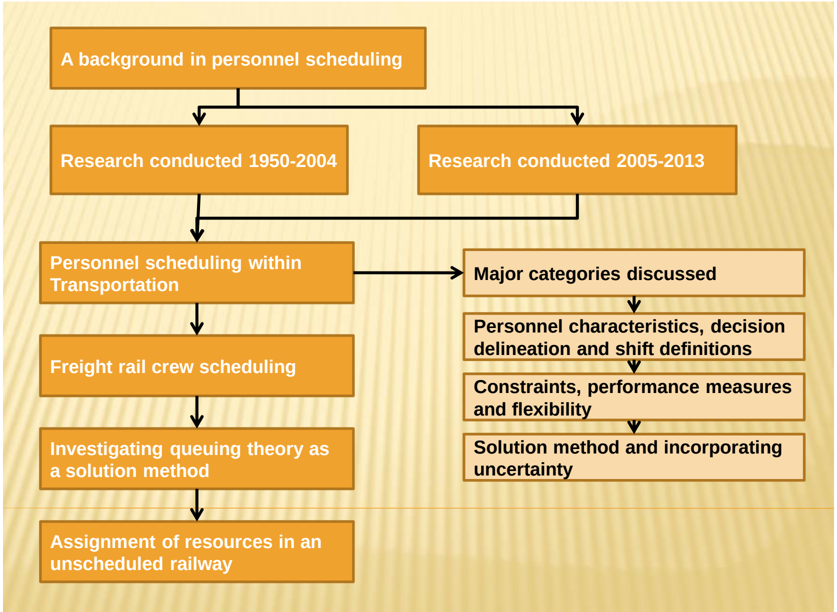

Figure 2.1 Overview of the literature review storyline

2.1 Personnel Scheduling Background

This section will provide the reader with a background of personnel scheduling in general, irrespective of the industry in which the solution methods were applied.

The personnel scheduling problem was introduced by Dantzig and Edie in the 1950s (Van den Bergh et al., 2013). Personnel scheduling is the allocation of personnel to perform activities, considering customer demand, employee skills and so on, while managing profits. In service organisations, labour scheduling makes up a large portion of operational costs (Thompson, 1998). Desrosiers et al. (1995) discussed economic phenomena, such as the oil crises, which prompted investigation into how productivity improvements could be achieved within transportation. Other contributing factors prompting further investigation included a continued reduction in the labour cost, time-based competition and breakthroughs in computer technology (Desrosiers et al., 1995). Economic considerations and an increase in the relative importance of satisfying employee needs in staffing and scheduling problems have led to increased attention to personnel scheduling (Van den Bergh et al., 2013).

The services sector is characterised as being labour intensive and includes industries such as nursing, hospitality and call centres. Over the past few decades, there has been a high growth rate in the services sector. With labour being a direct cost component of the services sector, personnel scheduling was motivated by various economic considerations that affect the profitability of a business. Thompson (1998) defined three basic approaches to converting demand into employee requirements. The approaches are based on using productivity standards, service standards and economic standards. Productivity standards are based on the required productivity of employees, service standards are based on the required standard of service that must be delivered to the customer, and economic standards are based on what is required to deliver the service in the most economical way (Thompson, 1998). Solution methods applied by companies in various service related industries are also applied in the transportation industry. The application of the solution method depends on the nature of the service being offered. The nature includes many aspects that include constraints with respect to hours worked and employee preferences. Furthermore, it depends on the objective outcome (Pawar et al., 2013).

The literature review conducted on personnel scheduling problems indicated that either the technical features or the problem settings are addressed (Van den Bergh, et al., 2013).

2.1.1 Technical Features

The technical features include aspects such as personnel characteristics, types of decisions, flexibility with respect to shift decisions, coverage constraints and time-related constraints (Van den Bergh, et al., 2013).

Classification of personnel scheduling problems is important because consideration that include employee preferences and staffing needs of the organisation needs to be considered when creating work schedules (Pawar et al., 2013).

Baker (1976, cited in Van den Bergh et al., 2013), proposed one of the first classification methods for personnel scheduling problems, as follows:

- *Shift scheduling*: This schedule does not have any overlapping shifts and the schedule is created across a daily planning horizon. The staffing requirements of each individual can be managed independently to derive appropriate allocations.
- *Days off scheduling*: The length of an operating week and an employee’s work week is different, an operating week can be seven days while an employee works for five days.
- *Tour scheduling*: Tour scheduling is a combination of shift scheduling and days off scheduling, where the organisation operates 24/7 with multiple shifts in a day. This type of scheduling is dominant in industries such as transportation (airlines and rail) and health (Van den Bergh, et al., 2013).

The selection and combination of technical features depends on the application. It is often possible to combine several technical features into the same procedure (Van den Bergh, et al., 2013).

Technical features can be obtained from sources such as the employee’s labour contract; these are referred to as personnel characteristics. Personnel characteristics can include whether employees are full time versus part time, what their skill level is, grouping of employees, seniority, productivity levels and so on. Skill level of employees forms a heterogeneous set of personnel if certain tasks demand specific skills, which is generally more costly. Generally, seniority and productivity levels are used to a lesser extent (Van den Bergh, et al., 2013).

Personnel scheduling problems require decisions to be made. In reviewing the decision making policies contained in literature, most papers focused on creating feasible shift sequences based on a deterministic work load. Personnel scheduling problems generally do not integrate with other schedules e.g. rolling stock. Decisions to include flexibility on shifts can be included, e.g. to allow shifts to overlap or not, starting times, shift lengths and so on. Further research is required to incorporate forecasting and adjusting the workload distribution and other personnel characteristics (Van den Bergh, et al., 2013).

Time related constraints incorporate employee preferences with respect to shifts, days, and work locations and so on. Some preferences are governed by regulations, e.g. number of rest days between shifts. The combination of these features is incorporated in to the solution method depending on the application and the problem to be solved (Van den Bergh, et al., 2013).

One key feature that is relevant to this research project is the coverage constraint. This constraint simply determines the number of employees needed to cover the workload. The hard coverage constraint is a key characteristic to personnel scheduling problems for example past research had set a presence level of 75 percent. When the coverage constraint is used as a hard constraint it ensures that enough workers are available at each time interval. However, if it is used as a soft constraint the objective function ensures that the minimum number of employees required to perform the task is available. This constraint will decide on whether to allow over staffing or not. A review of past research indicated that the application of whether to overstaff or not is relatively evenly distributed. Typically the difference between the optimal and minimal capacity is of interest (Van den Bergh, et al., 2013).

Financial measures are commonly used to assess the feasibility of the coverage constraint being applied. These measures include personnel cost, overtime cost, cost of executing tasks, and other costs. The most frequently used measure is the cost of personnel (Van den Bergh, et al., 2013).

In respect of this research project technical features were selected after considering all regulations and policies applicable to the scheduling of crew as described in Section 1.1.3. The proposed system theory included the following technical features:

- All personnel are full time employees. Transnet invests at least two years to train drivers;
- The skill levels are homogenous. TFR implemented interventions that would increase flexibility for any driver to drive any locomotive on a particular route instead of training one driver to drive one type of locomotive;
- The heuristic does not integrate with other schedules in the system, e.g. locomotives;
- Shifts are based on a deterministic workload however is not based on a schedule;
- Shifts are allowed to overlap, however crew preferences such as work locations, shift sequences are not considered;
- Time related constraints are limited to 12-hour shifts as per the labour contract. Other constraints such as number of days off and so on are not incorporated into the heuristic; and
- The coverage constraint applied in the heuristic is aimed to have more than 75 percent coverage. The financial measure to track feasibility of the coverage constraint is personnel cost. The current personnel costs within TFR was compared to the personnel costs incurred in the heuristic.

The next section considers the second personnel scheduling problem aspect noted by Van den Bergh et al. (2013), namely, problem setting

2.1.2 Solution methods / Problem setting

Problem setting refers to the combination of a certain type of analysis with an evaluation technique (Van den Bergh, et al., 2013). The term ‘solution methods’ is used interchangeably with ‘problem setting’ in this report. Contributions by other authors, in the problem setting aspect of solving the personnel scheduling problem, have been summarised in a survey conducted by Alfares (2004, cited in Van den Bergh et al., 2013), namely, manual solution, integer programming, implicit modelling, decomposition, goal programming, work set generation, linear programming (LP) based solutions, construction improvement, metaheuristics and other solution methods.

Most of the solution methods are grouped under mathematical programming approaches. Some of the solution methods in the mathematical programming approach used to model the personnel scheduling problem are based on a goal, column generation, branch- and-price, dynamic programming, lagrange relaxation, linear, integer or mixed integer program. These allow researchers the opportunity to add a number of constraints based on their own needs (Van den Bergh, et al., 2013).

Metaheuristic solution methods are designed to manage complex optimisation problems where other methods have failed to be effective and/ or efficient. Their effectiveness lies in the production of reasonably good feasible solutions in a limited amount of time. One of the drawbacks is that they are unable to produce optimal solutions (Van den Bergh, et al., 2013).

Discrete event simulations are preferred by researchers when simulating personnel scheduling problems. There are benefits of using simulation methods, which include testing proposed system theories when it is too expensive to implement in the real world. (Van den Bergh, et al., 2013).

Constraint programming methods are used when the personnel scheduling problem is highly constrained. The problem can be solved using artificial intelligence research and exact methods that can guarantee feasible solutions for constraint satisfaction problems or optimal solution for constraint optimisation problems (Van den Bergh, et al., 2013).

Other solution methods include a queuing method. Queuing is mostly applied in call centre applications where staffing must satisfy specific service level criteria with minimum labour cost (Van den Bergh, et al., 2013).

Deterministic problem setting methods do not incorporate uncertainty; stochastic approaches try to incorporate it. It has been noted that past research barely considered taking the unpredictable availability of workers into account. Unpredictability can be caused due to illness, late arrivals and so on. This was identified as an area for further research (Van den Bergh, et al., 2013).

In respect of this research project the chosen solution method or problem setting approach is simulation. Furthermore, the scope does not consider the unpredictable availability of workers.

2.2 Personnel Scheduling within Transportation

While the solution methods in the broad category of personnel scheduling discussed previously is applied within transportation, train crew scheduling is a more recent area of research as compared with airline and bus crew scheduling and rostering (Van den Bergh, et al., 2013). European researchers conducted most research in personnel scheduling within transportation of passenger and freight industries (Ernest, et al., 2004). A review of past research in the scope of personnel scheduling within transportation was conducted. This was done to identify if there were any relevant technical features or solution methods that could be applied within freight rail personnel scheduling.

Based on the literature review conducted it was found that research on freight rail personnel scheduling, relevant to the South African industry, is limited. Jutte et al. (2011) discussed the history of personal scheduling in the transport industry from which the most important and relevant aspects considered in this research project are drawn.

The closest relation to train driver and crew scheduling is personnel scheduling within airlines. However, Jutte, et al. (2011) describes the crew scheduling problem for rail as fundamentally different to that of the airline industry whereby:

- The number of tasks that a train crew schedule must cover is considerably larger than that of an airline;
- Train drivers operate different types of engines. The option of splitting the crew scheduling problem into sub-problems for different engines is not possible; and
- Airlines use a hub-and-spoke network model, which is an unusual arrangement for railway networks (Jutte, et al., 2011).

Jutte et al. (2011) indicated that current research regarding train crew scheduling focuses on passenger railways and they describe major differences between passenger and freight railway crew scheduling problems. These are:

- The problem size is bigger and modelling is different in freight railway crew scheduling problems.
- Freight operates 24 hours a day and seven days a week, so partitioning the crew scheduling problem into daily problems does not work.
- Categorising crew members into different classes to be scheduled sequentially is nearly impossible.
- The deadhead selection process is more important for freight trains.
- Freight trains have various prioritisation rules attached to their operations (Jutte, et al., 2011).

It was found that there were no technical features or solution methods noted by Jutte et al. (2011) that could be applied to this research project.

The technical features and solution methods applied to other industries cannot be applied because if the unique nature of freight rail. For example, in the paragraphs above Jutte et al. (2011) listed the technical features that differentiate passenger rail from freight rail, hence rendering solutions in passenger rail non-applicable for freight rail

2.3 Freight Rail Crew Scheduling

Contributions made by past researchers relating to crew scheduling within freight rail are discussed in this section. The discussion is focused on the technical features and approaches to the solution methods that are applied across the world and relevant to this research project. The review does not make specific reference to the countries or railway companies as the combination of technical features and the solution method is unique to the company.

Vaidyanathan et al. (2007) argue that railroads are generally not profitable, influenced primarily by the need to raise already high wages to attract or retain employees. Labour cost is the largest component of railroad operating costs. Improving efficiency and effectiveness of the train crews may have a dramatic influence in reducing the cost of transportation (Vaidyanathan, et al., 2007).

The operational complexity in freight rail makes crew scheduling difficult. All contractual and legal requirements should be considered when scheduling crew (Jutte, et al., 2011).

Banihashemi and Haghani (2001) describe a four-step transit planning process. The steps are:

[1] Network route design.
[2] Setting frequencies and building timetables.
[3] Allocation of rolling stock to the timetable.
[4] Crew scheduling (Banihashemi & Haghani, 2001).

Inputs into the crew scheduling step include information from the allocation of the rolling stock to the timetable step, the driver work rules and workday cost structures to provide work schedules for drivers (Banihashemi & Haghani, 2001). The goal of railway crew scheduling is to optimise the assignment of trips to drivers in a way that incorporates labour rules and regulations, and other quality aspects (Bojovic & Milenkovic, 2010).

The timetable and rolling stock schedule together define the basic crew needed to operate the trains (Bojovic & Milenkovic, 2010). The trip from origin to destination is subdivided into pieces of work that cannot be further divided. These trips start and end at train yards where crew changes take place. Because of the complexity and operational constraints, the crew scheduling problem is decomposed into four phases:

- [1] Train services are partitioned into driver trips.
- [2] Feasible pairings (duties) are generated. Each pairing is a sequence of trips to be covered by a single crew belonging to that depot so that each pairing starts and ends at the same depot.
- [3] The pairing optimisation phase consists of making a selection of the best subset of the pairings generated in previous phases to ensure that all trips are covered at the minimum cost.
- [4] The crew rostering phase matches the sequence of duties that each crew need to perform over a given time period to cover all duties selected in the first phase (Bojovic & Milenkovic, 2010).

The measure of the schedule efficiency can be based on either the total number of shifts used or the total cost in paid hours or a combination of both, as discussed by Wren et al. (2003).

2.4 A review of the Annotated Bibliography of Personnel Scheduling and Rostering within the Railway Industry (1950-2004)

Ernest et al. (2004) presents the rail personnel scheduling process as different modules and the choice and combination of modules used depends on the application. The classification is divided into five groups, namely demand modelling, artificial intelligence approaches, constraint programming, metaheuristics and mathematical programming approaches

Ernest et al. (2004) created a bibliography of reviews for over 700 papers on personnel scheduling, with the earliest being Eddie, (1954). A list of various solution methods used for crew scheduling applicable to railways consisted of network flow, matching, enumeration, artificial intelligence, expert systems, constraint logic programming, constructive heuristic, simple local search, simulated annealing, tabu search, greedy adaptive search procedure, evolution, genetic algorithms, dynamic programming, mathematical programming, linear programming, integer programming, lagrangean relaxation, column generation, branch and cut, branch and price, set covering, set partitioning and combinations of the above mentioned methods (Ernest, et al., 2004). All the above-mentioned methods aim to find a minimum cost collection, covering each trip or duty once and are based on a train schedule (Ernest, et al., 2004). Extensive research exists on each of the above-mentioned solution methods. The mechanical operations will not be discussed. The solution methods listed are not relevant for this research project because the founding principle used is a schedule, whereas this research project focuses on scheduling personnel without the use of a train plan.

2.5 Personnel Scheduling within the Railway Industry (2005-2013)

Van den Bergh, et al. (2013) has produced a literature review of the most recent and relevant work applicable to railways. The literature review consists of 291 articles since 2004. This section will categorise key discussion points to provide context on what research has already been conducted and where gaps exist within personnel scheduling for railways. It will discuss the articles that are grouped into three major categories:

[1] Personnel characteristics, decision delineation and shift definitions.
[2] Constraints, performance measures and flexibility.
[3] Solution method incorporating uncertainty.

The sections below discuss past research conducted and their focus areas as discussed in (Van den Bergh, et al., 2013). The most important insight discussed in (Van den Bergh, et al., 2013) is that using deterministic personnel scheduling methods does not include uncertainty.

2.5.1 Personnel characteristics, decision delineation and shift definitions

The principles concerning personnel scheduling based on this category is matching the objective of cost minimisation while incorporating policy decisions and employee preferences to ensure sufficient coverage (Van den Bergh, et al., 2013). Most papers study full time employee personnel problems. Studies have been conducted on the scheduling of crew (team), which is mostly found in the transportation area where personnel scheduling is combined with vehicle routing. An increasing focus on personnel preferences and a flexible work environment will result in tour scheduling problems dominating in the research of personnel scheduling (Van den Bergh, et al., 2013).

2.5.2 Constraints, performance measures and flexibility

Hard and soft constraints are clustered into coverage, time-related, and fairness and balance constraints (Van den Bergh, et al., 2013).

The coverage constraint is critical to deciding how many employees are required to cover the workload, and can be used in two ways. First, soft constraints to determine the difference between the optimal and minimal capacity and second, hard constraints when understaffing or overstaffing is not allowed. The coverage constraint must incorporate breaks and skill categories (Van den Bergh, et al., 2013). Flexibility to ensure coverage has an associated cost, for example, the hard coverage constraint is used to ensure that a sufficient number of employees are available with the required skills set to perform the job and the soft constraint penalises the objective function value (Van den Bergh, et al., 2013).

Brucker (2010, cited in Van den Bergh et al., 2013) researched the creation of time related constraints by limiting the number of consecutive working or non-working days instead of tour or shift scheduling. Research was conducted on balance and fairness, which are applied as constraints (Van den Bergh, et al., 2013).

2.5.3 Solution method incorporating uncertainty

There is a wide range of research methodologies that combines analysis with a solution or evaluation technique. The various solution methods include, but are not limited to:

- The method of mathematical programming in which the personnel scheduling problem is modelled as a linear, integer or mixed integer program (Van den Bergh, et al., 2013).
- The method of using a set covering problem is very popular for a general shift scheduling problem (Van den Bergh, et al., 2013).
- The method of using metaheuristics because its strength comes from being able to develop reasonably good solutions within a defined time interval however, its weakness is that it cannot provide demonstrably optimal solutions or reduce the search space (Van den Bergh, et al., 2013).
- The methods of using discrete event simulations help researchers validate their deterministic optimisation approaches (Van den Bergh, et al., 2013).

- The method of using constraint programming guarantees feasible solutions for constraint satisfaction (Van den Bergh, et al., 2013).
- The method of using queuing theory to determine the degree to which predetermined service level criteria are satisfied (Van den Bergh, et al., 2013).

The current approach of using deterministic staffing and scheduling does not consider any form of uncertainty with the exception of queuing method (Van den Bergh, et al., 2013). This is a gap in the literature and is an area that requires further research. The incorporation of uncertainty is defined based on three types of uncertainty:

[1] *Uncertainty of demand*: (when the workload is unpredictable) In most of the research papers workload is estimated based on historical data, which results in the stochastic component e.g. changes in workload, being dropped. The one way to deal with variable workloads is to create capacity buffers.

[2] *Uncertainty of arrival*: (when the arrival patterns of the workload is unpredictable) Campbell (2011, cited in Van den Bergh et al. 2013) developed a two stage stochastic program to cater for uncertainty of arrival, each stage with a different planning horizon, the first is weekly or monthly and the second is daily.

[3] *Uncertainty of capacity*: (addresses deviations between planned and actual labour resources). Unpredictable capacity has not been fully investigated or dealt with. Most researchers model the decision of skilled staff being available using a 50 percent chance of them being present or absent (Van den Bergh, et al., 2013).

This research project attempted to further investigate a means of incorporating uncertainty into personnel schedules. The most relevant aspect of uncertainty is the uncertainty of arrivals as described in point two above.

2.6 Incorporating Uncertainty into Train Crew Personnel Scheduling Solution Methods

There has been a limited amount of research conducted into incorporating uncertainty into train crew scheduling solution methods. Based on this research, the solution methods in the literature still use a train timetable as the founding principle from which it operates.

Jutte et al. (2011) state that crew duties need to be robust to avoid the propagation of train delays as it can result in significant penalties or train cancellations. It is a major challenge to schedule freight crew to be both cost efficient and sufficiently robust to prevent operational disruptions (Jutte, et al., 2011). Disruptions take place in railway systems due to an accident, a breakdown of infrastructure or rolling stock (Abbink, et al. 2010). In addition, to minimise crew related operational disruptions, including various buffer times to accommodate any changes is one way to minimise delays (Jutte, et al., 2011).

Jutte and Thonemann (2012) introduce the concept of variability in the system. He explains that freight rail is a last minute business and a large number of the trains are scheduled at short notice resulting in short lead times for the generation of crew schedules.

As stated before, Kroon, et al. (2008) acknowledged that real time railway operations are subject to stochastic disturbances and therefore a timetable should be able to accommodate these disturbances. The approach used was to create process and buffer times between pairs of consecutive trains. The results indicated that average delays could be reduced by adjusting the timetable (Kroon, et al., 2008).

2.7 Investigating Queuing Theory as a Solution Method

As discussed above (Van den Bergh, et al., 2013), the current approach of using deterministic staffing and scheduling does not consider any form of uncertainty with the exception of queuing methods, and has not been discussed in any of the review papers. Hence, for the purposes of this research project, queuing theory was investigated as a possible solution to crew scheduling in the absence of timetables. This section discusses past research conducted on personnel scheduling using queuing theory (Ingolfsson, et al. 2002) and provides a comprehensive discussion relevant to this research project.

Flexible demand is used in the absence of known timetables, where the likelihood of future occurrences must be modelled using forecasting techniques (Ingolfsson, et al. 2002). The conversion from the forecast of occurrences to staffing requirements is accomplished by using techniques such as queuing theory or simulation where the outcome is the number of staff required at each skill level during each period (Ingolfsson, et al. 2002).

Typically, customer arrivals at service facilities are random and dynamic, with rapid changes in the average arrival rates. To understand more fully the relationship between delays and number of servers available at different times, queuing theory is the most appropriate tool to be used (Ingolfsson, et al., 2002).

Steady state formulas for a multi-server queuing model (M/M/s) are generally used to discuss how demand forecasts are converted to minimum employee requirements (Ingolfsson, et al., 2002). However, this assumes a stationary arrival and service process that is not adequate (Green, et al., cited in Ingolfsson, et al., 2002). A realistic representation of service stations (yards) is a queuing system that has time varying arrival and service processes. Usually arrival and service processes will be time varying. Service processes are also time varying because of random reductions in capacity, such as train deviations or infrastructure failures, or because the number of servers changes according to schedule changes throughout the day (Ingolfsson, et al., 2002).

There are situations when steady state queuing formulas can be used to approximate a time-varying system with adequate accuracy (Ingolfsson, et al., 2002). First, when the event frequency (arrival rate + service rate of all servers combined) is large compared with the natural period of the system for example a day or week and second, when instantaneous arrival rates are always smaller than the instantaneous service rate (arrival rate < service rate for all times).

However, when the event frequency is small or the instantaneous arrival rate is temporarily larger than the instantaneous service rate, then the accuracy of such approximation suffers and steady state formulas cannot be used (Ingolfsson, et al., 2002).

Being able to model variability in arrival rates is important in practice (Wren, et al., 2003). One method to model rush hour situations used an approximation based on an infinite server time varying queuing model (Ingolfsson, et al., 2002). The challenge with this model is that it does not model the structure of allowable shifts. It uses the number of employees on duty in each period as a decision variable (Ingolfsson, et al., 2002).

The application of queuing theory within transportation was done in the United States Air Force (Hong, et al., 1989). Queuing theory was used to assign the minimum number of crews required to complete a mission among bases within a specified time in an airlift operation. The objective was to minimise the waiting time of aircrafts at the bases by keeping rested crews available (Hong, et al., 1989).

Employee scheduling method aims to optimise any combination of cost efficiency and the minimum instantaneous level of service. Queuing theory was not applied to determine the number of train crews needed to drive trains based on the uncertainty of demand and arrival (Ingolfsson, et al., 2002). Queuing theory will not be applied in this research project due to the deficiencies discussed above.

2.8 Assignment of Resources in an Unscheduled Railway

Instead of using queuing theory, the principles and approach used in research conducted by Godwin et al. (2008) was applied. Godwin et al. (2008) developed a heuristic for the locomotive assignment problem in an unscheduled railway. The heuristic is divided into two phases; first, the initialisation to set the system and second, locomotive assignment where, through a series of if-then statements, availability based on specified constraints, for example maintenance, is confirmed for assignment (Godwin, et al., 2008). For the purposes of this research project a similar approach will be followed, in other words the use of simulation methods with an embedded heuristic.

There is research on how to incorporate variability into a personnel schedule. The research is limited managing the exceptions where variability is exists. The author reviewed past work conducted by Hong, et al. (1989) and Godwin et al. (2008). The research conducted by Godwin et al. (2008) is the most relevant research in relation to this research project. The set-up of the heuristic and the performance measures will be adapted and applied, as discussed in this research project.

In conclusion, after conducting a review of past research conducted on personnel scheduling, the author did not find literature that assigns crew to a machine (locomotive) without a schedule.

3 RESEARCH METHOD

The purpose of this chapter is to document the approach followed in the development of a computerised simulation model to facilitate crew scheduling based on the replication of train movements. The intention was to gain familiarity with train movements to identify critical assumptions that were incorporated into the development of the computerised simulation model for crew scheduling.

3.1 Research Method

The research method chosen for this report was based on the paradigm illustrated in Figure 1.2 which details the simplified adapted model of the modelling process (Sargent, 2013).

An iterative process was used to develop a valid computerised simulation model as suggested by Sargent (2013). The first step in the process was to define the problem entity, idea or the proposed system theory. The second step was to develop a conceptual model. The conceptual model was the graphical and statistical representation that mimics the problem entity developed for this study. The third and final step was the implementation of the conceptual model on a computer. The result was a valid computerised simulation model (Sargent, 2013).

The process was detailed to allow for repeatability and validity purposes. The approaches applied in this research project aimed to ensure that:

- The correct approaches have been applied;
- The quality of the measurement procedure is repeatable and accurate;
- Each step taken was done in an unbiased manner; and
- Each conclusion drawn was done without personal interest.

The case study chosen was based on the Natal Corridor in TFR. An investigation on the current situation was completed as outlined in

Chapter 1. The investigation included gathering information from interviews, operational data and past diagnostic work conducted by consultants.

The data gathered from the company was used to develop a statistical model of the train movements. This then provided the input into developing the simulation model. It was also used to identify relevant technical features that defined the personnel characteristics and coverage constraints. These were incorporated into the simulation model. The current situation data was also used for comparative purposes to assess the change.

Quantitative research methods cannot easily facilitate investigation of stochastic train arrival and departure rates (Godwin, et al., 2008). Godwin et al. (2008) used simulation to compare and illustrate improvements in locomotive assignment in an unscheduled railway. The flexibility of simulation allows the testing and amending of scenarios. The stochastic arrival and departure rates are fundamentally different to; first, the current situation in which TFR operates, and second, all research concluded to date on crew scheduling, which is based on a timetable. Hence, it was decided that simulation would be used to investigate the outcomes of the proposed crew scheduling methodology

3.1.1 The proposed system theory or problem entity

The proposed system theory or problem entity is the scheduling of crew for random train departures.

The current situation in TFR that negates the running of a scheduled railway is described, in detail, in Chapter 1. The key contributing factors to this unscheduled railway were, in summary,

- Schedule planning does not take into account:

    - arrival and departure rates per yard leading to inaccurate yard processing capacity and ultimately, delays in train cycle times,
    - integration of train plans with other commodities entering the yard,
    - that assets are not reset to their original positions in the plan;
- Challenges experienced in the execution of the plan because of misalignment of the plan with actual asset positions and poor monitoring of asset positions;
- Lack of resource and infrastructure reliability and capacity.

These issues resulting in an unscheduled railway, all impact on the capacity scheduling of personnel. This is because the two crew scheduling methods employed by TFR assume scheduled arrival and departure times (which is not the case in reality). Consequently, there is a lack of crew coverage or an over capacity of crew. Adding to this situation is that data on actual crew behaviour is not recorded appropriately for accurate analysis.

A review of past work from personnel scheduling in general to personnel scheduling within freight rail is documented in Chapter 2. The objective was to identify past work conducted on the incorporation of variable train arrival and departure rates into crew schedules for freight railway systems. The outcome indicated that limited research has been conducted on this subject.

Taking the above into consideration and that crew scheduling is dependent on train movements, the approach employed by this research is to first, statistically model the current train movements based on actual real world data, and to then use this model to develop a simulation model for crew scheduling.

3.1.2 The conceptual model

Once the problem entity was defined, the conceptual model was developed based on the problem entity data. The conceptual model was validated with expert input to ensure that the assumption and theories contained within the model were correct and is discussed in Section 4.3.3. Validation of the conceptual model ensured that the model representation of the problem entity was 'reasonable' for its intended purpose (Sargent, 2013).

3.1.3 The computerised model

The conceptual model was converted into a computerised program using AnyLogic simulation software (AnyLogic, 2012). Data information gathered on train operations within TFR was used as input data into the simulation model to simulate train movements in the system. The proposed crew scheduling system, detailed in the conceptual model was programmed into the simulation.

It is important to note that validation of the computerised model was based on whether computer programming and implementation of the conceptual model were correct.

Various techniques were used, such as historical data validation, extreme condition test, expert review and simulation fidelity. These are discussed later in Chapter 4.

Transnet has a system to schedule crew based on a plan however this research project attempts to schedule crew without a plan. Furthermore, because an existing system either modelled or in a real world situation, does not exist for scheduling crew without the use of a train timetable, a subjective approach for non-observable systems was used to explore the model's behaviour. TFR crew scheduling experts validated the behaviour of the computerised model against the intended outcome or purpose of the problem entity. Operational validity classifications for observable and non-observable systems are detailed in Table 3.1 (Sargent, 2013).

Table 3.1 Operational validity classification

(Sargent, 2013)

Decision approach	*Observable system*	*Non-observable system*
Subjective approach	• Comparison using graphical displays • Explore model behaviour	• Explore model behaviour • Comparison to other models
Objective approach	• Comparison using statistical tests and procedures	• Comparison to other models using statistical tests

3.2 Simulation Methodological Approach

A simulation methodological approach was chosen for this research project. Generally, the benefits of using simulation methods are:

- Provision of superior insight into complex theoretical relations when empirical data limitations exist (Davis, et al., 2007).
- Provision of an analytically precise means of specifying the assumptions and theoretical logic that forms the basis of the research question (Davis, et al., 2007).
- Revealing the relationships between multiple underlying processes (Davis, et al., 2007).

Motraghi and Marinov (2012) previously used simulation methodological approaches in researching freight rail, illustrating the merits of moving urban freight via rail. Furthermore, Malavasi and Ricci (2001) used simulation to test the application of a neural model for consequent failures in rail.

In the field of reliability of the railway systems, the use of simulation models has proven to be a very useful tool for the study of the most effective operational measures and infrastructure improvements aimed to increase the reliability of the system (Malavasi & Ricci, 2001). The use of simulation models for the study of the evolution of the complex railway systems require the reproduction of:

- *Physical rules*: Relationships among time, space, speed, acceleration, forces, energy, interactions with signally systems, route configuration and safety constraints, etc. (Malavasi & Ricci, 2001).
- *Choices depending on the operators*: Conflicts resolution, actions to be taken in case of failure, etc. (Malavasi & Ricci, 2001).

Godwin et al. (2008) used simulation to determine tactical locomotive fleet sizing for a rail system that does not have a train schedule. Their research was based on Indian Railways, which draws certain parallels to South Africa's rail system. For example, both are developing countries, they operate without a schedule, and the same rail network is shared between freight and passenger trains. Without having to focus on sub-optimisation, Godwin et al. (2008) focused on the locomotive assignment problem of allocating a set of locomotives to operate freight trains at minimum cost., Most past research on the locomotive assignment problem, as with personnel scheduling, was based on fixed schedules and did not address fleet sizing of locomotives (Godwin, et al., 2008).

3.3 Data Collection, Management and Analysis

The data collection, management and analysis for the proposed system theory or problem entity, the conceptual and computerised model followed a structured approach. The remaining sections of this chapter describe the scope of the data collected, sources of data, sampling procedures, description of procedures and the statistical treatment of the data used at each stage of the modelling process.

3.3.1 Scope of data collected

A structured approach was employed to collect and analyse the data and contextualise the current situation. The data collected was on the train arrival times, train processing times, train departure times, crew scheduling methods, number of trains planned per day and the actual number of trains run per day between origin and destination points. All the information collected was used to establish train movement patterns and contributed to the design of the heuristic.

The objective was to model the current train movements to gain an understanding of:

- the relationship between train delays and crew waiting time as they run out of time;
- the number of successful train crew combinations; and
- the number of loads delivered per day.

Information and data collected was used to define the problem entity and the conceptual model that would then provide the input into the development of the simulation model for the crew scheduling.

The next section describes the sources of data, sampling procedures, description of procedures and the statistical treatment of the data.

3.3.2 Sources of data

The sources of data included information gathered through interviews, internal reports from diagnostic projects and captured data on train movements. Primary data was obtained from TFR, which comprises data captured per train from origin to destination on an Excel spreadsheet. Secondary data was obtained from previous diagnostic projects completed by the author on other corridors (Letsema, 2008, 2009a, 2009b).

To gain further depth and context of operations and crew management in TFR, interviews were conducted with both the resource manager and a retired Chief Operations Officer (COO). The resource manager provided context on the data received and validated assumptions, whereas the COO was used to validate the model (Appendix B).

Both individuals prefer to remain anonymous. Interviews were conducted with full ethical consideration Appendix C provides a letter issued by the University of the Witwatersrand, confirming the process, confidentiality and privacy policy that was applied in this research project.

3.3.3 Sampling procedures

The Natal corridor was selected as a case study for this research project. The selection was based on the following criteria:

- TFR is the only freight rail company in South Africa.
- Information is readily available from the company.
- Expert support and participation by the resource manager is available.
- Railway line routes across South Africa are classified into corridors, feeder lines and so on, the Natal corridor forms part of the group of main lines that transport commodities. A corridor was selected instead of branch and feeder lines because the volume of trains on the corridor is sufficient enough to conduct statistical analysis.

A random sample of 17 days of trains between Newcastle (NCS) and the destination point, Durban, was gathered. Seventeen days is a sufficient sample as there are no variances (e.g. seasonality demand fluctuations) in the number of trains or operations weekly, monthly or annually for this corridor. The data is contained in Appendix D. All days operate in the same way with no external influences that affect the train schedule at specific times, as confirmed by the resource manager (Appendix B).

The scope of the research project is to analyse and model the current situation and the simulation results on one pair of origin/destination points. Trains cancelled between the origin and a location named MTV were excluded from the scope (the planned versus actual train departures from NCS). A train plan exists with a design time of 10 hours between the origin and NCS, and eight hours from NCS to the final destination, Durban. The crew schedule is developed based on the train schedule either using the diagram or FIFO method.

3.3.4 Train Movement Data

The consultant reports, compiled by Letsema Consulting (Letsema, 2008; 2009a; 2009b), were used to structure and categorise the contributing factors that force TFR to run an unscheduled railway (These are detailed in Chapter 1 and summarised in section 3.3.2).

TFR designed an excel spreadsheet, which was used to capture the actual detailed train movements from origin to destination. This manual data capture spreadsheet can be found in Appendix D. The spreadsheet captures:

- Planned and actual train arrival and departure times;
- Train cancellations; and
- Differences between planned and actual.

The data received was for all trains planned over 17 days. The information was obtained from the CTC department as they control the signals authorising train movements on entrance to a yard, departure from a yard and while the train is en route.

Each yard has personnel that manage the train movements into the yard, train processing within the yard and train movements out of the yard. The information obtained from the yard personnel together with that from CTC allow trains to be tracked from origin to destination. This can be difficult because for a single wagon set, train numbers change when departing from each yard.

This actual train movement data were categorised into successful train crew combinations, crew overtime, and number of loads that departed per day. The data were used to determine the relationship between train delays and crew waiting time as they run out of time. It was also used to validate that trains do not depart according to the train schedule, which provided further evidence to support stochastic train arrival and departure rates (shown in the scatter plots, Figure 4.2 and 4.3, in Chapter 4) for the simulation.

The interquartile range was used to establish the extent of variability between an unscheduled system and running a scheduled railway. The interquartile range in Chapter 5 of the research report was used to prove that trains do not arrive or depart on time. Then the train arrivals and departures, and yard processing times were plotted into a histogram, which resulted in an exponential distribution and pareto distribution, respectively. This was embedded into the simulation to ensure that the simulations fidelity and validity was in line with the current situation.

In order to ensure that the simulation applied the distributions defined using the data received from TFR, the simulation data output was plotted into histograms. The distribution and goodness of fit of the simulation output data was compared with data received from TFR to determine if the simulation has applied the distributions as defined in the current situation.

3.3.5 Unstructured interviews with resource manager

Alvarez and Urla (2002) used unstructured interviews to gather information to determine what the information requirements were for an ERP system. They have been found to be very useful when conducting studies that involve identifying patterns and developing models.

Unstructured interviews were chosen because it allowed the interviewer to:

- Probe deeper into responses from the interviewee;

- Obtain greater breadth and depth of understanding on topics that would not ordinarily be disclosed; and
- Control the direction of the interview without the rigidity of structured questions.

Official or agreed upon guidelines on how to conduct an unstructured interview cannot be found. However, many researchers employ the use of the steps listed below (Punch, 1998; Fontana & Frey, 2005):

Assessing the setting

The setting is an operational train yard. Information was easily accessible from the office documents filed and the system.

Locating an informant

Through previous work related engagements, the interviewer had developed a professional rapport with the resource manager, who was selected to be interviewed because of his experience and exposure throughout TFR. The resource manager was able to supply the relevant documentation, data and assumptions that would be able to provide input into the simulation model.

Gaining trust

The interviewer had established a rapport with the resource manager as the interviewer is also an employee of Transnet. Information was therefore shared on request.

Establishing a rapport

The resource manager has an existing professional rapport with the interviewer because of the past professional engagements in the operational environment and as an employee of Transnet. Information sharing between Group and the Operational Divisions are allowed to take place.

Collecting empirical materials

For the purposes of this research project obtaining data and conducting interviews was sufficient as the information obtained was used to:

- Define and validate assumptions;
- Input into the simulation; and
- Establish a baseline for comparison with the results from the simulation.

In some instances, assumptions cannot be validated using the data as it is based on management decisions, company internal policy and procedures, and structure of the company. The reasons for or outcome of management decisions are not documented. The scope of the interview covered the following major topics:

- Operations of the line;
- Crewing scheduling and rostering methodologies;
- Train movements; and
- Train monitoring Excel spreadsheet.

The transcript of the interview is contained in Appendix B.

The interview was conducted in a professional and ethical manner. In order to ensure that confidentiality of the company and the interviewee were maintained, Wits University issued a letter to the company and it is included in Appendix C.

3.3.6 Documentation

Principles of governance for crew management were obtained from labour agreements with the company. The documentation was reviewed to identify what key assumptions from the current model of scheduling crew can be applied to the proposed simulated model. Personnel characteristics such as the amount of time a shift comprises of (12 hours), was included in the model however aspects that did not contribute to the solution was determined to be out of scope for this project. Examples of personnel characteristics that is out of scope are shift preferences, shift rotation schedule and so on. The application of technical features such as shift duration is detailed in Chapter 5. The shift time was used to calculate the buffer time available and the crew scheduling options applicable.

The critical research question was to identify if increasing crew coverage in a yard will increase the number of successful train crew combinations using a fundamentally different methodology. Hence, the rest of the information was not of benefit to this research project.

3.4 Statistical Treatment

The raw data of the actual train movements was received was cleaned up by correcting easily identifiable human errors. An example of an error is when data was typed incorrectly but could be determined through calculations. Information is manually captured, as Transnet does not have systems in place to record data. The number of errors was not significant. The data was transferred onto separate sheets for analysis purposes. Column names are used to describe the formulas in the sub-sections below. Refer to Appendix D, E, F, G, H, I, J and K for column reference names.

The ‘cleaned’ raw data was used to establish the following calculated information that was employed in the development of the statistical or conceptual model.

3.4.1 Baseline data for further analysis

- Crew waiting time for the train is equal to actual departure time less (design departure time plus design yard processing time).
- Time lost due to train delays is equal to sum (deviations of yard processing and drive times up to NCS).

- Time required to drive to Durban is equal to sum (design drive time and design yard processing times from NCS to DBN).

The data is included in Appendix D.

3.4.2 Establish number of trains run

- Number of trains planned is equal to the sum of trains planned to depart from the origin per day.
- Trains cancelled is equal to the sum of trains cancelled per day.
- Trains run is equal to the sum of trains that departed to NCS.
- Average delay to NCS is equal to the sum of train delays up to NCSdivided by the number of trains.

The data is included in Appendix E.

3.4.3 Establishing random departures

- Median is equal to the middle value minutes crew waiting for train at NCS per day.
- Min is equal to the minimum number of minutes per day.
- Max is equal to the maximum number of minutes per day.
- Quartile 1 = ($\frac{n+1}{4}$) where n = number of minutes.
- Quartile 3 = ($\frac{3(n+1)}{4}$) where n = number of minutes.
- Interquartile range = Quartile 3 - Quartile 1.
- Standard deviation crew waiting time per day = $\sigma = \sqrt{\frac{1}{n\sum_{i=1}^{n}(xi-\mu)^2}}$
    - σ = standard deviation
    - n = number of minute delays
    - μ = mean of time for crew waiting per day
    - i = value in data set.
- Standard deviation cumulative train delays per day is defined as $\sigma = \sqrt{\frac{1}{n\sum_{i=1}^{n}(xi-\mu)^2}}$.

- σ = standard deviation
- n = number of minute delays
- μ = mean of time for train delays per day
- i = value in data set.

A Scatter Plot was also used to confirm randomness of data. The inter-arrival and departure times (continuous random variables) were also fitted to exponential distributions.

The data is included in Appendix F.

3.4.4 Correlation graph

- The correlation graph plots the standard deviation of train delays against the standard deviation of crew waiting time to establish if there is a relationship between train delays and crew waiting time.
- The correlation graph is further discussed in Chapter 5.

The data is included in Appendix G.

3.4.5 Inter-departure times

- Inter-departure times is equal to the difference between two sequential departure times in minutes.
- The inter-departure times were sorted in ascending order. The data was plotted into a histogram and fitted with a probability density function curve to establish the distribution curve.

The data is included in Appendix H.

3.4.6 Inter-arrival times

- Inter-arrival times is equal to the difference between two sequential arrival times in minutes.

- The inter-arrival times were sorted in ascending order. The data was plotted into a histogram and fitted with a probability density function curve to establish the distribution curve.

The data is included in Appendix I.

3.4.7 Data sorting

- The number of minutes to process each train that arrived in the yard was captured. The amount of time taken to process each train is then sorted in ascending order.
- Extreme values exceeding 104 minutes were removed from the data set to stabilise the process and establish the distribution curve. These values were the exceptions and when included in the data set the outcomes are distorted. The data was plotted into a histogram and fitted with the probability density function curve.

The data is included in Appendix J.

3.4.8 Performance measures

- Trains were categorised into the following four categories:

  [1] *Trains with successful train crew combinations*: Assuming that crew arrived on time and had more than eight hours of shift hours remaining after train processing was completed This would be classified as successful train crew combinations. Crew need a minimum of eight hours of available shift time to drive the trains between yards. The eight-hour limit is defined in the labour contract with crew. The cost of successful combinations is equal to R840 multiplied by the number of crew that drove the train within their available time. For illustrative and confidentiality purposes a labour rate of R70 per hour was used for normal shift hours. The labour rate between 8 and 18 hours is considered ‘double time rate’ i.e. two times the normal hourly

rate. The cost of overtime is equal to the number of hours over time multiplied by R150 per hour.

[2] *Trains that ran with crew over time (over three hours)*: Assuming the train was delayed by more than three hours, but less than six hours, and the crew has a maximum of 15 hours left will move the train from NCS to Durban with three hours overtime incurred. TFR management exercise their discretion by how long should a crew member exceed their 12 hour shift. The resource manager indicated that they cannot exceed a total of 18 hours or 6 hours over their shift time.

[3] *Trains that ran with replacement crew*: If the train is delayed by more than six hours (three hours buffer time and three hours overtime) then replacement crew will be used to drive the train. The cost of replacement crew is also R840, therefore the cost of replacement crew is equal to the sum (number of incidents where crew waiting time > 15 hours) multiplied by R840.

[4] *Trains that ran the next day*: These are trains that arrive late and/or yard processing results in the train departing the next day.

- The cost of crew scheduled per day = number of trains planned per day multiplied by R840.
- The total number of crew used per day is equal to the replacement crew per day plus scheduled crew per day.
- The cost of crew (daily totals) is equal to the cost of replacement crew plus cost of scheduled crew + cost of overtime per day.
- For the purposes of this research project, time was the unit of measure used to categorise the data, establish assumptions and compare the results with the simulated models' output.
- The rand values used to calculate cost are illustrative and are not the actual hourly rate for normal and overtime. It is against company policy to disclose labour rates to the public.

The data is included in Appendix K.

4 PROBLEM ENTITY AND CONCEPTUAL MODEL DEVELOPMENT

Simulation models are not only used to simulate proposed system theories, but also to develop proposed system theories for existing and non-existent systems. This could include the design of a new system or modification of an existing system (Sargent, 2013).

A simplified adapted three-stage methodology based on Sargent (2013) was used to develop a computerised simulation model of the proposed system theory. The three-stage methodology is illustrated in Figure 1.2. This chapter provides the detail of how each stage was implemented and validated.

The first stage is defining the problem entity or proposed system theory. For this research project, the problem entity was to crew trains without the use of a train plan. The model was thus based on random train departures. According to the literature reviewed, no research was found to have been conducted on crew scheduling for random train departures.

Once the problem entity was defined, it was then translated into a conceptual model. The final step was to program a computerised simulation model of the conceptual model.

The intention of this research project was to explore the behaviour of the problem entity, that is, a crew scheduling model based on an unscheduled railway, since it has not been modelled previously and is not in existence. There is no real world system that crews trains without the use of a schedule and the concept has not been previously modelled. Therefore, this research project was considered exploratory.

Each stage of the model development and validation process was based on an understanding of how the system will be operated, that is, the problem entity or unscheduled railway. The problem entity and conceptual model were each validated and are discussed later in this chapter.

This chapter discusses the first two stages, namely the proposed system theory or problem entity and the conceptual model Furthermore, it discusses the validation methods used to ensure that the proposed system theory or problem entity, the conceptual model are reasonably implemented for their intended purpose.

4.1 Background

In 2007, TFR underwent a process of categorising all railway routes into feeder lines, branch lines, corridors and so on. Corridors were used to transport major revenue generating commodities for domestic or export purposes. The model for this research was developed based on the Natal corridor (Appendix A, Appendix B).

For the purposes of this research project, crew scheduling was modelled between two yards (Figure 4.1). The resource manager confirmed that crew management between two yards is independent of any other yards. The organisational structure and reporting lines within the company supports his view. The yard manager is responsible for the yard and contributes to the decision on how the resources are managed in the respective yard. Yards are independent because they are managed separately and not linked operationally to preceding or subsequent yards. Yards are only linked when trains arrive from one yard and depart to another yard. Variability does not increase as the train moves from the origin to the destination or vice versa. Therefore, the simulation was modelled using two yards. The simulation was used to model crew management between separate sets of yards by changing the input parameters, which are distance, speed and number of trains travelling between the two yards.

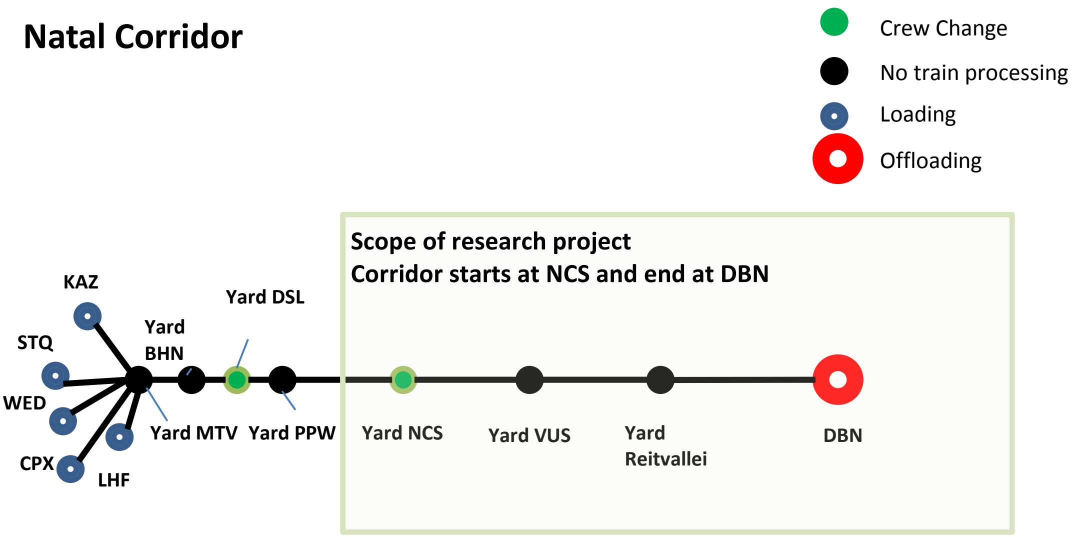

Figure 4.1 Corridor overview (illustrative)

4.2 The Problem Entity or Proposed System Theory

Defining the problem entity and scope is the first step in the process to developing a computerised simulation model. The simulation model, discussed in this chapter, was composed of two elements, namely train operations and crew operations.

4.2.1 Train operations

For the purposes of this research project, train operations were defined as all the activities required to move the train that already has crew from the point of origin to the destination, irrespective of whether the train is loaded or empty. This excluded the assignment of crew to trains in a yard as this research project investigated the impact of a heuristic to improve crew scheduling before the train departs from a yard. As discussed in earlier chapters, TFR aims to operate a scheduled railway. However, for many reasons, which include the low reliability of infrastructure and assets, train operations within TFR currently resemble an unscheduled railway. The variance in the current arrival and departure rates of trains to resemble an unscheduled railway or the random arrival and departure of trains are now analysed and discussed.

Raw 'cleaned' data on the movement of trains was used to establish if there was a relationship between train delays and crew waiting time. The longer the crew wait, the less time they have to drive trains. Furthermore, the data was used to investigate the impact of train delays on crew waiting time. The objective was to illustrate that scheduling crew based on a defined train plan is not reasonable and not what TFR does. For crew scheduling within TFR, it is not sufficient to accommodate for variance in the train plan by incorporating buffer times as discussed by Jutte et al. (2011). In order to minimise delays, the proposal was to minimise crew related operational disruptions, including various buffer times, to accommodate for any changes in the train plan (Jutte, et al., 2011).

Using a box and whisker graph, it was established that trains do not depart according to schedule and a correlation graph, illustrates that this negatively impacted on the crew's available shift time.

Furthermore, the inter arrival and departure times were placed on scatter plot graphs (Figure 4.2 and 4.3)

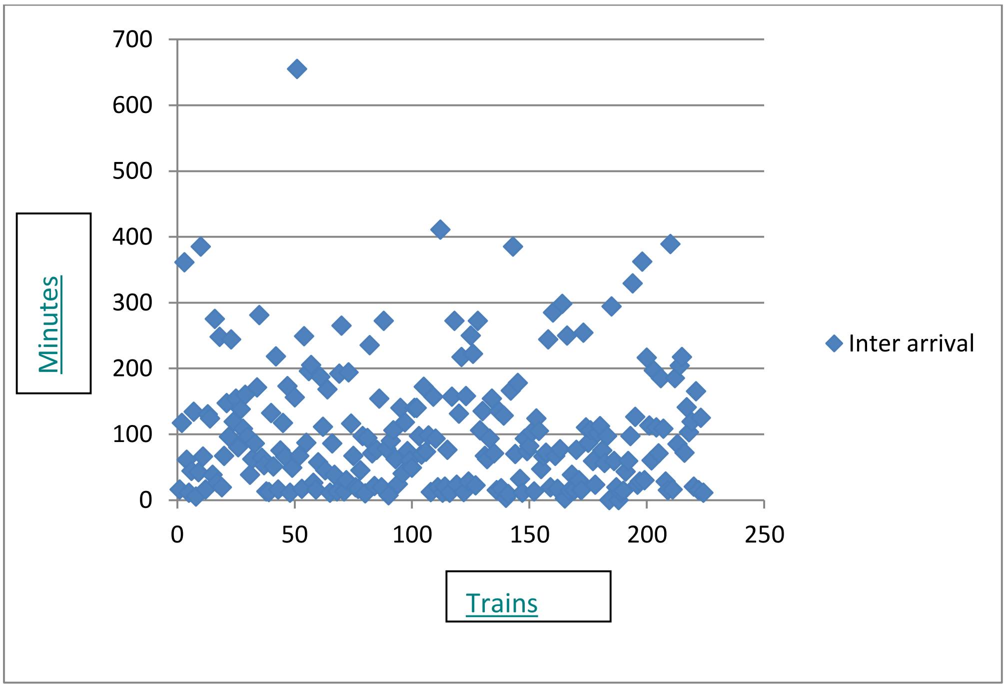

Figure 4.2 Scatter plot graph for inter-arrival times

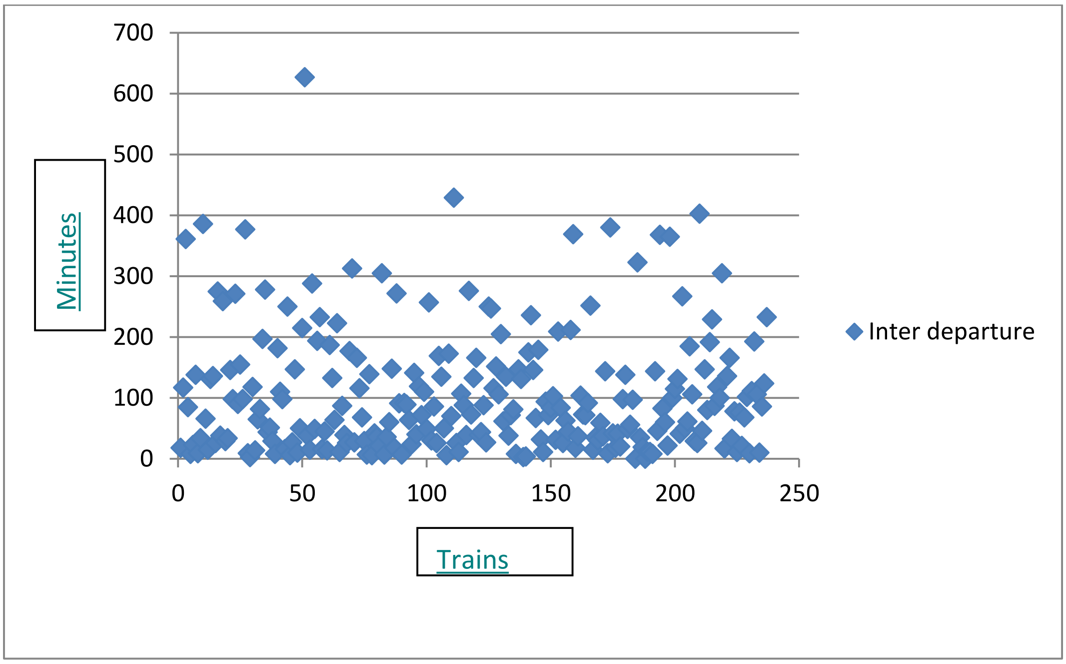

Figure 4.3 Scatter plot graph for inter-departure times

There is no relationship between trains from day 1 to day 17 and the inter-arrival and departure times. This indicates that the arrival and departure times of trains operate randomly. Therefore, the scheduling of crew without the use of a train plan or for random train departures is reasonable.

This section provides detail into the assumptions used to organise the data for analysis. The results of a comparative cost-benefit analysis between the current crew scheduling methodology and the proposed system theory are presented at the end of this section. The comparative analysis not only provided insight into the performance of the proposed system theory, but also the anticipated cost implications of the additional crew. The cost-benefit analysis was important to establish feasibility for management decisions.

The Impact of Train Delays on Crew Scheduling

First, it was established if there is a direct relationship between train delays and crew waiting time and to illustrate this, a correlation graph was used (Figure 4.4). The data used can be found in Appendix G.

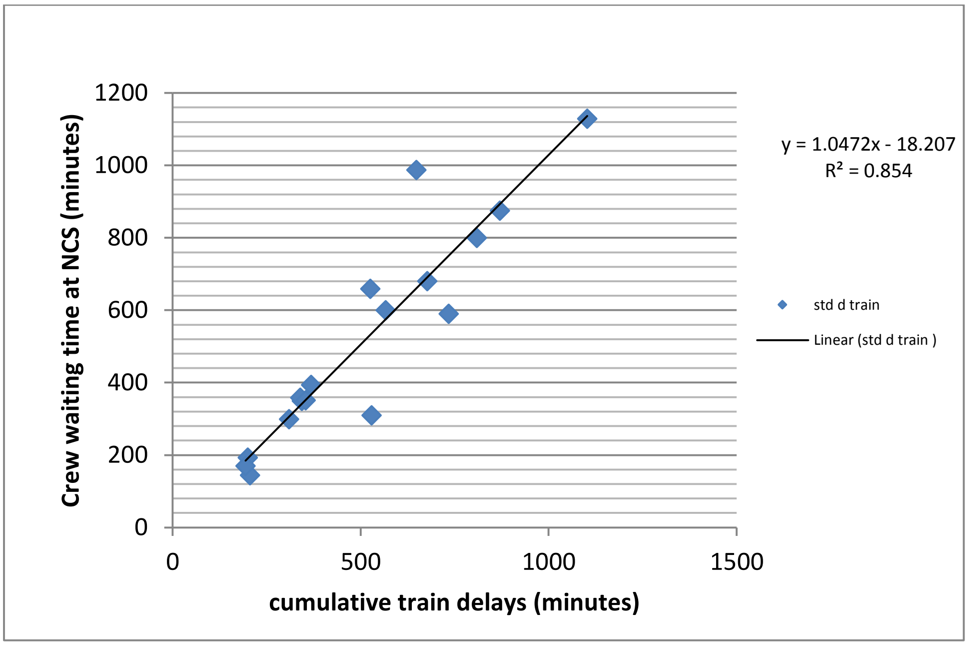

Figure 4.4 Correlation graph between train delays and crew waiting time

All train delays per train, up to arrival at NCS yard, were identified and summed up from the origin. The standard deviation was calculated per day for each of the 17 days.

The crew waiting time per train was identified and calculated, in other words the difference in time between the planned versus actual departure time. The standard deviation was calculated per day for each of the 17 days.

The standard deviations for the cumulative train delays and the crew waiting time were plotted onto the correlation graph to determine whether a relationship existed. The correlation graph does not indicate causality; however, it does indicate a relationship between train delays and crew waiting time. There could be other contributing factors to the waiting time in the yard, for example, the crew arrived late for duty, the train was waiting for a signal to depart, and so on. Further data collection and investigation is required to determine exactly how train delays affect crew waiting time.

Another major uncertainty was to understand the extent of variability between the planned train departure and actual train departure. A box and whisker graph was used (Figure 4.5) to illustrate the minimum, median, maximum and interquartile range for crew waiting time per day. The box and whisker graph was used to eliminate the effect that major outliers have on the data. The raw data is attached at Appendix E and F.

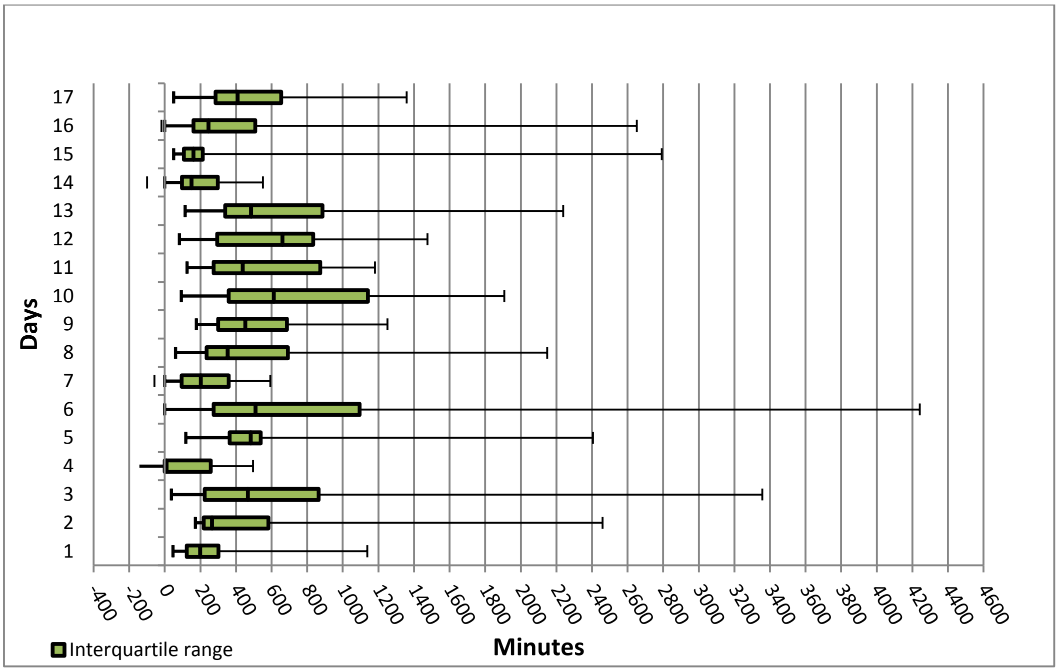

Figure 4.5 Planned versus actual train departure

The variance between the planned and actual train departures indicated that scheduling crew against a train plan is not feasible. Figure 4.5 demonstrates that trains do not depart according to plan. The variability between planned and actual departure times changes daily, preventing any form of feasible planning. Since crew is planned based on a train departure schedule, they incur overtime, being replaced, or having the train cancelled should there not be any crew available.

Assumptions for the Current Situation

This section provides detail on the assumptions used to organise the data on the current situation.

Using the data provided on the current situation, the following was established:

- The number of successful train crew combinations;
- The number of trains that departed the yard; and
- The cost of crew per day.

The following assumptions were made:

- To obtain the number of successful train crew combinations, the number of crew that still had sufficient available time to drive the train within their buffer time was counted per day. This was assuming the crew were on duty as planned. The scope of the simulation does not include assessing the impact of low crew presence on train departures. This allows the simulation outputs to be comparable to the current situation.
- To obtain the number of trains that departed for the day, all trains that departed were counted. However, assumptions were made for crew where successful train crew combinations were not possible. These were:
    - *To obtain the total overtime per day*: It was assumed that a driver can only drive a maximum of three hours over their total available time. The number of hours summed up and multiplied by the Rand value per hour.
    - *To obtain what would constitute replacement crew in the current situation*: If crews' available time exceeded six hours (three hours buffer and three hours overtime) then the crew would need to be replaced. This cost was incorporated into the daily totals. If the train ran on the day planned and the crew waiting time exceeded the six hours then a replacement crew would be used. The cost is allocated to the original planned departure

date. Crew replacement costs for trains that did not depart the yard on the day originally planned for were not considered in the current situation or the simulation.

- *Relief crew*: For trains that are staged/ stopped en route, should there be any deviations, was out of the scope of this research project.

The information contained in Table 4.1 details the number of trains that departed the yard; however, more importantly it details the number of crew planned versus used and the cost associated with the crew resources actually used. The cost included overtime and relief crew as per the assumptions detailed above. Using crew that incurs overtime or is a relief crew is more expensive. This was seen when the daily total cost of crew was compared to the cost as per the crew schedule (train plan).

Validation Process

This information obtained from the analysis (Appendix K) was used as a base to compare or validate the simulation results with respect to crewing requirements and identify any potential improvements.

Table 4.1 Cost analysis of base line current situation

	Planned departure from origin to NCS	Planned departure from NCS	Trains that ran (no roll overs) current	Success -ful train crew combina -tions	Cost of crew for successful train crew combina-tions	Cost of crew for the day as per train schedule	Overtime only (no daily rate included)	Replace-ment crew	Daily totals	Crew planned	Count of replace-ment crew (expired) for the day	Total crew used
Day 1	16	10	6	4	R 3 360	R 8 400	R 3 150	R 0	R 11 550	10	0	10
Day 2	12	11	8	3	R 2 520	R 9 240	R 3 850	R 1 680	R 14 770	11	2	13
Day 3	15	13	8	0	R 0	R 10 920	R 5 075	R 2 520	R 18 515	13	3	16
Day 4	9	15	10	5	R 4 200	R 12 600	R 5 250	R 840	R 18 690	15	1	16
Day 5	13	8	5	3	R 2 520	R 6 720	R 875	R 1 680	R 9 275	8	2	10
Day 6	18	17	10	1	R 840	R 14 280	R 2 625	R 5 040	R 21 945	17	6	23
Day 7	15	14	12	4	R 3 360	R 11 760	R 6 125	R 1 680	R 19 565	14	2	16
Day 8	14	17	12	1	R 840	R 14 280	R 5 075	R 5 040	R 24 395	17	6	23
Day 9	11	12	8	1	R 840	R 10 080	R 4 900	R 3 360	R 18 340	12	4	16
Day 10	15	16	7	1	R 840	R 13 440	R 3 500	R 2 520	R 19 460	16	3	19
Day 11	13	12	6	1	R 840	R 10 080	R 2 800	R 2 520	R 15 400	12	3	15
Day 12	16	13	7	3	R 2 520	R 10 920	R 4 375	R 1 680	R 16 975	13	2	15
Day 13	16	18	9	2	R 1 680	R 15 120	R 0	R 7 560	R 22 680	18	9	27
Day 14	12	16	9	2	R 1 680	R 13 440	R 4 900	R 3 360	R 21 700	16	4	20
Day 15	13	8	7	4	R 3 360	R 6 720	R 4 025	R 0	R 10 745	8	0	8
Day 16	13	14	10	5	R 4 200	R 11 760	R 3 675	R 840	R 16 275	14	1	15
Day 17	17	16	7	4	R 3 360	R 13 440	R 2 800	R 1 680	R 17 920	16	2	18
						R 63 000			R 298 200			

The raw ‘cleaned’ data from TFR, the train arrival, yard processing and train departure rates were further analysed by plotting histograms. Distributions with the best fit were determined (Figure 5.3) and then used in the development of a simulation model for train movements into the yard (Figure 5.7), and then used in the development of a simulation model for train movements into the yard.

The simulation randomly generated trains that will arrive at a yard using an exponential distribution (Figure 5.5). Yard processing varies due to the complexity involved. It was modelled based on a pareto distribution (Figure 5.8). Both these distributions were validated by statistical analyses of actual train data and are discussed in Section 5.1.

The model simulated the movement of trains from the home base to the receiving yard (loaded leg). It also independently simulated trains moving from the receiving yard to the home base (empty leg). The input parameters allowed the specification of trains planned to depart from the home base separately from the number of trains planned to depart from the receiving yard. This exploratory research project investigated the impact of the crewing heuristic on the crewing of trains from the home base to the receiving yard only. To summarise, the following two concepts were important for translating the problem entity or proposed system theory into a conceptual model:

[1] The train operations element was the simulation of train movements based on the existing railway operations within TFR.

[2] The train operations within TFR were reduced in scope to cater only for processes that affect the scheduling of crew. An example of this was yard train processing activities. The actual processing activities were not simulated; however, data collected from TFR was used to establish the distribution of time taken to process trains in a yard (Figure 5.7). This distribution was then fitted to the yard processing stage in the simulation model (Figure 5.8).

4.2.2 Crew operations

Currently within TFR, crew drive trains from origin to destination based on the following three methods. This excludes train movement in the yard or shunting. These are:

1. *Round trip*: Crew move the train from the home train yard to the planned destination yard and return to the home train yard with another train. This was incorporated into the simulation model. The crew can return on a train or a combi.
2. *Book off trip*: Crew move the train from the home train yard to the planned destination yard, stay over and return to the home train yard after a minimum rest period of eight hours. This was excluded from the simulation as if the crew stay over, they are then considered as part of the resource pool for the receiving yard.
3. *Cross point trip*: Two sets of crew move the trains between train yards to a designated point in the system, swap trains and each return to their home train yard with different trains to the ones on which they departed. The points at which the crew change trains is considered a virtual yard and can be simulated by using the correct inputs e.g. distance, number of trains and so on.

The simulation of time passing during yard processing did not provide depth on contributing factors to delays. However, once the train had completed the yard processing then it was ready to be crewed.

During interviews, the resource manager indicated that TFR management do make decisions that affect the movement of trains to reduce cycle times. This means that if trains or crews are delayed, one of the following decisions will be made, depending on the situation:

- If the train delays are not significant, crew could move the train as planned without incurring overtime.
- A driver can incur overtime and drive the train to a point past the planned crew change over point to either the end destination or a

point en route. The train can be stopped anywhere in the system if it does not reach it destination.

- If the train is moved to a point en route, it will be staged while waiting for relief crew to finally move it to the destination point.
- The trains wait for replacement crew or standby crew to move the train to its next destination point.

To summarise, the following two concepts are important for translating the proposed system theory into a conceptual model:

[1] The crew operations element was the crewing of trains without the use of a train plan. Even though TFR has a train plan, trains do not operate according to the plan. They randomly arrive and depart.

[2] Crew scheduling based on random train departures or without the use of a train plan was the proposed system theory. The behaviour of the simulation model for the proposed system theory or idea was explored. The simulation model incorporated a heuristic to crew trains without the use of a train plan or based on random train departures.

These two elements were combined in conceptual and computerised simulation models for this research project. The crewing of trains without a train schedule was considered to be the proposed system theory or problem entity.

4.3 The Conceptual Model

In the development of the conceptual model, scope and principle assumptions were established. Random train departures or scheduling of crew without the use of a train plan was the base principle. This does affect the amount of available time crew have to drive trains. Time cannot be inventoried, hence when the crew available time is less that the time required to drive the train between two points, one of three actions are taken:

1. The crew incurred overtime.
2. Replacement crew is arranged.
3. The train is stopped or staged en route waiting for relief crew.

Of the three options, the last two result in train delays, while all three result in increased costs.

The simulation generated crew to be on duty based on a heuristic that was embedded in the simulation to increase crew coverage, used as and when required.

Figure 4.6 illustrates the basic concept of the conceptual model. The concept was to increase the crew coverage to drive trains from the home depot to the receiving yard. The trains arrived at random and not according to a schedule.

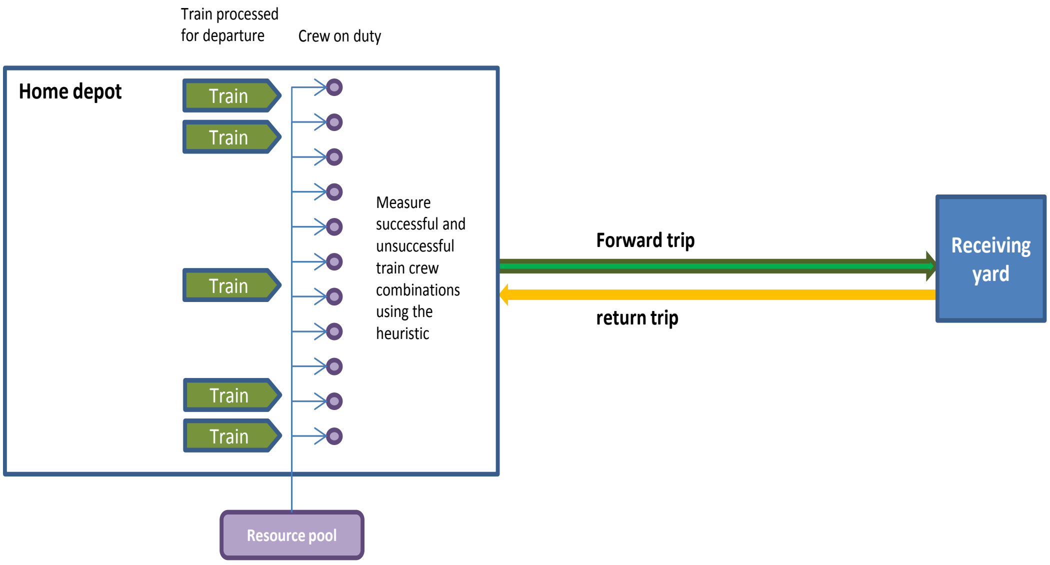

Figure 4.6 Illustration of conceptual model

The assumptions made to isolate the crewing of trains that need to depart randomly from other yard processes were as follows:

- *Exponential distribution for train arrivals at 30-minute intervals:* Trains cannot arrive simultaneously as they share the same infrastructure. This distribution was identified as the best fit after plotting the data into a histogram (Figure 5.5 in Section 5.1).
- *Pareto distribution for yard processing:* This distribution was identified as the best fit after plotting the TFR train data into a histogram (Figure 5.8 in Section 5.1).
- Infinite crew capacity at the departing yards was incorporated into the simulation model.
- Source randomly generated trains based on the number of trains required for the day as determined by the ITP.
- The ITP scheduled train departure times were not considered.
- The train movement method, which is either a book off train, cross point or a turnaround crew, was not considered. For all situations, the destination is the end point and crew either returned on a train or via road in a mini-bus/Kombi.
- In the simulation model, crew worked a maximum of 12 hours as per the working conditions stipulated in their contracts. TFR prefers to not exceed the 12-hour shifts to reduce the risk of loss of life and damage to equipment due to exhaustion.

As with Godwin et al. (2008), the conceptual model of simulation was broken up into two phases:

4.3.1 Phase 1: Initialisation

- Input variables, distance and speed, were used to calculate the time required to move the train between defined points.
- The total available time the crew has when they sign onto a shift is calculated as 12 hours, one hour admin time, which left 11 hours' drive time.
- The available time was subtracted from the time required to drive the train between the two defined points, which calculated the

buffer time. Buffer time is defined as the amount of time the crew has available before the time required to drive a train between two points exceeds their available time. For example, if a train crew has 12 hours duty, with a total of one hour admin time, a total amount of 11 hours available for drive time. Then there is a two hour buffer time if the driving time is nine hours.

- The input variable number of trains was used to specify the number of trains that must be generated at and depart from the specified home base. The number of trains and the buffer time was used to determine which crew scheduling option was implemented as defined below:
  - *Option 1*: The number of crew should be the same as the number of trains if the number of trains is equal to the number of slots. Slots are segments of time that a train can occupy a section of railway line. Slots are defined based on how long it takes to drive the longest section of rail between two signals. Slots are usually defined at 30 minute intervals; or
  - *Option 2*: Crew cannot be used to drive trains if the available time left is less than the drive time as there is insufficient capacity. If the number of trains is less than the number of slots then the calculation used to calculate when crews come on duty is one of the two following scenarios:
    - *Option 2a*: if the number of trains that should depart from the yard is less than an individual crews available buffer time, then crew should be planned to be on duty at the buffer time intervals. For example if there are four trains every 24 hours, drive time is nine hours, therefore buffer time is two hours, crew should be on duty every two hours, which means a total of 12 crew; or
    - *Option 2b*: If the number of trains that should depart from the yard is more than the number of crew needed, it should be based on the buffer time calculations. For example there

are 14 trains every 24 hours, which means the 12 crew in the example above will not be sufficient. The calculation for planning crew should be 24 hours divided by the number of trains, 14, therefore the crew should be on duty every 102 minutes or 1.7 hours (as long as it is less than the buffer time).

- If the time required to drive the train between two points, exceeds the crew available time then the standby crew is specified to ensure that should bunching occur, crew is available immediately to man the train with a 30-minute interval for signing on.

An example of the heuristic is illustrated in Figure 4.7.

4.3.2 Phase 2: Crew scheduling (The proposed system theory)

From the initialisation stage, a schedule for crew coverage was established to ensure that there is always crew available at specified intervals as opposed to being planned based on a train schedule.

A source randomly generated trains based on an exponential distribution of train arrivals as obtained from real data. The train was then processed in the yard using a general pareto distribution, also obtained from real data.

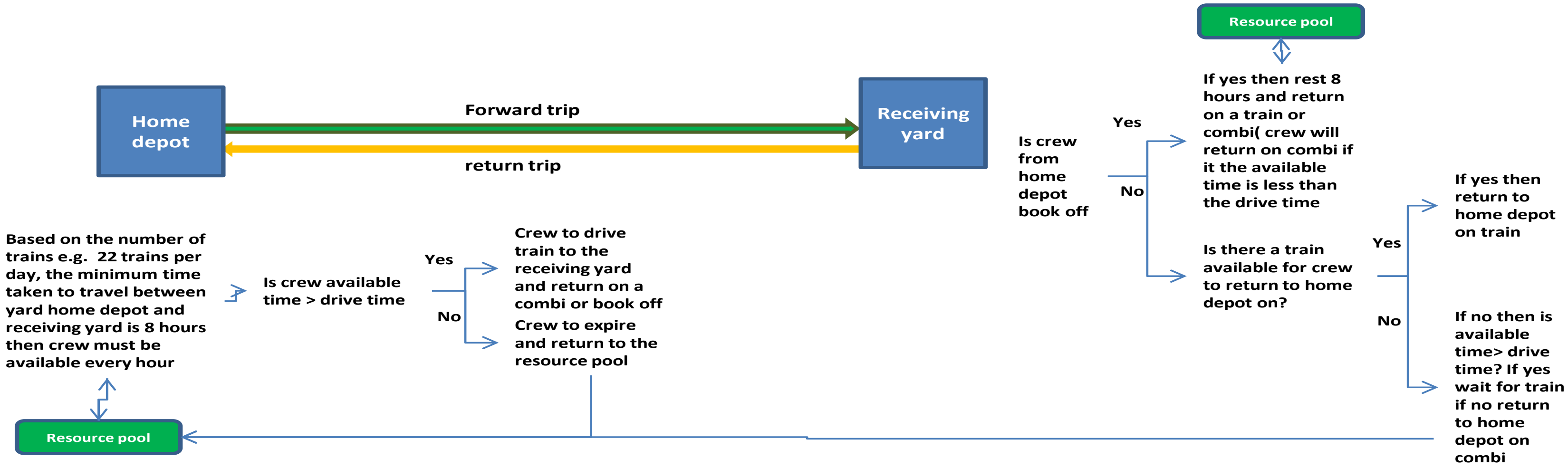

Figure 4.7 Conceptual model including detail on heuristic

When the train was released from yard processing, it needed to combine with crew. The simulation defined the combinations according to the following:

- *Successful combinations*: when the train/crew combination takes place without the train waiting before departing.
- *Unsuccessful combinations*: when the train waits for crew before departing.
- *Still in yard*: the train has not been released from yard processing; this could be due to asset and/or infrastructure failures.

Performance measures for assessing the impact of running the simulation were as follows:

- *Number of successful train crew combinations*: The train and crew combine without the train waiting for crew. The number of successful train crew combinations are counted, any improvements would result in an increased number of orders delivered per day.
- *Number of orders delivered per day*: The number of orders delivered to their destination per day, as any increase in the throughput will increase TFR's revenue (Godwin, et al., 2008). The number of trains that depart from the home depot.
- *Crew utilisation*: Calculated as a percentage of crew used to drive trains in a day. This measure measures the number of crew utilised relative to the number of trains per day. i.e. number of crew on shift divided by the number of trains that departed from the yard (Godwin, et al., 2008).

4.3.3 Conceptual model validity

Using Sargent's (2013) model development process, the conceptual model needed to be validated. This was done to ensure that the underlying theories and assumptions were correct and the models' representation of the problem entity was 'reasonable' for its intended purpose. The current resource manager and the recently retired Chief Operations Officer of TFR validated the model and if its behaviour was ‘reasonable’ for its intended purpose. The conceptual model was designed and presented to them for validation. Both individuals reviewed the conceptual model in detail and stated that the scope and assumptions contained in the model were valid for its purpose. They each had the opportunity to discuss and ask questions. A detailed explanation of the process of how the simulation operates was given to them. This explanation is provided later in this chapter. Furthermore, the theory to increase crew coverage using a heuristic to cater for high and low train traffic through yards is reasonable.

5 THE COMPUTERISED MODEL

The conceptual model was programmed into a computerised model. This chapter provides detail on the programming and the validation of the computerised model.

As mentioned in Chapter 4, each stage of the model development and validation process is based on an understanding of how the system will be operated, that is, the problem entity or unscheduled railway. However, it is for the reasons mentioned previously, that is, that there is no current real world situation of train crewing for unscheduled trains, that the computerised simulation model of crew scheduling, without the use of a train plan, could not be validated.

The Experimental Validation of the computerised becomes a challenge whereby Sargent (2013) states that:

> "Proposed system theories are developed from an understanding of how such a system will operate [In the case of this research, as an unscheduled railway]. They cannot be validated because the system does not exist on which to conduct experiments. If the proposed system theories cannot be validated, they remain as proposed system theories" (p. 16).

Simulation software package AnyLogic 6.6.0 was used to develop the simulation. This package was chosen as it was available to be used by the university students and supported the common simulation methodologies e.g. discrete event simulation. The graphical interface, tools and library objects allowed for modelling diverse areas, e.g. railway operations. Furthermore, technical support was also more easily available than other simulation software packages in South Africa (AnyLogic, 2012).

Appendix L consists of a full technical description of the model and the components. Figure 5.1 contains a description of the main page and the relevant objects.

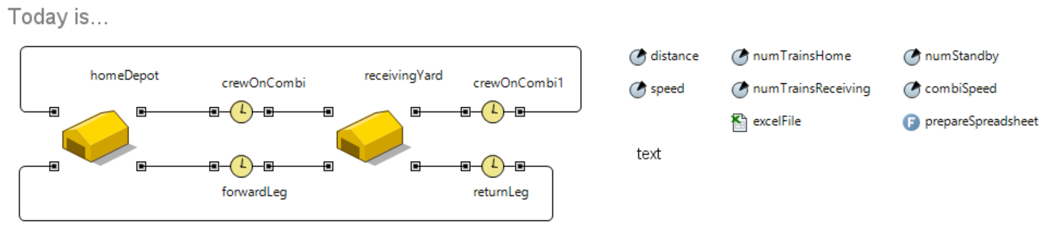

Figure 5.1 AnyLogic's main screen

(AnyLogic, 2012)

There were two yard objects; namely:

[1] homeDepot (p. 4/37 of Appendix L); and
[2] receivingYard (p. 4/37 of Appendix L).

Trains moved from the homeDepot to the receivingYard and vice versa. A train that moved from the homeDepot to the receivingYard was the loaded leg, and the wagons are off loaded at the destination (p. 3/37 of Appendix L). A train that moved from the receivingYard to the homeDepot was the empty leg and the wagons were loaded at the origin points (p. 3/37 of Appendix L).

Crews that drive the trains between the two yards had two options to return to their home base, i.e. the yard in which they boarded the train. Depending on how much available time is left, crew could return to their home base on a train, if available, or in a mini bus/Kombi.

The parameters used to establish the homeDepot and receivingYard constraints were (p. 1&2/37 of Appendix L):

- Distance between yards.
- Speed of trains travelling.
- Number of trains planned to depart from homeDepot.
- Number of trains planned to depart from the receivingYard.
- Number of standby crew.
- Kombi speed.

By changing the distance and number of trains, different combinations of yards can be simulated.

The function preparespreadsheet (p. 2/37 of Appendix L) and excel file was used to download the results of each simulation run. The data was used to analyse the impact of the heuristic and compare the results to the performance of TFR.

The logic that was programmed for the receivingYard and homeDepot objects was in the yard processing page of the simulation model. Figure 5.2 provides a full description of the logic and the objects.

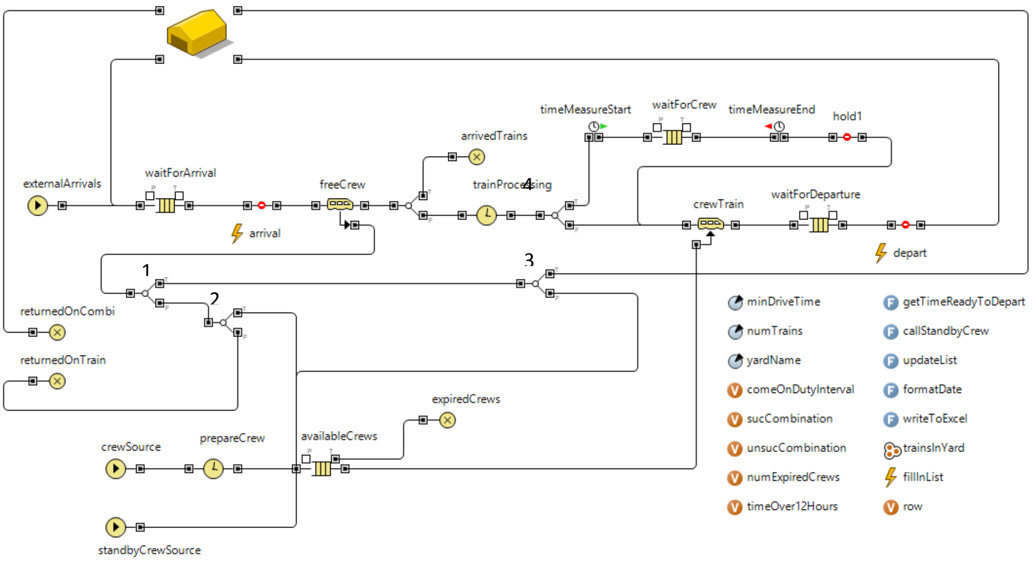

Figure 5.2 Yard processing activities

The same yard processing activities were executed for the homeDepot and receivingYard separately and independently. This was because the same assumptions and rules apply to both yard objects. However, as discussed previously the research investigated the simulation model based on the movement of trains from the home depot to the receiving yard only and therefore only the homeDepot is discussed further.

The parameters, namely, minDriveTime, numTrains and yardName defined the input types (p. 7/37 of Appendix L).

The functions are described below:

- *getTimeReadyToDepart (p. 7/37 of Appendix L):* This function calculated the amount of time a train waited after processing was complete.
- *callStandbyCrew (p. 8/37 of Appendix L):* This function contained the logic used when standby crew was called to drive the train from origin to destination.
- *updateList (p. 8/37 of Appendix L):* Defined how and when the data was updated for each simulation run.
- *formatDate (p. 8/37 of Appendix L):* Defined how the dates need to be presented for the comparative analysis between the simulation output and the data received from TFR.
- *writeToExcel (p. 9/37 of Appendix L):* Described what information was downloaded into excel after each simulation run.

The event fillInlist (p. 9/37 of Appendix L) was used to schedule when the data must be presented in the simulation. The event was scheduled to take place after each simulation run or when the simulation was timed out.

The variable types were defined per variable. However, the variable comeOnDutyInterval (p. 10/37 of Appendix L) was used to define when crew must come on duty as per the heuristic.

A full description of the objects logic is provided below:

- *externalArrivals (p. 11/37 of Appendix L):* This object generated trains to enter a yard. It used an exponential distribution using the parameters obtained from the histograms of the data received from TFR. The mean used to define the inter-arrival times was 93 minutes. The mean was calculated from the data received from TFR;

- *waitForArrival (p. 14/37 of Appendix L):* Once trains were generated, they entered into the queue 'WaitForArrival'. This was to simulate how the trains enter the yard. Due to the current set up of the infrastructure in South Africa, multiple trains cannot enter a train yard simultaneously. Trains need to enter the yard one at a time;
- *Arrival (p. 9/37 of Appendix L):* This object spaced out the arrival of trains i.e. trains enter a yard 30 minutes apart. This time was to cater for the movement of trains in the yard and other yard processing activities required. This does not happen in TFR. Trains arrive at any interval. The intention of applying a 30 slot was to stabilise the system, as the system cannot make management decisions on when is it okay to accept a train in less than 30 minutes or not.
- *freeCrew (p. 15/37 of Appendix L):* Once the train arrived in the yard, the crew disembarked from the train. The train proceeded to be processed and the crew either returned to their originating yard on a train or in a mini bus/Kombi.

After entering the yard, the logic of the train movements was as follows:

- *selectOutput (p. 15/37 of Appendix L):* This object determined if the crew arrived from another yard or was generated in the respective yard. If the train arrived from another yard it moved to the arrivedTrains sink, otherwise it moved onto the trainProcessing object.
- *arrivedTrains (p. 19/37 of Appendix L):* Trains that arrived from either the homeDepot or the receivingYard terminated at this object. The scope of this simulation did not track the processing and departure activities of trains that arrived from the preceding yard. The scope of this simulation was between the two specified yards.
- *TrainProcessing (p. 12/37 of Appendix L):* Trains that were generated from the externalArrivals (p. 11/37 of Appendix L) source object were then processed using the pareto distribution with a minimum of six minutes and a maximum of eight hours to process a train. The shape

parameter of K = 0.37565 was used to define the pareto distribution. The shape parameter was obtained from the probability density function graph of the data received from TFR. The mean of $\mu = 3.6931$ was also obtained from the probability density function graph and was compared to the simulation output data to validate the distribution applied to the yard processing activities.

- *selectOutput 4 (p. 18/37 of Appendix L):* Once the processing activities were completed, selectOuput 4 determined if there was crew available in the availableCrews (p. 13/37 of Appendix L) queue.

If there was no crew in the availableCrews queue then the following took place:

- timeMeasureStart (p. 17/37 of Appendix L) calculated the train waiting time until a crew becomes available.
- The trains enter into a waitForCrew (p. 16/37 of Appendix L) queue as there was no prioritisation applied to this simulation model; it was purely based on first come first serve principles.
- When crew did become available the timeMeasureEnd (p. 17/37 of Appendix L) stopped calculating the waiting time.
- The Hold (p. 16/37 of Appendix L) object counted the event as an unsuccessful train crew combination as the train had to wait for the crew to become available.
- *crewTrain (p. 13/37 of Appendix L):* This object combined the crew and the train. Train crew combinations were either successful i.e. when crew was available and the train did not need to wait, or was unsuccessful i.e. if the train had to wait for crew.
- *waitForDeparture (p. 14/37 of Appendix L):* Trains then waited for departure. Based on the current infrastructure constraints, two trains cannot travel in the same section of track at the same time. This is to prevent derailments and collisions. Trains therefore departed in 30 minutes intervals.

- *Depart (p. 9/37 of Appendix L):* The train departed from the yard and moved to the next yard. Because trains travel in both directions, the homeDepot and the receivingYard both generate trains to depart to each other.

The logic of the crew scheduling in the simulation was as follows:

- *selectOutput 1 (p. 17/37 of Appendix L):* The crew was dropped off after the train arrived in the yard, selectOutput 1 defined the two options available for crew to return to the home base.
- *selectOutput 2 (p. 17/37 of Appendix L):* If the crew did not originate from the respective yard, then selectOutput 2 checked the available time left for the crew. If the available time was less than the amount of time taken to drive the train back to their originating yard, then the crew returned in a mini bus/Kombi. While the simulated scenario for this research project was based on an eight-hour drive, the simulation condition allowed the user to simulate different scenarios using different drive times. If there was sufficient drive time available then the crew formed part of the available crew queue to return on a train.
  - *selectOutput 3 (p. 18/37 of Appendix L):* If the crew did not originate from the respective yard, then selectOutput 3 checked the available time left for the crew. If the available time was sufficient to drive back on a train to their originating yard, then the crew returned on a train. While the simulated scenario for this research project was based on an eight-hour drive time, the simulation condition allowed for different scenarios using different drive times to be simulated. If there was sufficient drive time available then the crew formed part of the available crew queue. Further detail on what took place with the crew, whether they return in a mini bus/Kombi or on a train, was not simulated. The crew was directed to the sink objects where they are counted.
- *CrewSource (p. 12/37 of Appendix L):* Generated crew based on the input parameters. Using the input parameters, the simulation used the

heuristic to determine how crew should come on duty over a period of 24 hours. This object calculated the amount of available time a crew had to drive a train between the origin and destination points after an hour of administration. The amount of available time for crew changes depended on the drive time between the origin and destination points.

- *StandbyCrewSource (p. 20/37 of Appendix L):* This object generated crew to be injected into the availableCrews queue if more than one train completed their yard processing activities almost simultaneously and there would be no crew if the train had to wait longer than the interval between crews coming on duty. If three trains were completed then the first train would be crewed, the second train would wait for the next scheduled crew but the third train would need to use a standby crew because the time taken to wait for the next crew would be double that of the second train. The maximum amount of train waiting time was the interval between the crews coming on duty.
- *prepareCrew (p. 16/37 of Appendix L):* Once the crew was generated, they needed to perform administrative activities e.g. signing on before becoming available to drive a train. These activities currently take a maximum of 30 minutes, therefore the simulation also allowed for 30 minutes preparation using this object;
- *availableCrews (p. 13/37 of Appendix L):* All crews with available time to drive a train between yards entered a queue. The reason for a queue was because of the principle of the first to expire was the first out. The queue was therefore organised so that crew with the least available shift time will be the first in the queue to drive a train. The rest will wait until a train arrives or they run out of available shift time. Crews expired when their waiting time exceeded their buffer time, i.e. Total time available less Drive time between yard is equal to buffer time. The principle was that, once waiting time exceeded the crew buffer time they would not have sufficient time available to drive a train between yards. If they did then they would incur overtime.

- *expiredCrews (p. 18/37 of Appendix L):* Once the crews waiting time exceeded their buffer time then they immediately moved into a sink. A resource pool with a definitive capacity was not used, as the scope of this research project was not to determine the optimum size of the resource pool.

5.1 Computerised model validation and verification

Validation and verification of the computerised model was based on the following techniques, as described in Sargent (2013):

- Historical data validity.
- Extreme condition test (verification).
- Expert review (verification).
- Simulation fidelity(verification).
- Experimental Validation.

Historical data validation

Historical raw data was used to develop the model. The distribution for the inter-arrival rates, yard processing times and inter-departure times were developed using the data received from TFR. The simulation model output data of train movements for the computerised model was used to determine whether the train movements in the computerised model behaved as the current train movement system, in TFR, does. A comparison of the inter-arrival and departure times between the computerised model and the current train movement system in TFR is demonstrated in Section 5.4. The data was plotted and the distributions compared (Sargent, 2013).

As done by Godwin et al. (2008), actual data (found in Appendix D) was used to validate input data and establish distributions that would simulate reality. The random sample of 17 days of train data was used to develop the probability distribution functions, details to follow. A TFR data capturer collected the data manually.

Furthermore, goodness of fit tests were used to determine how closely observed data represented a particular distribution (Griffiths, 2009).

This section compares the goodness of fit for the distributions established statistically from the data received from TFR with the simulation output data.

Probability density function and goodness of fit using data received from TFR. The raw ‘cleaned’ data received from TFR was used to establish that the distributions developed statistically and used as input to the simulation model resembled a close approximation of the train system currently operates in TFR

Probability density function of TFR data on train inter-arrival times. Data received from TFR on train inter-arrival times (raw data at Appendix I) were plotted in a histogram (Figure 5.3) to establish the distribution to be used for the generation of random train arrival rates. The distribution displayed was an exponential distribution and has been applied to the model (Godwin, et al., 2008). The mean parameter of 93 minutes was specified in the simulation coding. The mean included 25 percent of inter-arrival times that were under 30 minutes. This was indicative of trains in the same section of the railway line queuing outside the yard, ready to enter the yard.

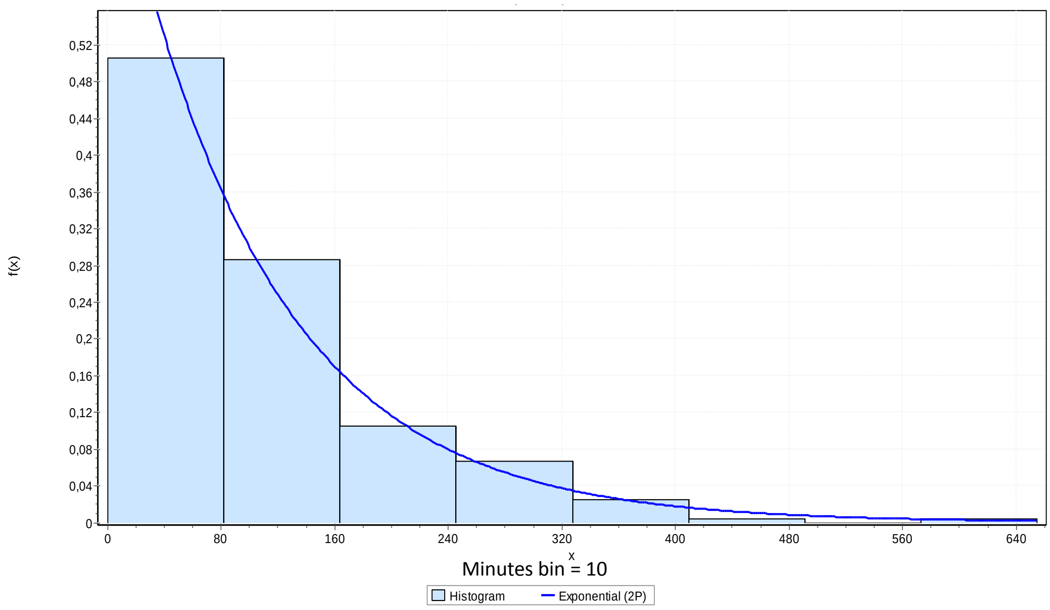

Figure 5.3 Train inter-arrival time's probability function

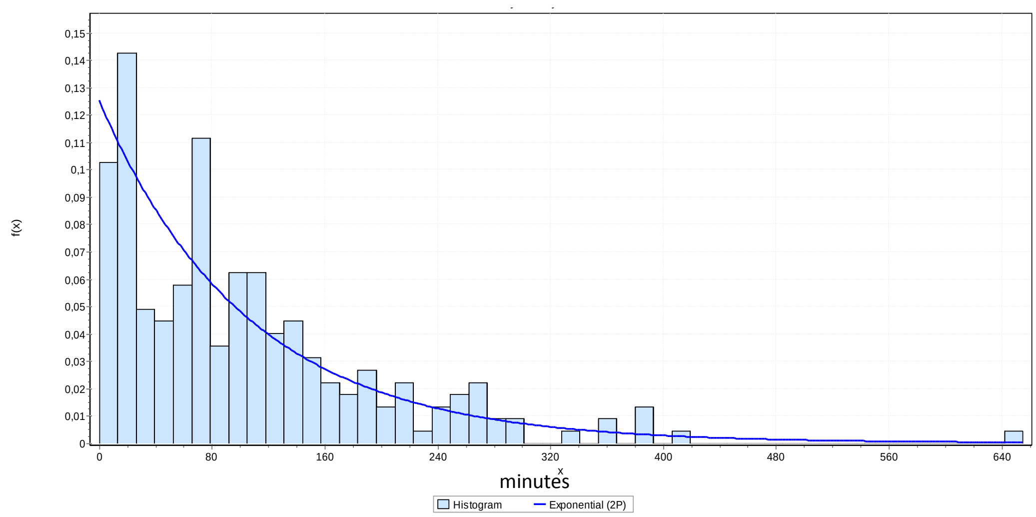

Figure 5.4 Reduced inter-arrival time's probability function

In order to validate that the probability density function graph is not asymptotic, the bin sizes were reduced to illustrate that the graph does in fact intersect the y-axis at 0.124 when x=0 (See Figure 5.4).

In order to test the goodness of fit for the probability functions for inter-arrival times, a statistical software package called Easyfit was used (Easyfit, 2012).

The three-parameter gamma distribution parameters were used to determine the validity of using an exponential distribution for inter-arrival times because of their flexibility in analysing skewed data. Gupta, Zeng and Wu (2010) state that when the shape parameter is equal to 1, the distribution reduces to an exponential distribution.

An exponential distribution was used in the simulation for inter arrival times. With the shape factor K = 0.997 the assumption of an exponential distribution was valid.

Probability density function of simulation output data. The simulation was repeated 17 times according to the data received from TFR with the same number of trains planned. The data output of the simulation was then used to establish if the model applied the specified distributions. The program Easyfit 5.5 was used to plot the data into the histogram and establish the goodness of fit (Easyfit, 2012).

Train inter-arrival times (raw data at Appendix M) were plotted into a histogram (Figure 5.5) to validate the distribution used in the simulation. The distributions resembled an exponential distribution, which was aligned with the distribution established from the data obtained from TFR for the inter-arrival times of trains.

TFR currently does not apply a rule that requires trains to enter a yard every 30 minutes. If a yard is blocked or cannot receive more trains means that the trains must wait on the track until one or more trains depart from the yard. The simulation model applied a rule that required trains to enter a yard every 30 minutes. The simulation calculated yard capacity, which was reduced according to how long trains stay in the yard; however, it did not incorporate rules blocked yards. The mean parameter was 207 minutes for simulation inter-arrival times. The mean from the simulation output data was different and not comparable to the specified mean of 93 minutes from the statistically modelled TFR data because:

- The waitForArrival object directed trains into a queue, which would result in a train waiting a minimum of 30 minutes to enter the yard depending on the trains' position in the queue.
- The Arrival object strictly enforced the rule that trains must arrive 30 minutes apart.

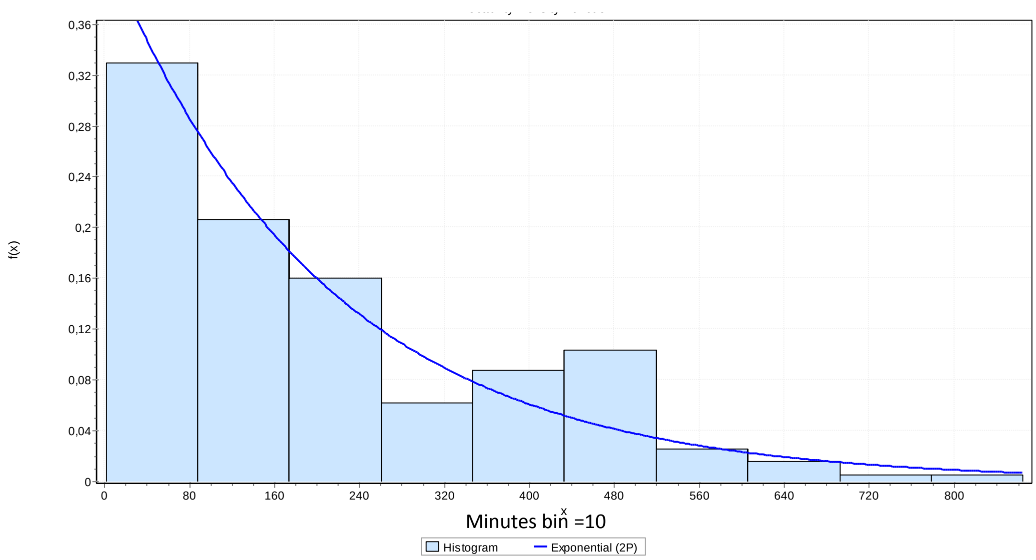

Figure 5.5 Probability density function for simulation data output for inter arrival times

Gupta, Zeng and Wu (2010) state that when the shape parameter is equal to 1, then the distribution reduces to an exponential distribution. The skewedness of the graph with K = 0.960, which is close to one, is indicative of an exponential distribution. This confirmed that the model had applied an exponential distribution to the inter-arrival times of trains.

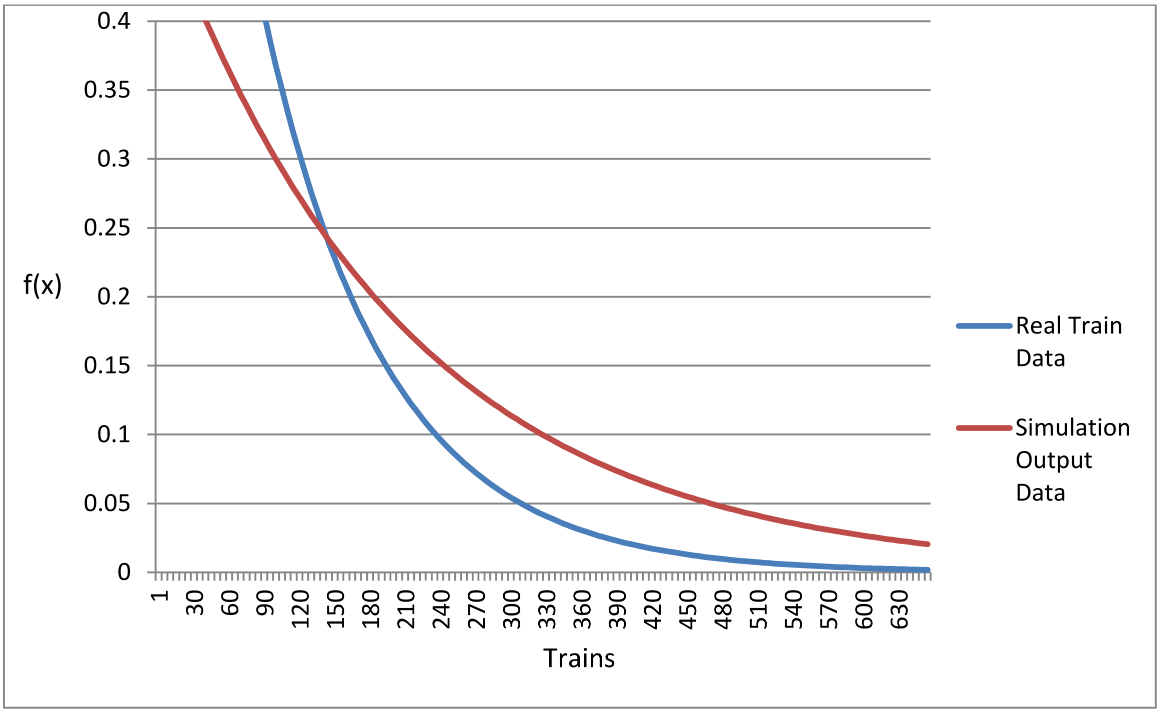

Figure 5.6 Probability Density Function for the inter-arrival times

The probability density function curves were incorporated into a single graph illustrating the difference between the Real Train data and the Simulation Output data. The differences were a result of the parameters applied in the simulation model as discussed above.

Probability density function of TFR data on yard processing times. As with Godwin et al. (2008), yard processing times (raw data at Appendix J) were plotted in a histogram (Figure 5.6) to establish the distribution to be used for the generation of train processing times. The distribution displayed was a general pareto distribution and were applied to the model. A general pareto distribution was used in the simulation for yard processing times. In order to stabilise the process the outliers ranging from 104 to 1 170 minutes (28 instances) were removed from the data set. Even though these trains are considered outliers, they were included as part of the simulation as one of the trains that arrived in the yard and therefore must depart. The total number of trains that arrived in the yard for processing according to the real world data is the same number of trains inputted into the system. The outliers were excluded from analysis only to avoid distortions.

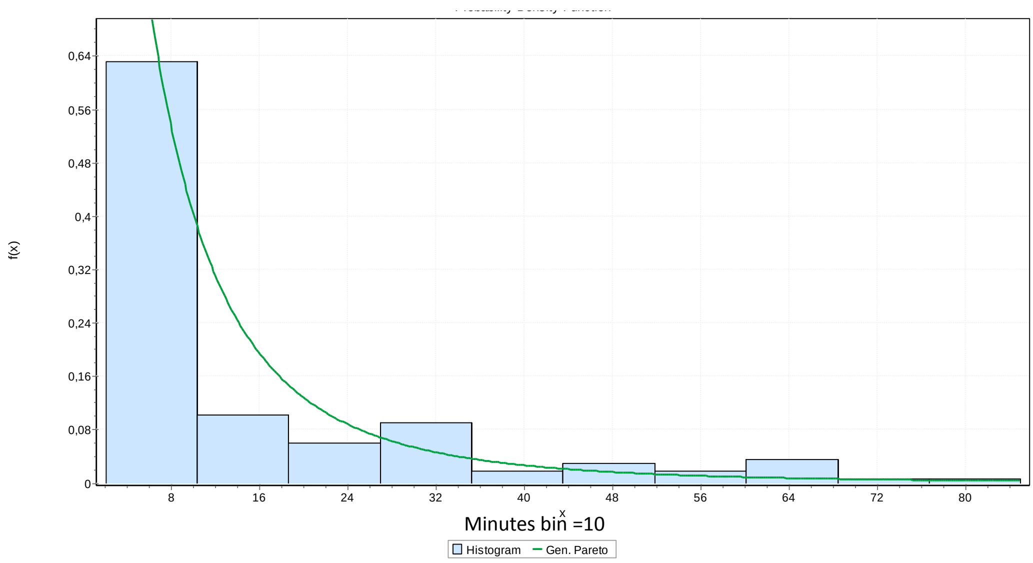

Figure 5.7 Yard processing times probability function

In order to validate that the probability density function graph is asymptotic, the view was expanded and the bin sizes were reduced to illustrate that the graph does not intersect the y-axis or the x-axis. A general pareto probability density function is J in shape and asymptotic with both orthogonal axes.

The data in Appendix J does not have any zero values for yard processing times. However, there are values that are less than 10 minutes. This could have been because of management decisions not to stop the train for a crew changeover but, rather to receive the train and immediately depart the train from the yard including the crew with which the train arrived.

Furthermore, data received from TFR in Appendix J indicated that the minimum and maximum number of minutes taken to process a train was two minutes and 1 170 minutes respectively. In order to establish the shape parameter used in the simulation model, 22 instances/values between 104 minutes and 1 170 minutes were removed as they were identified by the resource manager to be once-off, extreme values that depict unplanned incidents resulting in delays and therefore should not form part of the data set. Using the statistical software package, Easyfit (2012), the shape parameter for the general pareto distribution was K = 0, 375 and μ= 3.693. The shape parameter, minimum and maximum processing minutes were used to define the pareto distribution in the AnyLogic simulation model (AnyLogic, 2012).

Using the Kolmogorov Smirnov test in Easyfit (2012), the general pareto with a test statistic of 0.147, the goodness of fit test was ranked third. The distributions were ranked by the software for easy reference. The Kolmogorov Smirnov test for goodness of fit was used because it compares a sample set of data with a reference probability distribution. The goodness of fit outcome indicated that the assumption to use general pareto is valid for yard processing.

Probability density function of simulation output data. The general pareto distribution in the simulation model was specified with the following parameters; shape parameter K = 0.375 with the minimum and maximum number of minutes taken to process a train specified as 6 minutes and 480 minutes respectively.

The resource manager indicated that the minimum amount of time to process a train should be six minutes because of the following two reasons:

- Crew changeovers could take place within six minutes, if certain steps in the changeover process were eliminated. The resource manager indicated that one step that could be eliminated was to sign off and on in the crew journal when the train is stopped. Data on which steps are followed and which are not, is not recorded.
- The simulation should exclude data that would indicate any management decisions to not change crew, as the simulation model was not designed to include or analyse management decisions of such a nature (Appendix A, Appendix B).

The resource manager further requested that the maximum amount of time should be specified as 480 minutes because the model must be able to simulate exceptional incidents and delays. The maximum of 480 was a reasonable amount of time to standardise on, instead of 1 170 minutes.

The simulation was repeated 17 times, according to the data received from TFR, with the same number of trains planned. The data output of the simulation was then used to establish if the model applied the distributions specified in the model. The program Easyfit 5.5 was used to plot the data into a histogram and establish the goodness of fit (Easyfit, 2012).

Following the same procedure as the data from TFR; the simulation data was consolidated and outliers from the simulation data output ranging from 104 minutes to 480 minutes were removed from the data set in order to stabilise the process. Thirty-eight instances/values were removed from the data set used for analysis. However, it must be clear that the number of trains that planned to run in TFR was the same number used in the simulation. Only the extreme values from TFR read data were excluded from the analysis. This process was applied to the simulation output data to standardise the treatment of data in order to establish the distribution using the probability density function and comparative parameters.

The yard processing times (raw data at Appendix M) were plotted into a histogram (Figure 5.8) to validate the distribution used in the simulation.

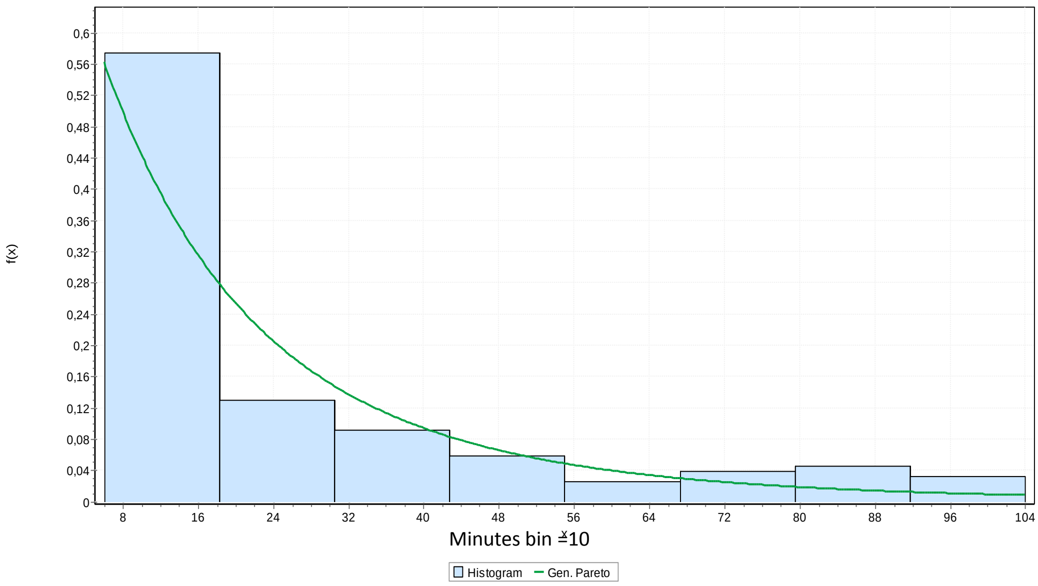

Figure 5.8 Yard processing times frequency distribution function

The shape parameter for the general pareto probability density function graph in Figure 5.8 is K = 0.176 which closely resemble the shape parameter K = 0.375 that was used to define the pareto distribution in the simulation model. Both shape test statistics were that of a pareto probability density function. As the sample set of simulation output data increased, the shape factor gets closer to the shape factor of the real data.

Furthermore µ = 3.859 from the simulation output data closely resembled the µ parameter from the data received from TFR, which is µ = 3.693.

Using the Kolmogorov Smirnov test in Easyfit (2012), the general pareto with a test statistic of 0.110 from the simulation output data which closely resembles the test statistic from the goodness of fit test established from the data received from TFR, 0.147.

This indicates that the assumption to use general pareto was applied in the yard processing stage of the simulation model.

Extreme condition test

Feinstein and Cannon (2001) describe simulation verification as the process of ensuring that the model is operating as intended. The method employed was testing the model using extreme values and evaluating the outcomes.

- *Scenario 1: One train for the day:* The model was run with one train for the day; the result was one successful train crew combination with six expired crews. The simulation implemented option 2a of the heuristic defined in Section 4.2.1, whereby the crew available time was three hours that resulted in seven crews being planned for the day.
- *Scenario 2: 24 trains for the day:* The model was run with 24 trains for the day; the result was 16 successful train crew combinations, zero unsuccessful, and nine expired crew. The simulation implemented option 2b of the heuristic defined in Section 4.2.1, whereby the crew schedule was defined by the 24 trains per 24 hours and was therefore on duty every hour. Eight trains remained in the yard representative of processing times or the yard being blocked.
- *Scenario 3: 48 trains for the day:* The model was run with 48 trains equal to the number of slots for the day; the result was 34 successful train crew combinations, zero unsuccessful train crew combinations and ten expired crew. The simulation implemented option 1 of the heuristic defined in Section 4.2.1, whereby the crew were scheduled to be on duty every 30 minutes. Fourteen trains remained in the yard representative of processing times or the yard being blocked.

The output of all three scenarios provided the information required to calculate the key performance indicators required for comparison with the current situation.

Expert review

Simulation programming experts from the AnyLogic technical team assisted with validating the logic of the computerised model. This was done to ensure that from a technical perspective the logic and implementation of the conceptual model was reasonable for its intended purpose. Conversations were held telephonically as working sessions and not captured as an interview.

Simulation fidelity

Feinstein and Cannon (2001) define fidelity as the level of realism that a simulation presents. This is divided into physical (for example, visual) and functional (for example, stimulus) characteristics (Feinstein & Cannon, 2001).

The simulation had input fields to simulate the movement of trains between yards. The physical characteristics of simulating the movement of trains between yards are described below:

- Distance between yards.
- Drive speeds, changed from time to time when there are speed restrictions between yards.
- Distance and speed, used to calculate the time taken to drive from one yard to the next.

Experimental Validation

As mentioned earlier, the computerised simulation model was not validated experimentally because there is no real world data available for this purpose. Additionally, no comparative simulation model could be located that may be used to validate the developed model.

5.2 Operational Validity-Subjective Approach to Validate a Non-observable System (Sargent, 2013)

5.2.1 Expert review

The simulation and the underlying assumptions were presented to the recently retired COO, with 40 years' experience in the field of railway operations in Europe, South Africa and other countries in a skype call on 29 November 2013. It was concluded that for the intended purpose, the scope, assumptions and results of the simulation was reasonable.

The feedback received was that the simulation does prove that by increasing coverage of crew in a yard, revenue increases. Generally, research into this area of rail logistics has not been performed. As a result, experiments cannot be conducted on the real world situation or a previously modelled problem entity of this nature. For this research project, the principle of increasing coverage of crew to increase the number of successful train crew combinations was proven as a proposed system theory.

A detailed review of the simulation was provided to the retired COO and the resource manager. They were afforded the opportunity to test the simulation and ask questions. The feedback was that the simulation with the coverage constraint/ heuristic shows improvement in the number of successful train- crew combinations.

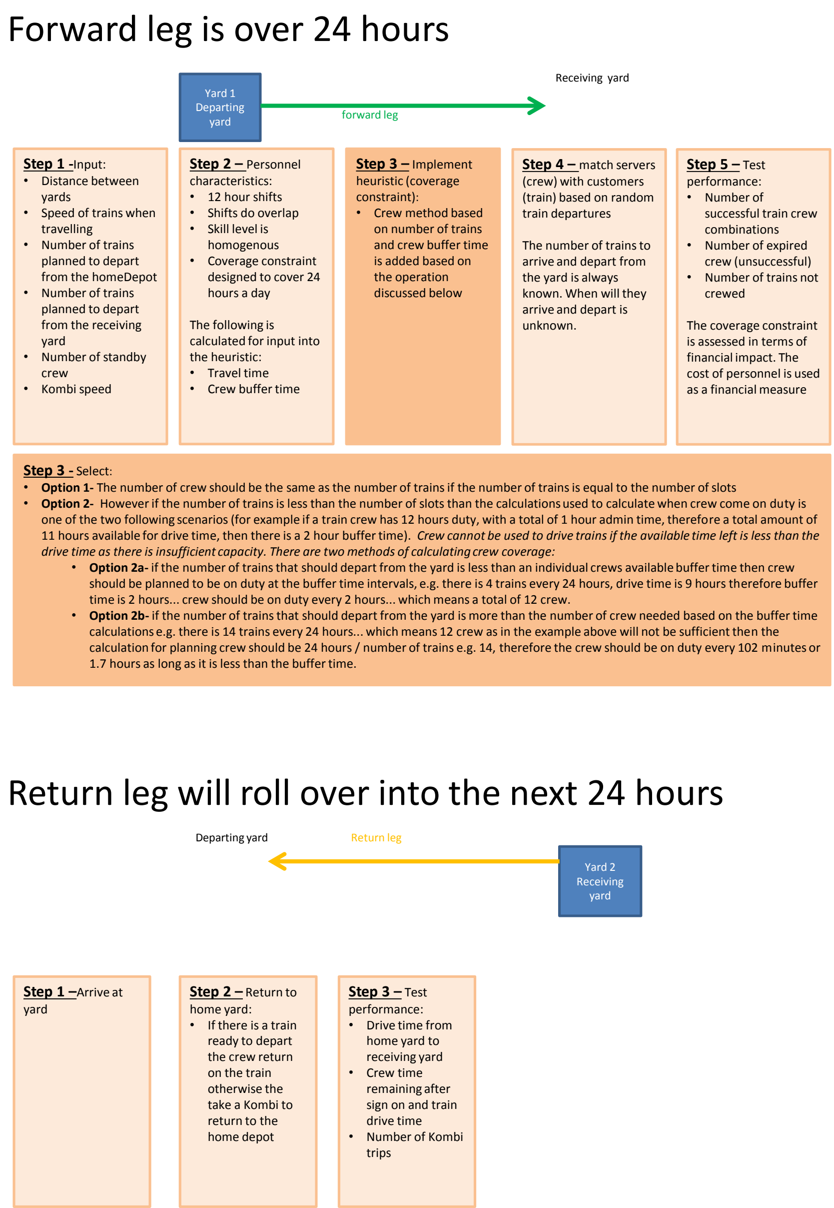

Figure 5.9 Description of simulation model

The experts hope to conduct further research into the model as there is potential in the theory for improvement in the crew scheduling environment. For full implementation into the South African environment, further research is required into the development of a full solution and its applications.

5.2.2 Comparisons of output behaviours

The simulation output data was compared to the current TFR performance with respect to crewing of trains. This was done based on the performance measures defined earlier. To recap, the performance measures for assessing the impact of running the simulation were defined as follows:

- *Number of successful train crew combinations*: The train and crew combine without the train waiting for crew. The number of successful train crew combinations are counted, any improvements will result in an increased number of orders delivered per day;
- *Number of orders delivered per day*: The number of orders delivered to their destination per day, as any increase in the throughput will increase TFR's revenue (Godwin, et al., 2008). The number of trains that depart from the home depot; and
- *Crew utilisation*: Calculated as a percentage of crew used to drive trains in a day. This measure is system focused and measures the number of crew utilisation relative to the number of trains per day, i.e. number of crew on shift divided by the number of trains that departed from the yard (Godwin, et al., 2008).

The simulation was designed to test the application of the rules as defined under Section 4.3.1. The application of the rules was based on assumptions made that allowed the results to be comparable with the current situation. Having applied the rules as defined above, the results are illustrated in the graphs in Figure 5.10 to 5.12. The complete data can be found at Appendix O.

Number of successful train crew combinations

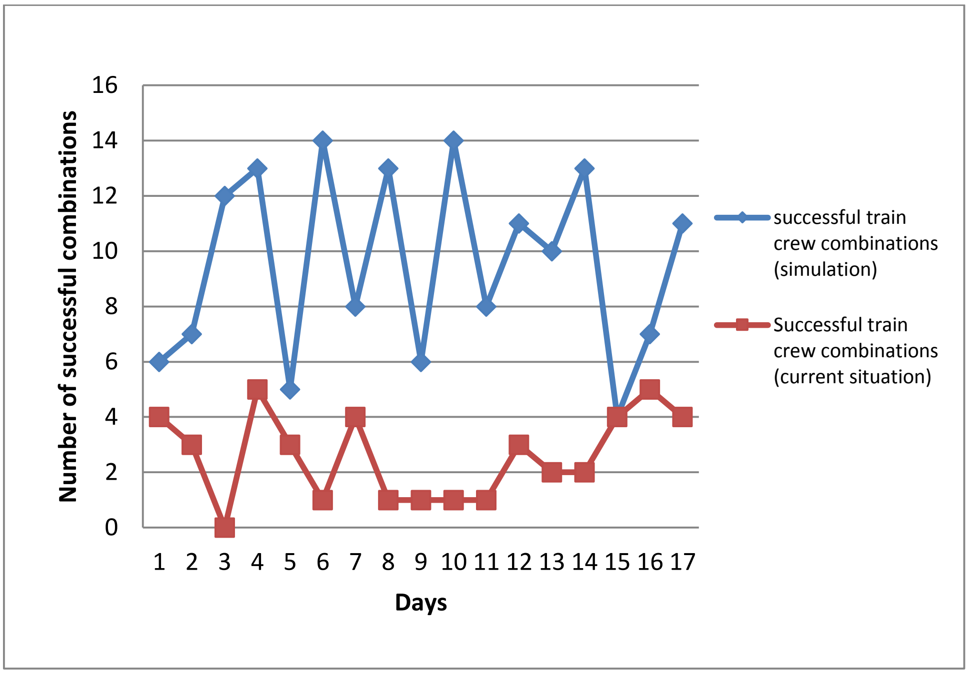

Figure 5.10 Number of successful train crew combinations

For the current situation, the number of successful train crew combinations was counted based on whether the train departed within the crew buffer time, assuming that they were on duty as planned. This assumption does not affect the results because the simulation is not assessing the variability of crew presence. The assumption allows the results to be comparable.

For the simulation, the number of successful train crew combinations was counted if the train did not wait for crew, assuming that the crew were on duty as per the heuristic defined above.

Figure 5.10 illustrates that there was an improvement in the number of successful train crew combinations using the simulated heuristic.

The number of loads delivered per day

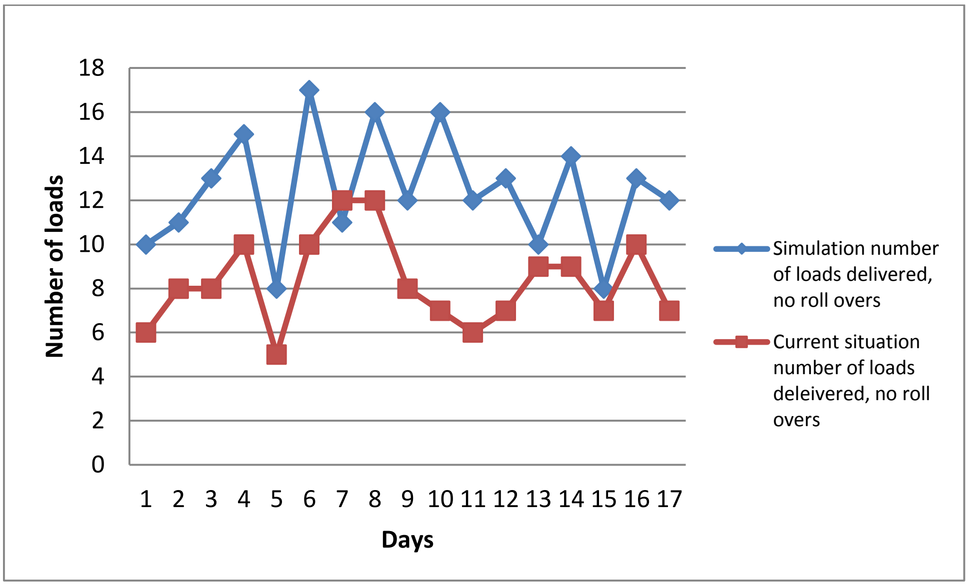

Figure 5.11 Number of loads delivered

For the current situation, the number of trains that departed the yard per day was counted.

For the simulation, the number of trains that departed the yard was counted. This included trains that did not wait for crew and trains that did wait for crew.

The simulation output indicated that there was an increase in the number of loads delivered per day. However, this cannot be directly related to an improvement in the simulated crew scheduling heuristic, because the data did not have sufficient information to determine how long a train waited for crew if they run out of time, resulting in less loads being delivered. It did indicate that any improvement in reducing train waiting time would increase the number of loads delivered.

Number of Crew Used

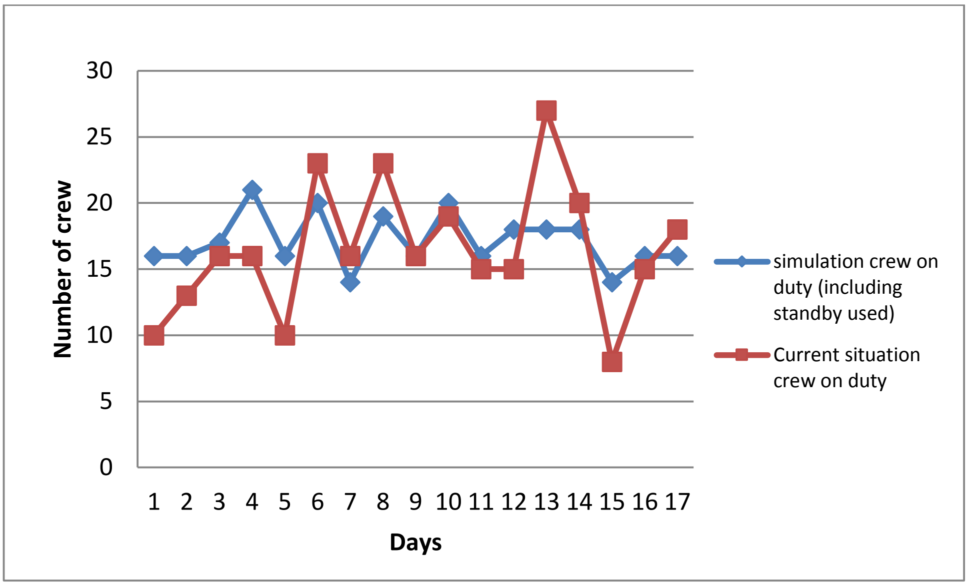

Figure 5.12 Number of crew used

For the current situation the number of crew planned according to the train schedule was counted, it included replacement crew that were required to drive the trains on the same day.

For the simulation, the number of crew planned to be on duty as per the heuristic and the number of standby crew used was counted.

There does not seem to be a significant difference in the number of crew used between the two approaches.

Crew utilisation was further investigated to understand if there was a relationship between the number of loads delivered, based on the simulation, and the number of crew used. There does not seem to be a relationship as indicated in Figure 5.12.

The crew utilisation was calculated as a percentage of crew used versus planned and plotted on the number of trains that departed per day. There seems to be a weak relationship between the number of trains and crew utilisation. The data is contained in Appendix G.

5.3 Assumptions for the Proposed System Theory

The trip parameters based on the trains running between NCS and Durban were used in the simulation model. The number of trains planned to depart from NCS per day was input into the simulation. The output for each day's iteration of the simulation was captured. This process was repeated for each of the 17 days.

The assumptions made were:

- Consistent block loads of 40 wagons depart from the yard to ensure that the volume and revenue impact is comparable with the current situation. The same assumption was made to establish the volume and revenue. Information on the train lengths for the current system was provided.
- Time taken for yard processing is representative of the time delay in the simulation using pareto distribution, which simulated time taken to process trains based on the current system.
- Crewing is the last stage of yard processing before obtaining the signal to depart from the yard. The last train processing step was maintained in the simulation model.
- Due to the complexity and lack of data to obtain visibility of time delays after the train has been crewed, it was assumed that there were no delays after the train is crewed and ready to depart. Both in the current situation and the simulation the crew will still drive the train to the next yard.

The results are summarised in Table 5.1 with full data attached in Appendix M. These results were used to establish the benefit of using the proposed system theory, the number of additional loads delivered per day. The cost associated, which was the number and cost of crew used to achieve the benefit, were calculated for comparative purposes.

Table 5.1 Simulation results

Day	Number of trains	Number of standby planned	Stand -by used	Expired crew	Success-ful combina-tions	Unsuccess-ful combina-tions	Yard pro-cessing
Day 1	10	3	4	0	6	4	0
Day 2	11	3	4	1	7	4	0
Day 3	13	3	4	1	12	1	0
Day 4	15	3	6	1	13	2	0
Day 5	8	3	4	0	5	3	0
Day 6	17	3	3	3	14	3	0
Day 7	14	3	0	0	8	3	0
Day 8	17	3	2	3	13	3	0
Day 9	12	3	4	0	6	6	0
Day 10	16	3	4	3	14	2	0
Day 11	12	3	4	0	8	4	0
Day 12	13	3	5	0	11	2	0
Day 13	18	3	0	5	10	0	8
Day 14	16	3	2	3	13	1	2
Day 15	8	3	2	0	4	4	0
Day 16	14	3	2	0	7	6	1
Day 17	16	3	0	5	11	1	4

5.4 Comparative Results (Validation)

The information from the current situation and the output from the simulation was consolidated and compared. The number of trains planned per day in the current situation was the same number of trains used in the simulation. This was done to establish the benefit of using the proposed system theory and the cost. The result from proposed system theory was compared to the benefits of using the current situation and the cost implications. In the comparative analysis, the cost of each crew schedule was established. Initially the cost of the crew scheduling methodology that uses a train plan, which is the current methodology, seems cheaper (R63 000) when compared with the proposed system theory (R265 440). However when the actual cost of the current methodology (R298 200) was compared to the proposed system theory, the current methodology was more expensive.

The additional cost of crew, when using the proposed system theory was averaged to establish what the additional cost per ton should be. The cost of additional crew using the proposed system theory was estimated to be R4 per ton. When using the actual cost of crew, TFR is currently incurring the cost; however, is not recovering it from the customer. The price quoted to the customer does not include overtime and relief crew but only the cost of the crew based on the schedule or train plan.

Next, the number of loads delivered per day was calculated for both crew scheduling methodologies. There was an increase in the number of loads delivered per day when using the proposed system theory. The additional loads were converted into additional revenue.

Assuming that in the current situation part of the train waiting time in the yard is due to crew unavailability, if this was reduced, the revenue impact could be an additional R20 million over the 17 days, as seen in Table 5.2. Using the pareto distribution for yard processing indicated that over 70 percent of trains were processed within 16 minutes. This indicates that there were no major problems within the yard processing activities. Full data is available at Appendix N.

Table 5.2 Cost analysis of simulation results

Train					Crew					R 150	
Total tons delivered based on simulation	Tons delivered as per normal schedule	additional loads delivered	Additional tons	Additional Revenue	cost of crew from simulation	cost of expired crew	Total cost of crew for simulation	Cost of crew for schedule planning	Additional cost	Amortise additional cost over total tons delivered	% increase in price *
19 200	11 520	4	7 680	R 1 152 000	R 13 440	R 0	R 13 440	R 8 400	R 5 040	R 4	3%
21 120	15 360	3	5 760	R 864 000	R 13 440	R 840	R 14 280	R 9 240	R 4 200	R 5	3%
24 960	15 360	5	9 600	R 1 440 000	R 14 280	R 840	R 15 120	R 10 920	R 3 360	R 7	5%
28 800	19 200	5	9 600	R 1 440 000	R 17 640	R 840	R 18 480	R 12 600	R 5 040	R 6	4%
15 360	9 600	3	5 760	R 864 000	R 13 440	R 0	R 13 440	R 6 720	R 6 720	R 2	2%
32 640	19 200	7	13 440	R 2 016 000	R 16 800	R 2 520	R 19 320	R 14 280	R 2 520	R 13	9%
21 120	23 040	-1	1 920	R -288 000	R 11 760	R 0	R 11 760	R 11 760	R 0	R 0	0%
30 720	23 040	4	7 680	R 1 152 000	R 15 960	R 2 520	R 18 480	R 14 280	R 1 680	R 18	12%
23 040	15 360	4	7 680	R 1 152 000	R 13 440	R 0	R 13 440	R 10 080	R 3 360	R 0	0
30 720	13 440	9	17 280	R 2 592 000	R 16 800	R 2 520	R 19 320	R 13 440	R 3 360	R 9	6%
23 040	11 520	6	11 520	R 1 728 000	R 13 440	R 0	R 13 440	R 10 080	R 3 360	R 7	5%
24 960	13 440	6	11 520	R 1 728 000	R 15 120	R 0	R 15 120	R 10 920	R 4 200	R 6	4%
19 200	17 280	1	1 920	R 288 000	R 15 120	R 4 200	R 19 320	R 15 120	R 0	R 0	0%
26 880	17 280	5	9 600	R 1 440 000	R 15 120	R 2 520	R 17 640	R 13 440	R 1 680	R 16	11%
15 360	13 440	1	1 920	R 288 000	R 11 760	R 0	R 11 760	R 6 720	R 5 040	R 3	2%
24 960	19 200	3	5 760	R 864 000	R 13 440	R 0	R 13 440	R 11 760	R 1 680	R 15	10%
23 040	13 440	5	9 600	R 1 440 000	R 13 440	R 4 200	R 17 640	R 13 440	R 0	R 0	0%
				R 20 160 000			R 265 440		R 51 240		

* average price increase per ton 4%

The comparative cost-benefit analysis indicated that additional crew is required to increase coverage and optimise the system. Past research conducted to improve coverage of the train schedule with crew while optimising the cost of crew, is not a reasonable method to schedule crew for trains. Trains currently depart randomly within the TFR environment.

In summary, this chapter defines crew scheduling without a train plan or for random train departures as the proposed system theory. This was reduced into a conceptual model and then programmed into a computerised model. The proposed system theory as encapsulated in the simulation model cannot be validated through a process of experimentation on a real world system that crews trains without the use of a train plan or a previously modelled system. The proposed system theory for this research project therefore remains as proposed system theory.

6 DISCUSSION

A train operation is a complicated process and requires an intense level of integration between all the subsystems to operate effectively and efficiently. In order to attain an increase in the number of loads delivered per day, TFR needs to establish short-, medium- and long-term goals. The goals need to be further subdivided into initiatives that the company can control and not simply manage. A prime initiative, which is within the company's control, is adapting the crew scheduling methodology to one that will support stochastic train arrival and departures. The simulation model attempted to assess if scheduling personnel without the use of a train plan is workable.

The company data does not capture the root causes and/or the resulting time impact of train delays when deviations occur. Furthermore, the current data does not allow the number of successful and unsuccessful train crew combinations to be determined, as was defined in this research project. However, with assumptions the number of successful train crew combinations can be established but the contribution that crew, as a function, has on the train delays cannot be determined. Crew could cause delays in one of two ways:

[1] Inappropriate scheduling, where crew are scheduled based on a train schedule when train departures are random; or

[2] The crew function does not operate optimally when crew arrive late for duty, crew intentionally delay train departures to incur overtime, and so on.

The scope of the research project focused on the former. It was noted that there was a relationship between train delays and crew waiting time. The simulation attempted to understand how to improve crew scheduling to increase crew coverage to cater for the variability of train departures, instead of scheduling crew according to a train timetable, which results in:

- Crew incurring overtime to drive the train part of the trip or the full trip.
- Replacement crew required at the yard.
- Train being staged en route, which requires relief crew.
- Train cancellations.

Based on the current data received from TFR, key assumptions were made to establish the total cost of crew based on the current situation. The analysis indicates that there is R63 000 used for overtime which offsets the additional cost of crew required in the simulation (R51 000).

The simulation was designed to test the application of the rules as defined under Section 4.2.1:

- *Option 1*: The number of crew should be the same as the number of trains if the number of trains is equal to the number of slots.
- *Option 2*: Crew cannot be used to drive trains if the available time left is less than the drive time as there is insufficient capacity. If the number of trains is less than the number of slots then the calculation used to calculate when crews come on duty is one of the two following scenarios:
    - *Option 2a*: if the number of trains that should depart from the yard is less than an individual crew's available buffer time, then crew should be planned to be on duty at the buffer time intervals. For example if there are four trains every 24 hours, drive time is nine hours, therefore buffer time is two hours, crew should be on duty every two hours, which means a total of 12 crew.
    - *Option 2b*: If the number of trains that should depart from the yard is more than the number of crew needed, it should be based on the buffer time calculations. For example, there are 14 trains every 24 hours, which means 12 crew as in the example above will not be sufficient. The calculation for planning crew should be 24 hours divided by the number of trains, 14,

therefore the crew should be on duty every 102 minutes or 1.7 hours as long as it is less than the buffer time.

The application of the rules was based on key assumptions made that allowed the results to be comparable with the current situation.

The key performance indicators used to determine if the proposed system theory being simulated has value, were:

- Number of successful train crew combinations.
- Number of additional loads delivered.
- Number of crew used.

The number of successful train crew combinations improved using the simulation heuristic. The heuristic aimed to increase crew coverage over defined time intervals. This created more flexibility in the system to accommodate for train delays. Increasing coverage implied that more resources are required, which was associated with more cost. With the improvement in the number of successful train crew combinations, there did not seem to be much difference between the two approaches in the actual number of crew used.

Crew utilisation was further investigated to understand if there is a relationship between the numbers of loads delivered based on the simulation and the number of crew used. There did not seem to be a relationship, hence it was not about increasing the number of crew per day, the heuristic is about ensuring that there is sufficient coverage during the course of the day based on the number of trains and travel time.

The number of loads delivered also improved; however, this could not be directly related to an improvement in the simulated crew scheduling heuristic. The data did not have sufficient information to determine how long a train waited for crew if they ran out of time, resulting is less loads being delivered. It did indicate that any improvement in reducing train waiting time would increase the number of loads delivered.

The simulation illustrated that there is an improvement in the number of successful train crew combinations and an increase in the number of loads delivered by increasing crew coverage over 24 hours instead of planning according to a train schedule. This would minimise the impact of disruptions of train delays on crew through the principle of optimising the train system and not sub-optimising crew as a function.

The increase in the number of successful train crew combinations implied that part of the train waiting time was due to crew unavailability. However, this assumption cannot be validated, as there were three options:

- *Overtime*: even if crew run out of time a decision to run the train whenever it is available could be made.
- *Relief*: obtain relief crew while the train is en route.
- Cancel the train and reschedule for another day.

With the first option, the train does not wait; however, it is not counted as a successful train crew combination because the data did not allow for identification of trains that ran with crew working overtime.

The simulation illustrated an improvement in successful train crew combinations by changing the way crew were scheduled, without incurring:

- Overtime;
- Possible train delays waiting for crew in the yard; and
- Possible train delays en route while waiting for relief crew.

The principle of increasing crew coverage throughout the day to cater for stochastic train departure rates and standby crew for train departures within a short space of time; shows promise as a solution.

6.1 Validation of the computerised model

The conceptual model was converted into a computerised program using AnyLogic simulation software (AnyLogic, 2012). Data information gathered on train operations within TFR was used as input data into the simulation model to simulate train movements in the system. The proposed crew scheduling system theory, detailed in the conceptual model was programmed into the simulation. Validation of the computerised model was based on whether computer programming and implementation of the conceptual model were correct. Various techniques were used, such as historical data validation, extreme condition test, expert review and simulation fidelity. These are discussed in Chapter 5.

It is important to note that a subjective approach for non- observable systems was used to explore the model's behaviour. TFR crew scheduling experts validated the behaviour of the computerised model against the intended outcome or purpose of the problem entity. The reason for using a subjective approach for a non-observable system is because the simulation model was based on a proposed future state whereby the crew is planned based on random train departures. It is not possible to compare a proposed future state where crew scheduling methodology is to crew trains based on random train departures and the current situation where crew is planned based on a train plan. The To-Be situation cannot be validated against the As-Is situation as they are not comparable.

Furthermore, based on research conducted, there is no evidence that the future state crew scheduling methodology has been either modelled or is currently in operation within a freight rail environment. Therefore, it is not possible to validate the computerised model described in this research project, based on another simulation model using the same crew scheduling principles or an actual situation where it has been implemented. Operational validity classifications for observable and non-observable systems are detailed in Table 3.1 (Sargent, 2013).

7 CONCLUSIONS

7.1 Restatement of the Problem

Crew scheduling based on a train schedule is ideal if trains run according to schedule. This would allow a minimum cost optimal schedule to be developed. The current situation on the Natal Corridor within TFR was used as a case study to establish insights such as the reliability of infrastructure and rolling stock is low, the train scheduling is inaccurate and the system does not run according to schedule. This presents a clear misalignment between train arrival/departures and crew scheduling. The proposed system theory was modelled to increase crew coverage in a yard irrespective of the train schedule. The theory was that it would increase the number of successful train crew combinations. This theory was tested as part of this research project.

7.2 Description of the Procedures

A literature review was conducted to establish if any past research was conducted on scheduling of crew without the use of a train plan. It was found that no past research was conducted on this topic; however, Godwin et al. (2008) developed a heuristic for the locomotive assignment problem in an unscheduled railway. Insights from Godwin et al. (2008) were applied in this research project.

Once the review was completed, the conceptual model was developed. While the conceptual model was being developed, data was collected from the TFR through various sources including interviews with experts. This data was used to:

- Translate the conceptual model into a computerised one. This meant that the input parameters to simulate train movements needed to be based on the current situation. The train movements programmed into the computerised simulation model were the same as the current situation. The impact of the crew scheduling methodology on the current system was assessed. The simulation output data and the current situation data was used to validate the goodness of fit of the distributions used;

- Assist in the design of the proposed system theory, .e.g. the shift working hours. The scope of the conceptual model was reduced to address only crew scheduling without the use of a train plan. This allowed the results of the current crew scheduling methodology to be compared with the proposed system theory; and
- Determine the level of achievement based on the Key Performance Indicators in line with Godwin et al. (2008):
    - Number of loads delivered.
    - Number of successful train crew combinations.
    - Number of crew used.

A computerised simulation model was developed without a train schedule to compare the results of increasing crew coverage to cater for random train departures against the current situation at the company.

The two sources of data were compared and the proposed system theory tested. A cost-benefit analysis was conducted on the two sets of data to establish the operational and monetary impact of the heuristic.

7.3 Major Findings

The data outputs from the simulation were analysed and the results indicated that while the number of crew used in both situations did not differ much. The number of successful train crew combinations and the number of loads delivered increased per day. Therefore, the proposed system theory to increase the crew coverage or schedule crew without a train plan is reasonable for the intended purpose. The proposed system theory demonstrated a positive impact on the number of successful train crew combinations and loads delivered.

The cost benefit analysis indicated that there was a financial benefit to increasing crew coverage. It seems that the benefit has the potential to outweigh the cost implications.

7.4 Conclusions

The proposed system theory to schedule crew without the use of a train schedule or for random departures has not been validated against a real world system or on a previously modelled system. Based on the research conducted, a real world system or previously modelled system that models the scheduling of crew without the use of a train plan does not exist. The computerised model will therefore remain as a proposed system theory; however, each stage of the simulation modelling process was validated to provide confidence in the model and its results. The proposed system theory, modelled as part of this research project, indicated that the number of successful train crew combinations and loads delivered increased. While generalisation has not been established, other complexities may predominate i.e. crew being one of the root causes for delays.

7.5 Recommendations for Further Investigation

Further investigation is required to understand the impact of crew on train waiting time in the yard because of the misaligned schedule. This research project attempted to understand how to optimise the system of running trains from the point of origin to its destination and back. It does not optimise the separate sub-systems such as crew scheduling and locomotive assignment. This may reduce the impact of misaligned schedules between the train and the crew on train delays and increase the number of loads delivered.

Investigation into the optimum crew capacity per yard and the crew rostering process is required to implement the proposed solution. Crew utilisation in the proposed model increases as the number of trains increase per day. Further investigation is required into which yards, based on the number of trains planned, it is feasible to implement this solution.

Further investigation into the feasibility of implementing this model nationwide is necessary, as this research project is designed to illustrate the feasibility of increased crew coverage and not the up-scaled feasibility.

Further work will need to be carried out on the experimental validation of the simulation model.

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APPENDIX A: PILOT STUDY

UNIVERSITY OF THE WITWATERSRAND

SCHOOL OF MECHANICAL, INDUSTRIAL & AERONAUTICAL ENGINEERING

PRODUCTION AND OPERATIONS MANAGEMENT – MECN 7006

CASE STUDY SOLUTION

CREW AT TRANSNET NOT MEETING EXPECTATIONS

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6 June 2011

INTRODUCTION

The Resource Manager, at TFR is responsible for the Crew and Locomotives capacity planning and execution, took a look at the performance compact results and was delighted with the excellent results. This good performance must be as a result of the efficiency optimisation project initiatives that were initiated to recover from the economic crisis. But, something is not making sense. The performance on the floor does not reflect these results.

During interviews with TFR resource management and the operations team, it was noted that a lot of emphasis was placed on managing expensive assets/ resources e.g. locomotives and wagons and optimising asset utilisation. Assets are seen as the revenue generating resources and utilisation is critical component in TFR's decision-making criteria when allocating assets (locomotives and wagons) to a specific customer.

The mindset within TFR is that crew is a "cheap" resource from a cost perspective and should fit into the process of enabling an increase in asset utilisation. From a cost perspective, crew salaries may be cheaper than buying a locomotive; however, crew does have the greatest impact (negatively or positively) on cycle time, which directly affects asset utilisation and revenue generation.

Frustration expressed by management, such as "Just look at the Crew… They have all the time in the world, do not care one minute if they delay a train, they sometimes even instigate stressful situations so that they can claim they are a safety risk to be sent home. Despite not working, they are still paid for their shift. They also sometimes create delays in the system, which means additional overtime. To cater for crew shortages we increased the number of drivers per yard and increased flexibility by multi skilling them... Crew performance is good as measured by their existing KPI's. Something isn't adding up."

PROPOSED SOLUTIONS

In addressing this case study, the process we are going to follow is to understand what TFR must do well to meet or exceed customer expectations. Using this as the foundation for our analysis we will use a SWOT methodology tool and a fishbone diagram to identify root causes and key levers that would assist TFR to meet the objectives identified that TFR must do well. For each of the levers identified we will outline in more detail specific gaps and proposed solutions on a way forward.

What Must They Do Well

Deliver commodities on time in full (cycle times; correct number of wagons)

- Flexible to changes in traffic mix to accommodate commodity seasonal market demands;

- Deliver a cost effective service;
- Deliver a predictable and reliable service;
- Operate the trains within the safe operating limits (speeding, hard breaking, line traffic rules); and
- Build and maintain customer relationships.

SWOT

Strengths:

- Assets and infrastructure;
- Captured market;
- Large mix of assets to cater for a variety of traffic mix;
- Large base of employees;
- Management initiatives to improve service delivery;
- They do have system that can track trains in real time and can be used for reporting;
- Can track wagon positions in the system;
- Their reporting structure is hierarchical and operators do execute instructions;
- They do benchmark internal processes with other railways; and
- The company provides education for employees to build capability.

Weaknesses:

- High cycle times (cycle times impacted by reliability of assets and resources, and operational inefficiencies);
- Large variety of information systems that do not communicate to each other and only serve a specific purpose;
- People not aware of systems in place or how to use them;
- Can track wagons in real time but not locomotives or crew;
- Lack of information sharing between departments;
- top management does not communicate key information to the operators in an optimal way, they communicate via notice boards to employees that is not literate;
- There is lack of alignment on who is the customer and what value each department add to the process;
- Lack of adequate preventative maintenance;
- Crew roster not aligned with system requirements;
- SOP's not adequate;
- Measures reliability based on failures per million km (should be based on impacts service delivery);
- Lack of information sharing between departments;
- Functional departments operating in silos;
- Performance management system and consequence management does not facilitate accountability and is influenced by internal political agendas;
- Technical & Ops measurements not aligned (PPM vs Cycle time);

- Performance measures not filtered through the organisation;
- Lack of competent and willing workforce;
- Resource availability low due to high cycle times;
- Lack of management involvement in operations, management do not forecast or predict the ripple effect of decisions or instructions they make;
- The culture is one of complacency, no urgency, lack of attitude or managing the railway as administrative activities;
- Low morale, motivation and deterioration of work ethic;
- Ageing assets (Locos, wagons, infrastructure);
- Loss of asset capacity as a result of incidents; and
- Condition of their facilities is not conducive to improving employee morale, motivation and performance.

Opportunities:

- Industry growth demand in specific commodities (existing and new customers);
- Expansion into SADC;
- New advanced technology;
- Increase productivity on the ground by improving working environment and conditions;
- Increase capacity through the decrease of cycle times; and
- Benchmark with international industry standards and Measure availability as asset in the right place, at the right time and able to deliver the service in full.

Threats:

- Unreasonable non-value added targets from Government;
- High variance in environmental conditions;
- Vandalism, cable theft tarpaulin theft and hijackings;
- Informal settlements posing threat of pedestrian crossing;
- Level of illiteracy in the available national workforce is low; and
- Corruption.

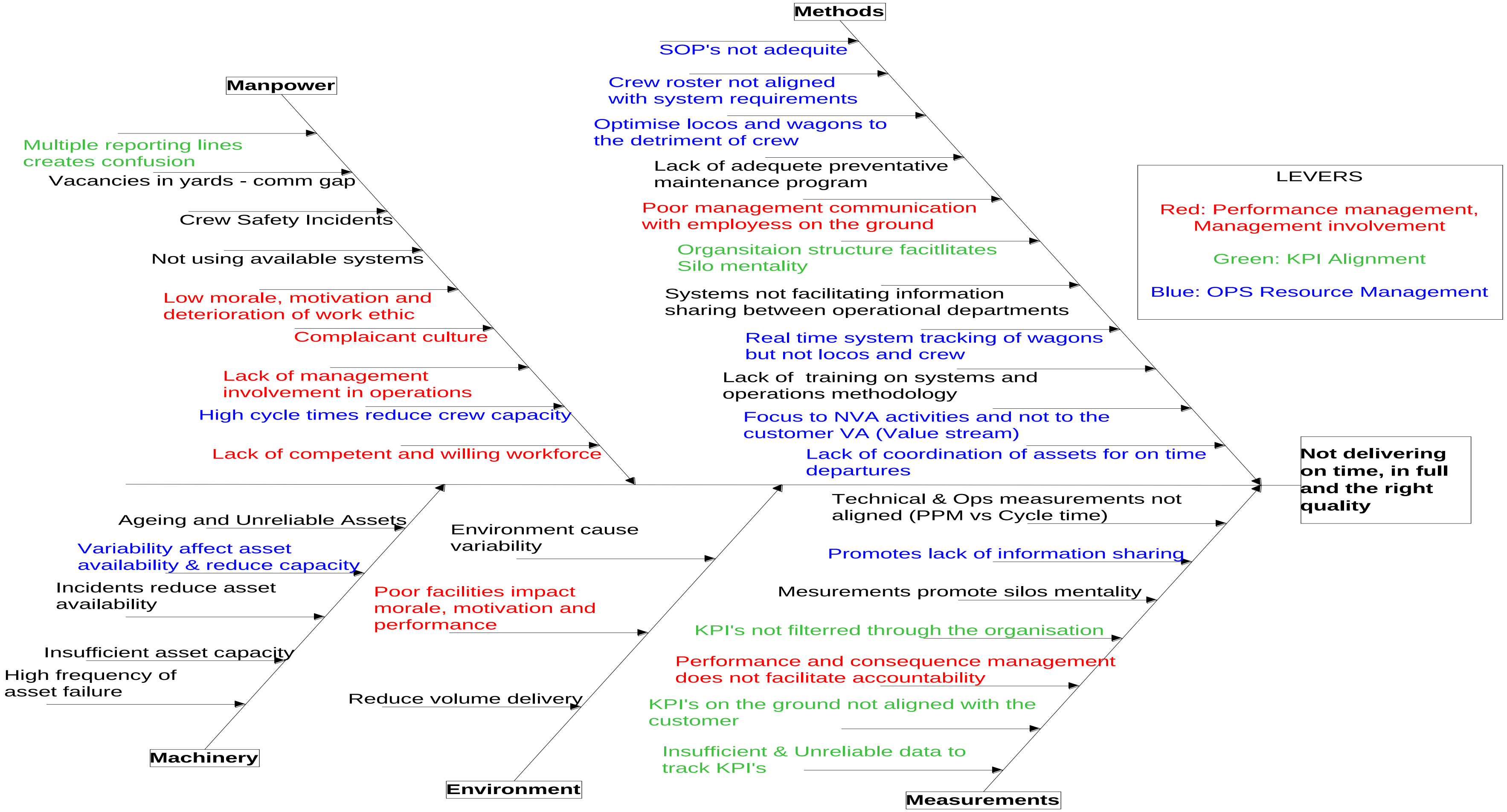


Figure A.1 Diagnostics

Based on the outcomes of the diagnostics we have identified three key levers that will have the greatest impact on what TFR must do well. These levers are: (1) KPI alignment, (2) Management involvement and (3) Operational resource management.

SOLUTION (1): KPI ALIGNMENT

In this proposal to identify the incentive that drives behaviour, two incentives are considered. The first incentive is the employee's payment structures, and the second is the short-term incentive scheme.

Payment Structure:
TFR's crew is part of the bargaining unit employees and is paid for hours worked or on duty. Their normal time, overtime and shift cycles are in line with general industry standards. They work an average of 60 hours per week, of which 40 hours normal time and effectively 20 hours overtime.

This is much more than the Basic Conditions of Employment Act, 1997, when working five days per week, which allows for a maximum of 10 hours per week overtime, or with a collective agreement 15 hours per week.

The daily and weekly rest periods of 12 hours per day and two days per week, is also in line with the Basic Conditions of employment. The four consecutive rest days every third week that makes provision for shift changeover is also in line with general industry norms.

Since the basic conditions of employment act govern the local agreements for permanent bargaining unit employees, management have to use methods other than wages to incentives employees to achieve objectives.

Short-Term Incentive Scheme (STI):
Transnet have developed a fairly extensive STI scheme that is well aligned with their shareholders strategic objectives.

As described in the case, these KPI's are applicable throughout the organization down to the bargaining unit employees who can earn from 6% on target, up to a maximum of 22% of their annual pensionable salary.

Even with this scheme in place, TFR is still experiencing great difficulty with a lack of competent, willing and empowered workforce that leads to poor organizational performance.

From this case, it is no surprise that the Transnet STI scheme is not effective and has not managed to change the human behaviour on the ground. At TFR, the focus at the ground level is mainly on Safety, and safety did improve from a DIFR of 1.3 in 2009 to 0.94 in 2010, and a 17% reduction in safety incidents.

Proposed changes to the Transnet KPI System

Based on this it is proposed that Transnet revise their KPI's in order to ensure that they effectively utilise the lever that is available to positively influence the human behaviour from the top management down to the ground floor, by introducing the principles of the balanced score card as per Kaplan and Norton.

The KPI model must therefore include four focus areas, namely: A Clear Customer perspective; what must the unit do well and excel at; Continuous improvement and learning; and Shareholder value.

Clear Customer perspective:

Transnet must identify a measure that can be aligned with the focus point of the organization and clearly measure customer satisfaction. This focus point is captured in their vision; e.g. "… to deliver integrated, efficient, safe, reliable and cost-effective services …"

Therefore a measure that incorporates time (efficient), quality (reliable, safe), and value for money (cost effectiveness) must be implemented from top management down to the ground level in order to create goal alignment and customer focus, using an OTIF (On time in full) measurement which can be understood throughout the organization.

What the unit must do well and excel at:

The second measure that Transnet need to put in place is internal measures that can translate the customer perspective onto the ground level in a manner that will influence the employee's behaviour.

This internal measure must create goal alignment from the vision down throughout the hierarchy to the ground level employees.

The employees must understand, relate to and be able to influence these measures, which must relate to time, flexibility, quality and value for money. The measures must guard against cost, poor response time and variability.

Continuous improvement and learning:

Improvement targets must be established for each level in the organization down to the ground level that can measure the improvement against the measures devised under the above areas.

Shareholder value:

Their current measure includes EBITDA, RONA and Gearing which is a reflection of value to the shareholder. However, Transnet must find measures that will support these measures but can be understood and influenced by the lower levels in the organization.

Principles of the KPI's

It is important that the score card is consistent throughout the organisation and at all levels. The KPI score cards must include the following principles:

- The measures must be SMART (specific; measurable; achievable; relevant and timely);
- All levels must understand their measures and know how they can influence them;
- All levels must understand why they are getting a bonus and the reasons behind the magnitude of the bonus;
- These measures and progress against the measures must be visually displayed and communicated on at least a monthly basis; and
- Employees must be empowered to put action plans in place to improve against the measures.

SOLUTION (2): MANAGEMENT INVOLVEMENT

There are a number of issues cropping up in the case study, identified in red in the fishbone diagram, which we aim to address using the lever of 'Management Involvement'. The main aim of the initiative is to bridge the gap identified in the case study between management and the workers on the ground. In some instances, management involvement will directly address root causes through direct action and in other instances; issues will be addressed indirectly due to the fact that they are symptoms of the current state of management.

The aim of this section is to demonstrate that consistent management involvement correctly applied can address many of the root causes at TFR with regard to employees, and most importantly crew. Crew is highlighted specifically due to the direct impact that crew have on delivering value to the client as well as the focus on examples and incidences cited in the case study. In the following section, we will outline how management involvement is the lever to: bridge the gap between management and the workforce, executing consistent performance and disciplinary management, training optimization and lastly facilitating an environment that is conducive to respect, a positive work ethic and esteem.

Performance Management

The value of established KPI's that are in alignment with organizational objectives and meeting customer expectations (as outlined in the previous section) is only realized when management consistently measure the performance of employees in achieving the basic requirements of the job and take the necessary corrective action. This is one of the key areas of accountability for management.

The first step in performance management is addressing structural issues relating to job functions. Jobs and functions need to be classified / clustered correctly in terms of what the core function of the role is. The basic requirements an employee needs to have in order to fulfil the function also need to be established.

The second step in performance management is evaluating the person against the requirements of the job.

Performance management is not just about managing people who are not performing, but also about recognizing top performers. It is important to differentiate between a non-performer and a top-performer and that the expectations are clearly outlined in terms of what a person needs to do in order to achieve.

Performance management allows the organization to set the norms of performance in the organization and manage people against these norms in terms of who is rewarded for going over and beyond the basic requirements and those that are not meeting requirements. The consequences of each should be clear to employees and enforced by management in order to establish a culture that rewards good performance and is not seen to be biased.

When it comes to crew in TFR there are no clear KPI’s and managers communicate vague guidelines in terms of safety, training, and absenteeism as the basic requirements. This does not lay the foundation for the basic requirements of the job and in many cases leads to the idea that crew who have a favourable outcome in their performance process are ‘favoured’ by their manager. Unclear reporting lines also blur this responsibility and allow crew to take advantage of the situation and ‘slip through the cracks’ of performance and disciplinary action.

Without clear, consistent and transparent actions taken, directly related to performance of individuals, there will be no credibility with employees regarding management’s stance towards the concept of performance. Performers need to be assured that they are being rewarded. Consistent and transparent performance management facilitates is a clear understanding of expectations of performance for employees.

Non-performers need to understand why they are in the processes of non-performance and understand the gap between where they are and what the job requires of them in order to meet their KPI’s. Performance management facilitates a conversation between a manager and the employee around what that employee needs to do. It is not just about setting targets and seeing if someone can make it. The onus is on the organization as well as the employee to ensure that these basic standards are met. A manager needs to know that he is providing the employee with the right support in terms of training, coaching, mentoring etc.

The performance conversation is a two-way conversation and a manager should receive input from the employee as to whether there are inherent flaws in the job that obstruct the employee from achieving the necessary results. It then becomes the manager’s responsibility to address any issues prohibiting the employee from being enabled in their position to perform their job successfully. In this manner managers will be exposed to issues that crew experience on the ground, and by facilitating an enabling action for the employee to execute their job, they are building good will with the employee and strengthening the work ethic.

Management needs to know that they have given as much as they possibly could (within reasonable limits) to enable the employee to do their job. If the person consistently fails to achieve the expected performance and all other areas have been adequately addressed (such as training, coaching etc.), then incapacity due to poor performance is the appropriate course of action and must be taken to protect the foundations of a high performance culture.

In the example of the driver instigating an argument with his supervisor and then citing emotional stress as a safety risk, he may be falling short on the possible KPI of ‘driving hours per week / month’, should this be a regular occurrence. If proper performance management was taking place this issue would be addressed in a performance review as not meeting the minimum requirements of the job, namely a minimum amount of driving hours per week / month. If the incident was one of insubordination then the matter should have been dealt with as a disciplinary action.

Disciplinary Action

The next management responsibility that we are going to address in highlighting management involvement is that of their role in disciplinary matters. The case study provides a list of disciplinary actions metered out for driving incidents. There are also insinuations in the text to disciplinary matters flying under the radar, drivers are only disciplined if they are caught, and sometimes knowing the right people can get you out of trouble. Clear reporting lines are also imperative in addressing disciplinary matters. In the organogram of the yard structure, there are confused reporting lines, which seem to be contributing to the confusion in responsibility. This is something that needs to be addressed.

Management are the watchdogs for disciplinary issues and need to use the Disciplinary Code as the tool through with discipline is applied. The disciplinary code specifies behaviours that are not acceptable to the running of the business in question. These behaviours prohibit the operational efficiency of the business as a whole. Actions addressing discipline issues need to be transparent and metered out consistently, fairly and openly across the board.

The question of application of the disciplinary code is based on the rule of precedence. Staff conduct issues in the organization need to be addressed openly and consistently by management through the appropriate channels; namely verbal cautions, verbal warnings, written warnings and disciplinary hearings. Unacceptable behaviour that is ignored or inappropriately dealt with - is inadvertently being reinforced, which could lead to more serious offences or a lack of regard for management who are responsible for upholding the Disciplinary

Code. This seems to be an underlying problem with regard to drivers in the case study who are able to get away with offences that go unnoticed.

It is important that the Disciplinary Code is made available via the right channels, such as when a new employee starts it is in the induction pack, it is referred to in team meetings and shop stewards need to advise the members of their union accordingly (the union would have signed off on the disciplinary code).

In the logistics industry, which equates to moving goods from point A to point B, time is money. When it comes to drivers purposefully wasting time, this has an adverse effect on the operational outcomes of the business and should be a disciplinary offence. This type of behaviour is unacceptable as it has a direct impact on the value that is delivered to the client. Due to lack of management visibility on the floor, issues such as this go unattended and lead to greater crew productivity and efficiency issues.

Training

Out of the TFR workforce of 22 571 permanent employees only 351 employees are reported to having received 'customised transport and logistics training' and 1 600 supervisors trained in 'basic management and supervisory skills'. What this means is that only 8.6% of staff has received any training over the past year, which is inadequate in driving a performance culture.

Training plays a huge role in operational readiness of staff and has the biggest potential of changing the behaviour of staff on the floor. If one is to consider having the right person in the right place at the right time to fulfil a function, it logically follows that this person needs to have the right skills. The role of managers, in conjunction with Human Resources/ Learning and Development, is to facilitate an effective training reporting system as well as a formal platform for assessment of training needs.

Critical as a measurement tool in this space is a transparent reporting system including data such as – who has been trained; what the test results are; and number of times a person has been trained. These measurements are then matched against the expected standard of training and required knowledge levels for specific positions in order to enable both employees and the organisation as a whole to achieve the required levels of performance. With an effective training reporting system in place, it logically follows that the areas requiring improvement can then be identified and addressed through targeted and on-going training programmes.

With management involvement, each staff member should have their training needs clearly outlined and monitored in their performance appraisal process, which should be happening more than once a year, as indicated in the case study. Regular input and encouragement from management contributes towards growing staff and can have a positive effect on morale and retention and a significant contribution to the overall sustainability of the business.

While crew may be perceived as a ‘cheap resource’ at TFR, it is the crew that are driving the million rand trains. Without the necessary training and monitoring of their skill requirements along with regular performance appraisals and keeping a tight handle on each crew members performance, TFR stands to lose a lot of money when a driver makes an error or brakes to quickly resulting in a collision or de-railed train. Disciplinary action cannot be effected against a driver for negligent driving if their training log is not up-to-date. This highlights the fundamental necessity of training in this space.

The three-pronged approach to management involvement, namely regular performance management, fair, prompt and consistent disciplinary action and up-to-date training empowers managers to closely manage their staff and have a positive input in driving the right behaviour on the floor. In order to ensure that management are driven to achieve the top performance of their staff, all three of these areas should be represented as KPI’s on management’s performance contracts.

SOLUTION (3): OPERATIONAL RESOURCE MANAGEMENT

We can equate a train logistics system to a production line. The raw materials that get inputted into the system can be equated to the commodities loaded onto trains by mines, rail infrastructure can be equated to the conveyer belts that link machinery and the train yards can be equated to the machinery. While the train is staged or stopped at a yard, there is a material handling process whereby materials are inputted and train processing happens to ensure on time departures of trains from the yard to its next destination. Please see Figure A.2.

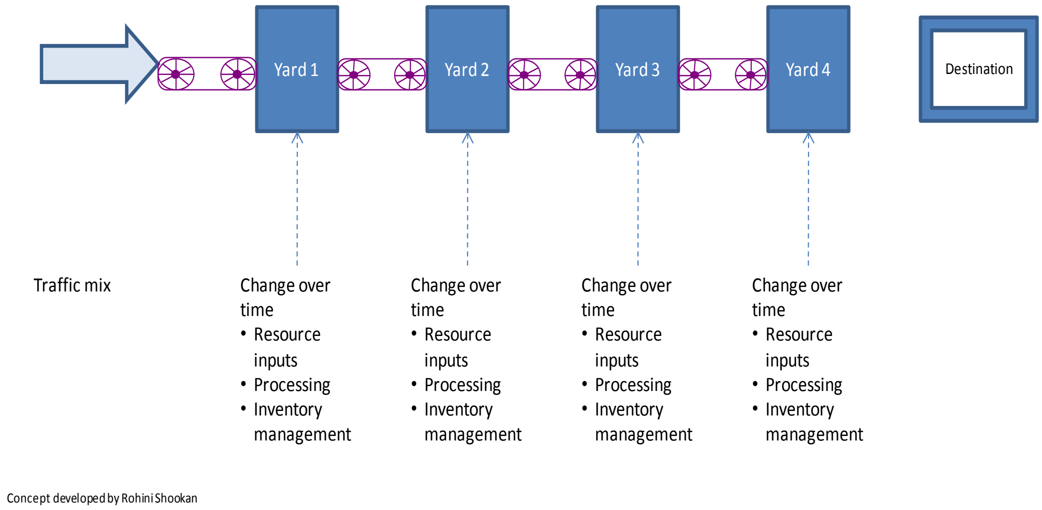


Figure A.2 Train system as a logistics system and a production system

Breaking down the train system into a production system enables TFR to understand the management of operational resources from a different perspective. The train system is made up of machinery and equipment that can be managed by improving OEE (reliability, availability and quality); however, there is one critical input into the train service that:

1. Directly impacts on service delivery (OTIF);
2. Is influenced by and influences variability in the system;
3. Management of the resource is strictly regulated; and
4. Directly influences the number of incidents related to safety. This critical resource is crew or train drivers.

Current management methods includes; 1. Performance management procedures regulated by the main agreement, 2. Crew rostering methodologies that is optimised for crew utilisation (diagram and FIFO), 3. Payment structures based on hours worked, 4. KPI's more focused on reducing safety related incidents and increasing availability of individuals.

The proposed solutions relating to management involvement and KPI's that was addressed earlier in this document aims to positively influence the human relations aspects of crew management. To close the gap between managing the human relations aspect the focus for the rest of this section will be on improving the technical management aspect of crew.

Currently resource management defines a crew's customer to be a locomotive (or consist of locomotives used to move wagons). According to information in TFR's efficiency optimisation project there is sufficient crew capacity in terms of numbers. However, there is a significant amount of variation or incidents that are as a result of crew and variation in the system is also high. The variation in the system significantly reduces crew capacity.

When the customer is the locomotive; capacity is calculated based on locomotive cycle times and variation significantly reduces crew capacity, two things need to happen; 1, improve planning (capacity calculation and rostering methodology) and 2, improve execution (short interval controls).

Improving planning
From a crew perspective the customer should be the train and in order to meet the needs of the train, crew must be available for duty and have sufficient capacity to move the train between its origin destination pairs (between yards depending on train and locomotive cycle times). Crew rosters are currently developed using the assumption that the train will be on time (as scheduled on the ITP) and crew will have sufficient capacity (time) available to move the train between its origin destination pairs. Variation is catered for by scheduling standby crew. Standby crew is used to absorb variation in the system by making sure there is crew available to move the train.

Let's for a moment equate crew to perishable inventory. Consider that when a set of crew signs on for duty, their capacity decreases as time passes, so using FIFO optimises for crew utilisation and not meeting the needs of the customer (the train). Using the diagram method is not that much different from FIFO, the only difference is intervals at which a name can be assigned to a specific train (i.e. who will drive what train at what time). With FIFO names are assigned in 12 hour intervals while with the diagram it can be forecasted at any interval, even a year in advance.

In order to change to being more customer focused resource management should optimise for meeting customer needs by calculating the amount of time that can lapse before the available crew time does not meet customer needs, i.e. at what point must crew be 'used by'.

Capacity required per yard should also be calculated using First Expiry First Out (FEFO) and an appropriate algorithm to forecast consumption of capacity.

Once crew capacity is determined and the consumption rate defined TFR needs to change its rostering method to incorporate the principle that if crew capacity has passed its 'use by' time limit, they should be rescheduled (taking into account the main agreement regulations) for the next train as described in Figure A3.

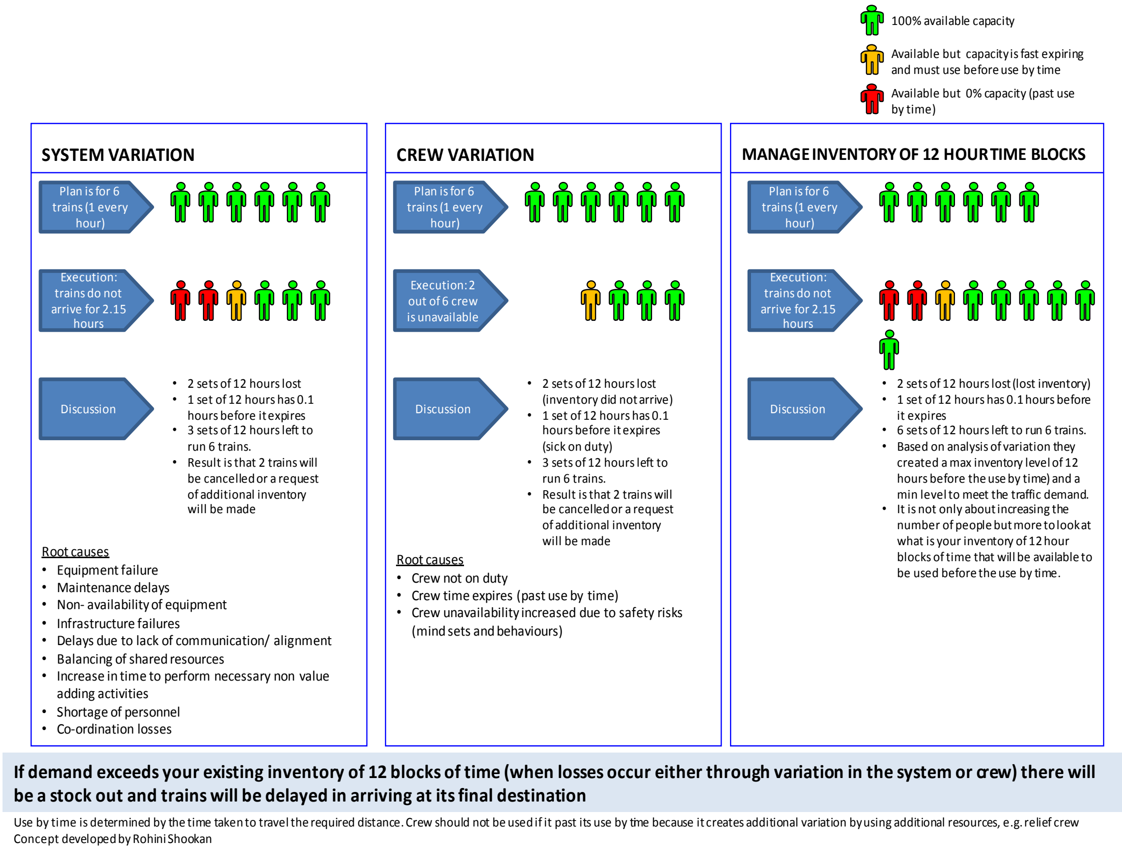


Figure A.3 How would it change our current management style of crew management if we considered crew time perishable inventory?

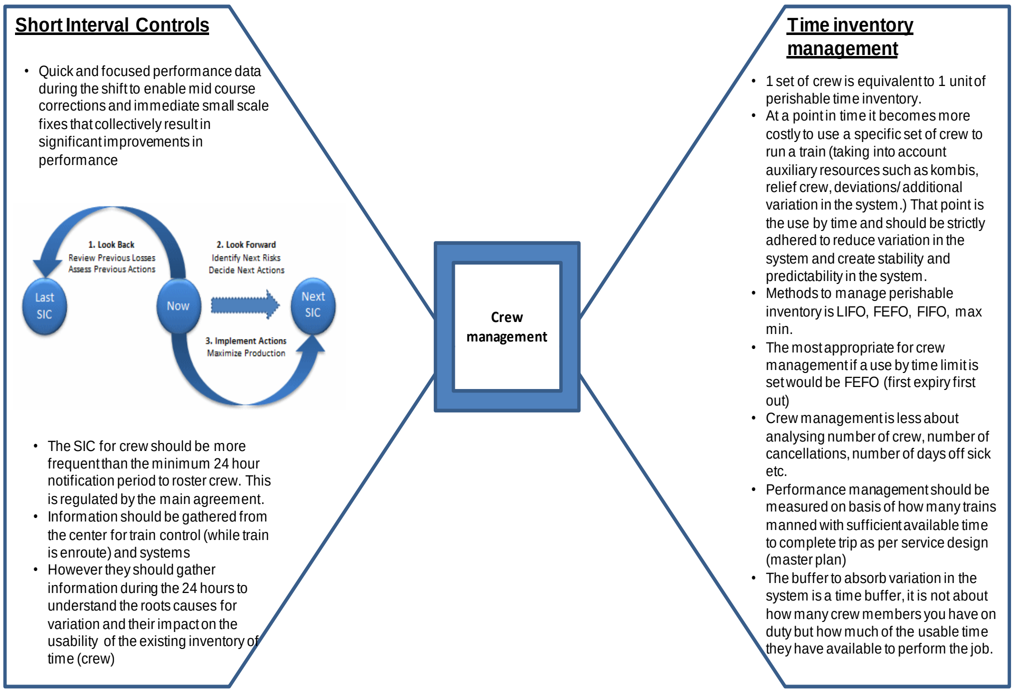
Improving execution

Changing the rostering method is improving the planning process, however it is during execution that value to the customer is created and delivered i.e. moving the train between its origin destination points.

In order to meet the needs of the train during execution, resource management must have performance data readily available to make immediate corrective decisions that result in performance improvement (reduction of cycle times) and service delivery OTIF to TFR's customer.

Resource management should leverage performance data gathered by other departments and available systems that track and monitor train movements. While doing this they need to do two things; 1 build relationships with other departments to develop corrective measures that improve the service and not achieve departmental KPI's, and 2 uses the information to replan crew requirements to meet the needs of the train. Variation during execution increases the demand for crew capacity because crew relief (buffer) is needed when existing crew capacity perishes, so replanning and the communication of the replans are critical to success.

Figure A.4 shows that optimal crew management incorporates the planning of crew (Time Inventory Management) based on the consumption rate, which is determined during execution (short interval controls).



Concept developed by Rohini Shookan

Figure A.4 How to improve the planning and utilisation of crews inventory of time

In conclusion, from a technical perspective resource management should change their frame of reference to define the customer as the train and calculate capacity based on the consumption rate using FIFO. They should also focus on meeting the needs of customers during execution by using performance data that would inform optimal corrective decisions that would reduce cycle times in the system but also meet the needs of TFR's customer.

This interview with the Resource Manager took place on 23 August 2011.

Table A.1 Interview Guide

Question	Response
What is your opinion regarding the current crew behaviour and what have you done to mitigate the associated risks	Just look at the Crew… They have all the time in the world, do not care one minute if they delay a train, they sometimes even instigate stressful situations so that they can claim they are a safety risk to get sent home. Despite not working, they are still paid for their shift. They also sometimes create delays in the system, which means additional overtime. To cater for crew shortages we increased the number of drivers per yard and increased flexibility by multi skilling them... Crew performance is good as measured by their existing KPI’s. Something isn’t adding up.
How many yards have you worked in	I have worked in yards across Transnet's national footprint. I was at Ermelo, Steelpoort, and many others.
Who decides what crew scheduling method to use	The section manager responsible for crew in the yard. There is no guideline on when must the diagram versus the FIFO method be used.
How is the crew performing	There is a culture in South Africa is difficult to manage because of the unions. Crew generally don’t want to work but want to get paid for their shift so they will log faults on the loco whether they are true or not. This takes time out of the system because it delays the train from departing. We have to investigate all faults because of the risk to safety. Also they come late or do not come at all. Transnet allows employees 6 days a year to not come to work for one day only if they are not feeling well. this is called an x99.
Do you track capacity and how is it calculated	capacity is calculated based on the number of trains required to run over a month. We then take out personnel for sick leave, annual leave and training. We generally plan for 70% availability excluding the personnel on leave and training.
Are the drivers technically competent	They are trained for two years and if they do no perform in a competent manner then we performance manage them. There are cost implications to their non-performance. It results in damage or loss of life so their competence is strictly managed. We track their performance on an excel spreadsheet called Incident_consequence_management.
How do you track the crew performance	We don’t track what time they arrive and whether they are driving the train that they are planned to drive or if they arrive on time. We simply track the time they arrived to calculate their shift duration. There is no link to the planned train right now. We track their technical competence and performance manage them accordingly. We also track their leave. We do not keep a record of the reasons as to who logs faults for no reason or other such data. Right now there is no capacity. The structure is under review. We are planning to have a crew monitor position. This person will capture all relevant data that will be used to manage crew.

Question	Response
What must crew do well in order to be effective	Deliver commodities on time in full (cycle times; correct number of wagons) Flexible to changes in traffic mix to accommodate commodity seasonal market demands Deliver a cost effective service Deliver a predictable and reliable service Operate the trains within the safe operating limits (speeding, hard breaking, line traffic rules) Build and maintain customer relationships
What are the challenges experienced in general	High cycle times (cycle times impacted by reliability of assets and resources, and operational inefficiencies) Large variety of information systems that do not communicate to each other and only serve a specific purpose People not aware of systems in place or how to use them Can track wagons in real time but not locomotives or crew Lack of information sharing between departments Top management does not communicate key information to the operators in an optimal way, they communicate via notice boards to employees that is not literate There is lack of alignment on who is the customer and what value each department add to the process Lack of adequate preventative maintenance Crew roster not aligned with system requirements SOP's not adequate Measures reliability based on failures per million km (should be based on impacts service delivery) Lack of information sharing between departments Functional departments operating in silos Performance management system and consequence management does not facilitate accountability and is influenced by internal political agendas Technical & Ops measurements not aligned (PPM vs Cycle time) Performance measures not filtered through the organisation Lack of competent and willing workforce Resource availability low due to high cycle times Lack of management involvement in operations, management do not forecast or predict the ripple effect of decisions or instructions they make The culture is one of complacency, no urgency, lack of attitude or managing the railway as administrative activities Low morale, motivation and deterioration of work ethic Ageing assets (Locos, wagons, infrastructure) Loss of asset capacity as a result of incidents Condition of their facilities is not conducive to improving employee morale, motivation and performance

Question	Response
What advantages does Transnet have in the logistics space that could be used to leverage in the market place	Assets and infrastructure Captured market Large mix of assets to cater for a variety of traffic mix Large base of employees Management initiatives to improve service delivery They do have system that can track trains in real time and can be used for reporting Can track wagon positions in the system Their reporting structure is hierarchical and operators do execute instructions They do benchmark internal processes with other railways The company provides education for employees to build capability
How does crew scheduling take place	There are two basic methods: - First in First out and - The Diagram Both methods are developed based on the integrated train plan. The integrated train plan is used to determine the capacity requirements. Because of the variability in the system buffer is created and Transnet uses stand by crew many times. The first in first out principle is based on when a crew member arrives in the yard. If he arrives first in the yard, he will be schedule for the first train the next day. This is not effective because there may be a misalignment between the train schedule and the rest time allocated to the crew member, it could be longer or shorter. Second, if the crew does come on duty and the train he is schedule to drive the next shift does not arrive then the crew run out of time and an alternative solution must be found The diagram is a fixed schedule to which crew members are assigned. Both methods calculate the available capacity based on the train plan and the number of crew that need to go on training and leave and so on. Transnet plans to have approximately 70% of the crew capacity available to drive trains.
Is crew behaviour a problem in the yards and what is being done to address the problems	Crew is definitely a problem. They cause safety related incidents, at times the create incidents to not drive trains, the go off sick which is unplanned, the schedules don't work which causes more problems and there are issues related to non-performance. Transnet does implement a performance management process to discipline non-performance and the crew are required to attend regular training sessions.
What would you do to improve crewing	Automate the process based on when trains will actually arrive and depart. Crew needs to be planned close to when the train arrives and needs to depart. This cannot be done now because standby crew needs to be notified a minimum of 24 hours before they need to arrive for a shift. Sometimes crew and the standby crew run out of time.

Question	Response
What is your opinion on what is being presented as solutions in the assignment	I agree with all three suggestions. Some of them are already being addressed in improving execution e.g. the crew KPIs. The long term plan is to change the organisational structure and address the KPIs. Improving planning of crew by changing the crewing rostering methodology to increase availability will help significantly, however before anything can be recommended the cost of crew is a problem. Furthermore impact on crew working terms and conditions need to be assessed as the unions must approve.
Provide detail of key aspects that must be managed in a train yard	Refer to the diagram

APPENDIX B: INTERVIEWS

The intention of these interviews was to understand and determine what assumptions should be used in the design of the simulation. These interviews took place on 29 November 2013.

Table B.1 Interview with resource manager

Question	Answer
Where have your worked in Transnet?	I have worked on the coal line and NATCOR, which is a corridor, and most of the lines in Transnet. The biggest corridor was the coal line where the complexity of crew management in Ermelo was high and we had to manage 12 hour exceedings on top of the other KPIs because the contract penalties with our customers.
How is the crew schedule currently developed?	They are based on the ITP. Once the train plan is finalised weekly the crew assignment takes place. Crew assignment generally happens either using the ‘First in First out’ method or the Diagram.
How often do trains arrive and depart on time as per the ITP?	It doesn’t happen.
What happens when trains arrive and depart off schedule?	The resource managers and the countdown managers in the yards communicate with each other to establish a new crew roster based on the actual train movements.
What are the reasons the trains are not on time?	There is no specific answer to this question because Transnet is short of resources and has ageing assets. Also the Central Train Control (CTC) prioritises trains based on decisions made in top management.
So when train are late how are crew rescheduled / assigned?	Depending on the situation either the crew drives the train from the origin to destination and incurs overtime because no alternative plan can be made; or a standby crew is used if available; or the train has to wait for crew to come on duty; or we run the train to a yard en route to the destination and either use the cross point system or relieve the crew.
If I analyse the data will I be able to tell which option was used?	Unfortunately not, the data does not detail the reasons for method used to reassign or reschedule crew. It sometimes gives the reasons for rescheduling the train or delays.

Question	Answer
Do you capture the times the crew comes on duty, boards the train and the performance relative to the schedule?	Crew performance is not linked to train performance, the reason is that the train arrival and departure times cannot be influenced by crew; even though crew do delay the trains when they arrive late for instance. Crew performance is measured on number of kilometres driven and overtime.
What operational rules must I apply in the simulation model?	1. Trains cannot arrive and depart simultaneously, the trains enter a queue and are mostly planned to enter the yard 30 minutes apart. 2. There are different speeds at which trains move. This is as a result of speed restrictions. 3. Crew either return to their home base, i.e. the yard that scheduled them, either by minibus / Kombi or by train. 4. You need standby crews to cater for trains departing one after the other.
Are there any rules governing crew scheduling and management?	There is the variation agreement and the main agreement. Both have the rules governing working hours and overtime. There are limits to working overtime so we try to minimise it as much as possible; however, given the shortage of resources and train arrivals / departures sometimes we have no choice. Train deviations are managed and train delays because of crew are also monitored and managed.
Will the data tell me which trains were delayed because of crew?	Crew does not usually delay trains because there are many options available to eliminate before a train is significantly delayed or cancelled due to crew.
How do the various functions integrate to move the train between origin and destination points?	The ITP is developed weekly however to accommodate for rescheduling the functions work independently and rely on the yard planners to provide information so that it results in a co-ordinated effort.
What information do the yard planners provide?	What trains are arriving and departing, the estimated times for arrival and departure, the priorities of train movements. They communicate between yards to notify other yards if they should move trains or not as certain receiving yards may be blocked.

Question	Answer
Are their dependencies between yards that need to be considered in a simulation, i.e. do they work independently or in an integrated manner?	Yards work independently and are managed independently. They also receive a different commodity trains. No two trains operate or receive the same commodities in the network. The train system is very complex and each yard has its own structure to manage the operations. Each yard also chooses whether they want to implement the diagram or FIFO method of crew scheduling and assignment.
What is the structure in a yard?	Generally, there are yard managers, planners, resource managers that manage crew, locomotive managers. Some yards have representatives from infrastructure or Transnet Engineering for the maintenance of locomotives and/or wagons.
What is the reporting structure?	They all report within their various functional disciplines but they also have a dotted reporting line to the yard manager, this causes a conflict when there are differing priorities between a yard manager and the functional discipline manager.
How is that managed?	Currently there are two reporting lines. The delegations has been changed recently to allow the yard manager to make the decision on how the integration should take place in a yard however performance is still not measured in an integrated manner and the KPIs drive different priorities, meaning the functional discipline managers also drive different priorities.
Are there systems that Transnet uses to schedule and reschedule crew?	Currently both are done manually.
What are the major challenges you experience	Crew arrive on duty and run out of time waiting for trains. This results in trains having to wait for relief crew or standby crew. Sometimes crew also arrive late resulting in train delays.
How has Transnet mitigated the risk of non-availability of crew when needed?	Previously, crew were specialised per locomotive, per route; however, recently Transnet has created flexibility in the system to ensure that trains do depart. They have multi-skilled the crew to be able to drive different types of locomotives.
What changes happened?	Well there were improvements in the train departures. Train rescheduling and cancellations did reduce; however, other crew capacity problems needed to be solved as a result, i.e. the total number of crew available needed to be adjusted to be able to cater for changes in the plan.

Question	Answer
What were the capacity challenges	Crew now being used in a different way to better suit random train arrivals and departures however crew were still incurring overtime and there was insufficient coverage.

Table B.2 Interview with COO

Question	Answer
The principle the model is developed on, is that of increasing coverage and availability, is this correct?	The principles of the model are correct and there is value in establishing a method to schedule crew in an unscheduled railway environment. This needs further research to be able to implement within the South African environment as this is an exploratory research project to test the principle. Now that the principle has been tested, research into a full-scale implementation needs to be conducted. System optimisation is critical to the success of a railway.
The simulation has a heuristic embedded in it to link the number of trains with increasing the number of crew and their availability in the yard?	The heuristic as it is in the simulation does make sense however, in certain instances, when trains need to wait for the next crew to come on duty and it is planned, managers may find that hard to accept. Each functional unit is driven by different KPI's, for example a yard managers KPI is the number of trains that he departs from his yard per day. So, letting the train wait for crew will not be acceptable to him; however; it will be acceptable for the crewing department because their KPIs are based on the number of kilometres driven and overtime hours.
What are your thoughts on the improvements?	These improvements could significantly improve the efficiency of train operations and revenue, however there is a progression in maturity that needs to take place, i.e. from unscheduled to scheduled. Research into this area has not been performed before and is important with high competition in the market to increase volumes exported from various countries. A final solution should be developed and its applications investigated.

APPENDIX C: LETTER FROM WITS

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University of the Witwatersrand

28 March 2012

Capacity Planning Research

Dear Sir

Rohini Shookan (Student number: 9802119H) is currently registered for her masters at the University of Witwatersrand. She is required to deliver a research report to complete her masters degree. Her chosen research topic is based on capacity planning. To execute this research she needs support from Transnet Freight Rail to:

- Get access to data
- Validate the accuracy of the information
- Assist with vetting the level of sensitivity of the information and how to approach documenting it

The intention of the research is to add new thinking to the existing body of knowledge and we are very excited to work with Transnet Freight Rail.

The University of the Witwatersrand Human Resources Ethics Committee, HREC (Non-Medical) ensures that all research in which humans are involved either as informants or subjects (carried out in the University by undergraduates, post-graduates, staff or affiliated staff in the name of the University) respects the rights of individuals and that:

- the informant or subject has consented to the research without coercion;
- the questions posed are not insulting or embarrassing;
- confidential matters that could place the informant in an embarrassing, false or compromising position vis-à-vis authorities, are handled circumspectly;

- the privacy and wishes of informants are respected, i.e. anonymity of the informant is maintained if required; the informant is informed as fully as possible as to the aims and possible implications of the research.

Yours sincerely,

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APPENDIX D: TRAIN DATA

Table D.1 Train Data

TRAIN ORIGIN	PPW-NCS											Reitvallei - Destination					
ITP Trains #	Transit Design (PPW-NCS)	Tran-sit (PPW - NCS)	Devi-ation (PPW - NCS)	Cumu-lative delays origin to NCS	Arrival NCS	Dwell time De-sign NCS	Actual Dwell NCS	Devi-ation	Planned Departure	Departure NCS	Cumu-lative delays origin to NCS departure	Transit Design (Rietvallei – Destina-tion)	Actual Transit (Rietvallei – Destina-tion)	Deviation (Rietvallei – Destina-tion)	Cumu-lative delays origin to destina-tion	Planned arrival at Desti-nation	Arrival at Destination
5902	144	155	10	179	01/07/2013 14:20	10	06	0	01/07/2013 11:46	01/07/2013 14:26	179	123	90	0	281	01/07/2013 22:29	01/07/2013 23:25
8986	144	123	0	163	01/07/2013 14:04	10	04	0	01/07/2013 12:16	01/07/2013 14:08	163	123	190	67	231	01/07/2013 22:13	01/07/2013 23:00
8906	144	124	0	243	01/07/2013 16:17	10	06	0	01/07/2013 12:52	01/07/2013 16:23	243	123	79	0	250	02/07/2013 00:26	01/07/2013 23:25
8908	144	171	26	1191	02/07/2013 09:40	10	07	0	01/07/2013 15:44	02/07/2013 09:47	1191	123	206	83	1274	02/07/2013 17:49	02/07/2013 19:00
8816	144	135	0	361	01/07/2013 22:18	10	06	0	01/07/2013 17:36	01/07/2013 22:24	361	123	589	466	827	02/07/2013 06:27	02/07/2013 13:32
8912	144	121	0	1183	02/07/2013 13:12	10	07	0	01/07/2013 18:11	02/07/2013 13:19	1183	123	67	0	1183	02/07/2013 21:21	02/07/2013 20:00
2464	144	119	0	330	02/07/2013 00:14	10	06	0	01/07/2013 19:50	02/07/2013 00:20	330	123	20	0	373	02/07/2013 08:23	02/07/2013 07:08

TRAIN ORIGIN	PPW-NCS											Reitvallei - Destination					
ITP Trains #	Transit Design (PPW-NCS)	Transit (PPW-NCS)	Deviation (PPW-NCS)	Cumulative delays origin to NCS	Arrival NCS	Dwell time Design NCS	Actual Dwell NCS	Deviation	Planned Departure	Departure NCS	Cumulative delays origin to NCS departure	Transit Design (Rietvallei – Destination)	Actual Transit (Rietvallei – Destination)	Deviation (Rietvallei – Destination)	Cumulative delays origin to destination	Planned arrival at Destination	Arrival at Destination
8984	144	132	0	157	01/07/2013 23:19	10	30	19	01/07/2013 21:26	01/07/2013 23:49	177	123	56	0	264	02/07/2013 07:28	02/07/2013 08:04
8918	144	128	0	156	01/07/2013 23:30	10	27	16	01/07/2013 22:59	01/07/2013 23:57	173	123	61	0	259	02/07/2013 07:39	02/07/2013 08:20
8412	144	170	25	214	02/07/2013 02:28	10	10	0	01/07/2013 23:10	02/07/2013 02:38	214	123	373	250	760	02/07/2013 10:37	02/07/2013 19:42
8902	144	198	53	177	02/07/2013 02:33	10	14	03	02/07/2013 01:40	02/07/2013 02:47	181	123	91	0	304	02/07/2013 10:42	02/07/2013 12:17
8922	144	144	0	100	02/07/2013 03:15	10	06	0	02/07/2013 01:51	02/07/2013 03:21	100	123	81	0	179	02/07/2013 11:24	02/07/2013 11:57
8904	144	180	35	730	02/07/2013 15:54	10	07	0	02/07/2013 04:05	02/07/2013 16:01	730	123	167	44	774	03/07/2013 00:03	02/07/2013 22:35
8924	144	162	17	223	02/07/2013 10:46	10	07	0	02/07/2013 07:17	02/07/2013 10:53	223	123	1087	964	1256	02/07/2013 18:55	03/07/2013 12:00
8982	144	151	06	202	02/07/2013 11:02	10	06	0	02/07/2013 08:20	02/07/2013 11:08	202	123	69	0	267	02/07/2013 19:11	02/07/2013 19:18
5000	144	161	16	490	02/07/2013 15:16	10	19	08	02/07/2013 09:06	02/07/2013 15:35	498	123	434	311	809	02/07/2013 23:25	03/07/2013 02:15

TRAIN ORIGIN	PPW-NCS											Reitvallei - Destination					
ITP Trains #	Transit Design (PPW-NCS)	Tran-sit (PPW - NCS)	Devi-ation (PPW - NCS)	Cumu-lative delays origin to NCS	Arrival NCS	Dwell time De-sign NCS	Actual Dwell NCS	Devi-ation	Planned Departure	Departure NCS	Cumu-lative delays origin to NCS departure	Transit Design (Rietvallei – Destina-tion)	Actual Transit (Rietvalle i – Destina-tion)	Deviation (Rietvalle i – Destina-tion)	Cumu-lative delays origin to destina-tion	Planned arrival at Desti-nation	Arrival at Destination
8908	144	136	0	336	02/07/2013 20:29	10	07	0	02/07/2013 15:44	02/07/201 3 20:36	336	123	81	0	639	03/07/20 13 04:38	03/07/2013 08:40
8816	144	124	0	513	03/07/2013 01:03	10	59	48	02/07/2013 17:36	03/07/201 3 02:02	562	123	90	0	589	03/07/20 13 09:12	03/07/2013 09:50
8912	144	126	0	224	02/07/2013 20:55	10	19	08	02/07/2013 18:11	02/07/201 3 21:14	233	123	85	0	728	03/07/20 13 05:04	03/07/2013 12:40
2464	144	144	0	1258	03/07/2013 16:29	10	25	14	02/07/2013 19:50	03/07/201 3 16:54	1272	123	526	403	2136	04/07/20 13 00:38	04/07/2013 15:05
8984	144	123	0	274	03/07/2013 01:22	10	11	00	02/07/2013 21:26	03/07/201 3 01:33	274	123	70	0	331	03/07/20 13 09:31	03/07/2013 09:20
8918	144	125	0	232	03/07/2013 02:29	10	07	0	02/07/2013 22:59	03/07/201 3 02:36	232	123	69	0	316	03/07/20 13 10:38	03/07/2013 11:04
2472	144	121	0	363	03/07/2013 06:32	10	08	0	03/07/2013 01:32	03/07/201 3 06:40	363	123	178	55	677	03/07/20 13 14:41	03/07/2013 19:51
8902	144	129	0	243	03/07/2013 04:56	10	06	0	03/07/2013 01:40	03/07/201 3 05:02	243	123	181	58	324	03/07/20 13 13:05	03/07/2013 14:00
8922	144	10	0	2467	04/07/2013 16:03	10	178	167	03/07/2013 01:51	04/07/201 3 19:01	2634	123	87	0	2649	05/07/20 13 00:12	05/07/2013 01:20

TRAIN ORIGIN	PPW-NCS											Reitvallei - Destination						
ITP Trains #	Transit Design (PPW-NCS)	Tran-sit (PPW - NCS)	Devi-ation (PPW - NCS)	Cumu-lative delays origin to NCS	Arrival NCS	Dwell time De-sign NCS	Actual Dwell NCS	Devi-ation	Planned Departure	Departure NCS	Cumu-lative delays origin to NCS departure	Transit Design (Rietvallei – Destina-tion)	Actual Transit (Rietvallei – Destina-tion)	Deviation (Rietvallei – Destina-tion)	Cumu-lative delays origin to destina-tion	Planned arrival at Desti-nation	Arrival at Destination
8924	144	148	03	349	03/07/2013 10:36	10	35	24	03/07/2013 07:17	03/07/2013 11:11	373	123	144	21	776	03/07/2013 18:45	04/07/2013 01:35
8982	144	191	46	270	03/07/2013 12:35	10	06	0	03/07/2013 08:20	03/07/2013 12:41	270	123	69	0	283	03/07/2013 20:44	03/07/2013 19:50
5000	144	11	0	863	03/07/2013 20:35	10	165	154	03/07/2013 09:06	03/07/2013 23:20	1017	123	458	335	1428	04/07/2013 04:44	04/07/2013 14:10
5902	144	163	18	229	03/07/2013 15:09	10	07	0	03/07/2013 11:46	03/07/2013 15:16	229	123	126	03	248	03/07/2013 23:18	03/07/2013 23:25
8658	144	136	0	385	03/07/2013 18:47	10	264	253	03/07/2013 11:47	03/07/2013 23:11	638	123	201	78	716	04/07/2013 02:56	04/07/2013 07:25
8486	144	80	0	702	04/07/2013 00:51	10	30	19	03/07/2013 12:16	04/07/2013 01:21	722	123	253	130	912	04/07/2013 09:00	04/07/2013 12:23
8906	144	180	35	636	03/07/2013 23:15	10	08	0	03/07/2013 12:52	03/07/2013 23:23	636	123	100	0	684	04/07/2013 07:24	04/07/2013 07:45
8912	144	138	0	1744	04/07/2013 22:03	10	215	204	03/07/2013 18:11	05/07/2013 01:38	1949	123	340	217	2166	05/07/2013 06:12	05/07/2013 12:10
2464	144	157	12	367	04/07/2013 01:29	10	06	0	03/07/2013 19:50	04/07/2013 01:35	367	123	521	398	765	04/07/2013 09:38	04/07/2013 15:00

TRAIN ORIGIN	PPW-NCS											Reitvallei - Destination					
ITP Trains #	Transit Design (PPW-NCS)	Tran-sit (PPW - NCS)	Devi-ation (PPW - NCS)	Cumu-lative delays origin to NCS	Arrival NCS	Dwell time De-sign NCS	Actual Dwell NCS	Devi-ation	Planned Departure	Departure NCS	Cumu-lative delays origin to NCS departure	Transit Design (Rietvallei – Destina-tion)	Actual Transit (Rietvalle i – Destina-tion)	Deviation (Rietvalle i – Destina-tion)	Cumu-lative delays origin to destina-tion	Planned arrival at Desti-nation	Arrival at Destination
8984	144	161	16	1016	04/07/2013 13:26	10	06	0	03/07/2013 21:26	04/07/201 3 13:32	1016	123	74	0	1016	04/07/20 13 21:35	04/07/2013 19:45
8814	144	110	0	3445	06/07/2013 08:11	10	33	22	04/07/2013 00:36	06/07/201 3 08:44	3467	123	188	65	3546	06/07/20 13 16:20	06/07/2013 16:30
8902	144	122	0	233	04/07/2013 03:57	10	05	0	04/07/2013 01:40	04/07/201 3 04:02	233	123	661	538	816	04/07/20 13 12:06	04/07/2013 21:20
8922	144	122	0	106	04/07/2013 02:31	10	09	0	04/07/2013 01:51	04/07/201 3 02:40	106	123	70	0	165	04/07/20 13 10:40	04/07/2013 10:30
8904	144	132	0	194	04/07/2013 06:48	10	31	20	04/07/2013 04:05	04/07/201 3 07:19	214	123	80	0	223	04/07/20 13 14:57	04/07/2013 14:15
8946	204	144	0	535	04/07/2013 11:29	10	28	17	04/07/2013 03:59	04/07/201 3 11:57	552	123	300	177	731	04/07/20 13 19:38	04/07/2013 22:20
8924	144	127	0	1334	05/07/2013 03:59	10	06	0	04/07/2013 07:17	05/07/201 3 04:05	1334	123	878	755	2089	05/07/20 13 12:08	05/07/2013 22:55
8982	144	136	0	297	04/07/2013 12:33	10	08	0	04/07/2013 08:20	04/07/201 3 12:41	297	123	96	0	297	04/07/20 13 20:42	04/07/2013 19:15
5000	144	146	01	304	04/07/2013 13:51	10	10	0	04/07/2013 09:06	04/07/201 3 14:01	304	123	219	96	401	04/07/20 13 22:00	04/07/2013 20:49

TRAIN ORIGIN	PPW-NCS											Reitvallei - Destination					
ITP Trains #	Transit Design (PPW-NCS)	Tran-sit (PPW - NCS)	Devi-ation (PPW - NCS)	Cumu-lative delays origin to NCS	Arrival NCS	Dwell time De-sign NCS	Actual Dwell NCS	Devi-ation	Planned Departure	Departure NCS	Cumu-lative delays origin to NCS departure	Transit Design (Rietvallei – Destina-tion)	Actual Transit (Rietvallei – Destina-tion)	Deviation (Rietvallei – Destina-tion)	Cumu-lative delays origin to destina-tion	Planned arrival at Desti-nation	Arrival at Destination
5902	144	170	25	328	04/07/2013 16:54	10	17	06	04/07/2013 11:46	04/07/2013 17:11	334	123	114	0	372	05/07/2013 01:03	05/07/2013 01:28
8658	204	149	0	96	04/07/2013 13:39	10	30	19	04/07/2013 14:47	04/07/2013 14:09	116	123	1074	951	1111	04/07/2013 22:48	05/07/2013 14:10
8540	264	136	0	251	04/07/2013 20:32	10	07	0	04/07/2013 20:32	04/07/2013 20:39	251	123	72	0	870	05/07/2013 06:41	05/07/2013 15:58
8908	144	131	0	357	04/07/2013 20:48	10	07	0	04/07/2013 15:44	04/07/2013 20:55	357	123	91	0	481	05/07/2013 04:57	05/07/2013 06:15
2464	144	131	0	528	05/07/2013 04:10	10	05	0	04/07/2013 19:50	05/07/2013 04:15	528	123	222	99	629	05/07/2013 12:19	05/07/2013 13:45
8984	144	117	0	266	05/07/2013 01:06	10	05	0	04/07/2013 21:26	05/07/2013 01:11	266	123	79	0	266	05/07/2013 09:15	05/07/2013 07:30
8918	144	127	0	229	05/07/2013 00:00	10	65	54	04/07/2013 22:59	05/07/2013 01:05	283	123	86	0	354	05/07/2013 08:09	05/07/2013 09:35
8902			0	00				0	00/01/1900 00:00		00			0	00		
8910			0	00				0	00/01/1900 00:00		00			0	00		

TRAIN ORIGIN	PPW-NCS											Reitvallei - Destination					
ITP Trains #	Transit Design (PPW-NCS)	Tran-sit (PPW - NCS)	Devi-ation (PPW - NCS)	Cumu-lative delays origin to NCS	Arrival NCS	Dwell time De-sign NCS	Actual Dwell NCS	Devi-ation	Planned Departure	Departure NCS	Cumu-lative delays origin to NCS departure	Transit Design (Rietvallei – Destina-tion)	Actual Transit (Rietvallei – Destina-tion)	Deviation (Rietvallei – Destina-tion)	Cumu-lative delays origin to destina-tion	Planned arrival at Desti-nation	Arrival at Destination
8924	144	47	0	153	05/07/2013 04:59	10	06	0	05/07/2013 07:17	05/07/2013 05:05	153	123	593	470	763	05/07/2013 13:08	05/07/2013 22:04
8982	144	101	0	50	05/07/2013 07:35	10	65	54	05/07/2013 08:20	05/07/2013 08:40	104	123	1183	1060	1164	05/07/2013 15:44	06/07/2013 08:00
5902	144	117	0	588	05/07/2013 19:54	10	06	0	05/07/2013 11:46	05/07/2013 20:00	588	123	308	185	833	06/07/2013 04:03	06/07/2013 08:00
8906	144	347	202	379	05/07/2013 18:30	10	37	26	05/07/2013 12:52	05/07/2013 19:07	405	123	95	0	456	06/07/2013 02:39	06/07/2013 03:15
8908	144	128	0	1017	06/07/2013 00:03	10	45	34	05/07/2013 15:44	06/07/2013 00:48	1051	123	49	0	1099	06/07/2013 08:12	06/07/2013 08:00
8816	144	126	0	187	05/07/2013 19:37	10	08	0	05/07/2013 17:36	05/07/2013 19:45	187	123	68	0	659	06/07/2013 03:46	06/07/2013 10:30
8984	144	134	0	330	06/07/2013 01:30	10	07	0	05/07/2013 21:26	06/07/2013 01:37	330	123	83	0	376	06/07/2013 09:39	06/07/2013 09:24
8918	144	129	0	715	06/07/2013 08:53	10	07	0	05/07/2013 22:59	06/07/2013 09:00	715	123	133	10	725	06/07/2013 17:02	06/07/2013 16:35
8814	144	144	0	500	06/07/2013 08:37	10	68	57	06/07/2013 00:36	06/07/2013 09:45	557	123	221	98	655	06/07/2013 16:46	06/07/2013 19:10

TRAIN ORIGIN	PPW-NCS											Reitvallei - Destination					
ITP Trains #	Transit Design (PPW-NCS)	Tran-sit (PPW - NCS)	Devi-ation (PPW - NCS)	Cumu-lative delays origin to NCS	Arrival NCS	Dwell time De-sign NCS	Actual Dwell NCS	Devi-ation	Planned Departure	Departure NCS	Cumu-lative delays origin to NCS departure	Transit Design (Rietvallei – Destina-tion)	Actual Transit (Rietvalle i – Destina-tion)	Deviation (Rietvalle i – Destina-tion)	Cumu-lative delays origin to destina-tion	Planned arrival at Desti-nation	Arrival at Destination
8902	144	143	0	2476	07/07/2013 17:48	10	08	0	06/07/2013 01:40	07/07/201 3 17:56	2476	123	139	16	2498	08/07/20 13 01:57	07/07/2013 22:40
5994		117	117	465	06/07/2013 04:46			0	05/07/2013 20:02	06/07/201 3 04:51	465		126	126	651	06/07/20 13 09:20	06/07/2013 11:54
8946		101	101	716	06/07/2013 09:50			0	06/07/2013 00:01	06/07/201 3 09:59	716		350	350	1135	06/07/20 13 14:24	06/07/2013 20:20
8924	144	201	56	625	06/07/2013 14:48	10	31	20	06/07/2013 07:17	06/07/201 3 15:19	645	123	147	24	669	06/07/20 13 22:57	06/07/2013 22:23
8982	144	131	0	309	06/07/2013 12:57	10	09	0	06/07/2013 08:20	06/07/201 3 13:06	309	123	71	0	309	06/07/20 13 21:06	06/07/2013 19:10
5000	144	131	0	427	06/07/2013 15:33	10	50	39	06/07/2013 09:06	06/07/201 3 16:23	467	123	71	0	1306	06/07/20 13 23:42	07/07/2013 13:14
5902	144	126	0	4343	09/07/2013 09:35	10	68	57	06/07/2013 11:46	09/07/201 3 10:43	4400	123	51	0	4887	09/07/20 13 17:44	10/07/2013 01:26
8986	144	146	01	616	06/07/2013 22:29			0	06/07/2013 12:21	06/07/201 3 22:49	616		142	142	820	07/07/20 13 03:03	07/07/2013 05:49
8906	144	146	01	591	06/07/2013 22:16	10	07	0	06/07/2013 12:52	06/07/201 3 22:23	591	123	132	09	648	07/07/20 13 06:25	07/07/2013 07:20

TRAIN ORIGIN	PPW-NCS											Reitvallei - Destination					
ITP Trains #	Transit Design (PPW-NCS)	Transit (PPW - NCS)	Deviation (PPW - NCS)	Cumulative delays origin to NCS	Arrival NCS	Dwell time Design NCS	Actual Dwell NCS	Deviation	Planned Departure	Departure NCS	Cumulative delays origin to NCS departure	Transit Design (Rietvallei – Destination)	Actual Transit (Rietvallei – Destination)	Deviation (Rietvallei – Destination)	Cumulative delays origin to destination	Planned arrival at Destination	Arrival at Destination
808842	144	228	83	1038	07/07/2013 06:19	10	67	56	06/07/2013 13:16	07/07/2013 07:26	1094	123	72	0	1120	07/07/2013 14:28	07/07/2013 14:55
1540	144	146	01	301	06/07/2013 20:01	10	05	0	06/07/2013 15:16	06/07/2013 20:06	301	123	339	216	537	07/07/2013 04:10	07/07/2013 07:45
8908	144	125	0	305	06/07/2013 20:12	10	05	0	06/07/2013 15:44	06/07/2013 20:17	305	123	71	0	305	07/07/2013 04:21	07/07/2013 02:30
8816	144	137	0	2047	08/07/2013 03:05	10	07	0	06/07/2013 17:36	08/07/2013 03:12	2047	123	101	0	2360	08/07/2013 11:14	08/07/2013 15:40
5646	144	162	17	1257	07/07/2013 14:27	10	104	93	06/07/2013 17:46	07/07/2013 16:11	1350	123	266	143	1568	07/07/2013 22:36	08/07/2013 03:45
8984	144	117	0	78	06/07/2013 21:38	10	06	0	06/07/2013 21:26	06/07/2013 21:44	78	123	70	0	78	07/07/2013 05:47	07/07/2013 04:15
8918	144	132	0	453	07/07/2013 06:06	10	689	678	06/07/2013 22:59	07/07/2013 17:35	1131	123	109	0	1222	07/07/2013 14:15	08/07/2013 02:51
804472	144	60	0	2838	08/07/2013 21:15	10	105	94	06/07/2013 23:42	08/07/2013 23:00	2932	123	46	0	2968	09/07/2013 05:24	09/07/2013 06:00
8814	144	140	0	952	07/07/2013 16:04	10	13	02	07/07/2013 00:36	07/07/2013 16:17	954	123	75	0	996	08/07/2013 00:13	08/07/2013 00:10

TRAIN ORIGIN	PPW-NCS											Reitvallei - Destination					
ITP Trains #	Transit Design (PPW-NCS)	Tran-sit (PPW - NCS)	Devi-ation (PPW - NCS)	Cumu-lative delays origin to NCS	Arrival NCS	Dwell time De-sign NCS	Actual Dwell NCS	Devi-ation	Planned Departure	Departure NCS	Cumu-lative delays origin to NCS departure	Transit Design (Rietvallei – Destina-tion)	Actual Transit (Rietvallei – Destina-tion)	Deviation (Rietvallei – Destina-tion)	Cumu-lative delays origin to destina-tion	Planned arrival at Desti-nation	Arrival at Destination
8902	144	91	0	93	07/07/2013 01:41	10	05	0	07/07/2013 01:40	07/07/2013 01:46	93	123	790	667	897	07/07/2013 09:50	07/07/2013 22:40
8922	144	227	82	302	07/07/2013 06:49	10	10	0	07/07/2013 01:51	07/07/2013 06:59	302	123	124	01	363	07/07/2013 14:58	07/07/2013 16:00
8910	144	101	0	275	07/07/2013 10:03	10	09	0	07/07/2013 02:13	07/07/2013 10:12	275	123	334	211	503	07/07/2013 18:12	07/07/2013 21:40
8924	144	116	0	333	07/07/2013 11:59	10	09	0	07/07/2013 07:17	07/07/2013 12:08	333	123	217	94	427	07/07/2013 20:08	07/07/2013 21:32
8982	144	127	0	87	07/07/2013 13:06	10	10	0	07/07/2013 08:20	07/07/2013 13:16	87	123	81	0	91	07/07/2013 21:15	07/07/2013 20:25
5000	144	135	0	326	07/07/2013 13:42	10	10	0	07/07/2013 09:06	07/07/2013 13:52	326	123	117	0	1088	07/07/2013 21:51	08/07/2013 10:15
5902	144	133	0	132	07/07/2013 13:25	10	20	09	07/07/2013 11:46	07/07/2013 13:45	142	123	154	31	192	07/07/2013 21:34	07/07/2013 22:05
1510	144	127	0	41	07/07/2013 16:14	10	45	34	07/07/2013 16:27	07/07/2013 16:59	76	123	83	0	101	08/07/2013 00:23	08/07/2013 00:30
8912	144	152	07	316	07/07/2013 22:54	10	07	0	07/07/2013 18:11	07/07/2013 23:01	316	123	91	0	771	08/07/2013 07:03	08/07/2013 14:00

TRAIN ORIGIN	PPW-NCS											Reitvallei - Destination					
ITP Trains #	Transit Design (PPW-NCS)	Tran-sit (PPW - NCS)	Devi-ation (PPW - NCS)	Cumu-lative delays origin to NCS	Arrival NCS	Dwell time De-sign NCS	Actual Dwell NCS	Devi-ation	Planned Departure	Departure NCS	Cumu-lative delays origin to NCS departure	Transit Design (Rietvallei – Destina-tion)	Actual Transit (Rietvallei – Destina-tion)	Deviation (Rietvallei – Destina-tion)	Cumu-lative delays origin to destina-tion	Planned arrival at Desti-nation	Arrival at Destination
2464	144	204	59	132	07/07/2013 21:43	10	85	74	07/07/2013 19:50	07/07/2013 23:08	206	123	117	0	325	08/07/2013 05:52	08/07/2013 09:00
8984	144	132	0	153	07/07/2013 23:15	10	29	18	07/07/2013 21:26	07/07/2013 23:44	172	123	90	0	241	08/07/2013 07:24	08/07/2013 08:15
8918	144	137	0	307	08/07/2013 03:24	10	06	0	07/07/2013 22:59	08/07/2013 03:30	307	123	103	0	364	08/07/2013 11:33	08/07/2013 11:55
1572	144	144	0	624	08/07/2013 09:21	10	12	01	07/07/2013 23:24	08/07/2013 09:33	625	123	1258	1135	1763	08/07/2013 17:30	09/07/2013 12:21
8814	144	119	0	483	08/07/2013 07:56	10	06	0	08/07/2013 00:36	08/07/2013 08:02	483	123	271	148	631	08/07/2013 16:05	08/07/2013 17:25
2472	144	125	0	227	08/07/2013 00:31	10	13	02	08/07/2013 01:32	08/07/2013 00:44	229	123	270	147	593	08/07/2013 08:40	08/07/2013 14:30
8902	144	119	0	713	08/07/2013 12:37	10	04	0	08/07/2013 01:40	08/07/2013 12:41	713	123	297	174	887	08/07/2013 20:46	08/07/2013 20:50
8946	144	97	0	237	08/07/2013 09:14	10	26	15	08/07/2013 06:32	08/07/2013 09:40	252	123	554	431	683	08/07/2013 17:23	08/07/2013 23:50
2466	144	129	0	440	08/07/2013 14:03	10	06	0	08/07/2013 07:16	08/07/2013 14:09	440	123	181	58	498	08/07/2013 22:12	08/07/2013 22:32

TRAIN ORIGIN	PPW-NCS											Reitvallei - Destination					
ITP Trains #	Transit Design (PPW-NCS)	Transit (PPW-NCS)	Deviation (PPW-NCS)	Cumulative delays origin to NCS	Arrival NCS	Dwell time Design NCS	Actual Dwell NCS	Deviation	Planned Departure	Departure NCS	Cumulative delays origin to NCS departure	Transit Design (Rietvallei – Destination)	Actual Transit (Rietvallei – Destination)	Deviation (Rietvallei – Destination)	Cumulative delays origin to destination	Planned arrival at Destination	Arrival at Destination
8924	144	119	0	263	08/07/2013 10:51	10	21	10	08/07/2013 07:17	08/07/2013 11:12	273	123	346	223	496	08/07/2013 19:00	08/07/2013 21:08
8982	144	128	0	351	08/07/2013 13:39	10	06	0	08/07/2013 08:20	08/07/2013 13:45	351	123	64	0	351	08/07/2013 21:48	08/07/2013 20:25
5000	144	175	30	446	08/07/2013 16:23	10	07	0	08/07/2013 09:06	08/07/2013 16:30	446	123	88	0	499	09/07/2013 00:32	09/07/2013 00:48
5902	144	130	0	540	08/07/2013 20:15	10	06	0	08/07/2013 11:46	08/07/2013 20:21	540	123	86	0	547	09/07/2013 04:24	09/07/2013 03:40
8486	144	141	0	303	08/07/2013 17:03	10	07	0	08/07/2013 12:16	08/07/2013 17:10	303	123	81	0	303	09/07/2013 01:12	08/07/2013 20:25
8906	144	133	0	410	08/07/2013 19:01	10	08	0	08/07/2013 12:52	08/07/2013 19:09	410	123	87	0	410	09/07/2013 03:10	09/07/2013 02:17
5510	144	135	0	738	09/07/2013 04:21	10	52	41	08/07/2013 16:27	09/07/2013 05:13	779	123	161	38	901	09/07/2013 12:30	09/07/2013 15:00
8912	144	137	0	253	08/07/2013 22:04	10	07	0	08/07/2013 18:11	08/07/2013 22:11	253	123	542	419	736	09/07/2013 06:13	09/07/2013 14:05
2464	144	128	0	339	09/07/2013 00:24	10	203	192	08/07/2013 19:50	09/07/2013 03:47	532	123	147	24	694	09/07/2013 08:33	09/07/2013 14:28

TRAIN ORIGIN	PPW-NCS											Reitvallei - Destination					
ITP Trains #	Transit Design (PPW-NCS)	Transit (PPW-NCS)	Deviation (PPW-NCS)	Cumulative delays origin to NCS	Arrival NCS	Dwell time Design NCS	Actual Dwell NCS	Deviation	Planned Departure	Departure NCS	Cumulative delays origin to NCS departure	Transit Design (Rietvallei – Destination)	Actual Transit (Rietvallei – Destination)	Deviation (Rietvallei – Destination)	Cumulative delays origin to destination	Planned arrival at Destination	Arrival at Destination
8984	144	168	23	336	09/07/2013 02:44	10	33	22	08/07/2013 21:26	09/07/2013 03:17	358	123	81	0	604	09/07/2013 10:53	09/07/2013 14:40
8918	144	157	12	956	09/07/2013 14:02	10	30	19	08/07/2013 22:59	09/07/2013 14:32	976	123	89	0	1149	09/07/2013 22:11	10/07/2013 00:35
1574	144	149	04	1019	09/07/2013 15:54	10	1170	1159	08/07/2013 23:24	10/07/2013 11:24	2179	123	364	241	2573	10/07/2013 00:03	11/07/2013 01:57
8902	144	140	0	280	09/07/2013 05:30	10	09	0	09/07/2013 01:40	09/07/2013 05:39	280	123	1421	1298	1580	09/07/2013 13:39	10/07/2013 10:40
8922	144	138	0	845	09/07/2013 15:35	10	07	0	09/07/2013 01:51	09/07/2013 15:42	845	123	-430	0	855	09/07/2013 23:44	09/07/2013 14:20
2466	144	132	0	501	09/07/2013 11:13	10	26	15	09/07/2013 07:16	09/07/2013 11:39	516	123	122	0	516	09/07/2013 19:22	09/07/2013 19:05
8924	144	136	0	103	09/07/2013 08:22	10	06	0	09/07/2013 07:17	09/07/2013 08:28	103	123	624	501	608	09/07/2013 16:31	10/07/2013 00:37
8982	144	107	0	275	09/07/2013 11:25	10	08	0	09/07/2013 08:20	09/07/2013 11:33	275	123	126	03	417	09/07/2013 19:34	09/07/2013 21:25
5902	144	148	03	702	09/07/2013 22:45	10	06	0	09/07/2013 11:46	09/07/2013 22:51	702	123	112	0	948	10/07/2013 06:54	10/07/2013 10:35

TRAIN ORIGIN	PPW-NCS											Reitvallei - Destination					
ITP Trains #	Transit Design (PPW-NCS)	Tran-sit (PPW - NCS)	Devi-ation (PPW - NCS)	Cumu-lative delays origin to NCS	Arrival NCS	Dwell time De-sign NCS	Actual Dwell NCS	Devi-ation	Planned Departure	Departure NCS	Cumu-lative delays origin to NCS departure	Transit Design (Rietvallei – Destina-tion)	Actual Transit (Rietvallei – Destina-tion)	Deviation (Rietvallei – Destina-tion)	Cumu-lative delays origin to destina-tion	Planned arrival at Desti-nation	Arrival at Destination
8906	144	132	0	643	09/07/2013 22:56	10	21	10	09/07/2013 12:52	09/07/2013 23:17	653	123	79	0	692	10/07/2013 07:05	10/07/2013 07:10
8908	144	215	70	468	09/07/2013 23:16	10	12	01	09/07/2013 15:44	09/07/2013 23:28	469	123	100	0	530	10/07/2013 07:25	10/07/2013 08:05
2464	144	120	0	763	10/07/2013 07:52	10	06	0	09/07/2013 19:50	10/07/2013 07:58	763	123	129	06	810	10/07/2013 16:01	10/07/2013 16:32
8984	144	11	0	458	10/07/2013 00:32	10	131	120	09/07/2013 21:26	10/07/2013 02:43	579	123	104	0	616	10/07/2013 08:41	10/07/2013 11:00
8940	144	128	0	215	10/07/2013 00:43	10	32	21	09/07/2013 22:06	10/07/2013 01:15	237	123	245	122	390	10/07/2013 08:52	10/07/2013 11:19
8918	144	120	0	372	10/07/2013 03:20	10	02	0	09/07/2013 22:59	10/07/2013 03:22	372	123	76	0	513	10/07/2013 11:29	10/07/2013 12:55
8814	144	131	0	1286	10/07/2013 21:31	10	07	0	10/07/2013 00:36	10/07/2013 21:38	1286	123	76	0	1286	11/07/2013 05:40	11/07/2013 04:15
2472	144	111	0	459	10/07/2013 08:15	10	56	45	10/07/2013 01:32	10/07/2013 09:11	504	123	128	05	509	10/07/2013 16:24	10/07/2013 17:00
8902	144	208	63	780	10/07/2013 14:15	10	34	23	10/07/2013 01:40	10/07/2013 14:49	803	123	824	701	1504	10/07/2013 22:24	11/07/2013 09:25

TRAIN ORIGIN	PPW-NCS											Reitvallei - Destination					
ITP Trains #	Transit Design (PPW-NCS)	Tran-sit (PPW - NCS)	Devi-ation (PPW - NCS)	Cumu-lative delays origin to NCS	Arrival NCS	Dwell time De-sign NCS	Actual Dwell NCS	Devi-ation	Planned Departure	Departure NCS	Cumu-lative delays origin to NCS departure	Transit Design (Rietvallei – Destina-tion)	Actual Transit (Rietvallei – Destina-tion)	Deviation (Rietvallei – Destina-tion)	Cumu-lative delays origin to destina-tion	Planned arrival at Desti-nation	Arrival at Destination
5000	144	169	24	313	10/07/2013 14:03	10	07	0	10/07/2013 09:06	10/07/2013 14:10	313	123	1185	1062	1936	10/07/2013 22:12	12/07/2013 01:01
8658	144	06	0	171	10/07/2013 10:26	10	307	296	10/07/2013 12:16	10/07/2013 15:33	468	123		0	468	10/07/2013 18:35	11/07/2013 03:50
8906	144	121	0	284	10/07/2013 16:53	10	08	0	10/07/2013 12:52	10/07/2013 17:01	284	123	70	0	284	11/07/2013 01:02	10/07/2013 23:10
8908	144	133	0	157	10/07/2013 17:21	10	07	0	10/07/2013 15:44	10/07/2013 17:28	157	123	71	0	157	11/07/2013 01:30	10/07/2013 23:58
1510	144	139	0	546	11/07/2013 01:13	10	148	137	10/07/2013 16:27	11/07/2013 03:41	683	123	77	0	706	11/07/2013 09:22	11/07/2013 11:00
8748		119	119	2000	11/07/2013 22:34		07	07	10/07/2013 14:53	11/07/2013 22:41	2007		224	224	2297	11/07/2013 22:34	11/07/2013 08:10
8816	144	128	0	1088	11/07/2013 11:15	10	09	0	10/07/2013 17:36	11/07/2013 11:24	1088	123	57	0	1088	11/07/2013 19:24	11/07/2013 16:55
5646	144	138	0	1133	11/07/2013 12:17	10	09	0	10/07/2013 17:46	11/07/2013 12:26	1133	123	415	292	1425	11/07/2013 20:26	12/07/2013 00:25
8912	144	239	94	1182	11/07/2013 13:50	10	51	40	10/07/2013 18:11	11/07/2013 14:41	1222	123	430	307	1529	11/07/2013 21:59	12/07/2013 03:20

TRAIN ORIGIN	PPW-NCS											Reitvallei - Destination					
ITP Trains #	Transit Design (PPW-NCS)	Transit (PPW-NCS)	Deviation (PPW-NCS)	Cumulative delays origin to NCS	Arrival NCS	Dwell time Design NCS	Actual Dwell NCS	Deviation	Planned Departure	Departure NCS	Cumulative delays origin to NCS departure	Transit Design (Rietvallei – Destination)	Actual Transit (Rietvallei – Destination)	Deviation (Rietvallei – Destination)	Cumulative delays origin to destination	Planned arrival at Destination	Arrival at Destination
2464	144	126	0	651	11/07/2013 06:07	10	06	0	10/07/2013 19:50	11/07/2013 06:13	651	123	147	24	711	11/07/2013 14:16	11/07/2013 15:00
8984	144	122	0	288	11/07/2013 01:35	10	10	0	10/07/2013 21:26	11/07/2013 01:45	288	123	101	0	325	11/07/2013 09:44	11/07/2013 09:40
8940	144	135	0	1197	11/07/2013 17:35	10	17	06	10/07/2013 22:06	11/07/2013 17:52	1204	123	128	05	1287	12/07/2013 01:44	12/07/2013 02:51
8918	144	125	0	575	11/07/2013 07:53	10	06	0	10/07/2013 22:59	11/07/2013 07:59	575	123	85	0	575	11/07/2013 16:02	11/07/2013 14:45
8924	144	143	0	211	11/07/2013 10:08	10	311	300	11/07/2013 07:17	11/07/2013 15:19	512	123	133	10	522	11/07/2013 18:17	11/07/2013 23:20
8982	144	163	18	2429	12/07/2013 07:54	10	08	0	11/07/2013 08:20	12/07/2013 08:02	2429	123	122	0	2623	12/07/2013 16:03	12/07/2013 19:15
5000	144	132	0	558	11/07/2013 17:50	10	10	0	11/07/2013 09:06	11/07/2013 18:00	558	123		0	573	12/07/2013 01:59	
5902	144	164	19	#VALUE!	11/07/2013 16:24	10	07	0	11/07/2013 11:46	11/07/2013 16:31	#VALUE!	123	173	50	#VALUE!	12/07/2013 00:33	13/07/2013 01:20
8908	144	151	06	285	11/07/2013 20:05	10	160	149	11/07/2013 15:44	11/07/2013 22:45	434	123	94	0	844	12/07/2013 04:14	12/07/2013 13:05

TRAIN ORIGIN	PPW-NCS											Reitvallei - Destination					
ITP Trains #	Transit Design (PPW-NCS)	Transit (PPW - NCS)	Deviation (PPW - NCS)	Cumulative delays origin to NCS	Arrival NCS	Dwell time Design NCS	Actual Dwell NCS	Deviation	Planned Departure	Departure NCS	Cumulative delays origin to NCS departure	Transit Design (Rietvallei – Destination)	Actual Transit (Rietvallei – Destination)	Deviation (Rietvallei – Destination)	Cumulative delays origin to destination	Planned arrival at Destination	Arrival at Destination
8816	144	126	0	329	11/07/2013 22:31	10	07	0	11/07/2013 17:36	11/07/2013 22:38	329	123	147	24	410	12/07/2013 06:40	12/07/2013 07:45
8912	144	149	04	171	11/07/2013 20:23	10	04	0	11/07/2013 18:11	11/07/2013 20:27	171	123	76	0	1696	12/07/2013 04:32	13/07/2013 04:55
2464	144	131	0	222	11/07/2013 22:43	10	413	402	11/07/2013 19:50	12/07/2013 05:36	625	123	243	120	748	12/07/2013 06:52	12/07/2013 15:00
8984	144	148	03	246	12/07/2013 01:29	10	11	00	11/07/2013 21:26	12/07/2013 01:40	246	123	86	0	519	12/07/2013 09:38	12/07/2013 13:35
8940	144	137	0	894	12/07/2013 12:45	10	06	0	11/07/2013 22:06	12/07/2013 12:51	894	123	418	295	1214	12/07/2013 20:54	13/07/2013 02:10
8918	144	138	0	828	12/07/2013 12:34	10	06	0	11/07/2013 22:59	12/07/2013 12:40	828	123	119	0	895	12/07/2013 20:43	12/07/2013 21:40
8410	144	129	0	1189	12/07/2013 18:50	10	25	14	11/07/2013 23:24	12/07/2013 19:15	1203	123	218	95	1311	13/07/2013 02:59	13/07/2013 04:44
8814	144	154	09	907	12/07/2013 15:32	10	05	0	12/07/2013 00:36	12/07/2013 15:37	907	123	71	0	907	12/07/2013 23:41	12/07/2013 22:10
8902	144	105	0	501	12/07/2013 09:04	10	05	0	12/07/2013 01:40	12/07/2013 09:09	501	123	103	0	501	12/07/2013 17:13	12/07/2013 15:10

TRAIN ORIGIN	PPW-NCS											Reitvallei - Destination					
ITP Trains #	Transit Design (PPW-NCS)	Transit (PPW - NCS)	Deviation (PPW - NCS)	Cumulative delays origin to NCS	Arrival NCS	Dwell time Design NCS	Actual Dwell NCS	Deviation	Planned Departure	Departure NCS	Cumulative delays origin to NCS departure	Transit Design (Rietvallei – Destination)	Actual Transit (Rietvallei – Destination)	Deviation (Rietvallei – Destination)	Cumulative delays origin to destination	Planned arrival at Destination	Arrival at Destination
8946	144	00	0	00		10	00	0	12/07/2013 06:32		00	123	00	0	00	00/01/19 00 08:09	
8982	144	411	266	330	12/07/2013 12:02	10	06	0	12/07/2013 08:20	12/07/2013 12:08	330	123	1387	1264	1594	12/07/2013 20:11	13/07/2013 16:20
5000	144	139	0	788	12/07/2013 20:54	10	220	209	12/07/2013 09:06	13/07/2013 00:34	997	123	65	0	1049	13/07/2013 05:03	13/07/2013 08:23
8912	144	109	0	324	12/07/2013 22:39	10	05	0	12/07/2013 18:11	12/07/2013 22:44	324	123	76	0	324	13/07/2013 06:48	13/07/2013 04:55
8906	144	150	05	101	12/07/2013 14:18	10	07	0	12/07/2013 12:52	12/07/2013 14:25	101	123	240	117	1605	12/07/2013 22:27	13/07/2013 23:00
5902	144	148	03	311	12/07/2013 16:54	10	07	0	12/07/2013 11:46	12/07/2013 17:01	311	123	78	0	359	13/07/2013 01:03	13/07/2013 00:55
2472	144	08	0	1062	13/07/2013 10:52	10	126	115	12/07/2013 22:31	13/07/2013 12:58	1178	123	195	72	1255	13/07/2013 19:01	13/07/2013 22:00
8908	144	130	0	252	12/07/2013 18:37	10	07	0	12/07/2013 15:44	12/07/2013 18:44	252	123	84	0	254	13/07/2013 02:46	13/07/2013 02:00
8918	144	131	0	195	13/07/2013 01:44	10	38	27	12/07/2013 22:59	13/07/2013 02:22	222	123	92	0	376	13/07/2013 09:53	13/07/2013 12:18

TRAIN ORIGIN	PPW-NCS											Reitvallei - Destination					
ITP Trains #	Transit Design (PPW-NCS)	Transit (PPW-NCS)	Deviation (PPW-NCS)	Cumulative delays origin to NCS	Arrival NCS	Dwell time Design NCS	Actual Dwell NCS	Deviation	Planned Departure	Departure NCS	Cumulative delays origin to NCS departure	Transit Design (Rietvallei – Destination)	Actual Transit (Rietvallei – Destination)	Deviation (Rietvallei – Destination)	Cumulative delays origin to destination	Planned arrival at Destination	Arrival at Destination
8816	144	153	08	749	13/07/2013 05:48	10	06	0	12/07/2013 17:36	13/07/2013 05:54	749	123	62	0	749	13/07/2013 13:57	13/07/2013 12:35
2464	144	148	03	298	13/07/2013 00:32	10	65	54	12/07/2013 19:50	13/07/2013 01:37	352	123	211	88	517	13/07/2013 08:41	13/07/2013 12:08
8910	144	115	0	729	13/07/2013 12:16	10	05	0	13/07/2013 02:13	13/07/2013 12:21	729	123	265	142	871	13/07/2013 20:25	13/07/2013 22:05
8922	144	158	13	284	13/07/2013 06:07	10	588	577	13/07/2013 01:51	13/07/2013 15:55	862	123	73	0	862	13/07/2013 14:16	13/07/2013 22:10
8814	144	142	0	790	13/07/2013 13:33	10	69	58	13/07/2013 00:36	13/07/2013 14:42	848	123	60	0	852	13/07/2013 21:42	13/07/2013 21:10
5994	144	114	0	633	13/07/2013 11:59	10	04	0	13/07/2013 02:33	13/07/2013 12:03	633	123	261	138	1128	13/07/2013 20:08	14/07/2013 03:55
5000	144	151	06	841	13/07/2013 22:57	10	09	0	13/07/2013 09:06	13/07/2013 23:06	841			0	841		14/07/2013 15:55
8982	144	586	441	957	13/07/2013 23:35	10	06	0	13/07/2013 08:20	13/07/2013 23:41	957	123	135	12	1326	14/07/2013 07:44	14/07/2013 13:30
1572	144	14	0	1627	14/07/2013 01:51	70	140	69	13/07/2013 02:24	14/07/2013 04:11	1697	183	96	0	1697	14/07/2013 14:00	14/07/2013 07:14

TRAIN ORIGIN	PPW-NCS											Reitvallei - Destination					
ITP Trains #	Transit Design (PPW-NCS)	Transit (PPW - NCS)	Deviation (PPW - NCS)	Cumulative delays origin to NCS	Arrival NCS	Dwell time Design NCS	Actual Dwell NCS	Deviation	Planned Departure	Departure NCS	Cumulative delays origin to NCS departure	Transit Design (Rietvallei – Destination)	Actual Transit (Rietvallei – Destination)	Deviation (Rietvallei – Destination)	Cumulative delays origin to destination	Planned arrival at Destination	Arrival at Destination
8658		87	87	801	12/07/2013 23:26			0	12/07/2013 10:49	13/07/2013 00:08	801		199	199	1328	12/07/2013 23:26	13/07/2013 08:55
5902	144	170	25	413	13/07/2013 18:31	10	08	0	13/07/2013 11:46	13/07/2013 18:39	413	123		0	413	14/07/2013 02:40	14/07/2013 08:50
8486		137	137	789	13/07/2013 18:33			0	13/07/2013 02:15	13/07/2013 17:07	789			0	973	13/07/2013 18:33	14/07/2013 04:00
8906	144	132	0	3363	14/07/2013 19:52	10	07	0	13/07/2013 12:52	14/07/2013 19:59	3363	123		0	3363	15/07/2013 04:01	14/07/2013 13:10
1548	144	157	12	3356	15/07/2013 02:04	10	12	01	13/07/2013 12:46	15/07/2013 02:16	3357		00	0	3363	15/07/2013 03:35	
8908	144	165	20	437	13/07/2013 22:43	10	08	0	13/07/2013 15:44	13/07/2013 22:51	437	123		0	437	14/07/2013 06:52	14/07/2013 17:35
8816	144	110	0	550	14/07/2013 01:36	10	11	00	13/07/2013 17:36	14/07/2013 01:47	550	123		0	550	14/07/2013 09:45	14/07/2013 14:25
8984	144	131	0	909	14/07/2013 12:07	10	14	03	13/07/2013 21:26	14/07/2013 12:21	912	123		0	912	14/07/2013 20:16	14/07/2013 19:05
8940	144	116	0	149	13/07/2013 23:50	10	21	10	13/07/2013 22:06	14/07/2013 00:11	159	123		0	159	14/07/2013 07:59	14/07/2013 13:50

TRAIN ORIGIN	PPW-NCS											Reitvallei - Destination					
ITP Trains #	Transit Design (PPW-NCS)	Tran-sit (PPW - NCS)	Devi-ation (PPW - NCS)	Cumu-lative delays origin to NCS	Arrival NCS	Dwell time De-sign NCS	Actual Dwell NCS	Devi-ation	Planned Departure	Departure NCS	Cumu-lative delays origin to NCS departure	Transit Design (Rietvallei – Destina-tion)	Actual Transit (Rietvallei – Destina-tion)	Deviation (Rietvallei – Destina-tion)	Cumu-lative delays origin to destina-tion	Planned arrival at Desti-nation	Arrival at Destination
8918	144	118	0	174	14/07/2013 01:06	10	04	0	13/07/2013 22:59	14/07/2013 01:10	174			0	174		
1572		1577	1577	1821	15/07/2013 04:11	10		0	13/07/2013 22:00	14/07/2013 04:20	1821			0	1921		
8902	144	98	0	428	14/07/2013 06:05	10		0	14/07/2013 01:40	2013/07/06:10	428	123		0	428	14/07/2013 14:14	14/07/2013 12:50
8922	144	121	0	614	14/07/2013 11:08	10	14	03	14/07/2013 01:51	14/07/2013 11:22	617	123		0	617	14/07/2013 19:17	14/07/2013 19:53
8910	144	105	0	401	14/07/2013 07:55	10	165	154	14/07/2013 02:13	14/07/2013 10:40	555	123		0	555	14/07/2013 16:04	14/07/2013 21:14
2466		123	123	698	14/07/2013 09:22		1045	1045	13/07/2013 22:14	15/07/2013 02:47	1743			0	1847	14/07/2013 13:56	15/07/2013 14:02
8924	144		0	256	2013/07/11:24	10		0	14/07/2013 07:17	14/07/2013 11:40	256	123		0	929	#VALUE!	15/07/2013 13:17
8982	144	137	0	271	14/07/2013 12:30	10	11	00	14/07/2013 08:20	14/07/2013 12:41	271	123	110	0	280	14/07/2013 20:39	14/07/2013 20:25
5000	144	129	0	531	14/07/2013 17:19	10	07	0	14/07/2013 09:06	14/07/2013 17:26	531	123		0	531	15/07/2013 01:28	15/07/2013 05:22

TRAIN ORIGIN	PPW-NCS											Reitvallei - Destination					
ITP Trains #	Transit Design (PPW-NCS)	Tran-sit (PPW - NCS)	Devi-ation (PPW - NCS)	Cumu-lative delays origin to NCS	Arrival NCS	Dwell time De-sign NCS	Actual Dwell NCS	Devi-ation	Planned Departure	Departure NCS	Cumu-lative delays origin to NCS departure	Transit Design (Rietvallei – Destina-tion)	Actual Transit (Rietvallei – Destina-tion)	Deviation (Rietvallei – Destina-tion)	Cumu-lative delays origin to destina-tion	Planned arrival at Desti-nation	Arrival at Destination
8918	144	132	0	222	15/07/2013 02:15	10	13	02	14/07/2013 22:59	15/07/2013 02:28	224	123		0	253	15/07/2013 10:24	15/07/2013 10:30
8906	144	132	0	453	14/07/2013 19:52	10	07	0	14/07/2013 12:52	14/07/2013 19:59	453	123		0	453	15/07/2013 04:01	15/07/2013 03:15
5902	144	142	0	317	14/07/2013 14:12	10	07	0	14/07/2013 11:46	14/07/2013 14:19	317	123		0	317	14/07/2013 22:21	14/07/2013 23:10
8940	144	127	0	196	15/07/2013 00:46	10	36	25	14/07/2013 22:06	15/07/2013 01:22	221	123	233	110	365	15/07/2013 08:55	15/07/2013 11:05
8816	144	117	0	578	15/07/2013 02:29	10	10	0	14/07/2013 17:36	15/07/2013 02:39	578	123	60	0	640	15/07/2013 10:38	15/07/2013 10:37
8946	144	124	0	259	15/07/2013 11:17		48	48	15/07/2013 08:21	15/07/2013 12:05	307	123	338	215	522	15/07/2013 19:16	15/07/2013 22:25
2472	144	139	0	308	15/07/2013 03:12	10	119	108	14/07/2013 22:31	15/07/2013 05:11	417	123	99	0	595	15/07/2013 11:21	15/07/2013 15:44
8984	144	147	02	273	15/07/2013 01:45	10	12	01	14/07/2013 21:26	15/07/2013 01:57	274	123	71	0	700	15/07/2013 09:54	15/07/2013 16:10
8986	144	124	0	271	14/07/2013 16:04	10	33	22	14/07/2013 12:16	14/07/2013 16:37	293	123		0	293	15/07/2013 00:13	15/07/2013 11:32

TRAIN ORIGIN	PPW-NCS											Reitvallei - Destination					
ITP Trains #	Transit Design (PPW-NCS)	Transit (PPW-NCS)	Deviation (PPW-NCS)	Cumulative delays origin to NCS	Arrival NCS	Dwell time Design NCS	Actual Dwell NCS	Deviation	Planned Departure	Departure NCS	Cumulative delays origin to NCS departure	Transit Design (Rietvallei – Destination)	Actual Transit (Rietvallei – Destination)	Deviation (Rietvallei – Destination)	Cumulative delays origin to destination	Planned arrival at Destination	Arrival at Destination
1548	144	157	12	670	15/07/2013 02:04	10	12	01	14/07/2013 15:16	15/07/2013 02:16	671	123		0	691	15/07/2013 10:13	16/07/2013 04:15
2464	144	134	0	27	14/07/2013 18:15	10	07	0	14/07/2013 19:50	14/07/2013 18:22	27	123		0	27	15/07/2013 02:24	14/07/2013 23:00
8902	144	110	0	305	15/07/2013 05:48	10	09	0	15/07/2013 01:40	15/07/2013 05:57	305	123	171	48	353	15/07/2013 13:57	15/07/2013 14:00
8906	144	96	0	165	15/07/2013 14:14	10	07	0	15/07/2013 12:52	15/07/2013 14:50	165	123	221	98	263	15/07/2013 22:23	15/07/2013 23:00
8986	144	148	03	86	15/07/2013 13:23	10	07	0	15/07/2013 12:16	15/07/2013 13:28	86	123	182	59	145	15/07/2013 21:32	15/07/2013 22:00
8904	144	126	0	199	16/07/2013 06:32	10	07	0	16/07/2013 04:05	16/07/2013 07:49	199	123	152	29	271	16/07/2013 14:41	16/07/2013 17:00
2466	144	125	0	248	16/07/2013 08:22	10		0	16/07/2013 05:46	16/07/2013 08:39	248	123	130	07	376	16/07/2013 16:31	16/07/2013 18:30
5902	144	176	31	154	15/07/2013 13:46	10	07	0	15/07/2013 11:46	15/07/2013 14:28	154	123	146	23	212	15/07/2013 21:55	15/07/2013 23:25
8984	144	164	19	204	16/07/2013 00:22	10	07	0	15/07/2013 21:26	16/07/2013 00:30	204	123	75	0	443	16/07/2013 08:31	16/07/2013 11:35

TRAIN ORIGIN	PPW-NCS											Reitvallei - Destination					
ITP Trains #	Transit Design (PPW-NCS)	Transit (PPW - NCS)	Deviation (PPW - NCS)	Cumulative delays origin to NCS	Arrival NCS	Dwell time Design NCS	Actual Dwell NCS	Deviation	Planned Departure	Departure NCS	Cumulative delays origin to NCS departure	Transit Design (Rietvallei – Destination)	Actual Transit (Rietvallei – Destination)	Deviation (Rietvallei – Destination)	Cumulative delays origin to destination	Planned arrival at Destination	Arrival at Destination
8982	144	159	14	1623	16/07/2013 09:33	10	07	0	16/07/2013 08:20	16/07/2013 09:40	1623	123	84	0	1773	16/07/2013 17:42	16/07/2013 19:30
8816	144	111	0	246	15/07/2013 20:46	10	07	0	15/07/2013 17:36	15/07/2013 20:55	246	123	188	65	500	16/07/2013 04:55	16/07/2013 09:08
2464	144	139	0	109	15/07/2013 20:16	10	07	0	15/07/2013 19:50	15/07/2013 22:35	109	123	45	0	335	16/07/2013 04:25	16/07/2013 09:02
8924	144	130	0	457	16/07/2013 14:26	10	07	0	16/07/2013 07:17	16/07/2013 14:31	457	123	233	110	620	16/07/2013 22:35	17/07/2013 01:13
8940	144	128	0	347	16/07/2013 03:15	10	07	0	15/07/2013 22:06	16/07/2013 03:22	347	123	686	563	932	16/07/2013 11:24	16/07/2013 21:03
5000	144	191	46	1932	17/07/2013 16:40	10	07	0	16/07/2013 09:06	18/07/2013 07:50	1932	123	89	0	2336	18/07/2013 00:49	18/07/2013 22:00
8902	144	123	0	125	16/07/2013 02:15	10	07	0	16/07/2013 01:40	16/07/2013 02:41	125	123	120	0	169	16/07/2013 10:24	16/07/2013 11:21
8814	144	115	0	225	17/07/2013 02:24	10	07	0	17/07/2013 00:36	17/07/2013 02:42	225	123	75	0	242	17/07/2013 10:33	17/07/2013 10:10
8986	144	125	0	209	16/07/2013 15:09	10	07	0	16/07/2013 12:16	16/07/2013 15:26	209	123	169	46	255	16/07/2013 23:18	16/07/2013 23:28

TRAIN ORIGIN	PPW-NCS											Reitvallei - Destination					
ITP Trains #	Transit Design (PPW-NCS)	Transit (PPW - NCS)	Deviation (PPW - NCS)	Cumulative delays origin to NCS	Arrival NCS	Dwell time Design NCS	Actual Dwell NCS	Deviation	Planned Departure	Departure NCS	Cumulative delays origin to NCS departure	Transit Design (Rietvallei – Destination)	Actual Transit (Rietvallei – Destination)	Deviation (Rietvallei – Destination)	Cumulative delays origin to destination	Planned arrival at Destination	Arrival at Destination
8984	144	120	0	87	16/07/2013 21:54	10	07	0	16/07/2013 21:26	16/07/2013 22:55	87	123	170	47	162	17/07/2013 06:03	17/07/2013 07:35
8940	144	130	0	214	17/07/2013 00:59	10	07	0	16/07/2013 22:06	17/07/2013 01:22	214	123	259	136	351	17/07/2013 09:08	17/07/2013 11:32
2472	144	124	0	477	17/07/2013 05:48	10	07	0	16/07/2013 22:31	17/07/2013 05:54	477	123	195	72	754	17/07/2013 13:57	17/07/2013 18:30
8816	144	141	0	261	16/07/2013 21:38	10	07	0	16/07/2013 17:36	17/07/2013 22:09	261	123	58	0	668	17/07/2013 05:47	17/07/2013 11:50
8918	144	132	0	652	17/07/2013 09:25	10	07	0	16/07/2013 22:59	17/07/2013 09:43	652	123	72	0	676	17/07/2013 17:34	17/07/2013 17:15
5902	144	127	0	220	16/07/2013 14:54	10	07	0	16/07/2013 11:46	16/07/2013 15:00	220	123	1522	1399	1630	16/07/2013 23:03	17/07/2013 22:25
8910	144	107	0	557	17/07/2013 10:37	10	07	0	17/07/2013 02:13	17/07/2013 11:10	557	123	1749	1626	2218	17/07/2013 18:46	18/07/2013 22:45
8906	144	138	0	68	16/07/2013 12:38	10	07	0	16/07/2013 12:52	16/07/2013 12:45	68	123	91	0	81	16/07/2013 20:47	16/07/2013 20:15
8912	144	147	02	2657	18/07/2013 14:12	10	07	0	16/07/2013 18:11	18/07/2013 14:50	2657	123	-12	0	2689	18/07/2013 22:21	18/07/2013 21:07

TRAIN ORIGIN	PPW-NCS											Reitvallei - Destination					
ITP Trains #	Transit Design (PPW-NCS)	Transit (PPW - NCS)	Deviation (PPW - NCS)	Cumulative delays origin to NCS	Arrival NCS	Dwell time Design NCS	Actual Dwell NCS	Deviation	Planned Departure	Departure NCS	Cumulative delays origin to NCS departure	Transit Design (Rietvallei – Destination)	Actual Transit (Rietvallei – Destination)	Deviation (Rietvallei – Destination)	Cumulative delays origin to destination	Planned arrival at Destination	Arrival at Destination
8982	144	135	0	327	17/07/2013 12:58	10	07	0	17/07/2013 08:20	17/07/2013 13:08	327	123	95	0	340	17/07/2013 21:07	17/07/2013 20:05
5000	144	131	0	2050	18/07/2013 18:05	10	07	0	17/07/2013 09:06	18/07/2013 18:20	2050	123	-185	0	2059	19/07/2013 02:14	18/07/2013 21:07
8906	144	148	03	127	17/07/2013 14:41	10	07	0	17/07/2013 12:52	17/07/2013 14:48	127	123	89	0	167	17/07/2013 22:50	17/07/2013 22:20
8912	144	129	0	166	17/07/2013 20:00	10	07	0	17/07/2013 18:11	17/07/2013 20:10	166	123	73	0	201	18/07/2013 04:09	18/07/2013 03:30
5902	144	145	00	345	17/07/2013 17:00	10	07	0	17/07/2013 11:46	18/07/2013 01:45	345	123	123	00	534	18/07/2013 01:09	18/07/2013 12:54
1558	144	130	0	500	17/07/2013 19:45	10	07	0	17/07/2013 11:47	17/07/2013 19:53	500	123	123	00	1576	18/07/2013 03:54	18/07/2013 21:07
8486	144	229	84	843	18/07/2013 02:03	10	07	0	17/07/2013 12:16	18/07/2013 03:14	843	123	123	00	1042	18/07/2013 10:12	18/07/2013 14:33
8816	144	121	0	988	18/07/2013 09:22	10	07	0	17/07/2013 17:36	18/07/2013 09:41	988	123	123	00	1048	18/07/2013 17:31	18/07/2013 18:26
5646	144	162	17	663	18/07/2013 04:38	10	07	0	17/07/2013 17:46	18/07/2013 04:51	663	123	123	00	1459	18/07/2013 12:47	19/07/2013 02:07

TRAIN ORIGIN	PPW-NCS											Reitvallei - Destination					
ITP Trains #	Transit Design (PPW-NCS)	Transit (PPW-NCS)	Deviation (PPW-NCS)	Cumulative delays origin to NCS	Arrival NCS	Dwell time Design NCS	Actual Dwell NCS	Deviation	Planned Departure	Departure NCS	Cumulative delays origin to NCS departure	Transit Design (Rietvallei – Destination)	Actual Transit (Rietvallei – Destination)	Deviation (Rietvallei – Destination)	Cumulative delays origin to destination	Planned arrival at Destination	Arrival at Destination
2464	144	137	0	157	17/07/2013 22:05	10	07	0	17/07/2013 19:50	18/07/2013 01:12	157	123	123	00	177	18/07/2013 06:14	18/07/2013 09:31
8984	144	123	0	98	17/07/2013 22:16	10	07	0	17/07/2013 21:26	17/07/2013 22:26	98	123	123	00	140	18/07/2013 06:25	18/07/2013 07:07
8940	144	162	17	288	18/07/2013 02:30	10	07	0	17/07/2013 22:06	18/07/2013 03:03	288	123	123	00	386	18/07/2013 10:39	18/07/2013 12:40
8918	144	158	13	236	18/07/2013 02:50	10	07	0	17/07/2013 22:59	18/07/2013 05:59	236	123	123	00	529	18/07/2013 10:59	18/07/2013 18:52
1574	144	120	0	1428	18/07/2013 22:02	10	07	0	17/07/2013 23:24	18/07/2013 22:13	1428	123	123	00	1428	19/07/2013 06:11	19/07/2013 06:12
2472	144	128	0	377	18/07/2013 06:59	10	07	0	18/07/2013 01:32	18/07/2013 07:41	377	123	123	00	377	18/07/2013 15:08	18/07/2013 15:19
8902	144	129	0	204	18/07/2013 04:19	10	07	0	18/07/2013 01:40	18/07/2013 04:30	204	123	123	00	205	18/07/2013 12:28	18/07/2013 12:20
8910	144	116	0	498	18/07/2013 09:45	10	07	0	18/07/2013 02:13	18/07/2013 12:54	498	123	123	00	498	18/07/2013 17:54	18/07/2013 20:07
8904	144	178	33	620	18/07/2013 14:08	10	07	0	18/07/2013 04:05	18/07/2013 14:40	620	123	123	00	631	18/07/2013 22:17	18/07/2013 22:51

TRAIN ORIGIN	PPW-NCS											Reitvallei - Destination					
ITP Trains #	Transit Design (PPW-NCS)	Tran-sit (PPW - NCS)	Devi-ation (PPW - NCS)	Cumu-lative delays origin to NCS	Arrival NCS	Dwell time De-sign NCS	Actual Dwell NCS	Devi-ation	Planned Departure	Departure NCS	Cumu-lative delays origin to NCS departure	Transit Design (Rietvallei – Destina-tion)	Actual Transit (Rietvallei – Destina-tion)	Deviation (Rietvallei – Destina-tion)	Cumu-lative delays origin to destina-tion	Planned arrival at Desti-nation	Arrival at Destination
8946	144	127	0	437	18/07/2013 15:47	10	07	0	18/07/2013 09:17	18/07/2013 16:16	437	123	123	00	437	18/07/2013 23:56	18/07/2013 23:26

APPENDIX E: WORKINGS

Table E.1 Workings introductory information

Date	Number of trains planned	Trains cancelled	Trains run to NCS	Average delay to NCS
01/07/2013 00:00	19	4	16	270
02/07/2013 00:00	23	11	12	321
03/07/2013 00:00	23	9	15	391
04/07/2013 00:00	25	16	11	264
05/07/2013 00:00	23	11	13	490
06/07/2013 00:00	23	5	18	355
07/07/2013 00:00	25	10	15	335
08/07/2013 00:00	22	11	14	475
09/07/2013 00:00	25	14	11	565
10/07/2013 00:00	26	11	15	884
11/07/2013 00:00	25	12	14	548
12/07/2013 00:00	26	12	16	570
13/07/2013 00:00	25	8	17	486
14/07/2013 00:00	22	11	12	341
15/07/2013 00:00	21	10	13	213
16/07/2013 00:00	23	11	13	300
17/07/2013 00:00	27	10	17	409

Table E.2 Workings data

Row Labels	Sum of Time required 2	Count of cancellation	Sum of buffer time 2	Sum of crew waiting for train -plan versus actual departure less processing time	Sum of total time 2	Sum of Cumulative delays origin to NCS departure		Sum of anything more than 13 hours requires different crew as crew cannot run trains after their shift has ended- double crew usage	number of trains		
01/07/2013 13:27	479		121	47	526	173	173	9	16	Median	199
01/07/2013 16:08	479	1	121	56	535	181	181	9		Q1	124
01/07/2013 16:19	479		121	79	558	100	100	9		Q3	302
01/07/2013 02:44	479		121	101	580	163	163	10		min	47
01/07/2013 11:54	479		121	132	611	177	177	10		max	1137
01/07/2013 02:14	479		121	149	628	179	179	10		std d crew time	344
01/07/2013 22:48	479		121	157	636	202	202	11		std d train time	349
01/07/2013 13:38	479		121	197	676	214	214	11			
01/07/2013 03:20	479		121	200	679	243	243	11			
01/07/2013 21:45	479		121	205	684	223	223	11			
01/07/2013 10:18	479		121	259	738	330	330	12			
01/07/2013 08:04	479		121	277	756	361	361	14			
01/07/2013 23:34	479		121	378	857	498	498	14			
01/07/2013 18:33	479		121	705	1184	730	730	20			
01/07/2013 06:12	479		121	1072	1551	1191	1191	28			
01/07/2013 08:39	479		121	1137	1616	1183	1183	27			
01/07/2013 08:14		1									
01/07/2013 15:04		1									
01/07/2013 16:41		1									

Row Labels	Sum of Time required 2	Count of cancellation	Sum of buffer time 2	Sum of crew waiting for train -plan versus actual departure less processing time	Sum of total time 2	Sum of Cumulative delays origin to NCS departure		Sum of anything more than 13 hours requires different crew as crew cannot run trains after their shift has ended- double crew usage	number of trains		
02/07/2013 02:15		1							12		
02/07/2013 08:39	479		121	172	651	233	233	11		Median	266
02/07/2013 16:08	479		121	191	670	243	243	11		Q1	219
02/07/2013 13:27	479		121	206	685	232	232	11		Q3	582
02/07/2013 21:45	479		121	223	702	373	373	12		min	172
02/07/2013 11:54	479		121	236	715	274	274	12		max	2459
02/07/2013 22:48	479		121	250	729	270	270	12		std d crew time	677
02/07/2013 06:12	479		121	281	760	336	336	13		std d train time	680
02/07/2013 16:00	479		121	297	776	363	363	13			
02/07/2013 08:04	479		121	495	974	562	562	16			
02/07/2013 23:34	479		121	843	1322	1017	1017	22			
02/07/2013 10:18	479		121	1253	1732	1272	1272	29			
02/07/2013 16:19	479		121	2459	2938	2634	2634	49			
02/07/2013 02:44		1									
02/07/2013 03:20		1									
02/07/2013 05:00		1									
02/07/2013 13:52		1									
02/07/2013 15:04		1									
02/07/2013 15:25		1									
02/07/2013 16:41		1									

Row Labels	Sum of Time required 2	Count of cancellation	Sum of buffer time 2	Sum of crew waiting for train -plan versus actual departure less processing time	Sum of total time 2	Sum of Cumulative delays origin to NCS departure		Sum of anything more than 13 hours requires different crew as crew cannot run trains after their shift has ended- double crew usage	number of trains		
02/07/2013 17:01		1									
02/07/2013 18:33		1									
02/07/2013 21:00		1									
03/07/2013 16:19	479		121	38	517	106	106	9	15	Median	467
03/07/2013 16:08	479		121	131	610	233	233	10		Q1	225
03/07/2013 18:33	479		121	183	662	214	214	11		Q3	865
03/07/2013 02:14	479		121	199	678	229	229	11		min	38
03/07/2013 22:48	479		121	250	729	297	297	12		max	3357
03/07/2013 23:34	479		121	284	763	304	304	13		std d crew time	870
03/07/2013 10:18	479		121	334	813	367	367	14		std d train time	874
03/07/2013 21:00	479		121	467	946	552	552	16			
03/07/2013 03:20	479		121	620	1099	636	636	18			
03/07/2013 02:15	479		121	673	1152	638	638	19			
03/07/2013 02:44	479		121	774	1253	722	722	21			
03/07/2013 11:54	479		121	955	1434	1016	1016	24			
03/07/2013 21:45	479		121	1237	1716	1334	1334	29			
03/07/2013 08:39	479		121	1876	2355	1949	1949	39			
03/07/2013 15:04	479		121	3357	3836	3467	3467	64			
03/07/2013 05:24		1									
03/07/2013 05:44		1									

Row Labels	Sum of Time required 2	Count of cancellation	Sum of buffer time 2	Sum of crew waiting for train -plan versus actual departure less processing time	Sum of total time 2	Sum of Cumulative delays origin to NCS departure		Sum of anything more than 13 hours requires different crew as crew cannot run trains after their shift has ended- double crew usage	number of trains		
03/07/2013 06:12		1									
03/07/2013 06:55		1									
03/07/2013 08:04		1									
03/07/2013 08:14		1									
03/07/2013 13:27		1									
03/07/2013 16:00		1									
03/07/2013 16:41		1									
04/07/2013 21:45	479	1	121	-142	336	153	153	6	9	Median	115
04/07/2013 02:15	479		121	-48	430	116	116	7		Q1	-3
04/07/2013 05:00	479		121	-03	475	251	251	8		Q3	300
04/07/2013 16:08								8		min	-142
04/07/2013 16:41								8		max	494
04/07/2013 22:48	479	1	121	09	488	104	104	8		std d crew time	206
04/07/2013 13:27	479		121	115	594	283	283	10		std d train time	144
04/07/2013 11:54	479		121	214	693	266	266	12			
04/07/2013 06:12	479		121	300	779	357	357	13			
04/07/2013 02:14	479		121	314	793	334	334	13			
04/07/2013 10:18	479		121	494	973	528	528	16			
04/07/2013 00:55		1									
04/07/2013 01:30		1									

Row Labels	Sum of Time required 2	Count of cancellation	Sum of buffer time 2	Sum of crew waiting for train -plan versus actual departure less processing time	Sum of total time 2	Sum of Cumulative delays origin to NCS departure		Sum of anything more than 13 hours requires different crew as crew cannot run trains after their shift has ended- double crew usage	number of trains		
04/07/2013 03:20		1									
04/07/2013 06:55		1									
04/07/2013 08:04		1									
04/07/2013 08:14		1									
04/07/2013 08:39		1									
04/07/2013 09:24		1									
04/07/2013 13:52		1									
04/07/2013 16:00		1									
04/07/2013 16:19		1									
04/07/2013 17:01		1									
04/07/2013 18:33		1									
04/07/2013 21:00		1									
05/07/2013 08:04	479		121	118	597	187	187	10	13	Median	483
05/07/2013 11:54	479		121	240	719	330	330	12		Q1	364
05/07/2013 22:48	479		121	275	754	309	309	13		Q3	538
05/07/2013 03:20	479		121	364	843	405	405	14		min	118
05/07/2013 23:34	479		121	426	905	467	467	15		max	2405
05/07/2013 21:45	479		121	471	950	645	645	16		std d crew time	567
05/07/2013 02:14	479		121	483	962	588	588	16		std d train time	599
05/07/2013 17:01	479		121	528	1008	465	465	17			
05/07/2013 06:12	479		121	533	1012	1051	1051	17			

Row Labels	Sum of Time required 2	Count of cancellation	Sum of buffer time 2	Sum of crew waiting for train -plan versus actual departure less processing time	Sum of total time 2	Sum of Cumulative delays origin to NCS departure		Sum of anything more than 13 hours requires different crew as crew cannot run trains after their shift has ended- double crew usage	number of trains		
05/07/2013 15:04	479		121	538	1017	557	557	17			
05/07/2013 13:27	479		121	590	1069	715	715	18			
05/07/2013 21:00	479		121	597	1077	716	716	18			
05/07/2013 16:08	479		121	2405	2884	2476	2476	48			
05/07/2013 05:00		1									
05/07/2013 05:44		1									
05/07/2013 08:14		1									
05/07/2013 08:39		1									
05/07/2013 09:24		1									
05/07/2013 09:54		1									
05/07/2013 13:52		1									
05/07/2013 16:00		1									
05/07/2013 16:19		1									
05/07/2013 16:41		1									
05/07/2013 18:33		1									
06/07/2013 16:08	479		121	-04	474	93	93	8	18	Median	514
06/07/2013 11:54	479		121	07	486	78	78	8		Q1	279
06/07/2013 06:12	479		121	262	741	305	305	12		Q3	1099
06/07/2013 23:34	479		121	275	754	326	326	13		min	-4
06/07/2013 05:44	479		121	279	758	301	301	13		max	4246
06/07/2013 21:45	479		121	280	759	333	333	13		std d crew time	1103
06/07/2013 22:48	479		121	285	764	87	87	13		std d	1129

Row Labels	Sum of Time required 2	Count of cancellation	Sum of buffer time 2	Sum of crew waiting for train -plan versus actual departure less processing time	Sum of total time 2	Sum of Cumulative delays origin to NCS departure		Sum of anything more than 13 hours requires different crew as crew cannot run trains after their shift has ended- double crew usage	number of trains		
										train time	
06/07/2013 16:19	479		121	297	776	302	302	13			
06/07/2013 16:41	479		121	468	947	275	275	16			
06/07/2013 03:20	479		121	560	1039	591	591	17			
06/07/2013 03:00	479		121	627	1106	616	616	18			
06/07/2013 15:04	479		121	930	1409	954	954	23			
06/07/2013 03:44	479		121	1079	1558	1094	1094	26			
06/07/2013 13:27	479		121	1105	1584	1131	1131	26			
06/07/2013 08:14	479		121	1334	1813	1350	1350	30			
06/07/2013 08:04	479		121	2005	2484	2047	2047	41			
06/07/2013 14:10	479		121	2827	3306	2932	2932	55			
06/07/2013 02:14	479		121	4246	4725	4400	4725	79			
06/07/2013 07:19		1									
06/07/2013 13:52		1									
06/07/2013 18:33		1									
06/07/2013 21:44		1									
06/07/2013 22:24		1									
07/07/2013 16:00	479		121	-58	420	229	229	7	15	Median	260
07/07/2013 06:55	479		121	21	500	76	76	8		Q1	152
07/07/2013 02:14	479		121	108	587	142	142	10		Q3	418
07/07/2013 11:54	479		121	127	606	172	172	10		min	-58
07/07/2013 21:00	479		121	177	656	252	252	11		max	650

Row Labels	Sum of Time required 2	Count of cancellation	Sum of buffer time 2	Sum of crew waiting for train -plan versus actual departure less processing time	Sum of total time 2	Sum of Cumulative delays origin to NCS departure		Sum of anything more than 13 hours requires different crew as crew cannot run trains after their shift has ended- double crew usage	number of trains		
07/07/2013 10:18	479		121	187	666	206	206	11		std d crew time	199
07/07/2013 21:45	479		121	224	703	273	273	12		std d train time	193
07/07/2013 13:27	479		121	260	739	307	307	12			
07/07/2013 08:39	479		121	279	758	316	316	13			
07/07/2013 22:48	479		121	314	793	351	351	13			
07/07/2013 21:44	479		121	402	881	440	440	15			
07/07/2013 23:34	479		121	433	912	446	446	15			
07/07/2013 15:04	479		121	435	914	483	483	15			
07/07/2013 13:52	479		121	598	1077	625	625	33			
07/07/2013 16:08	479		121	650	1129	713	713	19			
07/07/2013 00:55		1									
07/07/2013 02:15		1									
07/07/2013 03:20		1									
07/07/2013 05:44		1									
07/07/2013 06:12		1									
07/07/2013 08:04		1									
07/07/2013 15:25		1									
07/07/2013 16:19		1									
07/07/2013 18:33		1									
07/07/2013 18:59		1									

Row Labels	Sum of Time required 2	Count of cancellation	Sum of buffer time 2	Sum of crew waiting for train -plan versus actual departure less processing time	Sum of total time 2	Sum of Cumulative delays origin to NCS departure		Sum of anything more than 13 hours requires different crew as crew cannot run trains after their shift has ended- double crew usage	number of trains		
08/07/2013 21:45	479		121	60	539	103	103	9	14	Median	353
08/07/2013 22:48	479	1	121	182	661	275	275	11		Q1	235
08/07/2013 16:08	479		121	228	707	280	280	12		Q3	692
08/07/2013 08:39	479		121	229	708	253	253	12		min	60
08/07/2013 21:44	479		121	252	731	516	516	12		max	2149
08/07/2013 02:44	479		121	283	762	303	303	13		std d crew time	529
08/07/2013 11:54	479		121	340	819	358	358	14		std d train time	309
08/07/2013 03:20	479		121	366	845	410	410	14			
08/07/2013 10:18	479		121	466	945	532	532	16			
08/07/2013 02:14	479		121	504	983	540	540	16			
08/07/2013 06:55	479	1	121	755	1234	779	779	21			
08/07/2013 16:19	479		121	820	1299	845	845	22			
08/07/2013 13:27	479		121	922	1401	976	976	23			
08/07/2013 13:52	479		121	2149	2628	2179	2179	44			
08/07/2013 06:12		1									
08/07/2013 08:04		1									
08/07/2013 09:54		1									
08/07/2013 12:34		1									
08/07/2013 14:54		1									
08/07/2013 15:04		1									

Row Labels	Sum of Time required 2	Count of cancellation	Sum of buffer time 2	Sum of crew waiting for train -plan versus actual departure less processing time	Sum of total time 2	Sum of Cumulative delays origin to NCS departure		Sum of anything more than 13 hours requires different crew as crew cannot run trains after their shift has ended- double crew usage	number of trains		
08/07/2013 16:41		1									
08/07/2013 18:33		1									
08/07/2013 23:34		1									
09/07/2013 12:34	479		121	178	657	237	237	11	11	Median	453
09/07/2013 13:27	479		121	252	731	372	372	12		Q1	300
09/07/2013 23:34	479		121	293	772	313	313	13		Q3	686
09/07/2013 11:54	479		121	306	785	579	579	13		min	178
09/07/2013 16:00	479		121	448	927	504	504	15		max	1251
09/07/2013 06:12	479		121	453	932	469	469	16		std d crew time	309
09/07/2013 03:20	479		121	614	1093	653	653	18		std d train time	299
09/07/2013 02:14	479		121	654	1133	702	702	19			
09/07/2013 10:18	479		121	717	1196	763	763	20			
09/07/2013 16:08	479		121	778	1257	803	803	21			
09/07/2013 15:04	479		121	1251	1730	1286	1286	29			
09/07/2013 02:44		1									
09/07/2013 05:24		1									
09/07/2013 08:04		1									
09/07/2013 08:39		1									
09/07/2013 09:24		1									
09/07/2013 15:25		1									

Row Labels	Sum of Time required 2	Count of cancellation	Sum of buffer time 2	Sum of crew waiting for train -plan versus actual departure less processing time	Sum of total time 2	Sum of Cumulative delays origin to NCS departure		Sum of anything more than 13 hours requires different crew as crew cannot run trains after their shift has ended- double crew usage	number of trains		
09/07/2013 16:19		1									
09/07/2013 16:41		1									
09/07/2013 17:01		1									
09/07/2013 18:33		1									
09/07/2013 18:59		1									
09/07/2013 21:00		1									
09/07/2013 21:45		1									
09/07/2013 22:48		1									
10/07/2013 06:12	479		121	93	572	157	157	10	15	Median	612
10/07/2013 02:44	479		121	186	665	468	468	11		Q1	360
10/07/2013 03:20	479		121	238	717	284	284	12		Q3	1142
10/07/2013 11:54	479		121	248	727	288	288	12		min	93
10/07/2013 21:45	479		121	471	950	512	512	16		max	1907
10/07/2013 23:34	479		121	523	1002	558	558	17		std d crew time	525
10/07/2013 13:27	479		121	529	1008	575	575	17		std d train time	659
10/07/2013 10:18	479		121	612	1091	651	651	18			
10/07/2013 06:55	479		121	663	1142	683	683	19			
10/07/2013 08:04	479		121	1057	1536	1088	1088	26			
10/07/2013 08:14	479		121	1109	1588	1133	1133	26			
10/07/2013 12:34	479		121	1175	1654	1204	1204	28			
10/07/2013 08:39	479		121	1219	1698	1222	1222	28			

Row Labels	Sum of Time required 2	Count of cancellation	Sum of buffer time 2	Sum of crew waiting for train -plan versus actual departure less processing time	Sum of total time 2	Sum of Cumulative delays origin to NCS departure		Sum of anything more than 13 hours requires different crew as crew cannot run trains after their shift has ended- double crew usage	number of trains		
10/07/2013 22:48	479		121	1411	1890	2429	2429	32			
10/07/2013 07:19	479		121	1907	2386	2007	2007	40			
10/07/2013 02:14		1									
10/07/2013 05:44		1									
10/07/2013 14:54		1									
10/07/2013 15:04		1									
10/07/2013 16:00		1									
10/07/2013 16:08		1									
10/07/2013 16:19		1									
10/07/2013 16:41		1									
10/07/2013 18:33		1									
10/07/2013 18:59		1									
10/07/2013 21:00		1									
11/07/2013 08:39	479		121	125	604	171	171	10	13	Median	438
11/07/2013 22:48	479		121	217	696	330	330	12		Q1	274
11/07/2013 11:54	479		121	243	722	246	246	12		Q3	874
11/07/2013 02:14	479		121	274	753			13		min	125
11/07/2013 08:04	479		121	291	770	329	329	13		max	1180
11/07/2013 06:12	479		121	410	889	434	434	15		std d crew time	339
11/07/2013 16:08	479		121	438	917	501	501	15		std d train time	358

Row Labels	Sum of Time required 2	Count of cancellation	Sum of buffer time 2	Sum of crew waiting for train -plan versus actual departure less processing time	Sum of total time 2	Sum of Cumulative delays origin to NCS departure		Sum of anything more than 13 hours requires different crew as crew cannot run trains after their shift has ended- double crew usage	number of trains		
11/07/2013 10:18	479		121	575	1054	625	625	18			
11/07/2013 13:27	479		121	810	1289	828	828	21			
11/07/2013 12:34	479		121	874	1353	894	894	23			
11/07/2013 15:04	479		121	890	1369	907	907	23			
11/07/2013 23:34	479		121	917	1396	997	997	23			
11/07/2013 13:52	479		121	1180	1659	1203	1203	28			
11/07/2013 02:44		1									
11/07/2013 03:20		1									
11/07/2013 14:54		1									
11/07/2013 16:00		1									
11/07/2013 16:19		1									
11/07/2013 16:41		1									
11/07/2013 17:01		1									
11/07/2013 18:33		1									
11/07/2013 18:59		1									
11/07/2013 21:00	479	1	121								
11/07/2013 21:45		1									
11/07/2013 22:24		1									
12/07/2013 03:20	479	1	121	82	561	101	101	9	16	Median	662
12/07/2013 06:12	479		121	169	648	252	252	11		Q1	294
12/07/2013 13:27	479		121	192	671	222	222	11		Q3	834
12/07/2013 08:39	479		121	262	741	324	324	12		min	82
12/07/2013 02:14	479		121	304	783	311	311	13		max	1476

Row Labels	Sum of Time required 2	Count of cancellation	Sum of buffer time 2	Sum of crew waiting for train -plan versus actual departure less processing time	Sum of total time 2	Sum of Cumulative delays origin to NCS departure		Sum of anything more than 13 hours requires different crew as crew cannot run trains after their shift has ended- double crew usage	number of trains		
12/07/2013 10:18	479		121	336	815	352	352	14		std d crew time	369
12/07/2013 17:01	479		121	559	1038	633	633	17		std d train time	393
12/07/2013 16:41	479		121	597	1076	729	729	18			
12/07/2013 08:04	479		121	727	1206	749	749	20			
12/07/2013 02:15	479		121	798	1277	801	801	21			
12/07/2013 23:34	479		121	829	1308	841	841	17			
12/07/2013 16:19	479		121	833	1312	862	862	22			
12/07/2013 15:04	479		121	835	1314	848	848	22			
12/07/2013 16:00	479		121	856	1335	1178	1178	22			
12/07/2013 22:48	479		121	910	1389	957	957	23			
12/07/2013 13:52	479		121	1476	1955	1697	1697	33			
12/07/2013 05:24		1									
12/07/2013 05:44		1									
12/07/2013 06:55		1									
12/07/2013 08:14		1									
12/07/2013 11:54		1									
12/07/2013 12:34		1									
12/07/2013 16:08		1									
12/07/2013 18:33		2									
12/07/2013 18:59		1									

Row Labels	Sum of Time required 2	Count of cancellation	Sum of buffer time 2	Sum of crew waiting for train -plan versus actual departure less processing time	Sum of total time 2	Sum of Cumulative delays origin to NCS departure		Sum of anything more than 13 hours requires different crew as crew cannot run trains after their shift has ended- double crew usage	number of trains		
12/07/2013 21:45		1									
13/07/2013 12:34	479		121	114	593	159	159	10	16	Median	485
13/07/2013 13:27	479		121	120	599	174	174	10		Q1	340
13/07/2013 22:48	479		121	250	729	271	271	12		Q3	886
13/07/2013 21:45	479		121	252	731	#VALUE!		12		min	114
13/07/2013 13:52	479		121	369	848	1821	1821	14		max	2239
13/07/2013 02:14	479		121	402	881	413	413	15		std d crew time	648
13/07/2013 06:12	479		121	416	895	437	437	15		std d train time	987
13/07/2013 08:04	479		121	480	959	550	55	16			
13/07/2013 23:34	479		121	489	968	531	531	16			
13/07/2013 16:41	479		121	496	975	555	555	16			
13/07/2013 16:19	479	1	121	560	1039	617	617	17			
13/07/2013 11:54	479		121	884	1363	912	912	23			
13/07/2013 02:15	479		121	892	1371	789	789	23			
13/07/2013 21:44	479		121	1712	2191	1743	1743	37			
13/07/2013 03:20	479		121	1856	2335	3363	3363	22			
13/07/2013 05:44	479		121	2239	2718	3357	3357	45			
13/07/2013 16:08								0			
13/07/2013 08:14											
13/07/2013 08:39		1									

Row Labels	Sum of Time required 2	Count of cancellation	Sum of buffer time 2	Sum of crew waiting for train -plan versus actual departure less processing time	Sum of total time 2	Sum of Cumulative delays origin to NCS departure		Sum of anything more than 13 hours requires different crew as crew cannot run trains after their shift has ended- double crew usage	number of trains		
13/07/2013 09:24		1									
13/07/2013 10:18		1									
13/07/2013 14:54		1									
13/07/2013 18:59		1									
13/07/2013 21:00		1									
14/07/2013 10:18	479		121	-98	380	27	27	6	12	Median	248
14/07/2013 02:14	479		121	142	621	317	317	10		Q1	195
14/07/2013 12:34	479		121	185	664	221	221	11		Q3	396
14/07/2013 13:27	479		121	198	677	224	224	11		min	-98
14/07/2013 21:00	479		121	223	702	307	307	12		max	649
14/07/2013 16:08	479		121	246	725	305	305	12		std d crew time	194
14/07/2013 02:44	479		121	250	729	293	293	12		std d train time	170
14/07/2013 11:54	479		121	260	739	274	274	12			
14/07/2013 16:00	479		121	389	868	417	417	14			
14/07/2013 03:20	479		121	416	895	453	453	14			
14/07/2013 08:04	479		121	532	1011	578	578	17			
14/07/2013 05:44	479		121	649	1128	671	671	19			
14/07/2013 07:19		1									
14/07/2013 08:14		1									
14/07/2013 08:39		1									

Row Labels	Sum of Time required 2	Count of cancellation	Sum of buffer time 2	Sum of crew waiting for train -plan versus actual departure less processing time	Sum of total time 2	Sum of Cumulative delays origin to NCS departure		Sum of anything more than 13 hours requires different crew as crew cannot run trains after their shift has ended- double crew usage	number of trains		
14/07/2013 14:54		2									
14/07/2013 15:04		1									
14/07/2013 16:19		1									
14/07/2013 18:33		1									
14/07/2013 21:45		1									
14/07/2013 22:48		1									
14/07/2013 23:34		1									
15/07/2013 16:08	479		121	50	529	125	125	9	13	Median	162
15/07/2013 02:44	479		121	61	540	86	86	9		Q1	107
15/07/2013 22:48	479		121	69	548	1623	1623	9		Q3	213
15/07/2013 03:20	479		121	107	586	165	165	10		min	50
15/07/2013 02:14	479		121	151	630	154	154	11		max	2793
15/07/2013 10:18	479		121	154	633	109	109	11		std d crew time	734
15/07/2013 21:44	479		121	162	641	248	248	11		std d train time	590
15/07/2013 11:54	479		121	173	652	204	204	11			
15/07/2013 08:04	479		121	188	667	246	246	11			
15/07/2013 18:33	479		121	213	692	199	199	12			
15/07/2013 12:34	479		121	305	784	347	347	13			
15/07/2013 21:45	479		121	423	902	457	457	15			
15/07/2013 23:34	479		121	2793	3272	1932	1932	55			
15/07/2013 03:00		1									

Row Labels	Sum of Time required 2	Count of cancellation	Sum of buffer time 2	Sum of crew waiting for train -plan versus actual departure less processing time	Sum of total time 2	Sum of Cumulative delays origin to NCS departure		Sum of anything more than 13 hours requires different crew as crew cannot run trains after their shift has ended- double crew usage	number of trains		
15/07/2013 08:39		1									
15/07/2013 13:27		1									
15/07/2013 14:54		2									
15/07/2013 15:04		1									
15/07/2013 16:19		1									
15/07/2013 16:41		1									
15/07/2013 21:00		1									
15/07/2013 22:24		1									
16/07/2013 03:20	479		121	-17	461	68	68	8	13	Median	262
16/07/2013 11:54	479		121	78	557	87	87	9		Q1	179
16/07/2013 15:04	479		121	115	594	225	225	10		Q3	526
16/07/2013 02:44	479		121	179	658	209	209	11		min	-17
16/07/2013 02:14	479		121	183	662	220	220	11		max	2668
16/07/2013 12:34	479		121	185	664	214	214	11		std d crew time	809
16/07/2013 08:04	479		121	262	741	261	261	12		std d train time	799
16/07/2013 22:48	479		121	277	756	327	327	13			
16/07/2013 16:00	479		121	432	911	477	447	15			
16/07/2013 16:41	479		121	526	1005	557	557	17			
16/07/2013 13:27	479		121	633	1112	652	652	19			
16/07/2013 23:34	479		121	1983	2462	2050	2050	41			
16/07/2013 08:39	479		121	2668	3147	2657	2657	52			

Row Labels	Sum of Time required 2	Count of cancellation	Sum of buffer time 2	Sum of crew waiting for train -plan versus actual departure less processing time	Sum of total time 2	Sum of Cumulative delays origin to NCS departure		Sum of anything more than 13 hours requires different crew as crew cannot run trains after their shift has ended- double crew usage	number of trains		
16/07/2013 05:44		1									
16/07/2013 06:55		1									
16/07/2013 10:18		1									
16/07/2013 14:54		2									
16/07/2013 16:08		1									
16/07/2013 16:19		1									
16/07/2013 17:01		1									
16/07/2013 18:33		1									
16/07/2013 18:59		1									
16/07/2013 21:45		1									
17/07/2013 11:54	479		121	49	528	98	98	9	17	Median	409
17/07/2013 03:20	479		121	105	584	127	127	10		Q1	286
17/07/2013 08:39	479		121	108	587	166	166	10		Q3	654
17/07/2013 16:08	479		121	159	638	204	204	11		min	49
17/07/2013 12:34	479		121	286	765	288	288	13		max	1358
17/07/2013 10:18	479		121	311	790	157	157	13		std d crew time	354
17/07/2013 16:00	479		121	358	837	377	377	14		std d train time	351
17/07/2013 23:45	479		121	408	887	437	437	15			
17/07/2013 13:27	479		121	409	888	236	236	15			
17/07/2013 02:15	479		121	475	954	500	500	16			

Row Labels	Sum of Time required 2	Count of cancellation	Sum of buffer time 2	Sum of crew waiting for train -plan versus actual departure less processing time	Sum of total time 2	Sum of Cumulative delays origin to NCS departure		Sum of anything more than 13 hours requires different crew as crew cannot run trains after their shift has ended- double crew usage	number of trains		
17/07/2013 18:33	479		121	624	1103	620	620	18			
17/07/2013 16:41	479		121	630	1109	498	298	18			
17/07/2013 08:14	479		121	654	1133	663	663	19			
17/07/2013 02:14	479		121	828	1307	345	345	17			
17/07/2013 02:44	479		121	887	1366	843	843	23			
17/07/2013 08:04	479		121	954	1433	988	988	24			
17/07/2013 13:52	479		121	1358	1837	1428	1248	31			
17/07/2013 05:44		1									
17/07/2013 06:55											
17/07/2013 09:24		1									
17/07/2013 09:54		1									
17/07/2013 15:04		1									
17/07/2013 15:25		1									
17/07/2013 16:19		1									
17/07/2013 21:45		1									
17/07/2013 22:48		1									
17/07/2013 23:34		1									
18/07/2013 02:14		1									
18/07/2013 02:44		1									
18/07/2013 03:20		1									
18/07/2013 05:24		1									
18/07/2013 05:44		1									
18/07/2013 08:39		1									

Row Labels	Sum of Time required 2	Count of cancellation	Sum of buffer time 2	Sum of crew waiting for train -plan versus actual departure less processing time	Sum of total time 2	Sum of Cumulative delays origin to NCS departure		Sum of anything more than 13 hours requires different crew as crew cannot run trains after their shift has ended- double crew usage	number of trains		
18/07/2013 09:54		1									
18/07/2013 10:18		1									
18/07/2013 13:27		1									
18/07/2013 15:04		1									
18/07/2013 16:08		1									
18/07/2013 16:19		1									
(blank)		2									
Grand Total	115950	189	29282	#VALUE!	#VALUE!	#VALUE!		4093			

APPENDIX F: BOX AND WHISKER GRAPH

Table F.1 Box and Whisker graph data

statistic	week 1	differences	week 2	differences	week 3	differences	week 4	differences	week 5	differences	week 6	differences	week 7	differences	week 8	differences	week 9	d
min	47	47	172	172	38	38	-142		118	118	-4	-4	-58	-58	60	60	178	1
Q1	124	77	219	47	225	187	-2	-144	364	246	279	275	152	94	235	175	300	1
median	199	74	266	47	467	243	9	11	483	119	514	235	260	108	353	118	453	1
Q3	302	104	582	317	865	398	257	248	538	55	1099	585	418	158	692	339	686	2
max	1137	835	2459	1877	3357	2493	494	237	2405	1867	4246	3148	650	233	2149	1457	1251	5

statistic	week 10	differences	week 11	differences	week 12	differences	week 13	differences	week 14	differences	week 15	differences	week 16	differences	week 17	differences
min	93	93	125	125	82	82	114	114	-98	-98	50	50	-17	-17	49	49
Q1	360	267	274	149	294	212	340	226	195	97	107	57	179	162	286	237
median	612	253	438	164	662	369	484.5	145	248	53	162	55	262	83	409	123
Q3	1142	530	874	436	834	172	886	402	396	148	213	51	526	264	654	245
max	1907	765	1180	306	1476	643	2239	1353	649	253	2793	2580	2668	2142	1358	704

APPENDIX G: CORRELATION GRAPH

Table G.1 Correlation graph data

	std d train	std d crew
Day 1	349	344
Day 2	680	677
Day 3	874	870
Day 4	144	206
Day 5	599	567
Day 6	1129	1103
Day 7	193	199
Day 8	309	529
Day 9	299	309
Day 10	659	525
Day 11	358	339
Day 12	393	369
Day 13	987	648
Day 14	170	194
Day 15	590	734
Day 16	799	809
Day 17	351	354

APPENDIX H: INTERDEPARTURE TIMES

Table H.1 Interdeparture times – actual and sorted data

Actual data	
Departure NCS	minutes
01/07/2013 14:08	
01/07/2013 14:26	18
01/07/2013 16:23	117
01/07/2013 22:24	361
01/07/2013 23:49	85
01/07/2013 23:57	8
02/07/2013 00:20	23
02/07/2013 02:38	138
02/07/2013 02:47	9
02/07/2013 03:21	34
02/07/2013 09:47	386
02/07/2013 10:53	66
02/07/2013 11:08	15
02/07/2013 13:19	131
02/07/2013 15:35	136
02/07/2013 16:01	26
02/07/2013 20:36	275
02/07/2013 21:14	38
03/07/2013 01:33	259
03/07/2013 02:02	29
03/07/2013 02:36	34
03/07/2013 05:02	146
03/07/2013 06:40	98
03/07/2013 11:11	271
03/07/2013 12:41	90
03/07/2013 15:16	155
03/07/2013 16:54	98
03/07/2013 23:11	377
03/07/2013 23:20	9
03/07/2013 23:23	3
04/07/2013 01:21	118
04/07/2013 01:35	14
04/07/2013 02:40	65
04/07/2013 04:02	82
04/07/2013 07:19	197
04/07/2013 11:57	278
04/07/2013 12:41	44
04/07/2013 13:32	51
04/07/2013 14:01	29
04/07/2013 14:09	8
04/07/2013 17:11	182
04/07/2013 19:01	110

Sorted data	
Departure NCS	minutes
14/07/2013 19:59	0
15/07/2013 02:16	0
03/07/2013 23:23	3
11/07/2013 22:41	3
11/07/2013 22:45	4
05/07/2013 01:11	6
07/07/2013 16:17	6
09/07/2013 11:39	6
07/07/2013 13:52	7
07/07/2013 23:08	7
08/07/2013 09:40	7
01/07/2013 23:57	8
04/07/2013 14:09	8
11/07/2013 18:00	8
15/07/2013 02:47	8
02/07/2013 02:47	9
03/07/2013 23:20	9
14/07/2013 04:20	9
18/07/2013 07:50	9
05/07/2013 04:15	10
18/07/2013 14:50	10
06/07/2013 20:17	11
09/07/2013 23:28	11
12/07/2013 12:51	11
15/07/2013 02:39	11
18/07/2013 03:14	11
15/07/2013 02:28	12
04/07/2013 01:35	14
06/07/2013 09:59	14
02/07/2013 11:08	15
05/07/2013 20:00	15
13/07/2013 23:06	15
04/07/2013 20:55	16
06/07/2013 09:00	16
17/07/2013 20:10	17
01/07/2013 14:26	18
08/07/2013 03:30	18
13/07/2013 12:21	18
14/07/2013 11:40	18
15/07/2013 02:16	19
14/07/2013 12:41	20
07/07/2013 17:56	21

Actual data	
Departure NCS	minutes
04/07/2013 20:39	98
04/07/2013 20:55	16
05/07/2013 01:05	250
05/07/2013 01:11	6
05/07/2013 01:38	27
05/07/2013 04:05	147
05/07/2013 04:15	10
05/07/2013 05:05	50
05/07/2013 08:40	215
05/07/2013 19:07	627
05/07/2013 19:45	38
05/07/2013 20:00	15
06/07/2013 00:48	288
06/07/2013 01:37	49
06/07/2013 04:51	194
06/07/2013 08:44	233
06/07/2013 09:00	16
06/07/2013 09:45	45
06/07/2013 09:59	14
06/07/2013 13:06	187
06/07/2013 15:19	133
06/07/2013 16:23	64
06/07/2013 20:06	223
06/07/2013 20:17	11
06/07/2013 21:44	87
06/07/2013 22:23	39
06/07/2013 22:49	26
07/07/2013 01:46	177
07/07/2013 06:59	313
07/07/2013 07:26	27
07/07/2013 10:12	166
07/07/2013 12:08	116
07/07/2013 13:16	68
07/07/2013 13:45	29
07/07/2013 13:52	7
07/07/2013 16:11	139
07/07/2013 16:17	6
07/07/2013 16:59	42
07/07/2013 17:35	36
07/07/2013 17:56	21
07/07/2013 23:01	305
07/07/2013 23:08	7
07/07/2013 23:44	36
08/07/2013 00:44	60
08/07/2013 03:12	148
08/07/2013 03:30	18
08/07/2013 08:02	272
08/07/2013 09:33	91

Sorted data	
Departure NCS	minutes
18/07/2013 04:51	21
15/07/2013 14:50	22
02/07/2013 00:20	23
08/07/2013 14:09	24
02/07/2013 16:01	26
06/07/2013 22:49	26
09/07/2013 05:39	26
09/07/2013 23:17	26
13/07/2013 00:34	26
16/07/2013 15:26	26
05/07/2013 01:38	27
07/07/2013 07:26	27
10/07/2013 17:28	27
03/07/2013 02:02	29
04/07/2013 14:01	29
07/07/2013 13:45	29
16/07/2013 15:00	29
09/07/2013 03:47	30
14/07/2013 00:11	30
12/07/2013 19:15	31
12/07/2013 12:40	32
18/07/2013 01:45	33
02/07/2013 03:21	34
03/07/2013 02:36	34
13/07/2013 23:41	35
15/07/2013 01:57	35
07/07/2013 17:35	36
07/07/2013 23:44	36
13/07/2013 12:58	37
14/07/2013 01:47	37
02/07/2013 21:14	38
05/07/2013 19:45	38
11/07/2013 15:19	38
06/07/2013 22:23	39
10/07/2013 03:22	39
10/07/2013 14:49	39
08/07/2013 17:10	40
14/07/2013 12:21	41
16/07/2013 03:22	41
07/07/2013 16:59	42
14/07/2013 11:22	42
04/07/2013 12:41	44
10/07/2013 15:33	44
06/07/2013 09:45	45
13/07/2013 02:22	45
15/07/2013 05:57	46
16/07/2013 22:55	46
06/07/2013 01:37	49

Actual data	
Departure NCS	minutes
08/07/2013 09:40	7
08/07/2013 11:12	92
08/07/2013 12:41	89
08/07/2013 13:45	64
08/07/2013 14:09	24
08/07/2013 16:30	141
08/07/2013 17:10	40
08/07/2013 19:09	119
08/07/2013 20:21	72
08/07/2013 22:11	110
08/07/2013 23:00	49
09/07/2013 03:17	257
09/07/2013 03:47	30
09/07/2013 05:13	86
09/07/2013 05:39	26
09/07/2013 08:28	169
09/07/2013 10:43	135
09/07/2013 11:33	50
09/07/2013 11:39	6
09/07/2013 14:32	173
09/07/2013 15:42	70
09/07/2013 22:51	429
09/07/2013 23:17	26
09/07/2013 23:28	11
10/07/2013 01:15	107
10/07/2013 02:43	88
10/07/2013 03:22	39
10/07/2013 07:58	276
10/07/2013 09:11	73
10/07/2013 11:24	133
10/07/2013 14:10	166
10/07/2013 14:49	39
10/07/2013 15:33	44
10/07/2013 17:01	88
10/07/2013 17:28	27
10/07/2013 21:38	250
11/07/2013 01:45	247
11/07/2013 03:41	116
11/07/2013 06:13	152
11/07/2013 07:59	106
11/07/2013 11:24	205
11/07/2013 12:26	62
11/07/2013 14:41	135
11/07/2013 15:19	38
11/07/2013 16:31	72
11/07/2013 17:52	81
11/07/2013 18:00	8
11/07/2013 20:27	147

Sorted data	
Departure NCS	minutes
08/07/2013 23:00	49
14/07/2013 17:26	49
05/07/2013 05:05	50
09/07/2013 11:33	50
16/07/2013 08:39	50
04/07/2013 13:32	51
14/07/2013 18:22	56
14/07/2013 01:10	59
08/07/2013 00:44	60
15/07/2013 14:28	60
16/07/2013 09:40	61
11/07/2013 12:26	62
13/07/2013 01:37	63
06/07/2013 16:23	64
08/07/2013 13:45	64
04/07/2013 02:40	65
02/07/2013 10:53	66
12/07/2013 09:09	67
07/07/2013 13:16	68
18/07/2013 05:59	68
09/07/2013 15:42	70
08/07/2013 20:21	72
11/07/2013 16:31	72
12/07/2013 15:37	72
13/07/2013 17:07	72
10/07/2013 09:11	73
13/07/2013 15:55	73
18/07/2013 04:30	76
18/07/2013 03:03	78
17/07/2013 02:42	80
11/07/2013 17:52	81
04/07/2013 04:02	82
15/07/2013 13:28	83
12/07/2013 17:01	84
13/07/2013 00:08	84
01/07/2013 23:49	85
09/07/2013 05:13	86
18/07/2013 16:16	86
06/07/2013 21:44	87
17/07/2013 11:10	87
10/07/2013 02:43	88
10/07/2013 17:01	88
08/07/2013 12:41	89
03/07/2013 12:41	90
08/07/2013 09:33	91
08/07/2013 11:12	92
13/07/2013 18:39	92
12/07/2013 14:25	94

Actual data	
Departure NCS	minutes
11/07/2013 22:38	131
11/07/2013 22:41	3
11/07/2013 22:45	4
12/07/2013 01:40	175
12/07/2013 05:36	236
12/07/2013 08:02	146
12/07/2013 09:09	67
12/07/2013 12:08	179
12/07/2013 12:40	32
12/07/2013 12:51	11
12/07/2013 14:25	94
12/07/2013 15:37	72
12/07/2013 17:01	84
12/07/2013 18:44	103
12/07/2013 19:15	31
12/07/2013 22:44	209
13/07/2013 00:08	84
13/07/2013 00:34	26
13/07/2013 01:37	63
13/07/2013 02:22	45
13/07/2013 05:54	212
13/07/2013 12:03	369
13/07/2013 12:21	18
13/07/2013 12:58	37
13/07/2013 14:42	104
13/07/2013 15:55	73
13/07/2013 17:07	72
13/07/2013 18:39	92
13/07/2013 22:51	252
13/07/2013 23:06	15
13/07/2013 23:41	35
14/07/2013 00:11	30
14/07/2013 01:10	59
14/07/2013 01:47	37
14/07/2013 04:11	144
14/07/2013 04:20	9
14/07/2013 10:40	380
14/07/2013 11:22	42
14/07/2013 11:40	18
14/07/2013 12:21	41
14/07/2013 12:41	20
14/07/2013 14:19	98
14/07/2013 16:37	138
14/07/2013 17:26	49
14/07/2013 18:22	56
14/07/2013 19:59	97
14/07/2013 19:59	0
15/07/2013 01:22	323

Sorted data	
Departure NCS	minutes
14/07/2013 19:59	97
03/07/2013 06:40	98
03/07/2013 16:54	98
04/07/2013 20:39	98
14/07/2013 14:19	98
15/07/2013 22:35	100
17/07/2013 14:48	100
18/07/2013 07:41	102
12/07/2013 18:44	103
13/07/2013 14:42	104
11/07/2013 07:59	106
16/07/2013 14:31	106
18/07/2013 14:40	106
10/07/2013 01:15	107
04/07/2013 19:01	110
08/07/2013 22:11	110
18/07/2013 09:41	111
16/07/2013 00:30	115
07/07/2013 12:08	116
11/07/2013 03:41	116
01/07/2013 16:23	117
04/07/2013 01:21	118
17/07/2013 13:08	118
08/07/2013 19:09	119
18/07/2013 18:20	124
02/07/2013 13:19	131
11/07/2013 22:38	131
16/07/2013 02:41	131
06/07/2013 15:19	133
10/07/2013 11:24	133
09/07/2013 10:43	135
11/07/2013 14:41	135
02/07/2013 15:35	136
17/07/2013 22:26	136
02/07/2013 02:38	138
14/07/2013 16:37	138
07/07/2013 16:11	139
08/07/2013 16:30	141
14/07/2013 04:11	144
15/07/2013 05:11	144
03/07/2013 05:02	146
12/07/2013 08:02	146
05/07/2013 04:05	147
11/07/2013 20:27	147
17/07/2013 01:22	147
08/07/2013 03:12	148
11/07/2013 06:13	152
03/07/2013 15:16	155

Actual data	
Departure NCS	minutes
15/07/2013 01:57	35
15/07/2013 02:16	19
15/07/2013 02:16	0
15/07/2013 02:28	12
15/07/2013 02:39	11
15/07/2013 02:47	8
15/07/2013 05:11	144
15/07/2013 05:57	46
15/07/2013 12:05	368
15/07/2013 13:28	83
15/07/2013 14:28	60
15/07/2013 14:50	22
15/07/2013 20:55	365
15/07/2013 22:35	100
16/07/2013 00:30	115
16/07/2013 02:41	131
16/07/2013 03:22	41
16/07/2013 07:49	267
16/07/2013 08:39	50
16/07/2013 09:40	61
16/07/2013 12:45	185
16/07/2013 14:31	106
16/07/2013 15:00	29
16/07/2013 15:26	26
16/07/2013 22:09	403
16/07/2013 22:55	46
17/07/2013 01:22	147
17/07/2013 02:42	80
17/07/2013 05:54	192
17/07/2013 09:43	229
17/07/2013 11:10	87
17/07/2013 13:08	118
17/07/2013 14:48	100
17/07/2013 19:53	305
17/07/2013 20:10	17
17/07/2013 22:26	136
18/07/2013 01:12	166
18/07/2013 01:45	33
18/07/2013 03:03	78
18/07/2013 03:14	11
18/07/2013 04:30	76
18/07/2013 04:51	21
18/07/2013 05:59	68
18/07/2013 07:41	102
18/07/2013 07:50	9
18/07/2013 09:41	111
18/07/2013 12:54	193
18/07/2013 14:40	106

Sorted data		
Departure NCS	minutes	
07/07/2013 10:12	166	
10/07/2013 14:10	166	
18/07/2013 01:12	166	
09/07/2013 08:28	169	
09/07/2013 14:32	173	
12/07/2013 01:40	175	
07/07/2013 01:46	177	
12/07/2013 12:08	179	
04/07/2013 17:11	182	
16/07/2013 12:45	185	
06/07/2013 13:06	187	
17/07/2013 05:54	192	
18/07/2013 12:54	193	
06/07/2013 04:51	194	
04/07/2013 07:19	197	
11/07/2013 11:24	205	
12/07/2013 22:44	209	
13/07/2013 05:54	212	
05/07/2013 08:40	215	
06/07/2013 20:06	223	
17/07/2013 09:43	229	
06/07/2013 08:44	233	
18/07/2013 22:13	233	
12/07/2013 05:36	236	
11/07/2013 01:45	247	
05/07/2013 01:05	250	
10/07/2013 21:38	250	
13/07/2013 22:51	252	
09/07/2013 03:17	257	
03/07/2013 01:33	259	
16/07/2013 07:49	267	
03/07/2013 11:11	271	
08/07/2013 08:02	272	
02/07/2013 20:36	275	
10/07/2013 07:58	276	
04/07/2013 11:57	278	
06/07/2013 00:48	288	
07/07/2013 23:01	305	Outlier
17/07/2013 19:53	305	Outlier
07/07/2013 06:59	313	Outlier
15/07/2013 01:22	323	Outlier
01/07/2013 22:24	361	Outlier
15/07/2013 20:55	365	Outlier
15/07/2013 12:05	368	Outlier
13/07/2013 12:03	369	Outlier
03/07/2013 23:11	377	Outlier
14/07/2013 10:40	380	Outlier
02/07/2013 09:47	386	Outlier

Actual data	
Departure NCS	minutes
18/07/2013 14:50	10
18/07/2013 16:16	86
18/07/2013 18:20	124
18/07/2013 22:13	233

Sorted data		
Departure NCS	minutes	
16/07/2013 22:09	403	Outlier
09/07/2013 22:51	429	Outlier
05/07/2013 19:07	627	Outlier
01/07/2013 14:08		

Outliers where trains depart more than five hours apart

APPENDIX I: INTERARRIVAL TIMES

Table I.1 Interarrival times – actual and sorted data

Actual data	
Arrival NCS	minutes
01/07/2013 14:04	
01/07/2013 14:20	16
01/07/2013 16:17	117
01/07/2013 22:18	361
01/07/2013 23:19	61
01/07/2013 23:30	11
02/07/2013 00:14	44
02/07/2013 02:28	134
02/07/2013 02:33	5
02/07/2013 03:15	42
02/07/2013 09:40	385
02/07/2013 10:46	66
02/07/2013 11:02	16
02/07/2013 13:12	130
02/07/2013 15:16	124
02/07/2013 15:54	38
02/07/2013 20:29	275
02/07/2013 20:55	26
03/07/2013 01:03	248
03/07/2013 01:22	19
03/07/2013 02:29	67
03/07/2013 04:56	147
03/07/2013 06:32	96
03/07/2013 10:36	244
03/07/2013 12:35	119
03/07/2013 15:09	154
03/07/2013 16:29	80
03/07/2013 18:47	138
03/07/2013 20:35	108
03/07/2013 23:15	160
04/07/2013 00:51	96
04/07/2013 01:29	38
04/07/2013 02:31	62
04/07/2013 03:57	86
04/07/2013 06:48	171
04/07/2013 11:29	281
04/07/2013 12:33	64
04/07/2013 13:26	53
04/07/2013 13:39	13
04/07/2013 13:51	12
04/07/2013 16:03	132
04/07/2013 16:54	51

Sorted data	
Arrival NCS	minutes
14/07/2013 19:52	0
15/07/2013 02:04	0
13/07/2013 18:33	2
11/07/2013 22:34	3
02/07/2013 02:33	5
08/07/2013 09:21	7
11/07/2013 22:43	9
07/07/2013 16:14	10
01/07/2013 23:30	11
05/07/2013 04:10	11
06/07/2013 20:12	11
09/07/2013 22:56	11
10/07/2013 00:43	11
12/07/2013 12:45	11
15/07/2013 02:15	11
17/07/2013 22:16	11
04/07/2013 13:51	12
09/07/2013 11:25	12
10/07/2013 14:15	12
04/07/2013 13:39	13
06/07/2013 22:29	13
07/07/2013 06:19	13
12/07/2013 18:50	13
13/07/2013 22:57	14
15/07/2013 02:29	14
11/07/2013 17:50	15
13/07/2013 23:50	15
14/07/2013 01:51	15
16/07/2013 15:09	15
17/07/2013 20:00	15
01/07/2013 14:20	16
02/07/2013 11:02	16
04/07/2013 20:48	16
06/07/2013 08:53	16
16/07/2013 21:54	16
05/07/2013 19:54	17
07/07/2013 13:42	17
13/07/2013 12:16	17
11/07/2013 20:23	18
03/07/2013 01:22	19
07/07/2013 13:25	19
08/07/2013 03:24	19

Actual data	
Arrival NCS	minutes
04/07/2013 20:32	218
04/07/2013 20:48	16
04/07/2013 22:03	75
05/07/2013 00:00	117
05/07/2013 01:06	66
05/07/2013 03:59	173
05/07/2013 04:10	11
05/07/2013 04:59	49
05/07/2013 07:35	156
05/07/2013 18:30	655
05/07/2013 19:37	67
05/07/2013 19:54	17
06/07/2013 00:03	249
06/07/2013 01:30	87
06/07/2013 04:46	196
06/07/2013 08:11	205
06/07/2013 08:37	26
06/07/2013 08:53	16
06/07/2013 09:50	57
06/07/2013 12:57	187
06/07/2013 14:48	111
06/07/2013 15:33	45
06/07/2013 20:01	168
06/07/2013 20:12	11
06/07/2013 21:38	86
06/07/2013 22:16	38
06/07/2013 22:29	13
07/07/2013 01:41	192
07/07/2013 06:06	265
07/07/2013 06:19	13
07/07/2013 06:49	30
07/07/2013 10:03	194
07/07/2013 11:59	116
07/07/2013 13:06	67
07/07/2013 13:25	19
07/07/2013 13:42	17
07/07/2013 14:27	45
07/07/2013 16:04	97
07/07/2013 16:14	10
07/07/2013 17:48	94
07/07/2013 21:43	235
07/07/2013 22:54	71
07/07/2013 23:15	21
08/07/2013 00:31	76
08/07/2013 03:05	154
08/07/2013 03:24	19
08/07/2013 07:56	272

Sorted data	
Arrival NCS	minutes
09/07/2013 15:54	19
13/07/2013 06:07	19
15/07/2013 02:04	19
09/07/2013 23:16	20
17/07/2013 17:00	20
07/07/2013 23:15	21
11/07/2013 01:35	22
10/07/2013 08:15	23
14/07/2013 12:30	23
15/07/2013 13:46	23
08/07/2013 14:03	24
02/07/2013 20:55	26
06/07/2013 08:37	26
10/07/2013 17:21	28
15/07/2013 14:14	28
16/07/2013 14:54	28
07/07/2013 06:49	30
14/07/2013 01:36	30
15/07/2013 20:46	30
12/07/2013 12:34	32
02/07/2013 15:54	38
04/07/2013 01:29	38
06/07/2013 22:16	38
13/07/2013 23:35	38
08/07/2013 17:03	40
02/07/2013 03:15	42
15/07/2013 03:12	43
02/07/2013 00:14	44
06/07/2013 15:33	45
07/07/2013 14:27	45
12/07/2013 23:26	47
05/07/2013 04:59	49
08/07/2013 22:04	49
04/07/2013 16:54	51
04/07/2013 13:26	53
14/07/2013 18:15	56
06/07/2013 09:50	57
14/07/2013 12:07	59
15/07/2013 01:45	59
15/07/2013 04:11	59
08/07/2013 21:15	60
16/07/2013 03:15	60
01/07/2013 23:19	61
04/07/2013 02:31	62
08/07/2013 13:39	62
11/07/2013 12:17	62
04/07/2013 12:33	64

Actual data	
Arrival NCS	minutes
08/07/2013 09:14	78
08/07/2013 09:21	7
08/07/2013 10:51	90
08/07/2013 12:37	106
08/07/2013 13:39	62
08/07/2013 14:03	24
08/07/2013 16:23	140
08/07/2013 17:03	40
08/07/2013 19:01	118
08/07/2013 20:15	74
08/07/2013 21:15	60
08/07/2013 22:04	49
09/07/2013 00:24	140
09/07/2013 02:44	140
09/07/2013 04:21	97
09/07/2013 05:30	69
09/07/2013 08:22	172
09/07/2013 09:35	73
09/07/2013 11:13	98
09/07/2013 11:25	12
09/07/2013 14:02	157
09/07/2013 15:35	93
09/07/2013 15:54	19
09/07/2013 22:45	411
09/07/2013 22:56	11
09/07/2013 23:16	20
10/07/2013 00:32	76
10/07/2013 00:43	11
10/07/2013 03:20	157
10/07/2013 07:52	272
10/07/2013 08:15	23
10/07/2013 10:26	131
10/07/2013 14:03	217
10/07/2013 14:15	12
10/07/2013 16:53	158
10/07/2013 17:21	28
10/07/2013 21:31	250
11/07/2013 01:13	222
11/07/2013 01:35	22
11/07/2013 06:07	272
11/07/2013 07:53	106
11/07/2013 10:08	135
11/07/2013 11:15	67
11/07/2013 12:17	62
11/07/2013 13:50	93
11/07/2013 16:24	154
11/07/2013 17:35	71

Sorted data	
Arrival NCS	minutes
02/07/2013 10:46	66
05/07/2013 01:06	66
13/07/2013 00:32	66
03/07/2013 02:29	67
05/07/2013 19:37	67
07/07/2013 13:06	67
11/07/2013 11:15	67
13/07/2013 11:59	67
09/07/2013 05:30	69
12/07/2013 09:04	70
07/07/2013 22:54	71
11/07/2013 17:35	71
16/07/2013 09:33	71
13/07/2013 01:44	72
17/07/2013 10:37	72
09/07/2013 09:35	73
08/07/2013 20:15	74
12/07/2013 15:32	74
04/07/2013 22:03	75
14/07/2013 17:19	75
08/07/2013 00:31	76
10/07/2013 00:32	76
14/07/2013 01:06	76
13/07/2013 13:33	77
08/07/2013 09:14	78
03/07/2013 16:29	80
12/07/2013 16:54	82
17/07/2013 02:24	85
04/07/2013 03:57	86
06/07/2013 21:38	86
06/07/2013 01:30	87
14/07/2013 09:22	87
08/07/2013 10:51	90
09/07/2013 15:35	93
11/07/2013 13:50	93
12/07/2013 14:18	93
07/07/2013 17:48	94
03/07/2013 06:32	96
04/07/2013 00:51	96
07/07/2013 16:04	97
09/07/2013 04:21	97
14/07/2013 19:52	97
15/07/2013 05:48	97
09/07/2013 11:13	98
14/07/2013 14:12	102
12/07/2013 18:37	103
17/07/2013 14:41	103

Actual data	
Arrival NCS	minutes
11/07/2013 17:50	15
11/07/2013 20:05	135
11/07/2013 20:23	18
11/07/2013 22:31	128
11/07/2013 22:34	3
11/07/2013 22:43	9
12/07/2013 01:29	166
12/07/2013 07:54	385
12/07/2013 09:04	70
12/07/2013 12:02	178
12/07/2013 12:34	32
12/07/2013 12:45	11
12/07/2013 14:18	93
12/07/2013 15:32	74
12/07/2013 16:54	82
12/07/2013 18:37	103
12/07/2013 18:50	13
12/07/2013 20:54	124
12/07/2013 22:39	105
12/07/2013 23:26	47
13/07/2013 00:32	66
13/07/2013 01:44	72
13/07/2013 05:48	244
13/07/2013 06:07	19
13/07/2013 10:52	285
13/07/2013 11:59	67
13/07/2013 12:16	17
13/07/2013 13:33	77
13/07/2013 18:31	298
13/07/2013 18:33	2
13/07/2013 22:43	250
13/07/2013 22:57	14
13/07/2013 23:35	38
13/07/2013 23:50	15
14/07/2013 01:06	76
14/07/2013 01:36	30
14/07/2013 01:51	15
14/07/2013 06:05	254
14/07/2013 07:55	110
14/07/2013 09:22	87
14/07/2013 11:08	106
14/07/2013 12:07	59
14/07/2013 12:30	23
14/07/2013 14:12	102
14/07/2013 16:04	112
14/07/2013 17:19	75
14/07/2013 18:15	56

Sorted data	
Arrival NCS	minutes
12/07/2013 22:39	105
08/07/2013 12:37	106
11/07/2013 07:53	106
14/07/2013 11:08	106
03/07/2013 20:35	108
16/07/2013 14:26	108
14/07/2013 07:55	110
16/07/2013 08:22	110
06/07/2013 14:48	111
14/07/2013 16:04	112
16/07/2013 02:15	113
07/07/2013 11:59	116
01/07/2013 16:17	117
05/07/2013 00:00	117
08/07/2013 19:01	118
03/07/2013 12:35	119
17/07/2013 16:40	119
02/07/2013 15:16	124
12/07/2013 20:54	124
17/07/2013 22:05	125
15/07/2013 13:23	126
11/07/2013 22:31	128
02/07/2013 13:12	130
10/07/2013 10:26	131
04/07/2013 16:03	132
02/07/2013 02:28	134
11/07/2013 10:08	135
11/07/2013 20:05	135
03/07/2013 18:47	138
08/07/2013 16:23	140
09/07/2013 00:24	140
09/07/2013 02:44	140
17/07/2013 12:58	141
03/07/2013 04:56	147
03/07/2013 15:09	154
08/07/2013 03:05	154
11/07/2013 16:24	154
05/07/2013 07:35	156
09/07/2013 14:02	157
10/07/2013 03:20	157
10/07/2013 16:53	158
03/07/2013 23:15	160
17/07/2013 19:45	165
12/07/2013 01:29	166
06/07/2013 20:01	168
04/07/2013 06:48	171
09/07/2013 08:22	172

Actual data	
Arrival NCS	minutes
14/07/2013 19:52	97
14/07/2013 19:52	0
15/07/2013 00:46	294
15/07/2013 01:45	59
15/07/2013 02:04	19
15/07/2013 02:04	0
15/07/2013 02:15	11
15/07/2013 02:29	14
15/07/2013 03:12	43
15/07/2013 04:11	59
15/07/2013 05:48	97
15/07/2013 11:17	329
15/07/2013 13:23	126
15/07/2013 13:46	23
15/07/2013 14:14	28
15/07/2013 20:16	362
15/07/2013 20:46	30
16/07/2013 00:22	216
16/07/2013 02:15	113
16/07/2013 03:15	60
16/07/2013 06:32	197
16/07/2013 08:22	110
16/07/2013 09:33	71
16/07/2013 12:38	185
16/07/2013 14:26	108
16/07/2013 14:54	28
16/07/2013 15:09	15
16/07/2013 21:38	389
16/07/2013 21:54	16
17/07/2013 00:59	185
17/07/2013 02:24	85
17/07/2013 05:48	204
17/07/2013 09:25	217
17/07/2013 10:37	72
17/07/2013 12:58	141
17/07/2013 14:41	103
17/07/2013 16:40	119
17/07/2013 17:00	20
17/07/2013 19:45	165
17/07/2013 20:00	15
17/07/2013 22:05	125
17/07/2013 22:16	11
18/07/2013 02:03	
18/07/2013 02:30	

Sorted data		
Arrival NCS	minutes	
05/07/2013 03:59	173	
12/07/2013 12:02	178	
16/07/2013 12:38	185	
17/07/2013 00:59	185	
06/07/2013 12:57	187	
07/07/2013 01:41	192	
07/07/2013 10:03	194	
06/07/2013 04:46	196	
16/07/2013 06:32	197	
17/07/2013 05:48	204	
06/07/2013 08:11	205	
16/07/2013 00:22	216	
10/07/2013 14:03	217	
17/07/2013 09:25	217	
04/07/2013 20:32	218	
11/07/2013 01:13	222	
07/07/2013 21:43	235	
03/07/2013 10:36	244	
13/07/2013 05:48	244	
03/07/2013 01:03	248	
06/07/2013 00:03	249	
10/07/2013 21:31	250	
13/07/2013 22:43	250	
14/07/2013 06:05	254	
07/07/2013 06:06	265	
08/07/2013 07:56	272	
10/07/2013 07:52	272	
11/07/2013 06:07	272	
02/07/2013 20:29	275	
04/07/2013 11:29	281	
13/07/2013 10:52	285	
15/07/2013 00:46	294	
13/07/2013 18:31	298	
15/07/2013 11:17	329	outlier
01/07/2013 22:18	361	outlier
15/07/2013 20:16	362	outlier
02/07/2013 09:40	385	outlier
12/07/2013 07:54	385	outlier
16/07/2013 21:38	389	outlier
09/07/2013 22:45	411	outlier
05/07/2013 18:30	655	outlier
01/07/2013 14:04		outlier
18/07/2013 02:03		outlier
18/07/2013 02:30		outlier

Outliers where trains depart more than five hours apart

APPENDIX J: YARD PROCESSING

Table J.1 Yard processing – actual and sorted data

Actual data	
Arrival NCS	Actual Dwell NCS
01/07/2013 14:20	6
01/07/2013 14:04	4
01/07/2013 16:17	6
02/07/2013 09:40	7
01/07/2013 22:18	6
02/07/2013 13:12	7
02/07/2013 00:14	6
01/07/2013 23:19	30
01/07/2013 23:30	27
02/07/2013 02:28	10
02/07/2013 02:33	14
02/07/2013 03:15	6
02/07/2013 15:54	7
02/07/2013 10:46	7
02/07/2013 11:02	6
02/07/2013 15:16	19
02/07/2013 20:29	7
03/07/2013 01:03	59
02/07/2013 20:55	19
03/07/2013 16:29	25
03/07/2013 01:22	11
03/07/2013 02:29	7
03/07/2013 06:32	8
03/07/2013 04:56	6
04/07/2013 16:03	178
03/07/2013 10:36	35
03/07/2013 12:35	6
03/07/2013 20:35	165
03/07/2013 15:09	7
03/07/2013 18:47	264
04/07/2013 00:51	30
03/07/2013 23:15	8
04/07/2013 22:03	215
04/07/2013 01:29	6
04/07/2013 13:26	6
06/07/2013 08:11	33
04/07/2013 03:57	5
04/07/2013 02:31	9
04/07/2013 06:48	31
04/07/2013 11:29	28

Sorted data	
Arrival NCS	Actual Dwell NCS
10/07/2013 03:20	2
01/07/2013 14:04	4
08/07/2013 12:37	4
11/07/2013 20:23	4
13/07/2013 11:59	4
14/07/2013 01:06	4
04/07/2013 03:57	5
05/07/2013 04:10	5
05/07/2013 01:06	5
06/07/2013 20:01	5
06/07/2013 20:12	5
07/07/2013 01:41	5
12/07/2013 15:32	5
12/07/2013 09:04	5
12/07/2013 22:39	5
13/07/2013 12:16	5
01/07/2013 14:20	6
01/07/2013 16:17	6
01/07/2013 22:18	6
02/07/2013 00:14	6
02/07/2013 03:15	6
02/07/2013 11:02	6
03/07/2013 04:56	6
03/07/2013 12:35	6
04/07/2013 01:29	6
04/07/2013 13:26	6
05/07/2013 03:59	6
05/07/2013 04:59	6
05/07/2013 19:54	6
06/07/2013 21:38	6
08/07/2013 03:24	6
08/07/2013 07:56	6
08/07/2013 14:03	6
08/07/2013 13:39	6
08/07/2013 20:15	6
09/07/2013 08:22	6
09/07/2013 22:45	6
10/07/2013 07:52	6
11/07/2013 06:07	6

Actual data	
Arrival NCS	Actual Dwell NCS
05/07/2013 03:59	6
04/07/2013 12:33	8
04/07/2013 13:51	10
04/07/2013 16:54	17
04/07/2013 13:39	30
04/07/2013 20:32	7
04/07/2013 20:48	7
05/07/2013 04:10	5
05/07/2013 01:06	5
05/07/2013 00:00	65
05/07/2013 04:59	6
05/07/2013 07:35	65
05/07/2013 19:54	6
05/07/2013 18:30	37
06/07/2013 00:03	45
05/07/2013 19:37	8
06/07/2013 01:30	7
06/07/2013 08:53	7
06/07/2013 08:37	68
07/07/2013 17:48	8
06/07/2013 04:46	
06/07/2013 09:50	
06/07/2013 14:48	31
06/07/2013 12:57	9
06/07/2013 15:33	50
09/07/2013 09:35	68
06/07/2013 22:29	
06/07/2013 22:16	7
07/07/2013 06:19	67
06/07/2013 20:01	5
06/07/2013 20:12	5
08/07/2013 03:05	7
07/07/2013 14:27	104
06/07/2013 21:38	6
07/07/2013 06:06	689
08/07/2013 21:15	105
07/07/2013 16:04	13
07/07/2013 01:41	5
07/07/2013 06:49	10
07/07/2013 10:03	9
07/07/2013 11:59	9
07/07/2013 13:06	10
07/07/2013 13:42	10
07/07/2013 13:25	20

Sorted data	
Arrival NCS	Actual Dwell NCS
11/07/2013 07:53	6
12/07/2013 12:45	6
12/07/2013 12:34	6
12/07/2013 12:02	6
13/07/2013 05:48	6
13/07/2013 23:35	6
02/07/2013 09:40	7
02/07/2013 13:12	7
02/07/2013 15:54	7
02/07/2013 10:46	7
02/07/2013 20:29	7
03/07/2013 02:29	7
03/07/2013 15:09	7
04/07/2013 20:32	7
04/07/2013 20:48	7
06/07/2013 01:30	7
06/07/2013 08:53	7
06/07/2013 22:16	7
08/07/2013 03:05	7
07/07/2013 22:54	7
08/07/2013 16:23	7
08/07/2013 17:03	7
08/07/2013 22:04	7
09/07/2013 15:35	7
10/07/2013 21:31	7
10/07/2013 14:03	7
10/07/2013 17:21	7
11/07/2013 22:34	7
11/07/2013 16:24	7
11/07/2013 22:31	7
12/07/2013 14:18	7
12/07/2013 16:54	7
12/07/2013 18:37	7
14/07/2013 19:52	7
14/07/2013 17:19	7
14/07/2013 19:52	7
14/07/2013 14:12	7
14/07/2013 18:15	7
03/07/2013 06:32	8
03/07/2013 23:15	8
04/07/2013 12:33	8
05/07/2013 19:37	8
07/07/2013 17:48	8
08/07/2013 19:01	8
09/07/2013 11:25	8
10/07/2013 16:53	8

Actual data	
Arrival NCS	Actual Dwell NCS
07/07/2013 16:14	45
07/07/2013 22:54	7
07/07/2013 21:43	85
07/07/2013 23:15	29
08/07/2013 03:24	6
08/07/2013 09:21	12
08/07/2013 07:56	6
08/07/2013 00:31	13
08/07/2013 12:37	4
08/07/2013 09:14	26
08/07/2013 14:03	6
08/07/2013 10:51	21
08/07/2013 13:39	6
08/07/2013 16:23	7
08/07/2013 20:15	6
08/07/2013 17:03	7
08/07/2013 19:01	8
09/07/2013 04:21	52
08/07/2013 22:04	7
09/07/2013 00:24	203
09/07/2013 02:44	33
09/07/2013 14:02	30
09/07/2013 15:54	1170
09/07/2013 05:30	9
09/07/2013 15:35	7
09/07/2013 11:13	26
09/07/2013 08:22	6
09/07/2013 11:25	8
09/07/2013 22:45	6
09/07/2013 22:56	21
09/07/2013 23:16	12
10/07/2013 07:52	6
10/07/2013 00:32	131
10/07/2013 00:43	32
10/07/2013 03:20	2
10/07/2013 21:31	7
10/07/2013 08:15	56
10/07/2013 14:15	34
10/07/2013 14:03	7
10/07/2013 10:26	307
10/07/2013 16:53	8
10/07/2013 17:21	7
11/07/2013 01:13	148
11/07/2013 22:34	7
11/07/2013 11:15	9
11/07/2013 12:17	9

Sorted data	
Arrival NCS	Actual Dwell NCS
12/07/2013 07:54	8
13/07/2013 18:31	8
13/07/2013 22:43	8
04/07/2013 02:31	9
06/07/2013 12:57	9
07/07/2013 10:03	9
07/07/2013 11:59	9
09/07/2013 05:30	9
11/07/2013 11:15	9
11/07/2013 12:17	9
13/07/2013 22:57	9
15/07/2013 05:48	9
02/07/2013 02:28	10
04/07/2013 13:51	10
07/07/2013 06:49	10
07/07/2013 13:06	10
07/07/2013 13:42	10
11/07/2013 01:35	10
11/07/2013 17:50	10
15/07/2013 02:29	10
03/07/2013 01:22	11
12/07/2013 01:29	11
14/07/2013 01:36	11
14/07/2013 12:30	11
08/07/2013 09:21	12
09/07/2013 23:16	12
15/07/2013 02:04	12
15/07/2013 01:45	12
15/07/2013 02:04	12
07/07/2013 16:04	13
08/07/2013 00:31	13
15/07/2013 02:15	13
02/07/2013 02:33	14
14/07/2013 12:07	14
14/07/2013 11:08	14
04/07/2013 16:54	17
11/07/2013 17:35	17
02/07/2013 15:16	19
02/07/2013 20:55	19
07/07/2013 13:25	20
08/07/2013 10:51	21
09/07/2013 22:56	21
13/07/2013 23:50	21
03/07/2013 16:29	25
12/07/2013 18:50	25
08/07/2013 09:14	26

Actual data	
Arrival NCS	Actual Dwell NCS
11/07/2013 13:50	51
11/07/2013 06:07	6
11/07/2013 01:35	10
11/07/2013 17:35	17
11/07/2013 07:53	6
11/07/2013 10:08	311
12/07/2013 07:54	8
11/07/2013 17:50	10
11/07/2013 16:24	7
11/07/2013 20:05	160
11/07/2013 22:31	7
11/07/2013 20:23	4
11/07/2013 22:43	413
12/07/2013 01:29	11
12/07/2013 12:45	6
12/07/2013 12:34	6
12/07/2013 18:50	25
12/07/2013 15:32	5
12/07/2013 09:04	5
	0
12/07/2013 12:02	6
12/07/2013 20:54	220
12/07/2013 22:39	5
12/07/2013 14:18	7
12/07/2013 16:54	7
13/07/2013 10:52	126
12/07/2013 18:37	7
13/07/2013 01:44	38
13/07/2013 05:48	6
13/07/2013 00:32	65
13/07/2013 12:16	5
13/07/2013 06:07	588
13/07/2013 13:33	69
13/07/2013 11:59	4
13/07/2013 22:57	9
13/07/2013 23:35	6
14/07/2013 01:51	140
12/07/2013 23:26	
13/07/2013 18:31	8
13/07/2013 18:33	
14/07/2013 19:52	7
15/07/2013 02:04	12
13/07/2013 22:43	8
14/07/2013 01:36	11
14/07/2013 12:07	14
13/07/2013 23:50	21

Sorted data		
Arrival NCS	Actual Dwell NCS	
09/07/2013 11:13	26	
01/07/2013 23:30	27	
04/07/2013 11:29	28	
07/07/2013 23:15	29	
01/07/2013 23:19	30	
04/07/2013 00:51	30	
04/07/2013 13:39	30	
09/07/2013 14:02	30	
04/07/2013 06:48	31	
06/07/2013 14:48	31	
10/07/2013 00:43	32	
06/07/2013 08:11	33	
09/07/2013 02:44	33	
14/07/2013 16:04	33	
10/07/2013 14:15	34	
03/07/2013 10:36	35	
15/07/2013 00:46	36	
05/07/2013 18:30	37	
13/07/2013 01:44	38	
06/07/2013 00:03	45	
07/07/2013 16:14	45	
15/07/2013 11:17	48	
06/07/2013 15:33	50	
11/07/2013 13:50	51	
09/07/2013 04:21	52	
10/07/2013 08:15	56	
03/07/2013 01:03	59	
05/07/2013 00:00	65	
05/07/2013 07:35	65	
13/07/2013 00:32	65	
07/07/2013 06:19	67	
06/07/2013 08:37	68	
09/07/2013 09:35	68	
13/07/2013 13:33	69	
07/07/2013 21:43	85	
07/07/2013 14:27	104	
08/07/2013 21:15	105	Outlier
15/07/2013 03:12	119	Outlier
13/07/2013 10:52	126	Outlier
10/07/2013 00:32	131	Outlier
14/07/2013 01:51	140	Outlier
11/07/2013 01:13	148	Outlier
11/07/2013 20:05	160	Outlier
03/07/2013 20:35	165	Outlier
14/07/2013 07:55	165	Outlier
04/07/2013 16:03	178	Outlier

Actual data	
Arrival NCS	Actual Dwell NCS
14/07/2013 01:06	4
15/07/2013 04:11	
14/07/2013 06:05	
14/07/2013 11:08	14
14/07/2013 07:55	165
14/07/2013 09:22	1045
14/07/2013 11:24	
14/07/2013 12:30	11
14/07/2013 17:19	7
15/07/2013 02:15	13
14/07/2013 19:52	7
14/07/2013 14:12	7
15/07/2013 00:46	36
15/07/2013 02:29	10
15/07/2013 11:17	48
15/07/2013 03:12	119
15/07/2013 01:45	12
14/07/2013 16:04	33
15/07/2013 02:04	12
14/07/2013 18:15	7
15/07/2013 05:48	9

Sorted data		
Arrival NCS	Actual Dwell NCS	
09/07/2013 00:24	203	Outlier
04/07/2013 22:03	215	Outlier
12/07/2013 20:54	220	Outlier
03/07/2013 18:47	264	Outlier
10/07/2013 10:26	307	Outlier
11/07/2013 10:08	311	Outlier
11/07/2013 22:43	413	Outlier
13/07/2013 06:07	588	Outlier
07/07/2013 06:06	689	Outlier
14/07/2013 09:22	1045	Outlier
09/07/2013 15:54	1170	Outlier

Outlier with more than 100 minutes of dwell time

APPENDIX K: CURRENT COST

Table K.1 Current cost data

Planned Departure	Departure NCS	Planned Departure	Departure NCS	Minutes late (train)	Next day minutes late (train)	Rounded up (hours)	Successful train crew combinations (within buffer time)	Overtime	Replacement (no overtime)
01/07/2013 11:46	01/07/2013 14:26			159	00	3	successful	0	0
01/07/2013 12:16	01/07/2013 14:08			111	00	2	successful	0	0
01/07/2013 12:52	01/07/2013 16:23			210	00	4		700	0
01/07/2013 15:44		01/07/2013 15:44	02/07/2013 09:47		1082	19		0	840
01/07/2013 17:36	01/07/2013 22:24			287	00	5		875	0
01/07/2013 18:11		01/07/2013 18:11	02/07/2013 13:19		1147	20		0	840
01/07/2013 19:50		01/07/2013 19:50	02/07/2013 00:20		269	5		875	0
01/07/2013 21:26	01/07/2013 23:49			142	00	3	successful	0	0
01/07/2013 22:59	01/07/2013 23:57			57	00	1	successful	0	0
01/07/2013 23:10		01/07/2013 23:10	02/07/2013 02:38		207	4		700	0
02/07/2013	02/07/2013			66	00	2	successful	0	0

Planned Departure	Departure NCS	Planned Departure	Departure NCS	Minutes late (train)	Next day minutes late (train)	Rounded up (hours)	Successful train crew combinations (within buffer time)	Overtime	Replacement (no overtime)
01:40	02:47								
02/07/2013 01:51	02/07/2013 03:21			89	00	2	successful	0	0
02/07/2013 04:05	02/07/2013 16:01			715	00	12		0	840
02/07/2013 07:17	02/07/2013 10:53			215	00	4		700	0
02/07/2013 08:20	02/07/2013 11:08			167	00	3	successful	0	0
02/07/2013 09:06	02/07/2013 15:35			388	00	7		0	840
02/07/2013 15:44	02/07/2013 20:36			291	00	5		875	0
02/07/2013 17:36		02/07/2013 17:36	03/07/2013 02:02		505	9		0	840
02/07/2013 18:11	02/07/2013 21:14			182	00	4		700	0
02/07/2013 19:50		02/07/2013 19:50	03/07/2013 16:54		1263	22		0	840
02/07/2013 21:26		02/07/2013 21:26	03/07/2013 01:33		246	5		875	0
02/07/2013 22:59		02/07/2013 22:59	03/07/2013 02:36		216	4		700	0
03/07/2013 01:32	03/07/2013 06:40			307	00	6		1050	0
03/07/2013 01:40	03/07/2013 05:02			201	00	4		700	0
03/07/2013 01:51		03/07/2013 01:51	04/07/2013 19:01		2469	42		0	840
03/07/2013	03/07/2013			233	00	4		700	0

Planned Departure	Departure NCS	Planned Departure	Departure NCS	Minutes late (train)	Next day minutes late (train)	Rounded up (hours)	Successful train crew combinations (within buffer time)	Overtime	Replacement (no overtime)
07:17	11:11								
03/07/2013 08:20	03/07/2013 12:41			260	00	5		875	0
03/07/2013 09:06	03/07/2013 23:20			853	00	15		0	840
03/07/2013 11:46	03/07/2013 15:16			209	00	4		700	0
03/07/2013 11:47	03/07/2013 23:11			683	00	12		0	840
03/07/2013 12:16		03/07/2013 12:16	04/07/2013 01:21		784	14		0	840
03/07/2013 12:52	03/07/2013 23:23			630	00	11		0	840
03/07/2013 18:11		03/07/2013 18:11	05/07/2013 01:38		1886	32		0	840
03/07/2013 19:50		03/07/2013 19:50	04/07/2013 01:35		344	6		1050	0
03/07/2013 21:26		03/07/2013 21:26	04/07/2013 13:32		965	17		0	840
04/07/2013 00:36		04/07/2013 00:36	06/07/2013 08:44		3367	57		0	840
04/07/2013 01:40	04/07/2013 04:02			141	00	3	successful	0	0
04/07/2013 01:51	04/07/2013 02:40			48	00	1	successful	0	0
04/07/2013 03:59	04/07/2013 11:57			477	00	8		0	840
04/07/2013 04:05	04/07/2013 07:19			193	00	4		700	0
04/07/2013		04/07/2013	05/07/2013		1247	21		0	840

Planned Departure	Departure NCS	Planned Departure	Departure NCS	Minutes late (train)	Next day minutes late (train)	Rounded up (hours)	Successful train crew combinations (within buffer time)	Overtime	Replacement (no overtime)
07:17		07:17	04:05						
04/07/2013 08:20	04/07/2013 12:41			260	00	5		875	0
04/07/2013 09:06	04/07/2013 14:01			294	00	5		875	0
04/07/2013 11:46	04/07/2013 17:11			324	00	6		1050	0
04/07/2013 14:47	04/07/2013 14:09			-38	00	-1	successful	0	0
04/07/2013 15:44	04/07/2013 20:55			310	00	6		1050	0
04/07/2013 19:50		04/07/2013 19:50	05/07/2013 04:15		504	9		0	840
04/07/2013 20:32	04/07/2013 20:39			06	00	1	successful	0	0
04/07/2013 21:26		04/07/2013 21:26	05/07/2013 01:11		224	4		700	0
04/07/2013 22:59		04/07/2013 22:59	05/07/2013 01:05		125	3	successful	0	0
05/07/2013 07:17	05/07/2013 05:05			-132	00	-3	successful	0	0
05/07/2013 08:20	05/07/2013 08:40			19	00	1	successful	0	0
05/07/2013 11:46	05/07/2013 20:00			493	00	9		0	840
05/07/2013 12:52	05/07/2013 19:07			374	00	7		0	840
05/07/2013 15:44		05/07/2013 15:44	06/07/2013 00:48		543	10		0	840
05/07/2013	05/07/2013			128	00	3	successful	0	0

Planned Departure	Departure NCS	Planned Departure	Departure NCS	Minutes late (train)	Next day minutes late (train)	Rounded up (hours)	Successful train crew combinations (within buffer time)	Overtime	Replacement (no overtime)
17:36	19:45								
05/07/2013 20:02		05/07/2013 20:02	06/07/2013 04:51		528	9		0	840
05/07/2013 21:26		05/07/2013 21:26	06/07/2013 01:37		250	5		875	0
05/07/2013 22:59		05/07/2013 22:59	06/07/2013 09:00		600	10		0	840
06/07/2013 00:01	06/07/2013 09:59			597	00	10		0	840
06/07/2013 00:36	06/07/2013 09:45			548	00	10		0	840
06/07/2013 01:40		06/07/2013 01:40	07/07/2013 17:56		2415	41		0	840
06/07/2013 07:17	06/07/2013 15:19			481	00	9		0	840
06/07/2013 08:20	06/07/2013 13:06			285	00	5		875	0
06/07/2013 09:06	06/07/2013 16:23			436	00	8		0	840
06/07/2013 11:46		06/07/2013 11:46	09/07/2013 10:43		4256	71		0	840
06/07/2013 12:21	06/07/2013 22:49			627	00	11		0	840
06/07/2013 12:52	06/07/2013 22:23			570	00	10		0	840
06/07/2013 13:16		06/07/2013 13:16	07/07/2013 07:26		1089	19		0	840
06/07/2013 15:16	06/07/2013 20:06			289	00	5		875	0
06/07/2013	06/07/2013			272	00	5		875	0

Planned Departure	Departure NCS	Planned Departure	Departure NCS	Minutes late (train)	Next day minutes late (train)	Rounded up (hours)	Successful train crew combinations (within buffer time)	Overtime	Replacement (no overtime)
15:44	20:17								
06/07/2013 17:36		06/07/2013 17:36	08/07/2013 03:12		2015	34		0	840
06/07/2013 17:46		06/07/2013 17:46	07/07/2013 16:11		1344	23		0	840
06/07/2013 21:26	06/07/2013 21:44			17	00	1	successful	0	0
06/07/2013 22:59		06/07/2013 22:59	07/07/2013 17:35		1115	19		0	840
06/07/2013 23:42		06/07/2013 23:42	08/07/2013 23:00		2837	48		0	840
07/07/2013 00:36	07/07/2013 16:17			940	00	16		0	840
07/07/2013 01:40	07/07/2013 01:46			05	00	1	successful	0	0
07/07/2013 01:51	07/07/2013 06:59			307	00	6		1050	0
07/07/2013 02:13	07/07/2013 10:12			478	00	8		0	840
07/07/2013 07:17	07/07/2013 12:08			290	00	5		875	0
07/07/2013 08:20	07/07/2013 13:16			295	00	5		875	0
07/07/2013 09:06	07/07/2013 13:52			285	00	5		875	0
07/07/2013 11:46	07/07/2013 13:45			118	00	2	successful	0	0
07/07/2013 16:27	07/07/2013 16:59			31	00	1	successful	0	0
07/07/2013	07/07/2013			289	00	5		875	0

Planned Departure	Departure NCS	Planned Departure	Departure NCS	Minutes late (train)	Next day minutes late (train)	Rounded up (hours)	Successful train crew combinations (within buffer time)	Overtime	Replacement (no overtime)
18:11	23:01								
07/07/2013 19:50	07/07/2013 23:08			197	00	4		700	0
07/07/2013 21:26	07/07/2013 23:44			137	00	3	successful	0	0
07/07/2013 22:59		07/07/2013 22:59	08/07/2013 03:30		270	5		875	0
07/07/2013 23:24		07/07/2013 23:24	08/07/2013 09:33		608	11		0	840
08/07/2013 00:36	08/07/2013 08:02			445	00	8		0	840
08/07/2013 01:32	08/07/2013 00:44			-48	00	-1	successful	0	0
08/07/2013 01:40	08/07/2013 12:41			660	00	11		0	840
08/07/2013 06:32	08/07/2013 09:40			187	00	4		700	0
08/07/2013 07:16	08/07/2013 14:09			412	00	7		0	840
08/07/2013 07:17	08/07/2013 11:12			234	00	4		700	0
08/07/2013 08:20	08/07/2013 13:45			324	00	6		1050	0
08/07/2013 09:06	08/07/2013 16:30			443	00	8		0	840
08/07/2013 11:46	08/07/2013 20:21			514	00	9		0	840
08/07/2013 12:16	08/07/2013 17:10			293	00	5		875	0
08/07/2013	08/07/2013			376	00	7		0	840

Planned Departure	Departure NCS	Planned Departure	Departure NCS	Minutes late (train)	Next day minutes late (train)	Rounded up (hours)	Successful train crew combinations (within buffer time)	Overtime	Replacement (no overtime)
12:52	19:09								
08/07/2013 16:27		08/07/2013 16:27	09/07/2013 05:13		765	13		0	840
08/07/2013 18:11	08/07/2013 22:11			239	00	4		700	0
08/07/2013 19:50		08/07/2013 19:50	09/07/2013 03:47		476	8		0	840
08/07/2013 21:26		08/07/2013 21:26	09/07/2013 03:17		350	6		1050	0
08/07/2013 22:59		08/07/2013 22:59	09/07/2013 14:32		932	16		0	840
08/07/2013 23:24		08/07/2013 23:24	10/07/2013 11:24		2159	36		0	840
09/07/2013 01:40	09/07/2013 05:39			238	00	4		700	0
09/07/2013 01:51	09/07/2013 15:42			830	00	14		0	840
09/07/2013 07:16	09/07/2013 11:39			262	00	5		875	0
09/07/2013 07:17	09/07/2013 08:28			70	00	2	successful	0	0
09/07/2013 08:20	09/07/2013 11:33			192	00	4		700	0
09/07/2013 11:46	09/07/2013 22:51			664	00	12		0	840
09/07/2013 12:52	09/07/2013 23:17			624	00	11		0	840
09/07/2013 15:44	09/07/2013 23:28			463	00	8		0	840
09/07/2013		09/07/2013	10/07/2013		727	13		0	840

Planned Departure	Departure NCS	Planned Departure	Departure NCS	Minutes late (train)	Next day minutes late (train)	Rounded up (hours)	Successful train crew combinations (within buffer time)	Overtime	Replacement (no overtime)
19:50		19:50	07:58						
09/07/2013 21:26		09/07/2013 21:26	10/07/2013 02:43		316	6		1050	0
09/07/2013 22:06		09/07/2013 22:06	10/07/2013 01:15		188	4		700	0
09/07/2013 22:59		09/07/2013 22:59	10/07/2013 03:22		262	5		875	0
10/07/2013 00:36	10/07/2013 21:38			1261	00	22		0	840
10/07/2013 01:32	10/07/2013 09:11			458	00	8		0	840
10/07/2013 01:40	10/07/2013 14:49			788	00	14		0	840
10/07/2013 09:06	10/07/2013 14:10			303	00	6		1050	0
10/07/2013 12:16	10/07/2013 15:33			196	00	4		700	0
10/07/2013 12:52	10/07/2013 17:01			248	00	5		875	0
10/07/2013 14:53		10/07/2013 14:53	11/07/2013 22:41		1907	32		0	840
10/07/2013 15:44	10/07/2013 17:28			103	00	2	successful	0	0
10/07/2013 16:27		10/07/2013 16:27	11/07/2013 03:41		673	12		0	840
10/07/2013 17:36		10/07/2013 17:36	11/07/2013 11:24		1067	18		0	840
10/07/2013 17:46		10/07/2013 17:46	11/07/2013 12:26		1119	19		0	840
10/07/2013		10/07/2013	11/07/2013		1229	21		0	840

Planned Departure	Departure NCS	Planned Departure	Departure NCS	Minutes late (train)	Next day minutes late (train)	Rounded up (hours)	Successful train crew combinations (within buffer time)	Overtime	Replacement (no overtime)
18:11		18:11	14:41						
10/07/2013 19:50		10/07/2013 19:50	11/07/2013 06:13		622	11		0	840
10/07/2013 21:26		10/07/2013 21:26	11/07/2013 01:45		258	5		875	0
10/07/2013 22:06		10/07/2013 22:06	11/07/2013 17:52		1185	20		0	840
10/07/2013 22:59		10/07/2013 22:59	11/07/2013 07:59		539	9		0	840
11/07/2013 07:17	11/07/2013 15:19			481	00	9		0	840
11/07/2013 08:20		11/07/2013 08:20	12/07/2013 08:02		1421	24		0	840
11/07/2013 09:06	11/07/2013 18:00			533	00	9		0	840
11/07/2013 11:46	11/07/2013 16:31			284	00	5		875	0
11/07/2013 15:44	11/07/2013 22:45			420	00	7		0	840
11/07/2013 17:36	11/07/2013 22:38			301	00	6		1050	0
11/07/2013 18:11	11/07/2013 20:27			135	00	3	successful	0	0
11/07/2013 19:50		11/07/2013 19:50	12/07/2013 05:36		585	10		0	840
11/07/2013 21:26		11/07/2013 21:26	12/07/2013 01:40		253	5		875	0
11/07/2013 22:06		11/07/2013 22:06	12/07/2013 12:51		884	15		0	840
11/07/2013		11/07/2013	12/07/2013		820	14		0	840

Planned Departure	Departure NCS	Planned Departure	Departure NCS	Minutes late (train)	Next day minutes late (train)	Rounded up (hours)	Successful train crew combinations (within buffer time)	Overtime	Replacement (no overtime)
22:59		22:59	12:40						
11/07/2013 23:24		11/07/2013 23:24	12/07/2013 19:15		1190	20		0	840
12/07/2013 00:36	12/07/2013 15:37			900	00	15		0	840
12/07/2013 01:40	12/07/2013 09:09			448	00	8		0	840
12/07/2013 06:32					00	0	successful	0	0
12/07/2013 08:20	12/07/2013 12:08			227	00	4		700	0
12/07/2013 09:06		12/07/2013 09:06	13/07/2013 00:34		927	16		0	840
12/07/2013 10:49		12/07/2013 10:49	13/07/2013 00:08		798	14		0	840
12/07/2013 11:46	12/07/2013 17:01			314	00	6		1050	0
12/07/2013 12:52	12/07/2013 14:25			92	00	2	successful	0	0
12/07/2013 15:44	12/07/2013 18:44			179	00	3	successful	0	0
12/07/2013 17:36		12/07/2013 17:36	13/07/2013 05:54		737	13		0	840
12/07/2013 18:11	12/07/2013 22:44			272	00	5		875	0
12/07/2013 19:50		12/07/2013 19:50	13/07/2013 01:37		346	6		1050	0
12/07/2013 22:31		12/07/2013 22:31	13/07/2013 12:58		866	15		0	840
12/07/2013		12/07/2013	13/07/2013		202	4		700	0

Planned Departure	Departure NCS	Planned Departure	Departure NCS	Minutes late (train)	Next day minutes late (train)	Rounded up (hours)	Successful train crew combinations (within buffer time)	Overtime	Replacement (no overtime)
22:59		22:59	02:22						
13/07/2013 00:36	13/07/2013 14:42			845	00	15		0	840
13/07/2013 01:51	13/07/2013 15:55			843	00	15		0	840
13/07/2013 02:13	13/07/2013 12:21			607	00	11		0	840
13/07/2013 02:15	13/07/2013 17:07			892	00	15		0	840
13/07/2013 02:24		13/07/2013 02:24	14/07/2013 04:11		1546	26		0	840
13/07/2013 02:33	13/07/2013 12:03			569	00	10		0	840
13/07/2013 08:20	13/07/2013 23:41			920	00	16		0	840
13/07/2013 09:06	13/07/2013 23:06			839	00	14		0	840
13/07/2013 11:46	13/07/2013 18:39			412	00	7		0	840
13/07/2013 12:46		13/07/2013 12:46	15/07/2013 02:16		2249	38		0	840
13/07/2013 12:52		13/07/2013 12:52	14/07/2013 19:59		1866	32		0	840
13/07/2013 15:44	13/07/2013 22:51			426	00	8		0	840
13/07/2013 17:36		13/07/2013 17:36	14/07/2013 01:47		490	9		0	840
13/07/2013 21:26		13/07/2013 21:26	14/07/2013 12:21		894	15		0	840
13/07/2013		13/07/2013	14/07/2013		379	7		0	840

Planned Departure	Departure NCS	Planned Departure	Departure NCS	Minutes late (train)	Next day minutes late (train)	Rounded up (hours)	Successful train crew combinations (within buffer time)	Overtime	Replacement (no overtime)
22:00		22:00	04:20						
13/07/2013 22:06		13/07/2013 22:06	14/07/2013 00:11		124	3	successful	0	0
13/07/2013 22:14		13/07/2013 22:14	15/07/2013 02:47		1712	29		0	840
13/07/2013 22:59		13/07/2013 22:59	14/07/2013 01:10		130	3	successful	0	0
14/07/2013 01:51	14/07/2013 11:22			570	00	10		0	840
14/07/2013 02:13	14/07/2013 10:40			506	00	9		0	840
14/07/2013 07:17	14/07/2013 11:40			262	00	5		875	0
14/07/2013 08:20	14/07/2013 12:41			260	00	5		875	0
14/07/2013 09:06	14/07/2013 17:26			499	00	9		0	840
14/07/2013 11:46	14/07/2013 14:19			152	00	3	successful	0	0
14/07/2013 12:16	14/07/2013 16:37			260	00	5		875	0
14/07/2013 12:52	14/07/2013 19:59			426	00	8		0	840
14/07/2013 15:16		14/07/2013 15:16	15/07/2013 02:16		659	11		0	840
14/07/2013 17:36		14/07/2013 17:36	15/07/2013 02:39		542	10		0	840
14/07/2013 19:50	14/07/2013 18:22			-88	00	-2	successful	0	0
14/07/2013		14/07/2013	15/07/2013		270	5		875	0

Planned Departure	Departure NCS	Planned Departure	Departure NCS	Minutes late (train)	Next day minutes late (train)	Rounded up (hours)	Successful train crew combinations (within buffer time)	Overtime	Replacement (no overtime)
21:26		21:26	01:57						
14/07/2013 22:06		14/07/2013 22:06	15/07/2013 01:22		195	4		700	0
14/07/2013 22:31		14/07/2013 22:31	15/07/2013 05:11		399	7		0	840
14/07/2013 22:59		14/07/2013 22:59	15/07/2013 02:28		208	4		700	0
15/07/2013 01:40	15/07/2013 05:57			256	00	5		875	0
15/07/2013 08:21	15/07/2013 12:05			223	00	4		700	0
15/07/2013 11:46	15/07/2013 14:28			161	00	3	successful	0	0
15/07/2013 12:16	15/07/2013 13:28			71	00	2	successful	0	0
15/07/2013 12:52	15/07/2013 14:50			117	00	2	successful	0	0
15/07/2013 17:36	15/07/2013 20:55			198	00	4		700	0
15/07/2013 19:50	15/07/2013 22:35			164	00	3	successful	0	0
15/07/2013 21:26		15/07/2013 21:26	16/07/2013 00:30		183	4		700	0
15/07/2013 22:06		15/07/2013 22:06	16/07/2013 03:22		315	6		1050	0
16/07/2013 01:40	16/07/2013 02:41			60	00	1	successful	0	0
16/07/2013 04:05	16/07/2013 07:49			223	00	4		700	0

Planned Departure	Departure NCS	Planned Departure	Departure NCS	Minutes late (train)	Next day minutes late (train)	Rounded up (hours)	Successful train crew combinations (within buffer time)	Overtime	Replacement (no overtime)
16/07/2013 05:46	16/07/2013 08:39			172	00	3	successful	0	0
16/07/2013 07:17	16/07/2013 14:31			433	00	8		0	840
16/07/2013 08:20	16/07/2013 09:40			79	00	2	successful	0	0
16/07/2013 09:06		16/07/2013 09:06	18/07/2013 07:50		2803	47		0	840
16/07/2013 11:46	16/07/2013 15:00			193	00	4		700	0
16/07/2013 12:16	16/07/2013 15:26			189	00	4		700	0
16/07/2013 12:52	16/07/2013 12:45			-07	00	-1	successful	0	0
16/07/2013 17:36	16/07/2013 22:09			272	00	5		875	0
16/07/2013 18:11		16/07/2013 18:11	18/07/2013 14:50		2678	45		0	840
16/07/2013 21:26	16/07/2013 22:55			88	00	2	successful	0	0
16/07/2013 22:06		16/07/2013 22:06	17/07/2013 01:22		195	4		700	0
16/07/2013 22:31		16/07/2013 22:31	17/07/2013 05:54		442	8		0	840
16/07/2013 22:59		16/07/2013 22:59	17/07/2013 09:43		643	11		0	840
17/07/2013 00:36	17/07/2013 02:42			125	00	3	successful	0	0
17/07/2013 02:13	17/07/2013 11:10			536	00	9		0	840

Planned Departure	Departure NCS	Planned Departure	Departure NCS	Minutes late (train)	Next day minutes late (train)	Rounded up (hours)	Successful train crew combinations (within buffer time)	Overtime	Replacement (no overtime)
17/07/2013 08:20	17/07/2013 13:08			287	00	5		875	0
17/07/2013 09:06		17/07/2013 09:06	18/07/2013 18:20		1993	34		0	840
17/07/2013 11:46		17/07/2013 11:46	18/07/2013 01:45		838	14		0	840
17/07/2013 11:47	17/07/2013 19:53			485	00	9		0	840
17/07/2013 12:16		17/07/2013 12:16	18/07/2013 03:14		897	15		0	840
17/07/2013 12:52	17/07/2013 14:48			115	00	2	successful	0	0
17/07/2013 17:36		17/07/2013 17:36	18/07/2013 09:41		964	17		0	840
17/07/2013 17:46		17/07/2013 17:46	18/07/2013 04:51		664	12		0	840
17/07/2013 18:11	17/07/2013 20:10			118	00	2	successful	0	0
17/07/2013 19:50		17/07/2013 19:50	18/07/2013 01:12		321	6		1050	0
17/07/2013 21:26	17/07/2013 22:26			59	00	1	successful	0	0
17/07/2013 22:06		17/07/2013 22:06	18/07/2013 03:03		296	5		875	0
17/07/2013 22:59		17/07/2013 22:59	18/07/2013 05:59		419	7		0	840
17/07/2013 23:24		17/07/2013 23:24	18/07/2013 22:13		1368	23		0	840

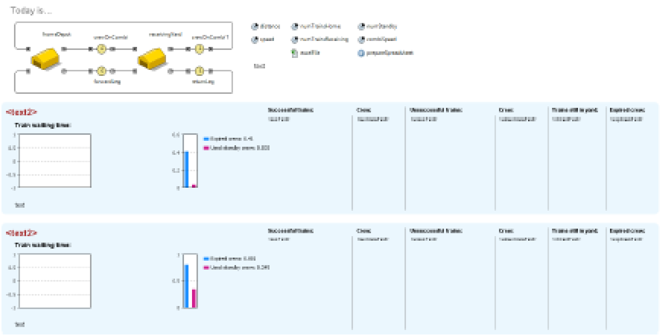
APPENDIX L: SIMULATION DETAIL

Model: Crewing of Trains write to excel4

Name	Value
General	
Java Package Name	crewing_of_trains_pareto
File Name	C:\Users\Rohini Shookan\Models\Crewing of Trains write to excel2 20131115\Crewing of Trains write to excel4\Crewing of Trains write to excel4.alp
Model Time	
Model Time Units	Minute

Active Object Class: Main

Name	Value
General	
Startup Code	prepareSpreadsheet();
Advanced	
Auto-create Datasets	true
Recurrence	1
Dataset Samples To Keep	100



Parameter: distance

Name	Value
General	
Type	double
Editor	
Editor Control	TEXT_BOX

Parameter: speed

Name	Value
General	
Type	double
Editor	
Editor Control	TEXT_BOX

Parameter: numTrainsHome

Name	Value
General	
Type	int
Editor	
Editor Control	TEXT_BOX

Parameter: numTrainsReceiving

Name	Value
General	
Type	int
Editor	
Editor Control	TEXT_BOX

Parameter: numStandby

Name	Value
General	
Type	int
Editor	
Editor Control	TEXT_BOX

Parameter: combiSpeed

Name	Value
General	
Type	double
Editor	
Editor Control	TEXT_BOX

Function: prepareSpreadsheet

Name	Value
General	
Return Type	void
Code	

Body	excelFile.getWorkbook().createSheet("Sim "+numTrainsHome+" and "+numTrainsReceiving+" trains as input");
	int sheetNum = excelFile.getNumberOfSheets();
	
	for(int j=1; j<=(numTrainsHome+numTrainsReceiving+3); j++)
	for(int i=1; i<=11; i++)
	excelFile.createCell(sheetNum, j, i);
	
	excelFile.setCellValue("Home Depot", sheetNum, 1, 1);

Name	Value

	excelFile.setCellValue("Receiving Yard", sheetNum, (numTrainsHome+3), 1);
	
	excelFile.setCellValue("Simulation with "+numTrainsHome+" trains as input", sheetNum, 2, 1);
	excelFile.setCellValue("Simulation with "+numTrainsReceiving+" trains as input", sheetNum, numTrainsHome+4, 1);
	
	excelFile.setCellValue("Arrival time", sheetNum, 2, 2);
	excelFile.setCellValue("Mins between arrivals", sheetNum, 2, 3);
	excelFile.setCellValue("Time to process the train", sheetNum, 2, 4);
	excelFile.setCellValue("Departure time", sheetNum, 2, 5);
	excelFile.setCellValue("Mins between departures", sheetNum, 2, 6);
	excelFile.setCellValue("Time crew came on duty", sheetNum, 2, 7);
	excelFile.setCellValue("Time crew boarded", sheetNum, 2, 8);
	excelFile.setCellValue("Mins between came on duty and boarding", sheetNum, 2, 9);
	excelFile.setCellValue("Number of normal crews", sheetNum, 2, 10);
	excelFile.setCellValue("Number of standby crews", sheetNum, 2, 11);

Delay: forwardLeg

Name	Value
General	
Type	Delay<T extends Entity>
Generic Parameters Substitute	Entity
Java Package Name	com.xj.anylogic.libraries.enterprise
Embedded Object Collection Type	ARRAY_LIST_BASED

Embedded Object Parameters:

Name	Value
Delay time is	false
Delay time	uniform(distance/speed, distance/speed+6)*hour()
Speed	10
Capacity	72
Maximum capacity	false
Animation type	Animator.PATH
Animation direction	true
Enable statistics	false

Delay: returnLeg

Name	Value
General	
Type	Delay<T extends Entity>
Generic Parameters Substitute	Entity
Java Package Name	com.xj.anylogic.libraries.enterprise
Embedded Object Collection Type	ARRAY_LIST_BASED

Embedded Object Parameters:

Name	Value

Embedded Object Parameters:

Name	Value
Delay time is	false
Delay time	uniform(distance/speed, distance/speed+6)*hour()
Speed	10
Capacity	72
Maximum capacity	false
Animation type	Animator.PATH
Animation direction	true
Enable statistics	false

Yard: homeDepot

Name	Value
General	
Type	Yard
Java Package Name	crewing_of_trains_pareto
Embedded Object Collection Type	ARRAY_LIST_BASED

Embedded Object Parameters:

Name	Value
minDriveTime	distance/speed
numTrains	numTrainsHome
yardName	"depot"

Yard: receivingYard

Name	Value
General	
Type	Yard
Java Package Name	crewing_of_trains_pareto
Embedded Object Collection Type	ARRAY_LIST_BASED

Embedded Object Parameters:

Name	Value
minDriveTime	distance/speed
numTrains	numTrainsReceiving
yardName	"receiving"

Delay: crewOnCombi

Name	Value
General	
Type	Delay<T extends Entity>
Generic Parameters Substitute	Entity
Java Package Name	com.xj.anylogic.libraries.enterprise
Embedded Object Collection Type	ARRAY_LIST_BASED

Embedded Object Parameters:

Name	Value
Delay time is	false

Embedded Object Parameters:

Name	Value
Delay time	distance/combiSpeed*hour()
Speed	10
Capacity	72
Maximum capacity	true
Animation type	Animator.PATH
Animation direction	true
Enable statistics	false

Delay: crewOnCombi1

Name	Value
General	
Type	Delay<T extends Entity>
Generic Parameters Substitute	Entity
Java Package Name	com.xj.anylogic.libraries.enterprise
Embedded Object Collection Type	ARRAY_LIST_BASED

Embedded Object Parameters:

Name	Value
Delay time is	false
Delay time	distance/combiSpeed*hour()
Speed	10
Capacity	72
Maximum capacity	true
Animation type	Animator.PATH
Animation direction	true
Enable statistics	false

Text: text

Name	Value
General	
Color	gray
Advanced	
x	30
y	20
General	
Alignment	LEFT
Font Name	SansSerif
Font Size	20
Text	Today is...
Advanced	
x	30
y	20
Dynamic	
Dynamic: Text	date()

Embedded Object Presentation: homeDepot_Presentation

Embedded Object Presentation: receivingYard_Presentation

Text: text3

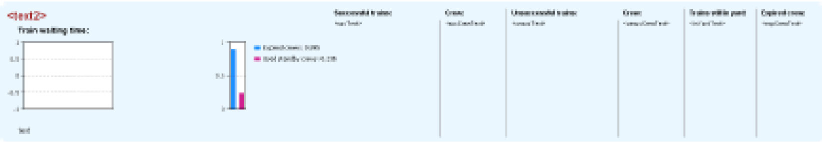
Name	Value
Advanced	
x	580
y	150
General	
Alignment	LEFT
Font Name	SansSerif
Font Size	14
Text	text
Advanced	
x	580
y	150
Dynamic	
Dynamic: Text	"Total number of combi trips: "+(crewOnCombi.in.count()+crewOnCombi1.in.count())

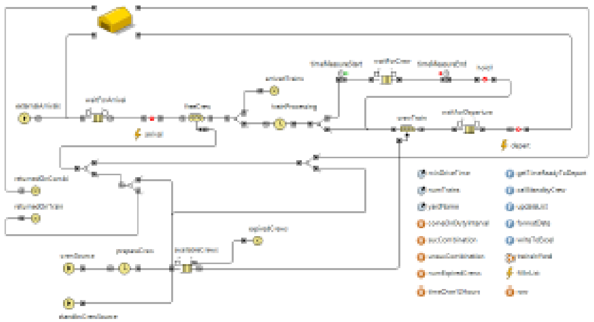
Excel File: excelFile

Name	Value
General	
File name	C:/Users/Rohini Shookan/Models/Crewing of Trains write to excel2 20131115/Day 1.xlsx

Active Object Class: Yard

Name	Value
General	
Startup Code	crewSource.inject(1); externalArrivals.inject(1);
Destroy Code	get_Main().excelFile.setCellValue(sucCombination+unsucCombination-standbyCrewSource.count(), get_Main().excelFile.getNumberOfSheets(), row, 10); get_Main().excelFile.setCellValue(standbyCrewSource.count(), get_Main().excelFile.getNumberOfSheets(), row, 11);
Advanced	
Auto-create Datasets	true
Recurrence	1
Dataset Samples To Keep	100





Parameter: minDriveTime

Name	Value
General	
Type	double
Editor	
Editor Control	TEXT_BOX

Parameter: numTrains

Name	Value
General	
Type	int
Editor	
Editor Control	TEXT_BOX

Parameter: yardName

Name	Value
General	
Type	String
Editor	
Editor Control	TEXT_BOX

Function: getTimeReadyToDepart

Name	Value

Name	Value
General	
Return Type	double
Code	

Body	if(trainProcessing.size() == 1)
	return trainProcessing.getRemainingTime(0);
	else{
	double t = trainProcessing.getRemainingTime(0);
	for(int i=1; i<trainProcessing.size(); i++)
	if(trainProcessing.getRemainingTime(i) < t)
	t = trainProcessing.getRemainingTime(i);
	return t;
	}

Function: callStandbyCrew

Name	Value
General	
Return Type	void
Code	

Body	int counter = 0;
	for(int i=0; i<trainProcessing.size(); i++)
	if(trainProcessing.getRemainingTime(i) < (11-minDriveTime)*hour())
	counter++;
	if(counter > 1 && standbyCrewSource.count() < get_Main().numStandby && availableCrews.size() == 0)
	standbyCrewSource.inject(min(counter, get_Main().numStandby - standbyCrewSource.count()));

Function: updateList

Name	Value
General	
Return Type	void
Code	

Body	/*String[] oldL = list.getItems();
	String[] newL = new String[oldL.length+1];
	for(int i=0; i<newL.length-1; i++)
	newL[i] = oldL[i];
	newL[newL.length-1] = value;
	list.setItems(newL); */
	list.setText(list.getText()+"\n"+value);

Arguments:

Name	Type
list	ShapeText
value	String

Function: formatDate

Name	Value
General	
Return Type	String
Code	

Body	java.text.DateFormat df = new
	java.text.SimpleDateFormat("HH:mm:ss");
	return df.format(date);

Arguments:

Name	Type
date	Date

Function: writeToExcel

Name	Value
General	
Return Type	void
Code	

Body	String isSuc = entity.isSuc ? "SUC" : "UNSUC";
	int sheetNum = get_Main().excelFile.getNumberOfSheets();
	get_Main().excelFile.setCellValue(entity.id+" "+isSuc, sheetNum, row, 1);
	get_Main().excelFile.setCellValue(formatDate(entity.arr), sheetNum, row, 2);
	get_Main().excelFile.setCellValue(entity.timeToProc, sheetNum, row, 4);
	get_Main().excelFile.setCellValue(formatDate(date()), sheetNum, row, 5);
	get_Main().excelFile.setCellValue(formatDate(entity.crewCameOnDuty), sheetNum, row, 7);
	get_Main().excelFile.setCellValue(formatDate(entity.crewBoarded), sheetNum, row, 8);
	get_Main().excelFile.setCellValue(entity.timeBetweenDAndB, sheetNum, row, 9);
	
	row++;

Arguments:

Name	Type
entity	Train

Event: depart

Name	Value
General	
Trigger Type	timeout
Mode	userControls
Timeout	1
Action	hold.setBlocked(false);

Event: arrival

Name	Value
General	
Trigger Type	timeout
Mode	userControls
Timeout	1
Action	hold2.setBlocked(false);

Event: fillInList

Name	Value
General	
Trigger Type	timeout

Name	Value
Mode	occuresOnce
Occurence Time	24*hour()
Action	for(Train t : trainsInYard) updateList(inYardText,t.id+" "+formatDate(t.arr)+" - N/A");

Variable: comeOnDutyInterval

Name	Value
General	
Type	double
Initial Value	24*hour()/(11*hour()-minDriveTime*hour()) >= numTrains ? (11*hour()-minDriveTime*hour()) : 24*hour()/numTrains

Variable: sucCombination

Name	Value
General	
Type	int

Variable: unsucCombination

Name	Value
General	
Type	int

Variable: numExpiredCrews

Name	Value
General	
Type	int

Variable: timeOver12Hours

Name	Value
General	
Type	int

Variable: row

Name	Value
General	
Type	int
Initial Value	yardName.equals("depot") ? 3 : get_Main().numTrainsHome+4

Collection: trainsInYard

Name	Value
General	
Collection Class	java.util.ArrayList
Element Class	Train

Port: port

Name	Value
General	
Show name	false

Port: port1

Name	Value
General	
Show name	false

Port: port2

Name	Value
General	
Show name	false

Port: port3

Name	Value
General	
Show name	false

Source: externalArrivals

Name	Value
General	
Type	Source<T extends Entity>
Generic Parameters Substitute	Train
Java Package Name	com.xj.anylogic.libraries.enterprise
Embedded Object Collection Type	ARRAY_LIST_BASED

Embedded Object Parameters:

Name	Value
Arrivals defined by	Source.INTERARRIVAL_TIME
Arrival rate	(numTrains-1)/day()
Interarrival time	exponential(1/(93*minute()))
Modify rate	false
Rate expression	baseRate
Entities per arrival	1
Limited number of arrivals	true
Maximum number of arrivals	numTrains-1
New entity	new Train()

On exit	entity.home = yardName;
	entity.id = self.count() < 9 ? "T00"+(self.count()+1) :
	"T0"+(self.count()+1);
	entity.arr = date();
	trainsInYard.add(entity);

Unique shape for each entity	false
Enable rotation	false

Embedded Object Parameters:

Name	Value
Enable vertical rotation	true

Delay: trainProcessing

Name	Value
General	
Type	Delay<T extends Entity>
Generic Parameters Substitute	Train
Java Package Name	com.xj.anylogic.libraries.enterprise
Embedded Object Collection Type	ARRAY_LIST_BASED

Embedded Object Parameters:

Name	Value
Delay time is	false
Delay time	min(pareto(0.375650,6)*minute(),8*hour())
Speed	10
Capacity	32
Maximum capacity	false
On enter	callStandbyCrew(); entity.startProc = time();

On exit	callStandbyCrew();
	entity.finProc = date();
	entity.timeToProc = time()-entity.startProc;

Animation type	Animator.PATH
Animation direction	true
Enable statistics	false

Source: crewSource

Name	Value
General	
Type	Source<T extends Entity>
Generic Parameters Substitute	Crew
Java Package Name	com.xj.anylogic.libraries.enterprise
Embedded Object Collection Type	ARRAY_LIST_BASED

Embedded Object Parameters:

Name	Value
Arrivals defined by	Source.INTERARRIVAL_TIME
Arrival rate	1
Interarrival time	comeOnDutyInterval
Modify rate	false
Rate expression	baseRate
Entities per arrival	1
Limited number of arrivals	false
Maximum number of arrivals	(int)(24*hour()/(11*hour()-minDriveTime*hour()))
New entity	new Crew()
On exit	entity.home = yardName; entity.shiftStartsAt = time();
Unique shape for each entity	false

Embedded Object Parameters:

Name	Value
Enable rotation	false
Enable vertical rotation	true

Queue: availableCrews

Name	Value
General	
Type	Queue<T extends Entity>
Generic Parameters Substitute	Crew
Java Package Name	com.xj.anylogic.libraries.enterprise
Embedded Object Collection Type	ARRAY_LIST_BASED

Embedded Object Parameters:

Name	Value
Capacity	100
Maximum capacity	true
On enter	hold1.setBlocked(waitForCrew.size()==0);
Enable exit on timeout	true
Timeout	min(12*hour()-(time()-entity.shiftStartsAt), (11-minDriveTime)*hour())
Enable preemption	true
Entity priority	entity.priority
Animation type	Animator.PATH
Animation direction	true
Enable statistics	false

Pickup: crewTrain

Name	Value
General	
Type	Pickup<TContainer extends Entity, T extends Entity>
Generic Parameters Substitute	Train, Crew
Java Package Name	com.xj.anylogic.libraries.enterprise
Embedded Object Collection Type	ARRAY_LIST_BASED

Embedded Object Parameters:

Name	Value
Pickup	Pickup.QUANTITY
Condition	true
Quantity	1

On pickup	if(container.isSuc)
	updateList(sucCrewText, entity.stBy+" "+formatDate(timeToDate(entity.shiftStartsAt))+" - "+formatDate(date()));
	else
	updateList(unsucCrewText, entity.stBy+" "+formatDate(timeToDate(entity.shiftStartsAt))+" - "+formatDate(date()));
	
	container.crewCameOnDuty = timeToDate(entity.shiftStartsAt);
	container.crewBoarded = timeToDate(time());
	container.timeBetweenDAndB = time() - entity.

Embedded Object Parameters:

Name	Value
	shiftStartsAt;
On exit	trainsInYard.remove(container);
Queue object	null

Queue: waitForDeparture

Name	Value
General	
Type	Queue<T extends Entity>
Generic Parameters Substitute	Entity
Java Package Name	com.xj.anylogic.libraries.enterprise
Embedded Object Collection Type	ARRAY_LIST_BASED

Embedded Object Parameters:

Name	Value
Capacity	100
Maximum capacity	false
Enable exit on timeout	false
Timeout	Double.POSITIVE_INFINITY
Enable preemption	false
Entity priority	0
Animation type	Animator.PATH
Animation direction	true
Enable statistics	false

Hold: hold

Name	Value
General	
Type	Hold<T extends Entity>
Generic Parameters Substitute	Train
Java Package Name	com.xj.anylogic.libraries.enterprise
Embedded Object Collection Type	ARRAY_LIST_BASED

Embedded Object Parameters:

Name	Value

On enter	self.setBlocked(true);
	depart.restart(30*minute());
	
	updateList(entity.isSuc ? sucText : unsucText, entity.id+" "+formatDate(entity.arr)+" - "+formatDate(entity.finProc)+" - "+formatDate(date()));
	
	// writing to Excel

Initially blocked	false

Queue: waitForArrival

Name	Value
General	

Name	Value
Type	Queue<T extends Entity>
Generic Parameters Substitute	Entity
Java Package Name	com.xj.anylogic.libraries.enterprise
Embedded Object Collection Type	ARRAY_LIST_BASED

Embedded Object Parameters:

Name	Value
Capacity	100
Maximum capacity	true
Enable exit on timeout	false
Timeout	Double.POSITIVE_INFINITY
Enable preemption	false
Entity priority	0
Animation type	Animator.PATH
Animation direction	true
Enable statistics	false

Dropoff: freeCrew

Name	Value
General	
Type	Dropoff<TContainer extends Entity, T extends Entity>
Generic Parameters Substitute	Entity, Entity
Java Package Name	com.xj.anylogic.libraries.enterprise
Embedded Object Collection Type	ARRAY_LIST_BASED

Embedded Object Parameters:

Name	Value
Dropoff	Dropoff.ALL
Condition	true
Quantity	1

SelectOutput: selectOutput

Name	Value
General	
Type	SelectOutput<T extends Entity>
Generic Parameters Substitute	Crew
Java Package Name	com.xj.anylogic.libraries.enterprise
Embedded Object Collection Type	ARRAY_LIST_BASED

Embedded Object Parameters:

Name	Value
Select True output	false
Condition	! (trainProcessing.size()>0 && (12*hour()-(time()-entity.shiftStartsAt))>=minDriveTime*hour()+getTimeReadyToDepart())
Probability	0.5
On exit (false)	entity.priority = 10;

Delay: prepareCrew

Name	Value
General	
Type	Delay<T extends Entity>
Generic Parameters Substitute	Crew
Java Package Name	com.xj.anylogic.libraries.enterprise
Embedded Object Collection Type	ARRAY_LIST_BASED

Embedded Object Parameters:

Name	Value
Delay time is	false
Delay time	1*hour()
Speed	10
Capacity	32
Maximum capacity	true
Animation type	Animator.PATH
Animation direction	true
Enable statistics	false

Queue: waitForCrew

Name	Value
General	
Type	Queue<T extends Entity>
Generic Parameters Substitute	Entity
Java Package Name	com.xj.anylogic.libraries.enterprise
Embedded Object Collection Type	ARRAY_LIST_BASED

Embedded Object Parameters:

Name	Value
Capacity	100
Maximum capacity	true
Enable exit on timeout	false
Timeout	Double.POSITIVE_INFINITY
Enable preemption	false
Entity priority	0
Animation type	Animator.PATH
Animation direction	true
Enable statistics	false

Hold: hold1

Name	Value
General	
Type	Hold<T extends Entity>
Generic Parameters Substitute	Train
Java Package Name	com.xj.anylogic.libraries.enterprise
Embedded Object Collection Type	ARRAY_LIST_BASED

Embedded Object Parameters:

Name	Value

Embedded Object Parameters:

Name	Value
On enter	self.setBlocked(true); unsucCombination++;
Initially blocked	true

SelectOutput: selectOutput1

Name	Value
General	
Type	SelectOutput<T extends Entity>
Generic Parameters Substitute	Train
Java Package Name	com.xj.anylogic.libraries.enterprise
Embedded Object Collection Type	ARRAY_LIST_BASED

Embedded Object Parameters:

Name	Value
Select True output	false
Condition	availableCrews.size() == 0
Probability	0.5
On exit (true)	entity.isSuc = false;
On exit (false)	sucCombination++; entity.isSuc = true;

TimeMeasureStart: timeMeasureStart

Name	Value
General	
Type	TimeMeasureStart<T extends Entity>
Generic Parameters Substitute	Entity
Java Package Name	com.xj.anylogic.libraries.enterprise
Embedded Object Collection Type	ARRAY_LIST_BASED

TimeMeasureEnd: timeMeasureEnd

Name	Value
General	
Type	TimeMeasureEnd<T extends Entity>
Generic Parameters Substitute	Train
Java Package Name	com.xj.anylogic.libraries.enterprise
Embedded Object Collection Type	ARRAY_LIST_BASED

Embedded Object Parameters:

Name	Value
TimeMeasureStart objects { tms1, ... }	{timeMeasureStart}
On enter	DataItem di = new DataItem(); di.setValue(self.dataset.getY(self.dataset.size()-1)); chart.addDataItem(di, "Train #"+entity.id, spectrumColor(self.in.count(), numTrains));
Dataset capacity	100

SelectOutput: selectOutput2

Name	Value
General	
Type	SelectOutput<T extends Entity>
Generic Parameters Substitute	Crew
Java Package Name	com.xj.anylogic.libraries.enterprise
Embedded Object Collection Type	ARRAY_LIST_BASED

Embedded Object Parameters:

Name	Value
Select True output	false
Condition	!entity.home.equals(yardName)
Probability	0.5

SelectOutput: selectOutput3

Name	Value
General	
Type	SelectOutput<T extends Entity>
Generic Parameters Substitute	Crew
Java Package Name	com.xj.anylogic.libraries.enterprise
Embedded Object Collection Type	ARRAY_LIST_BASED

Embedded Object Parameters:

Name	Value
Select True output	false
Condition	12*hour()-(time()-entity.shiftStartsAt) > 0
Probability	0.5
On exit (true)	//create_CrewShift(12*hour()-(time()- entity.shiftStartsAt), entity);

Sink: expiredCrews

Name	Value
General	
Type	Sink<T extends Entity>
Generic Parameters Substitute	Crew
Java Package Name	com.xj.anylogic.libraries.enterprise
Embedded Object Collection Type	ARRAY_LIST_BASED

Embedded Object Parameters:

Name	Value
On enter	numExpiredCrews++; updateList(expCrewText, entity.stBy+" "+formatDate(timeToDate(entity.shiftStartsAt))+" - "+formatDate(date()));

SelectOutput: selectOutput4

Name	Value
General	
Type	SelectOutput<T extends Entity>
Generic Parameters Substitute	Train

Name	Value
Java Package Name	com.xj.anylogic.libraries.enterprise
Embedded Object Collection Type	ARRAY_LIST_BASED

Embedded Object Parameters:

Name	Value
Select True output	false
Condition	!entity.home.equals(yardName)
Probability	0.5

Sink: arrivedTrains

Name	Value
General	
Type	Sink<T extends Entity>
Generic Parameters Substitute	Train
Java Package Name	com.xj.anylogic.libraries.enterprise
Embedded Object Collection Type	ARRAY_LIST_BASED

Sink: returnedOnCombi

Name	Value
General	
Type	Sink<T extends Entity>
Generic Parameters Substitute	Crew
Java Package Name	com.xj.anylogic.libraries.enterprise
Embedded Object Collection Type	ARRAY_LIST_BASED

Embedded Object Parameters:

Name	Value
On enter	if(12*hour()-(time()-entity.shiftStartsAt) < 0) timeOver12Hours += time()-entity.shiftStartsAt-12*hour();

Sink: returnedOnTrain

Name	Value
General	
Type	Sink<T extends Entity>
Generic Parameters Substitute	Crew
Java Package Name	com.xj.anylogic.libraries.enterprise
Embedded Object Collection Type	ARRAY_LIST_BASED

Embedded Object Parameters:

Name	Value
On enter	timeOver12Hours += time()-entity.shiftStartsAt-12*hour();

Hold: hold2

Name	Value
General	

Name	Value
Type	Hold<T extends Entity>
Generic Parameters Substitute	Entity
Java Package Name	com.xj.anylogic.libraries.enterprise
Embedded Object Collection Type	ARRAY_LIST_BASED

Embedded Object Parameters:

Name	Value
On enter	self.setBlocked(true); arrival.restart(30*minute());
Initially blocked	false

Source: standbyCrewSource

Name	Value
General	
Type	Source<T extends Entity>
Generic Parameters Substitute	Crew
Java Package Name	com.xj.anylogic.libraries.enterprise
Embedded Object Collection Type	ARRAY_LIST_BASED

Embedded Object Parameters:

Name	Value
Arrivals defined by	Source.MANUAL
Arrival rate	1
Interarrival time	comeOnDutyInterval
Modify rate	false
Rate expression	baseRate
Entities per arrival	1
Limited number of arrivals	false
Maximum number of arrivals	(int)(24*hour()/(11*hour()-minDriveTime*hour()))
New entity	new Crew()

On exit	entity.home = yardName;
	entity.shiftStartsAt = time();
	entity.sitBy = "S";

Unique shape for each entity	false
Enable rotation	false
Enable vertical rotation	true

Bar Chart: chart

Name	Value
General	
Scale Type	AUTO
Analysis Auto Update	true
Recurrence	1
Advanced	
x	-350
y	-170
Width	380
Height	160
Appearance	

Name	Value
Show Legend	true
Legend Place	EAST
Bars Direction	UP
Bars Relative Width	0.8

Bar Chart: chart2

Name	Value
General	
Scale Type	AUTO
Analysis Auto Update	true
Recurrence	1
Advanced	
x	20
y	-180
Width	240
Height	170
Appearance	
Show Legend	true
Legend Place	EAST
Bars Direction	UP
Bars Relative Width	0.6

Chart Items:

Title	Color	Value
Expired crews	dodgerBlue	numExpiredCrews
Used standby crews	violetRed	standbyCrewSource.count()

Rounded Rectangle: roundRectangle

Name	Value
General	
Lock	true
Fill Color	new Color(135, 206, 250, 42)
Advanced	
x	-350
y	-220
Width	1480
Height	250
Radius	10

Text: text

Name	Value
Advanced	
x	-320
y	0
General	

Name	Value
Alignment	LEFT
Font Name	SansSerif
Font Size	14
Text	text
Advanced	
x	-320
y	0
Dynamic	
Dynamic: Text	"Working time over 12 hours: "+timeOver12Hours+" min"

Text: text1

Name	Value
Advanced	
x	-320
y	-180
General	
Alignment	LEFT
Font Name	SansSerif
Font Size	14
Bold Font Style	true
Text	Train waiting time:
Advanced	
x	-320
y	-180

Text: text2

Name	Value
General	
Color	brown
Advanced	
x	-340
y	-210
General	
Alignment	LEFT
Font Name	SansSerif
Font Size	20
Bold Font Style	true
Advanced	
x	-340
y	-210
Dynamic	
Dynamic: Text	yardName.equals("depot") ? "At home depot:" : "At receiving yard:"

Text: text3

Name	Value
Advanced	

Name	Value
x	250
y	-210
General	
Alignment	LEFT
Font Name	SansSerif
Font Size	12
Bold Font Style	true
Text	Successful trains:
Advanced	
x	250
y	-210
Dynamic	
Dynamic: Text	//"Successful ("+listSuc.getItems().length+"):"

Text: text4

Name	Value
Advanced	
x	570
y	-210
General	
Alignment	LEFT
Font Name	SansSerif
Font Size	12
Bold Font Style	true
Text	Unsuccessful trains:
Advanced	
x	570
y	-210
Dynamic	
Dynamic: Text	//"Unsuccessful ("+listUnsuc.getItems().length+"):"

Text: text5

Name	Value
Advanced	
x	890
y	-210
General	
Alignment	LEFT
Font Name	SansSerif
Font Size	12
Bold Font Style	true
Text	Trains still in yard:
Advanced	
x	890
y	-210
Dynamic	
Dynamic: Text	//"Trains still in yard ("+listInYard.getItems().length+"):"

Text: sucText

Name	Value
Advanced	
x	250
y	-190
General	
Alignment	LEFT
Font Name	SansSerif
Font Size	10
Advanced	
x	250
y	-190

Text: unsucText

Name	Value
Advanced	
x	570
y	-190
General	
Alignment	LEFT
Font Name	SansSerif
Font Size	10
Advanced	
x	570
y	-190

Text: inYardText

Name	Value
Advanced	
x	890
y	-190
General	
Alignment	LEFT
Font Name	SansSerif
Font Size	10
Advanced	
x	890
y	-190

Text: text6

Name	Value
Advanced	
x	450
y	-210
General	
Alignment	LEFT

Name	Value
Font Name	SansSerif
Font Size	12
Bold Font Style	true
Text	Crew:
Advanced	
x	450
y	-210
Dynamic	
Dynamic: Text	//"Successful ("+listSuc.getItems().length+"):"

Text: sucCrewText

Name	Value
Advanced	
x	450
y	-190
General	
Alignment	LEFT
Font Name	SansSerif
Font Size	10
Advanced	
x	450
y	-190

Line: line

Name	Value
General	
Line Color	gray
Advanced	
x	440
y	20
dX	0
dY	-210

Line: line1

Name	Value
General	
Line Color	gray
Advanced	
x	560
y	20
dX	0
dY	-230

Text: text7

Name	Value

Name	Value
Advanced	
x	770
y	-210
General	
Alignment	LEFT
Font Name	SansSerif
Font Size	12
Bold Font Style	true
Text	Crew:
Advanced	
x	770
y	-210
Dynamic	
Dynamic: Text	//"Successful ("+listSuc.getItems().length+"):"

Text: unsucCrewText

Name	Value
Advanced	
x	770
y	-190
General	
Alignment	LEFT
Font Name	SansSerif
Font Size	10
Advanced	
x	770
y	-190

Line: line2

Name	Value
General	
Line Color	gray
Advanced	
x	760
y	20
dX	0
dY	-210

Line: line3

Name	Value
General	
Line Color	gray
Advanced	
x	880
y	20
dX	0

Name	Value
dY	-230

Line: line4

Name	Value
General	
Line Color	gray
Advanced	
x	1010
y	20
dX	0
dY	-230

Text: text8

Name	Value
Advanced	
x	1020
y	-210
General	
Alignment	LEFT
Font Name	SansSerif
Font Size	12
Bold Font Style	true
Text	Expired crew:
Advanced	
x	1020
y	-210
Dynamic	
Dynamic Text	//"Successful ("+listSuc.getItems().length+"):"

Text: expCrewText

Name	Value
Advanced	
x	1020
y	-190
General	
Alignment	LEFT
Font Name	SansSerif
Font Size	10
Advanced	
x	1020
y	-190

Group: warehouse

Name	Value
General	

Name	Value
Embedded Icon	true
Advanced	
x	230
y	80
Dynamic	
On Click	return true;

Polyline: _ps278

Name	Value
General	
Embedded Icon	true
Fill Color	new Color(0, 0, 0, 80)
Polyline closed	true
Advanced	
x	-6
y	26

Polyline: _ps279

Name	Value
General	
Embedded Icon	true
Fill Color	new Color(220, 178, 0)
Polyline closed	true
Advanced	
x	-32
y	13

Polyline: _ps280

Name	Value
General	
Embedded Icon	true
Fill Color	new Color(128, 96, 0)
Polyline closed	true
Advanced	
x	-28
y	15

Polyline: _ps281

Name	Value
General	
Embedded Icon	true
Fill Color	new Color(208, 162, 0)
Polyline closed	true
Advanced	
x	-6

Name	Value
y	26

Polyline: _ps282

Name	Value
General	
Embedded Icon	true
Fill Color	gold
Polyline closed	true
Advanced	
x	-6
y	11

Polyline: _ps283

Name	Value
General	
Embedded Icon	true
Fill Color	new Color(255, 229, 118)
Polyline closed	true
Advanced	
x	-19
y	-4

Polyline: _ps284

Name	Value
General	
Embedded Icon	true
Line Color	new Color(74, 53, 0)
Polyline closed	true
Advanced	
x	-6
y	26

Java Class: Crew

Name	Value
General	
Java Class Type	JAVA_CLASS

Text	/**
	 * Crew
	 */
	public class Crew extends com.xj.anylogic.libraries.enterprise.Entity implements java.io.Serializable {
	
	 double shiftStartsAt;
	 int priority = 0;
	 String home;
	 String atBy = "U";
	
	  /**
	  * Default constructor
	  */

Name	Value

	public Crew(){
	 }
	
	 /**
	  * Constructor initializing the fields
	  */
	 public Crew(double shiftStartsAt, int priority, String home){
	this.shiftStartsAt = shiftStartsAt;
	this.priority = priority;
	this.home = home;
	 }
	
	@Override
	public String toString() {
	return
	"shiftStartsAt = " + shiftStartsAt +" ";
	}
	
	/**
	 * This number is here for model snapshot storing purpose
	
	 * It needs to be changed when this class gets changed
	 */
	private static final long serialVersionUID = 1L;
	
	}

Java Class: Train

Name	Value
General	
Java Class Type	JAVA_CLASS

Text	/**
	 * Train
	 */
	public class Train extends com.xj.anylogic.libraries.enterprise.Entity implements java.io.Serializable {
	
	 String home;
	 String id;
	 Date arr;
	 Date finProc;
	 double startProc;
	 double timeToProc;
	 boolean isSuc;
	 Date crewCameOnDuty;
	 Date crewBoarded;
	 double timeBetweenDAndB;
	
	  /**
	   * Default constructor
	   */
	  public Train(){
	  }
	
	  /**
	   * Constructor initializing the fields
	   */
	  public Train(String id, String home){
	  this.id = id;
	this.home = home;
	  }
	
	@Override
	public String toString() {
	return
	"home = " + home +" ";
	}
	
	/**
	 * This number is here for model snapshot storing purpose

Name	Value
	* It needs to be changed when this class gets changed */ private static final long serialVersionUID = 1L; }

Simulation Experiment: Simulation

Name	Value
General	
Active Object Class	Main
Random Number Generation Type	randomSeed
Advanced	
Maximum Available Memory	64
Differention Equations Method	EULER
Mixed Equations Method	RK45_NEWTON
Algebraic Equations Method	MODIFIED_NEWTON
Absolute Accuracy	1.0E-5
Time Accuracy	1.0E-5
Relative Accuracy	1.0E-5
Fixed Time Step	0.0010
Presentation Top Group Persistent	true
Model Time	
Use Calendar	true
Stop Option	Stop at specified date
Initial Time	0.0
Final Time	1440.0
Initial Date	Tue Jun 11 00:00:00 GMT 2013
Final Date	Wed Jun 12 00:00:00 GMT 2013
Presentation	
CPU Time Balance	ratio_1_2
Execution Mode	realTimeScaled
Real Time Scale	25.0
Window	
Title	Crew Trains : Simulation
Real Time Of Simulation	false

Crew Trains

Experiment setup page

Run the model and switch to Main view

Distance between yards (km):

Train speed (km/h):

Number of trains per day (home depot):

Number of trains per day (receiving yard):

Max number of standby crews:

Combi speed (km/h):

Text: text

Name	Value
Advanced	
x	40
y	30
General	
Alignment	LEFT
Font Name	Serif
Font Size	28
Bold Font Style	true
Text	Crew Trains
Advanced	
x	40
y	30

Text: text1

Name	Value
Advanced	
x	40
y	63
General	
Alignment	LEFT
Font Name	Serif
Font Size	16
Italic Font Style	true
Text	Experiment setup page
Advanced	
x	40
y	63

Text: text2

Name	Value
Advanced	
x	50
y	200
General	
Alignment	LEFT
Font Name	Calibri
Font Size	16
Text	Distance between yards (km):
Advanced	
x	50
y	200

Text: text3

Name	Value
Advanced	
x	50
y	230
General	
Alignment	LEFT
Font Name	Calibri
Font Size	16
Text	Train speed (km/h):
Advanced	
x	50
y	230

Text: text4

Name	Value
Advanced	
x	50
y	260
General	
Alignment	LEFT
Font Name	Calibri
Font Size	16
Text	Number of trains per day (home depot):
Advanced	
x	50
y	260

Text: text5

Name	Value
Advanced	
x	50
y	290
General	

Name	Value
Alignment	LEFT
Font Name	Calibri
Font Size	16
Text	Number of trains per day (receiving yard):
Advanced	
x	50
y	290

Text: text6

Name	Value
Advanced	
x	50
y	320
General	
Alignment	LEFT
Font Name	Calibri
Font Size	16
Text	Max number of standby crews:
Advanced	
x	50
y	320

Text: text7

Name	Value
Advanced	
x	50
y	350
General	
Alignment	LEFT
Font Name	Calibri
Font Size	16
Text	Combi speed (km/h):
Advanced	
x	50
y	350

Image: image

Name	Value
General	
Images	sim_pic.png
Advanced	
x	290
y	10
Width	430
Height	180

Button: button

Name	Value
General	
Label Text	Run the model and switch to Main view
Dynamic: Enable	editbox2.getIntValue() <= 48 && editbox3.getIntValue() <= 48

Action	if (getState() == IDLE)
	run();
	getPresentation().setPresentable(getEngine().getRoot());

Advanced	
Font Name	Dialog
Font Size	11
x	40
y	120
Width	230
Height	30
Dynamic	
Dynamic: Label	getState() == IDLE ? "Run the model and switch to Main view" : "Switch to Main view"

Edit Box: editbox

Name	Value
General	
Default Value	"540"
Advanced	
Font Name	Dialog
Font Size	11
x	330
y	200
Width	70
Height	20

Edit Box: editbox1

Name	Value
General	
Default Value	"60"
Advanced	
Font Name	Dialog
Font Size	11
x	330
y	230
Width	70
Height	20

Edit Box: editbox2

Name	Value
General	

Name	Value
Default Value	"12"
Action	if(editbox2.getIntValue() > 48) getPresentation().showMessageDialog("The number of trains is more than the number of slots. Please reduce this value.");
Advanced	
Font Name	Dialog
Font Size	11
x	330
y	260
Width	70
Height	20

Edit Box: editbox3

Name	Value
General	
Default Value	"12"
Action	if(editbox3.getIntValue() > 48) getPresentation().showMessageDialog("The number of trains is more than the number of slots. Please reduce this value.");
Advanced	
Font Name	Dialog
Font Size	11
x	330
y	290
Width	70
Height	20

Edit Box: editbox4

Name	Value
General	
Default Value	"3"
Advanced	
Font Name	Dialog
Font Size	11
x	330
y	320
Width	70
Height	20

Edit Box: editbox5

Name	Value
General	
Default Value	"120"
Advanced	
Font Name	Dialog
Font Size	11
x	330
y	350

Name	Value
Width	70
Height	20

APPENDIX M: SIMULATION DATA

Table M.1 Simulation data

Day	Simulation with 10 trains as input	Arrival time	Train inter arrival times	Time to process the train	Departure time	Train inter departure times	Time crew came on duty	Time crew boarded	Mins between came on duty and boarding	30
1	T001 SUC	00:00:00		79,89	01:19:53		00:00:00	01:19:53	79,89261292	
1	T003 SUC	02:11:51	131	89,12	03:46:42	146	02:24:00	03:46:42	82,71660643	311
1	T004 UNSUC	04:01:06	109	16	05:48:00	121	04:48:00	05:48:00	60	109
1	T005 UNSUC	05:18:02	76	54	06:18:00	30	06:14:57	06:14:57	0	76
1	T006 SUC	06:14:57	56	35	06:49:27	31	06:14:57	06:49:27	34,51264704	56
1	T007 SUC	07:20:57	66	8	07:28:42	39	07:20:57	07:28:42	7,75065275	66
1	T008 SUC	07:22:47	01	34	08:24:45	56	07:20:57	08:24:45	63,79760657	1
1	T002 SUC	01:47:35	335	427	08:54:45	30	07:12:00	08:54:18	102,3005506	335
1	T009 UNSUC	09:17:19	449	35	10:36:00	101	09:36:00	10:36:00	60	449
1	T010 UNSUC	12:19:27	182	7	13:00:00	144	12:00:00	13:00:00	60	182
2	T001 UNSUC	00:00:00		11	01:00:00		00:00:00	01:00:00	60	
2	T005 SUC	01:09:08	69	12	02:12:21	72	02:00:00	02:12:21	12,36235135	69
2	T006 SUC	01:29:41	20	7	02:42:21	30	02:00:00	02:37:21	37,36332856	20
2	T003 SUC	00:16:56	72	179	03:59:02	76	02:10:54	03:59:02	108,1393797	72
2	T007 SUC	04:07:02	230	104	05:50:33	111	04:21:49	05:50:33	88,73960329	230
2	T009 UNSUC	05:44:59	97	7	07:32:43	102	06:32:43	07:32:43	60	97
2	T002 UNSUC	00:07:12	337	480	09:43:38	130	08:43:38	09:43:38	60	337

Day	Simulation with 10 trains as input	Arrival time	Train inter arrival times	Time to process the train	Departure time	Train inter departure times	Time crew came on duty	Time crew boarded	Mins between came on duty and boarding	30
1	T001 SUC	00:00:00		79,89	01:19:53		00:00:00	01:19:53	79,89261292	
1	T003 SUC	02:11:51	131	89,12	03:46:42	146	02:24:00	03:46:42	82,71660643	311
1	T004 UNSUC	04:01:06	109	16	05:48:00	121	04:48:00	05:48:00	60	109
1	T005 UNSUC	05:18:02	76	54	06:18:00	30	06:14:57	06:14:57	0	76
1	T006 SUC	06:14:57	56	35	06:49:27	31	06:14:57	06:49:27	34,51264704	56
1	T007 SUC	07:20:57	66	8	07:28:42	39	07:20:57	07:28:42	7,75065275	66
1	T008 SUC	07:22:47	01	34	08:24:45	56	07:20:57	08:24:45	63,79760657	1
1	T002 SUC	01:47:35	335	427	08:54:45	30	07:12:00	08:54:18	102,3005506	335
1	T009 UNSUC	09:17:19	449	35	10:36:00	101	09:36:00	10:36:00	60	449
1	T010 UNSUC	12:19:27	182	7	13:00:00	144	12:00:00	13:00:00	60	182
2	T001 UNSUC	00:00:00		11	01:00:00		00:00:00	01:00:00	60	
2	T005 SUC	01:09:08	69	12	02:12:21	72	02:00:00	02:12:21	12,36235135	69
2	T006 SUC	01:29:41	20	7	02:42:21	30	02:00:00	02:37:21	37,36332856	20
2	T003 SUC	00:16:56	72	179	03:59:02	76	02:10:54	03:59:02	108,1393797	72
2	T007 SUC	04:07:02	230	104	05:50:33	111	04:21:49	05:50:33	88,73960329	230
2	T009 UNSUC	05:44:59	97	7	07:32:43	102	06:32:43	07:32:43	60	97
2	T002 UNSUC	00:07:12	337	480	09:43:38	130	08:43:38	09:43:38	60	337

Day	Simulation with 10 trains as input	Arrival time	Train inter arrival times	Time to process the train	Departure time	Train inter departure times	Time crew came on duty	Time crew boarded	Mins between came on duty and boarding
1	T001 SUC	00:00:00		79,89	01:19:53		00:00:00	01:19:53	79,89261292
1	T003 SUC	02:11:51	131	89,12	03:46:42	146	02:24:00	03:46:42	82,71660643
1	T004 UNSUC	04:01:06	109	16	05:48:00	121	04:48:00	05:48:00	60
1	T005 UNSUC	05:18:02	76	54	06:18:00	30	06:14:57	06:14:57	0
1	T006 SUC	06:14:57	56	35	06:49:27	31	06:14:57	06:49:27	34,51264704
1	T007 SUC	07:20:57	66	8	07:28:42	39	07:20:57	07:28:42	7,75065275
1	T008 SUC	07:22:47	01	34	08:24:45	56	07:20:57	08:24:45	63,79760657
1	T002 SUC	01:47:35	335	427	08:54:45	30	07:12:00	08:54:18	102,3005506
1	T009 UNSUC	09:17:19	449	35	10:36:00	101	09:36:00	10:36:00	60
1	T010 UNSUC	12:19:27	182	7	13:00:00	144	12:00:00	13:00:00	60
2	T001 UNSUC	00:00:00		11	01:00:00		00:00:00	01:00:00	60
2	T005 SUC	01:09:08	69	12	02:12:21	72	02:00:00	02:12:21	12,36235135
2	T006 SUC	01:29:41	20	7	02:42:21	30	02:00:00	02:37:21	37,36332856
2	T003 SUC	00:16:56	72	179	03:59:02	76	02:10:54	03:59:02	108,1393797
2	T007 SUC	04:07:02	230	104	05:50:33	111	04:21:49	05:50:33	88,73960329
2	T009 UNSUC	05:44:59	97	7	07:32:43	102	06:32:43	07:32:43	60
2	T002 UNSUC	00:07:12	337	480	09:43:38	130	08:43:38	09:43:38	60
2	T004 UNSUC	00:24:07	16	480	11:17:13	93	11:17:13	11:17:13	0
2	T011 SUC	11:17:13	653	24	11:47:13	30	11:17:13	11:41:23	24,16974717
2	T008 SUC	04:42:08	395	480	12:42:08	54	10:54:32	12:42:08	107,5921665
2	T010 SUC	08:46:48	244	480	16:46:48	244	13:05:27	16:46:48	221,345755
3	T002 SUC	02:52:47		27	03:19:21		00:00:00	03:19:21	199,353573
3	T005 SUC	04:59:24	126	73	06:13:04	173	03:41:32	06:13:04	151,5356955
3	T006 SUC	05:57:04	57	39	06:43:04	30	05:32:18	06:35:42	63,40589122

Day	Simulation with 10 trains as input	Arrival time	Train inter arrival times	Time to process the train	Departure time	Train inter departure times	Time crew came on duty	Time crew boarded	Mins between came on duty and boarding
3	T001 UNSUC	00:00:00	357	480	08:23:04	100	07:23:04	08:23:04	60
3	T007 SUC	08:39:24	519	19	08:58:20	35	08:39:24	08:58:20	18,93217873
3	T008 SUC	09:17:31	38	30	09:47:23	49	08:39:24	09:47:23	67,98606212
3	T003 SUC	03:32:56	344	480	11:32:56	105	09:13:50	11:32:56	139,0988266
3	T004 SUC	04:30:09	57	480	12:30:09	57	11:04:36	12:30:09	85,54391638
3	T010 SUC	13:18:35	528	6	13:25:00	54	13:18:35	13:25:00	6,41356097
3	T009 SUC	11:40:02	98	83	13:55:00	30	13:18:35	13:47:04	28,48910988
3	T012 SUC	15:20:27	220	17	15:46:13	111	12:55:23	15:46:13	170,8406624
3	T013 SUC	18:03:41	163	15	18:19:01	152	14:46:09	18:19:01	212,8737496
3	T011 SUC	14:59:17	184	480	22:59:17	280	20:18:27	22:59:17	160,8241246
4	T003 SUC	00:43:49		24	01:24:14		00:30:00	01:24:14	54,24883231
4	T001 SUC	00:00:00	43	135	02:15:04	50	00:30:00	02:15:04	105,0768651
4	T006 SUC	02:32:06	152	6	02:45:04	30	00:00:00	02:38:30	158,5098211
4	T002 SUC	00:02:50	149	177	03:26:31	41	01:36:00	03:26:31	110,5320078
4	T007 UNSUC	03:21:33	198	8	04:05:35	39	04:05:35	04:05:35	0
4	T008 SUC	04:05:35	44	43	04:48:25	42	04:05:35	04:48:25	42,83604194
4	T009 SUC	04:51:09	45	12	05:18:25	30	03:12:00	05:03:21	111,3577386
4	T005 SUC	01:26:04	205	303	07:02:39	104	04:48:00	07:02:39	134,6655429
4	T010 SUC	07:21:35	355	71	08:32:09	89	07:21:35	08:32:09	70,55667783
4	T004 SUC	01:19:32	362	480	09:30:00	57	07:21:35	09:30:00	128,4012952
4	T012 SUC	09:35:32	496	10	10:00:38	30	06:24:00	10:00:38	216,6360527
4	T013 SUC	11:57:24	141	8	12:05:24	124	09:36:00	12:05:24	149,4100328
4	T014 SUC	12:32:16	34	40	13:12:30	67	11:12:00	13:12:30	120,5024741
4	T015 UNSUC	12:50:41	18	24	13:48:00	35	12:48:00	13:48:00	60

Day	Simulation with 10 trains as input	Arrival time	Train inter arrival times	Time to process the train	Departure time	Train inter departure times	Time crew came on duty	Time crew boarded	Mins between came on duty and boarding
4	T011 SUC	08:50:33	240	480	16:50:33	182	14:24:00	16:50:33	146,565997
5	T001 UNSUC	00:00:00		25	01:00:00		00:00:00	01:00:00	60
5	T002 UNSUC	01:00:06	60	7	04:00:00	180	03:00:00	04:00:00	60
5	T003 UNSUC	03:15:50	135	17	06:41:21	161	06:41:21	06:41:21	0
5	T005 SUC	06:25:35	189	7	07:11:21	30	06:41:21	06:48:06	6,747323699
5	T006 SUC	07:58:34	92	10	08:08:52	57	06:00:00	08:08:52	128,8753643
5	T004 SUC	06:11:21	107	155	08:46:29	37	08:42:09	08:46:29	4,332300305
5	T007 SUC	08:42:09	150	96	10:18:18	91	08:42:09	10:18:18	96,14779172
5	T008 SUC	11:07:31	145	7	11:14:23	56	09:00:00	11:14:23	134,3843365
6	T003 SUC	00:23:16		14	01:13:35		00:00:00	01:13:35	73,59345912
6	T005 SUC	00:58:28	35	30	02:29:53	76	01:24:42	02:29:53	65,18180998
6	T006 SUC	05:56:10	297	8	06:03:43	213	02:49:24	06:03:43	194,3096961
6	T001 SUC	00:00:00	356	480	08:00:00	116	04:14:07	08:00:00	225,8823529
6	T008 SUC	07:42:45	462	17	08:30:00	30	05:38:49	08:25:08	166,3208437
6	T002 SUC	00:02:48	459	480	09:00:00	30	07:03:31	08:30:00	86,47058824
6	T007 SUC	07:38:27	455	71	09:30:00	30	08:38:27	08:49:14	10,78680821
6	T009 SUC	07:59:45	21	17	10:00:00	30	08:38:27	08:55:52	17,40708599
6	T010 SUC	08:48:45	49	10	10:30:00	30	08:38:27	09:18:19	39,85904812
6	T004 SUC	00:48:12	480	480	11:00:00	30	08:28:14	09:30:00	61,76470588
6	T011 UNSUC	08:49:34	481	13	11:30:00	30	09:52:56	10:52:56	60
6	T012 UNSUC	08:59:46	10	8	12:17:38	47	11:17:38	12:17:38	60
6	T013 UNSUC	11:42:34	162	7	13:42:21	84	12:42:21	13:42:21	60
6	T015 SUC	15:47:01	244	11	15:58:12	135	14:07:03	15:58:12	111,1550134
6	T014 SUC	12:40:06	186	426	19:45:49	227	16:56:28	19:45:49	169,348226

Day	Simulation with 10 trains as input	Arrival time	Train inter arrival times	Time to process the train	Departure time	Train inter departure times	Time crew came on duty	Time crew boarded	Mins between came on duty and boarding
6	T017 SUC	19:57:33	437	123	22:00:48	134	18:21:10	22:00:48	219,632642
6	T016 SUC	18:23:56	93	256	22:39:32	38	19:45:52	22:39:32	173,6558554
7	T001 UNSUC	00:00:00		21	01:00:00		00:00:00	01:00:00	60
7	T002 UNSUC	00:42:37	42	62	02:42:51	102	01:42:51	02:42:51	60
7	T003 SUC	03:41:37	179	96	05:17:10	154	03:25:42	05:17:10	111,4578088
7	T004 SUC	06:10:19	148	115	08:05:44	168	05:08:34	08:05:44	177,1749091
7	T006 SUC	14:25:47	495	15	14:41:03	395	12:00:00	14:41:03	161,0588131
7	T007 SUC	15:22:11	56	9	15:31:31	50	13:42:51	15:31:31	108,6640917
7	T005 SUC	08:30:30	411	480	16:30:30	58	15:25:42	16:30:30	64,79579366
7	T008 SUC	17:28:33	538	85	18:53:31	143	17:08:34	18:53:31	104,9458367
7	T010 SUC	20:48:16	199	12	21:22:16	148	18:51:25	21:22:16	150,851382
7	T011 SUC	21:39:22	51	14	22:24:31	62	20:34:17	22:24:31	110,23738
7	T009 UNSUC	20:40:16	59	131	23:17:08	52	22:17:08	23:17:08	60
8	T002 UNSUC	00:30:50		10	01:00:00		00:00:00	01:00:00	60
8	T005 SUC	03:59:34	208	22	04:21:26	201	01:24:42	04:21:26	176,7440161
8	T006 SUC	04:12:30	12	81	05:50:55	89	02:49:24	05:50:55	181,5151775
8	T003 SUC	00:33:25	219	306	06:20:55	30	04:14:07	06:07:14	113,1158492
8	T007 UNSUC	05:50:30	317	21	06:50:55	30	06:11:24	06:11:24	0
8	T004 SUC	00:41:48	308	285	07:20:55	30	06:11:24	06:15:42	4,299183135
8	T008 SUC	06:50:48	369	7	07:50:55	30	05:38:49	06:57:50	79,00981606
8	T001 UNSUC	00:00:00	410	480	08:20:55	30	07:03:31	08:03:31	60
8	T009 SUC	11:57:35	717	47	12:44:25	263	09:52:56	12:44:25	171,4789974
8	T010 SUC	11:59:31	01	17	13:14:25	30	11:17:38	12:45:04	87,42347826
8	T011 SUC	15:57:53	238	41	16:38:23	203	12:42:21	16:38:23	236,0453922

Day	Simulation with 10 trains as input	Arrival time	Train inter arrival times	Time to process the train	Departure time	Train inter departure times	Time crew came on duty	Time crew boarded	Mins between came on duty and boarding
8	T013 SUC	17:13:04	75	26	17:39:25	61	14:07:03	17:39:25	212,3709042
8	T012 SUC	16:22:02	51	187	19:34:49	115	16:56:28	19:34:49	158,3560851
8	T015 SUC	20:49:23	267	9	21:12:02	97	18:21:10	21:12:02	170,8583602
8	T016 SUC	21:23:39	34	17	22:20:09	68	19:45:52	22:20:09	154,2807625
8	T017 SUC	22:18:54	55	25	22:58:23	38	21:10:35	22:58:23	107,8077543
9	T001 UNSUC	00:00:00		32	01:00:00		00:00:00	01:00:00	60
9	T003 UNSUC	01:29:37	89	75	03:00:00	120	02:00:00	03:00:00	60
9	T004 SUC	03:57:07	147	27	04:24:35	84	03:57:07	04:24:35	27,46972409
9	T005 SUC	04:25:15	28	51	05:17:46	53	03:57:07	05:17:46	80,64607773
9	T002 SUC	00:29:42	235	294	05:47:46	30	04:00:00	05:23:36	83,6147933
9	T007 SUC	04:45:27	255	31	06:17:46	30	05:57:07	05:58:31	1,395721744
9	T008 SUC	05:07:43	22	14	06:47:46	30	05:57:07	06:11:16	14,14353132
9	T009 UNSUC	05:22:41	14	14	07:17:46	30	06:00:00	07:00:00	60
9	T010 UNSUC	05:52:52	30	11	09:00:00	102	08:00:00	09:00:00	60
9	T012 UNSUC	08:23:39	150	6	11:00:00	120	10:00:00	11:00:00	60
9	T006 UNSUC	04:44:40	218	480	13:00:00	120	12:00:00	13:00:00	60
9	T011 SUC	06:56:58	132	480	15:27:07	147	14:00:00	15:27:07	87,12417614
10	T002 SUC	00:44:41		34	01:18:15		00:00:00	01:18:15	78,25808839
10	T005 SUC	02:51:55	127	7	03:27:57	129	01:30:00	03:27:57	117,9504071
10	T007 SUC	03:38:11	46	12	04:32:46	64	03:00:00	04:32:46	92,77757958
10	T006 UNSUC	03:26:09	12	54	05:30:00	57	04:30:00	05:30:00	60
10	T008 SUC	07:23:23	237	9	07:31:54	121	06:00:00	07:31:54	91,90527754
10	T001 SUC	00:00:00	443	480	08:01:54	30	07:53:23	08:00:00	6,615233124
10	T009 SUC	07:40:03	460	9	08:31:54	30	07:53:23	08:02:36	9,216719997

Day	Simulation with 10 trains as input	Arrival time	Train inter arrival times	Time to process the train	Departure time	Train inter departure times	Time crew came on duty	Time crew boarded	Mins between came on duty and boarding
10	T010 SUC	08:21:35	41	12	09:01:54	30	07:53:23	08:35:14	41,85303482
10	T003 SUC	02:20:48	360	480	10:20:48	78	07:53:23	10:20:48	147,4267128
10	T004 SUC	02:35:27	14	480	10:50:48	30	07:30:00	10:50:48	200,8114796
10	T013 SUC	10:55:29	500	13	11:20:48	30	09:00:00	11:08:08	128,1478541
10	T012 UNSUC	09:16:23	99	123	11:50:48	30	10:30:00	11:30:00	60
10	T015 SUC	15:41:20	384	8	15:49:34	238	12:00:00	15:49:34	229,5746137
10	T011 SUC	08:51:00	410	480	16:53:23	63	13:30:00	16:53:23	203,3847669
10	T016 SUC	16:19:27	448	227	20:36:01	222	18:00:00	20:36:01	156,0270689
10	T014 SUC	13:44:13	155	462	21:26:23	50	19:30:00	21:26:23	116,3899313
11	T001 UNSUC	00:00:00		46	01:00:00		00:00:00	01:00:00	60
11	T003 SUC	03:01:55	181	6	03:27:31	147	02:00:00	03:27:31	87,53030819
11	T002 UNSUC	02:51:09	10	41	05:00:00	92	04:00:00	05:00:00	60
11	T004 UNSUC	04:29:00	97	37	06:44:22	104	06:44:22	06:44:22	0
11	T005 SUC	06:14:22	105	55	07:14:22	30	06:44:22	07:09:51	25,47774082
11	T006 SUC	06:43:55	29	125	08:49:48	95	06:00:00	08:49:48	169,8003851
11	T007 SUC	08:27:02	103	343	14:09:59	320	12:00:00	14:09:59	129,9906726
11	T008 SUC	12:10:06	223	155	14:45:26	35	14:12:05	14:45:26	33,34700626
11	T010 SUC	14:17:45	127	7	15:15:26	30	14:12:05	14:48:56	36,84365151
11	T009 SUC	14:12:05	5	89	15:45:26	30	14:00:00	15:41:34	101,5812175
11	T011 SUC	15:37:00	84	9	17:20:57	95	16:00:00	17:20:57	80,95352631
11	T012 UNSUC	15:52:36	15	9	19:00:00	99	18:00:00	19:00:00	60
12	T001 UNSUC	00:00:00		38	01:00:00		00:00:00	01:00:00	60
12	T005 SUC	04:29:17	269	10	04:39:03	219	01:50:46	04:39:03	168,2833646
12	T004 SUC	02:09:53	139	195	05:54:45	75	03:41:32	05:54:45	133,2142707

Day	Simulation with 10 trains as input	Arrival time	Train inter arrival times	Time to process the train	Departure time	Train inter departure times	Time crew came on duty	Time crew boarded	Mins between came on duty and boarding
12	T006 UNSUC	05:57:14	227	8	06:32:18	37	05:32:18	06:32:18	60
12	T007 SUC	07:51:11	113	28	08:19:24	107	07:51:11	08:19:24	28,22222534
12	T008 SUC	08:55:31	64	34	09:29:28	70	07:51:11	09:29:28	98,29509787
12	T002 SUC	01:39:48	435	480	09:59:28	30	07:51:11	09:39:48	108,6210935
12	T003 SUC	01:59:31	19	480	10:29:28	30	07:23:04	10:09:48	166,7282979
12	T011 SUC	16:24:40	865	66	17:37:22	427	14:46:09	17:37:22	171,2175513
12	T009 SUC	09:24:12	420	480	18:07:22	30	16:36:55	17:55:31	78,59360365
12	T010 SUC	11:40:36	136	480	19:40:36	93	19:21:30	19:40:36	19,0891398
12	T012 SUC	19:06:51	446	19	20:10:36	30	19:21:30	19:40:39	19,13612301
12	T013 SUC	19:46:35	39	12	20:40:36	30	18:27:41	20:03:31	95,83410577
13	T002 SUC	02:12:10		49	03:00:58		00:00:00	03:00:58	180,9764828
13	T003 SUC	02:45:30	33	92	04:17:25	76	01:20:00	04:17:25	177,418101
13	T004 SUC	04:09:58	84	91	05:41:26	84	02:40:00	05:41:26	181,4423412
13	T001 SUC	00:00:00	249	480	08:00:00	138	05:20:00	08:00:00	160
13	T005 SUC	08:51:50	531	10	09:01:59	61	06:40:00	09:01:59	141,9851018
13	T006 SUC	10:50:49	118	29	11:20:12	138	08:00:00	11:20:12	200,2043192
13	T008 SUC	14:02:17	191	11	14:13:41	173	10:40:00	14:13:41	213,6963891
13	T007 SUC	13:15:50	46	104	14:59:38	45	12:00:00	14:59:38	179,6441889
13	T010 SUC	17:44:12	268	14	17:57:51	178	14:40:00	17:57:51	197,8633243
13	T011 SUC	23:16:41	332	9	23:46:47	348	20:00:00	23:46:47	226,792713
14	T001 UNSUC	00:00:00		49	01:00:00		00:00:00	01:00:00	60
14	T004 SUC	07:16:41	436	11	07:28:09	388	04:30:00	07:28:09	178,1531708
14	T005 SUC	07:45:31	28	7	07:58:09	30	06:00:00	07:54:00	114,0003171
14	T002 SUC	01:25:23	380	480	09:25:23	87	07:30:00	09:25:23	115,3862168

Day	Simulation with 10 trains as input	Arrival time	Train inter arrival times	Time to process the train	Departure time	Train inter departure times	Time crew came on duty	Time crew boarded	Mins between came on duty and boarding
14	T006 SUC	10:09:02	523	139	12:28:21	182	09:00:00	12:28:21	208,3576598
14	T007 SUC	12:43:46	154	9	12:58:21	30	10:30:00	12:52:40	142,6784276
14	T008 SUC	13:06:47	23	14	13:28:21	30	12:00:00	13:27:23	87,38485165
14	T009 SUC	13:22:00	15	11	13:58:21	30	13:43:46	13:54:51	11,07423833
14	T003 SUC	06:10:49	431	480	14:28:21	30	13:43:46	14:10:49	27,0547122
14	T011 SUC	16:56:30	645	7	17:03:50	155	13:30:00	17:03:50	213,8361315
14	T012 SUC	17:54:27	57	15	18:09:37	65	15:00:00	18:09:37	189,6251808
14	T013 SUC	18:32:01	37	55	19:27:17	77	16:30:00	19:27:17	177,2894158
14	T014 SUC	21:23:37	171	16	22:00:38	153	19:30:00	22:00:38	150,6414043
14	T010 SUC	13:42:15	461	480	22:30:38	30	21:00:00	22:13:46	73,7767865
15	T001 UNSUC	00:00:00		11	01:00:00		00:00:00	01:00:00	60
15	T002 SUC	03:56:13	236	17	04:13:06	193	03:00:00	04:13:06	73,11452122
15	T003 UNSUC	04:32:25	36	26	07:00:00	166	06:00:00	07:00:00	60
15	T004 UNSUC	05:25:33	53	6	10:00:00	180	09:00:00	10:00:00	60
15	T006 UNSUC	08:02:42	157	28	12:19:34	139	12:19:34	12:19:34	0
15	T008 SUC	12:19:34	256	7	12:49:34	30	12:19:34	12:26:24	6,846225319
15	T005 SUC	05:38:09	401	480	13:55:33	65	12:00:00	13:55:33	115,5581847
15	T007 SUC	11:27:35	349	480	19:27:35	332	18:00:00	19:27:35	87,5992925
16	T002 SUC	01:19:57		7	01:27:00		00:00:00	01:27:00	87,01260766
16	T003 SUC	01:51:14	31	54	02:45:35	78	01:42:51	02:45:35	62,7322751
16	T004 UNSUC	03:46:45	115	23	04:25:42	100	03:25:42	04:25:42	60
16	T005 UNSUC	04:47:53	61	9	05:17:53	52	05:17:53	05:17:53	0
16	T006 SUC	04:49:55	02	8	05:47:53	30	05:17:53	05:26:08	8,25071661
16	T001 SUC	00:00:00	289	480	08:00:00	132	05:08:34	08:00:00	171,4285714

Day	Simulation with 10 trains as input	Arrival time	Train inter arrival times	Time to process the train	Departure time	Train inter departure times	Time crew came on duty	Time crew boarded	Mins between came on duty and boarding
16	T007 SUC	09:29:55	569	8	09:37:32	97	06:51:25	09:37:32	166,1050895
16	T009 SUC	14:09:31	279	6	14:36:23	298	12:00:00	14:36:23	156,3873203
16	T008 SUC	13:28:58	40	78	15:06:23	30	13:42:51	14:48:23	65,54263558
16	T010 UNSUC	14:11:07	42	15	16:25:42	79	15:25:42	16:25:42	60
16	T011 UNSUC	16:32:04	140	10	18:08:34	102	17:08:34	18:08:34	60
16	T012 UNSUC	17:33:02	60	32	19:51:25	102	18:51:25	19:51:25	60
16	T013 UNSUC	20:07:44	154	8	21:34:17	102	20:34:17	21:34:17	60
17	T001 UNSUC	00:00:00		18	01:00:00		00:00:00	01:00:00	60
17	T002 SUC	02:54:39	174	13	03:07:34	127	01:30:00	03:07:34	97,573392
17	T003 SUC	06:35:48	221	9	06:45:15	217	03:00:00	06:45:15	225,2604184
17	T005 SUC	08:51:38	135	8	08:59:30	134	06:00:00	08:59:30	179,505025
17	T007 SUC	10:28:11	96	12	11:01:39	122	07:30:00	11:01:39	211,6586537
17	T010 SUC	14:19:08	230	8	14:26:48	205	10:30:00	14:26:48	236,8142683
17	T009 SUC	13:48:47	30	71	14:59:38	32	12:00:00	14:59:38	179,6359664
17	T004 SUC	06:40:51	427	480	15:29:38	30	13:30:00	15:05:48	95,81051819
17	T006 SUC	10:19:24	218	480	18:19:24	169	15:00:00	18:19:24	199,4105388
17	T011 SUC	18:28:53	489	18	18:49:24	30	16:30:00	18:47:19	137,3253176
17	T008 SUC	10:43:19	465	480	19:49:24	60	18:00:00	19:49:24	109,4105388
17	T015 SUC	21:59:03	675	7	23:04:09	194	19:30:00	23:04:09	214,154764

APPENDIX N: SIMULATION COST

Table N.1 Simulation cost data

Days	number of train	Simulation output	real world situation	additional loads delivered	number of loads delivered, no roll overs	simulation crew on duty	expired crew
Day 1	10	10	6	4	10	16	0
Day 2	11	11	8	3	11	16	1
Day 3	13	13	8	5	13	17	1
Day 4	15	15	10	5	15	21	1
Day 5	8	8	5	3	8	16	0
Day 6	17	17	10	7	17	20	3
Day 7	14	11	12	-1	11	14	0
Day 8	17	16	12	4	16	19	3
Day 9	12	12	8	4	12	16	0
Day 10	16	16	7	9	16	20	3
Day 11	12	12	6	6	12	16	0
Day 12	13	13	7	6	13	18	0
Day 13	18	10	9	1	10	18	5
Day 14	16	14	9	5	14	18	3
Day 15	8	8	7	1	8	14	0
Day 16	14	13	10	3	13	16	0
Day 17	16	12	7	5	12	16	5

APPENDIX O: PERFORMANCE OUTCOMES

Table O.1 Performance outcomes data

Day	number of train	successful train crew combinations (simulation)	Successful train crew combinations (current situation)	increase of successful train crew combinations	Simulation number of loads delivered, no roll overs	simulation crew on duty (including standby used)	Current situation number of loads delivered, no roll overs	Current situation crew on duty
Day 1	10	6	4	2	10	16	6	10
Day 2	11	7	3	4	11	16	8	13
Day 3	13	12	0	12	13	17	8	16
Day 4	15	13	5	8	15	21	10	16
Day 5	8	5	3	2	8	16	5	10
Day 6	17	14	1	13	17	20	10	23
Day 7	14	8	4	4	11	14	12	16
Day 8	17	13	1	12	16	19	12	23
Day 9	12	6	1	5	12	16	8	16
Day 10	16	14	1	13	16	20	7	19
Day 11	12	8	1	7	12	16	6	15
Day 12	13	11	3	8	13	18	7	15
Day 13	18	10	2	8	10	18	9	27
Day 14	16	13	2	11	14	18	9	20
Day 15	8	4	4	0	8	14	7	8
Day 16	14	7	5	2	13	16	10	15
Day 17	16	11	4	7	12	16	7	18