Master Thesis Report

Systems Engineering, Policy Analysis and Management

Multi-actor simulation-based design supported by multi-perspective visualization

A case study on the design for a new shunting process at the marshalling yard Utrecht

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NedTrain

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Preface

This thesis presents the results of my master thesis project for the MSc program 'Systems Engineering Policy Analysis & Management (SEPAM) at Delft University of Technology. The past six months I performed my thesis project at NedTrain B.V., the fleet maintenance company of the largest public transportation company in the Netherlands, Nederlandse Spoorwegen. Within this thesis project a clear contribution to the methodology of Simulation-Based Design has been established. Moreover the logistic processes on a marshalling yard of NedTrain are analysed and subsequently recommendations are given to improve these processes with a viable and supported solution for all involved actors.

This thesis project could not have been conducted without great help of a number of experts closely affiliated in the field of Simulation-Based Design and a large number of experts involved in the logistic process at the marshalling yard Cartesiusweg.

First of all I would like to thank the members of my thesis committee affiliated to the TU Delft for their useful ideas to adopt in my thesis project and for their critical reflections on the research approach, texts and results: Prof. dr. ir. A. Verbraeck, dr. L.J. Kortmann and dr. W.W. Veeneman.

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For the great support and latitude I got within my thesis project I sincerely want to thank my external supervisor. Not just on the subject of my research but on all kind of subjects he was of great support: Ir. M. Busstra.

Special thanks for all persons I interviewed and consulted one or more times during my research. Without the openness of the employees of NedTrain, Nederlandse Spoorwegen and ProRail this research would not have been successful as it is.

Finally I want to thank all colleagues at NedTrain for the enormous pleasant working atmosphere. Especially F. de Jong, A. de Vries and P. Bergmans have been very fun colleagues. As a graduate intern I had the feeling of being an integral member of the company, which made working at NedTrain a great pleasure and an extreme learning experience.

Certainly not to forget, my parents. I want to thank them for their moral support and interest in me and my thesis project. This was very important for me in finishing my masters.

Bart van Zaalen

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Executive Summary

The business strategy of NedTrain is changing. The fleet maintenance company of the largest provider of public transportation Nederlandse Spoorwegen (NS) encountered an increase on lead times of their maintenance processes and recidivism of defects. NedTrain has decided to develop four new Technical Centres (TC) in which small maintenance jobs can be executed while the train is parked on a marshalling yard during the night. One of these centres will be built at the marshalling yard Cartesiusweg (Ctw) in Utrecht. This TC will be specialized onto one or two specific type of trains to perform at a higher quality of maintenance.

The location for this new TC was already chosen and the tender for construction was almost finished. Then thoughts about the logistic processes arose since the location of the TC is not directly accessible from the parking tracks of the marshalling yard. The business case for the TC prescribed the requirement for the TC to be operational 24 hours a day. Due to its position location this requirement could not be met and because of the intense logistic process on Ctw problems according to the performance of the service company on Ctw were expected.

A thorough analysis of the technical system on which the logistic process is based indicated that the concerns about the accessibility of the TC were correct. After many interviews and operations monitoring during several nights shifts the problem of the logistic process on Ctw became clear. The lay-out of the marshalling yard Ctw can be described as a bottle, of which the access-track is the bottleneck. This single track, on which arriving and departing trains have to be shunted, has been identified as the main problem causing the logistic process not enabling 24 hour access to the TC. During the run-out and start-up of the train service a lot of trains are shunted onto or from the marshalling yard. These hours are approximately between 23.00 – 02.00 and 04.00 – 07.00 during the entire week. Shunting movements from a parking track to the TC cannot be performed during these time periods. Trains that have to be maintained in the TC and have to be operational in the morning will be delayed. Moreover, due to the extra shunting movements to be facilitated to shunt a train from a parking track to the TC the logistic process on Ctw gets disrupted. A redesign of the logistic processes was necessary, making the TC better accessible and thereby realize the given requirements.

The logic system at the marshalling yard Ctw is technically complex and performs within a multi-actor environment. Due to this challenging environment the method of Simulation-Based Design (SBD) has been selected to design a new logistic process plan. By applying this SDB method, critical actors participated in the design process for a new logistic process plan. Within this process the creation of Shared Understanding (SU) is very important, in which actors create a mutual understanding of the behaviour of the system, its problems and the problem solving direction. The design case of NedTrain has been used to improve the SBD methodology itself, because critics were given on the lack of multiple perspectives within the simulation. The opportunity was there to create a higher SU by the addition of multi-perspective visualization to the methodology of SBD. This opportunity was acted upon and within the design project at NedTrain it has been examined whether or not this addition is valuable.

A simulation model has been developed, in which the behaviour and performance of the system within the current situation, future situation with a TC and under implementation of solution alternatives could be simulated. This simulation has been used in a workshop, in which the critical actors discussed alternatives for the logistic process at the marshalling yard Ctw. Within this workshop an experiment with addition of multiple perspectives for visualization has been executed. For each actor his main Key Performance Indicator (KPI) has been visualized.

During the design workshop the actors discussed the alternatives and concluded the first step to improve the logistic process on Ctw is to start a collaboration between Bureau Locale Planning (BLP) and the Process Coordinator Logistics (PCL) of the marshalling yard Ctw. Within this collaboration the planned movements on the access-track on Ctw can be planned more intelligent and also the processes on the marshalling yard itself can be better streamlined. From the five alternatives discussed just one alternative has been identified to be feasible and was supported by all actors. By creating time windows of 20 minutes in which no traffic enters the access-track, shunting movements from the parking tracks to the TC can be performed. By implementation of this alternative the TC will be accessible 24 hours a day.

However, the viability on the long term is questionable. Since there will be more traffic to and from the marshalling yard in the future, the creation of these time windows will be more difficult. Therefore a study on the adjustment of the infrastructure has still been performed. Adjustment on the infrastructure so the TC becomes directly accessible from the parking tracks seemed to be a promising solution. However, during a second workshop it became clear the adjustments to the infrastructure created a logistic process in which the same kind of problem will occur as on the access-track. The extra investments and delay of the construction of the TC do not equal the benefits of adjusting the infrastructure. Therefore the selected alternative is to implement the time windows on the access-track, to be able to shunt trains to and from the TC 24 hours a day. A list of requirements and wishes has been drawn up to which the processes on and around Ctw have to comply in order to keep the accessibility of the TC as best possible.

The design workshop and method used has been experienced very positively by the participants. For the scientific experiment it has been concluded that the addition of multi-perspective visualization within an SBD process enhanced the level of SU. The approach has been experienced as successful and is intended to be used in the design process for the other 3 TCs. Besides the supported solution for the logistic problem on Ctw the effect of this research is even larger. Involved actors perceived the added value of a collaborative design process, which have led to collaboration between several actors already. So not just the logistic processes and accessibility of the TC on Ctw are guaranteed but also a culture change is enabled and put in motion.

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1. Introduction

Each week 185 trains have to be serviced within the 4 main service facilities of a marshalling yard near Utrecht, with 4845 meters of parking tracks and 31 switches. The process controller of this marshalling yard has to solve this enormous puzzle each and every day, but does never succeed in laying the puzzle without conflicts or concessions. Even if the best process controller tries to solve the puzzle it still will lead to a misfit. This is caused by safety issues raised by ProRail affecting the puzzling or because the puzzle pieces even do not fit each other, for example the order in which trains are shunted to and from the marshalling yard by the NS. It is a dynamic and complex puzzle, for which NedTrain would like to have a satisfying solution.

1.1 Design of complex systems

Large technological systems are due to its complexity hard to manage. These systems often perform in an environment in which a large set of different actors are involved, which makes it even more complex. Due to the multi-actor environment in which the design will be made the complexity within the design process increases, caused by the number of stakes and perspectives of actors, dynamics within this environment by actor interaction and uncertainty in the behaviour of actors involved (Xia & Lee, 2005). Therefore the design of a new system or artefact in a multi-actor environment can be described as creating understanding and definition of a problem and solving it through the process of finding a satisficing solution for all actors (Simon, 1996).

This design processes in which multiple actors are involved can be described as a multi-actor design, in which an iterative process is leading and all actors try to achieve their own goals (Fumarola et al. 2011b). Due to the complex environment and large set of actors these goals sometimes conflict with each other, which can lead to a capricious design process, resulting in unforeseen and unintended effects of the design process (Pruyt, 2010). Due to the fact that systems and its technology are becoming more complex and dynamic it is not feasible to master all the knowledge required to design a complex system. Collaboration between experts in different domains is therefore required to make a successful design (Piirainen et al. 2009).

A collaborative design approach is often used in the design for all kinds of physical but also informational artefacts. The interaction between all actors working on different elements using their own professionalism and knowledge of these elements leads to an approach so there can be dealt with the complexity of the design problems (Klein et al, 2003). However, within collaborative design processes there are several challenges to cope with.

To prevent for dissatisfying design results within collaborative design processes it is important to create a high level of shared understanding among all actors within the multi-actor environment (Piirianen et al. 2010). To increase the quality of design outcomes from a multi-actor design process it is therefore important to create a high level of shared understanding for solving the problem by finding a satisficing solution for all actors (Piirainen et al. 2010). The aim for collaborative design brings a lot of challenges, in which the creation for shared understanding is very important as Piirainen et al.(2009, p 248) note; “In addition to regular design challenges concerning e.g. stakeholder and requirement negotiations, collaborative design requires additional organization, negotiation and building of shared understanding on the issues concerning the design.” The importance of a high level of shared understanding is stated moreover by Conklin (2009 p.18); "The 'Holy Grail' of effective collaboration is creating shared understanding, which is a precursor to shared commitment."

The tool of simulation is used to solve the challenges and meet requirements in a multi-actor design as described by Piirainen and support decision making in different situations (den Hengst et al. 2007). However, technological systems are often simulated from a hard systems perspective in which the current and desired state of the system are taken for granted and the problem for which the system should be designed is structured. But the decision making process in a multi-actor environment is of a soft system perspective, which means problems are ill defined and unstructured and the design process is not goal-oriented (Fumarola, 2011 & den Hengst et al. 2007). Using simulation as a tool to understand complex problems and support the discussion among actors is a chance to combine these two system approaches (Robinson, 2001). The combination of these approaches should resolve the problem acknowledged by Ackoff that there was no attention for the decision making process in Operations Research (OR) and Systems Engineering (SE) (Fumarola et al., 2011b & Ackoff, 1979). Simulation in a multi-actor environment to support the design process is proved to be an effective soft OR technique (den Hengst et al., 2007 p. 670); "Collaborative simulation is a method for problem situations that are technologically and socially complex with diverging values and interests.".

Combining soft OR principles with the simulation methodology creates a set of opportunities within multi-actor design processes. Examples are; acceptance of outcomes (driven by a better understanding of the system), shared understanding, stakeholder involvement, higher quality of the used model and efficient model use (den Hengst et al, 2007).

From NedTrain there was a request for a new shunting process design i.e. a shunting plan for one of their marshalling yards. Like in most of all design processes, within this design process the soft and hard systems perspectives should be combined (Robinson, 2001). Simulation is concluded to be a promising tool to support this process. Especially the distributed actor field in which the marshalling yard and its processes are situated increases the complexity of the design process. In these complex design projects more and more the methodology of Simulation-Based Design (SBD) is used (Fumarola et al.2011 & den Hengst et al. 2007). Using the complementary SBD frameworks, which integrate the soft system methods within the hard systems approach, multi-actor design processes leave more room for negotiation and mutual learning (Huang et al., 2012). This framework is developed for the facilitation of a design process with multiple actors and aims for the creation of a higher shared understanding.

However, using simulation as a supportive tool for design processes within SBD still have its limitations. From an evaluation study on using simulation as a support tool during decision making processes led to discussion on the contribution of simulations to a higher shared understanding and in the end a high quality design which satisfies all actors. Fumarola et al. concluded that a lack of different perspectives exists within the design processes of the SBD approach (Fumarola et al. 2012b). This could result in unintended results of the design process since actors try to have intuitions from a single perspective simulation. Simulating and visualizing the particular system from a single perspective reduces important information about the reality, which is critical to get a better understanding of the system (Bürgi & Roos, 2003). Therefore the model should provide a simulation including different perspectives, so each actor perceives the system in his own way (Tekinay et al. 2010 & Fumarola et al. 2012b).

The gap identified in the methodology of SBD should be resolved to increase the utility of simulations within design processes. A simulation in which several perspectives are included should contribute to a higher understanding of the system and result in a better design for an artefact. By adding a set of visualizations on this simulation so that each actor can identify himself with the system can resolve the problem encountered within SBD.

Within this thesis report the conclusions on the effect of multi-perspective visualisation will be drawn from the design project for a new shunting process on a marshalling yard of NedTrain. In the next paragraph the research will be discussed in more detail.

1.2 Design Science Research

The methodology of Design Science Research has been used for the development of a more suitable SBD method within a multi-actor environment. The effect of multi-perspective visualization has been examined during the design for a new shunting plan on a marshalling yard of NedTrain.

The methodology of Design Science Research (DSR) has been chosen because it creates the opportunity to perform research and improve methodologies during the design for an artefact or theory within a specific environment (Kuechler et al. 2008 & Hevner et al. 2004). The environment in this case is a marshalling yard of NedTrain, on which trains are serviced. For the design process the methodology of SBD has been used to come to a satisfying design for the shunting processes on the marshalling yard of NedTrain. At the same time the effect of multi-perspective visualization on the level of shared understanding has been examined. Figure 1 gives an illustration of the way in which the design for a new shunting plan can be used to draw conclusions on the improvement of the design method used; Simulation-Based Design.

Because the research focussed mainly on the case at NedTrain, the case study research methodology of Yin has been used to justify and evaluate the use of multiple perspective visualization within an SBD project (Yin, 2003). The case of NedTrain will be discussed in the next section.

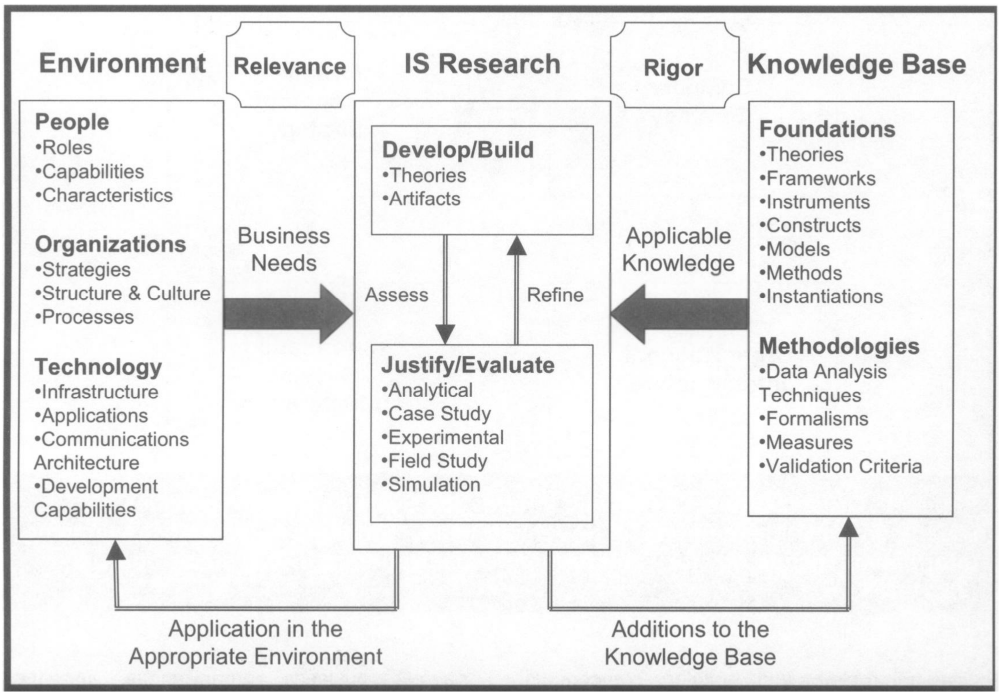

Figure 1: Information Systems Research Framework (Hevner et al. 2004)

1.3 Background case NedTrain

The strategy for planned and unplanned maintenance on rolling stock is for a change within NedTrain, the maintenance and overhaul company of the Dutch Railways. At the moment Service Centres (SC) of NedTrain can provide planned and unplanned maintenance 24 hours a day on locations scattered around The Netherlands (NedTrain, 2012a). In these SCs small maintenance can be serviced on all different type of trains. Large maintenance is serviced in Maintenance Centres (MC), which also operate 24 hours a day. Technicians working within the SCs should have expertise in the corrective maintenance of all type of trains and its systems (Busstra, 2012). These enormous amount of knowledge and ability to maintain all these type of systems is too much to deliver for a high quality maintenance service, because certain defects occur just once a year or even less. The effect is that repetitive defects occur on trains on the short term (Busstra, 2012 & NedTrain, 2012). This recurrent defects on trains costs a lot of money, claims a lot of capacity on the marshalling yards and in MCs, but most important the customers of NedTrain get dissatisfied.

The development of new Specialized Service Centres (SSC), in which larger maintenance jobs can be serviced to disburden the MCs is part of the new maintenance strategy of NedTrain. NedTrain will build new Technical Centres (TCs) located on the site of the SCs. Maintenance jobs which normally had to be serviced by the MCs are shifted to SSCs, which will be specialized for 2 to 3 different type of trains in order to increase the quality level of their service (NedTrain, 2012). To complete the new strategy personnel will be educated towards a higher level, to guarantee a higher quality level of maintenance (NedTrain, 2012).

On one of the service locations in Utrecht a first implementation with this new strategy will start soon. The development of the proposed TC is in progress and should be delivered by October 2013 (Smid & Busstra, 2011). The expected result of this new strategy including the construction of a new

TC and training of personnel is a more effective service on maintenance. This should result in less recurrent defects on trains, shorter lead times of trains under maintenance and a less disturbed planned maintenance in the MCs. This complies with the innovation perspective of NedTrain, in which the First Time Right principle is leading (NedTrain, 2012 & Busstra, 2012).

In the current situation on the location in Utrecht, Cartesiusweg (Ctw), the shunting processes do not align with the capacity of the service facilities. On this service location there are several service facilities like the Train Wash Installation (TWI), High Service Platform (HSP), Anti-Icing Installation (AII) and Service Pit (SP) in which small maintenance can be provided. Due to the unstructured shunting process the service facilities on this location are not used in an optimal way, especially the TWI (Busstra, 2012). This inefficiency should be eliminated, certainly in the near future when the first implementation is started with the new SSC. When the shunting processes do not align with the capacity of the service facilities, the effect of the new SSC will not be as big as it could be. Therefore it is desirable to make a shunting process design for the marshalling yard Ctw in the near future, but especially when the implementation with the new TC is started in October 2013.

As can be concluded from the previous section it is desirable to design a new shunting process for the marshalling yard Ctw and its service facilities. Because there are a lot of actors involved in the shunting process the design process can be considered as one within a multi-actor environment (Piirainen et al. 2009). Therefor this case is very applicable for the proposed DSR project.

1.4 Research objective

The aim to design a new shunting process design and to take advantage of the opportunity to close the gap identified within SBD can be formulated into 2 specific objectives for this research. To be able to comply with these objectives several research questions are composed.

The objective of this thesis project is twofold. Since this research has been performed by applying and testing new approaches within SBD it was a scientific oriented project which used a practical problem/project as research case. Therefore the project has 2 main objectives of which the first one is practical.

1. Development of a new multi-actor supported design for shunting processes on the marshalling yard Ctw
2. Creating insight in the effect of multi-perspective visualizations on shared understanding within a s multi-actor simulation-based design process

1.5 Research questions

For the overall research project a main research question is composed. Because of the twofold objective of this research project, the sub questions are divided into scientific and practical questions.

1.5.1 Main research question

To what extent does the addition of multi-perspective visualization contribute to an enhanced shared understanding in the multi-actor simulation-based design process for a logistic process design on a marshalling yard?

1.5.2 Scientific sub questions

1. Which simulation-based design approaches are available and which can be used best to support the design process for the case of the design for a new shunting process at the marshalling yard Ctw?

2. Which actors are important to involve in the multi-actor design for a new rail infrastructure control design?

3. How can the different actor perspectives on the marshalling yard system be visualized and which visualization is the best to enhance shared understanding?

4. How can shared understanding be operationalized and measured?

5. Do actors experience a higher shared understanding after they went through the design process with the support of a simulation model and the addition of a multi-perspective visualization?

6. Do actors experience a higher shared understanding and improvement of the design process using a simulation model with multi-perspective visualization instead of a design process with a single perspective visualization?

7. Does multi-perspective visualization help to resolve dilemmas during the decision making process?

8. Will the addition of multi-perspective visualization to the method of SBD be successful in other design projects for logistic processes on a railway network or even an SBD project in general?

1.5.3 Practical sub questions

1. How does the current shunting process look like on the marshalling yard Ctw in the current situation and in the future?

2. What are the requirements of NedTrain for the new shunting process design?

3. What are stakes and KPIs of involved actors?

4. What are alternative solutions to improve the process on the marshalling yard Ctw?

5. What is the effect of the new shunting process on actors KPIs?

6. Which alternative solutions should be implemented to improve the performance of the SC at Ctw in the future situation with a TC?

1.6 Project demarcation

Due to the twofold character of this project, the scope can also been divided into a scientific and practical one.

1.6.1 Scientific research

Research has been performed on the effect of multi-perspective visualization on the enhancement of shared understanding within simulation-based design for a new shunting process design. This case study research has not been used as an evaluation study for frameworks or methodologies currently developed in the area of simulation-based design or soft OR methods like the ten-step design method for simulation games and the simulation-based design framework for large scale infrastructure design (Fumarola et al. 2011; Fumarola et al. 2012; Tekinay et al., 2010 & Huang et al., 2012).

Within the scientific experiment on the enhancement of Shared Understanding (SU) the definition, operationalization and assessment method for SU has been defined to be able to conclude scientifically on the effect of the use of multi-perspective visualization. To strengthen the scientific conclusions a reference case has been used which is the design process of a shunting plan at the marshalling yard Watergraafsmeer.

1.6.2 Case study

The project focussed on the shunting processes on Ctw. Therefore the geographical delineation was the border of the marshalling yard. Secured rail sections of the main rail network under control of ProRail on which passenger trains run were not included in this research. The actor delineation was a lot larger, because the influence of external actors on the processes on the marshalling yard can be of a large extent.

Within the research only the soft process side of the marshalling yard has been analysed. Adjustments to the hardware of the marshalling yard were not an option for NedTrain, since ProRail is the owner of the marshalling yard. After the research was performed a post study on infrastructural adjustment to improve the logistic processes on Ctw was still executed. Since this was not within the scope of the research originally, a short explanation of this post study is given in the discussion section.

In order to come to an optimal marshalling process, the timeframe of this research was twofold. First of all the current situation has been analysed and simple adjustments to the shunting process have been discussed. The second time frame is the moment in which the new SC is in operation, starting December 2013. Discussions on the alternative solutions to implement were primary based on the second timeframe.

Because service demand on the rolling stock is changing over days and seasons, for each time frame 2 situations have been simulated (Bloem, 2012). The 2 situations are: summer and winter. For each of the categories a shunting process design was made using the multi-actor simulation-based design approach, taking into account the variation of defect trains within these situations.

Alternatives for a new shunting process were created in dialogue with actors involved. The following explains exactly how this worked out : 'the puzzle pieces are collected and shaped together into several alternatives by the researcher and together with the actors the puzzle will be solved'.

1.7 Research approach

To get useful answers on the design questions established in section 6 several research methods are used. The overall research project approach can be consulted in Appendix 1. A short description of important elements of the research will be discussed in next paragraphs.

1.7.1 Design process

For the simulation/experiment phase (3) of the research project there has to be created a thorough process design to structure the design process. Different alternatives for this design process will be examined and reflecting these alternatives on the environment in which the design process will be used the best design process will be chosen. This will be done on the basis of a literature study and analysis of the design process at Watergraafsmeer (Wgm). Because the design process in the design for a new shunting plan at Wgm will be used as a reference case, the design process which will be used in the case study on Ctw has to align with the one used at Wgm.

Depending on the willingness to cooperate and active participation of the actors the design process could be synchronous or a-synchronous. In the current situation and culture within the rail sector different actors are not used to interactively and jointly have a design or decision making process. According to Fumarola it is wishful to have all actors together working as interactive as possible towards a new systems design. In the design process the collaborative exploration of the solution space is extremely important, which requires a good understanding of the model (Fumarola, 2011b & den Hengst et al. 2007). To create the most effective collaborative design process the collaboration should already start before the actual simulation study is performed. "It can be concluded that to better support decision makers in a multi-actor environment, a multi-methodological approach can be used wherein simulation is used as a tool for conceptual design and discussion" (Fumarola et al., 2011b, pp. 124). Actors should therefor already collaborate in the early stage of the design process to get a thorough understanding of the systems complexity. This is also the conclusion of Fumarola et al. (2011b, pp. 115); "Modelling becomes a way of communicating between stakeholders and the stakeholders should be involved into the modelling effort from the very beginning." For both situations there will be an approach;

For the creation of shared understanding a synchronous design process was wishful. According to Mulder, Swaak and Kessels "synchronous settings are more suited for reaching shared understanding" (Mulder et al. 2002, p. 2).

Therefor the design process has been synchronous. The purpose of the process design was to create a setting in which trade-offs in stakes and interests can be managed, design can be made supported by a multi-perspective simulation model and results can be evaluated on actors KPIs.

1.7.2 Enhancement of shared understanding

In order to be able to draft conclusions on the effect of multi-perspective simulation on the enhancement of shared understanding pre-post tests will be used. Within the pre-test and post-test surveys were held in which questions have been asked to conclude on the level of shared understanding. Comparing the pre and post tests will give insight whether or not there is an increased shared understanding. A study on the perceived utility of multi-perspective simulation can invigorate conclusions of the pre- and post-tests. This will be done using a reference case; see next section.

Before these tests could be performed a clear definition and operationalization of shared understanding has been made. This has been done through a literature study, resulting in a survey including questions which support the construct of shared understanding. A first study on shared understanding led to an assessment framework to assess the level of shared understanding, which can be used to construct the survey (Mulder et al. 2002).

1.7.3 Multi-perspective visualization

For the visualization of actor perspectives a various set of alternative type of visualizations is available. The selection which visualization for a particular actor can be used best had to be made. It is important to end up with a multi-perspective visualization in which each actor can identify himself very well with the simulation. The visualization type used will be discussed in this thesis report and has been defined through interviews with actors and participants.

1.7.4 Test of new design process

Together with the chosen type of design process, the multi-actor simulation-based design process with multi-perspective visualization is developed. Whether or not this lead to an enhancement of SU will be tested on the case of NedTrain for the design of a new shunting process design at Ctw.

Moreover, the design process of Wgm will be used as a reference case in the research on the use of multi-perspective visualization. A clear description of this design process is necessary and the passive participation of important actors from that process is essential in the case study of Ctw to draw conclusions on the perceived utility of using multi-perspective simulation.

Impact of the designed shunting processes on KPIs will be evaluated using the same strategy of pre-test and post-test. To be able to give a good conclusion on the effect of this new shunting process the current situation and score on KPIs will be made explicit as well.

1.8 Thesis outline

The next chapter will give insight in the theoretical background of Simulation-Based Design, the design processes relating to this design approach, visualization used within simulation and discusses the construct of shared understanding. This chapter will be supported by the discussion of a recently performed design process similar to the case of Ctw, in which problems were recognized as identified by authors in the field of Simulation-Based Design. In the third chapter the background of the case study will be given, including a thorough actor analysis to determine which actors were critical to involve in the design process, so with which actors the design experiment was held and which design problem had to be resolved.

The setup for the experiment to test whether or not multi-perspective visualization contributes to an enhanced shared understanding is described in the fourth chapter. Within this chapter the process design will be drawn up, based on the theories and process design tools discussed in the second chapter. The results of the experiment will be discussed in the fifth chapter including a short analysis of what the design results mean for other SBD projects. Conclusions and recommendations on the scientific theoretical part of the research as well as on the practical design objectives will be given in chapter 6. Within chapter 7 the discussion on the findings for both the scientific and practical research is continued, with a reflection on the contribution of this DSR. The final chapter will give a reflection on the research project.

2. Background

The design for a new shunting plan at the marshalling yard Ctw can be concluded to be quite complex. Therefor a design approach is necessary so there can be dealt with the complex character of the design assignment. Simulation-Based Design is a very good design approach within these kind of environments as can be concluded already from the introduction. This methodology will be discussed within this chapter, followed by alternative design processes to be followed. The problem identified briefly in the introduction according to multi-perspective simulation is reflected on a recently performed design process at another marshalling yard of NedTrain. The proposed solution to resolve this gap or problem and to create a higher level of shared understanding is discussed in the third section, after which the construct of shared understanding will be elaborated in the final section.

2.1 Simulation-Based Design

For the design of complex systems Simulation-Based Design (SBD) is a prominent method to use. As discussed in the introduction most of the technological systems are not just complex because of its technological complexity but also due to the complex environment in which the systems perform. In these kind of multi-actor environments designs have to satisfy the actors involved, which means trade-offs have to be made between conflicting values and interests of these actors (Ding et al. 2009). The design for technological systems is therefore not just designing the most optimal technical solution, but also managing these trade-offs in the most optimal way. Simon denotes this as satisficing, in which the designer should compromise between satisfying actors and optimizing the system to be designed (Simon, 1996).

Because the design process for large technological systems is very complex due to the various professionalisms working on the design in parallel, a large set of tools has been developed to support the design process (Cho & Eppinger, 2005). One of the most prominent tools include simulation and optimization approaches, which are widely used to support decision making processes (Halim & Seck, 2011). Especially simulation is an outstanding tool in situations in which the experimentation and evaluation of designs is not possible because the system does not lend itself due to several reasons; too expensive, dangerous, impractical or even totally impossible (Daalen et al. 2009).

Because of the several opportunities which simulation offers, simulation techniques are more and more integrated in design processes. For the design assignment of NedTrain the choice for SBD has been made, in which a simulation of the shunting processes on the marshalling yard supports the design for a new shunting plan. The design for the marshalling yard in which the most optimal design should be made (hard systems thinking) can be combined with the soft systems thinking within the multi-actor setting in which the system performs (Huang et al. 2012). Fumarola et al. give a good summary of the potential of SBD; 'Participative simulation sessions have the potential to support the design processes: (1) in a multi-actor environment with diverging stakes, and (2) without ignoring the fact that human decision making relies on implicit knowledge that is insufficient and unreliable to evaluate decisions, thus requiring simulation for support.'(Fumarola et al. 2011b, p 107).

However, the use of simulation in design processes still raise inefficiencies or has negative side effects (Fumarola et al. 2010 & Tekinay et al. 2010);

- The construction of simulation models is time consuming
- Specialized skills are required for the construction of simulation models
- For an interactive design process as in SBD, simulation is not very applicable because of the lack of knowledge on Simulation and Modelling of participants
- Single perspective simulation models conflicts with the multi-actor environment in which SBD is used.

Tekinay and Fumarola already discussed and experimented with solutions to posed inefficiencies of the current use of Modelling and Simulation (M&S) in multi-actor design processes. The diversion of the simulation model into smaller parts, so kind of model components are created are introduced to ease the construction of models. Creating libraries with predefined components should help to develop a simulation model faster and participants can be invited more easily to co-develop a simulation model (Fumarola, 2010 & Tekinay, 2012). Using this component based modelling principle the construction of simulation models can be fastened. Specialized skills are not necessary anymore and because of that participants can interactively develop a simulation model for the support of a multi-actor design.

However there is still much room for improvement, especially because the inefficiency of single perspective simulation is still not addressed. As Fumarola et al. denote: ‘The design process of infrastructure systems is multi-actor by nature in which every actor has its own interests and perceives the system in his own way. Therefore, the models should support different perspectives from various actors.’ & ‘… the existing designs lack a common consistent framework resulting in a single perspective and statically defined models at different resolutions.’(Fumarola et al. 2010 p. 292).

In a recent design process for the same type of design assignment corresponding problems were identified (Wieten, 2012). In next paragraph first of all design processes available for SBD will be discussed, followed by the discussion of the design process used within the design project at Watergraafsmeer.

2.2 Design process of SBD

The design process of an SBD project can be arranged in a lot of different ways. Alternatives on how to arrange this process are discussed in the first paragraph. Tools to structure the design process in detail are discussed in the second paragraph. Subsequently the design process used in the case of Watergraafsmeer is discussed and reflected on the theory of SBD in the final paragraph of this section. A final decision on which design process to use and how to arrange this process will be made in the fourth chapter, based on this case and on the analysis of the design case at Cartesiusweg.

2.2.1 Alternative Simulation-Based Design processes

Three different frameworks have been found for the foundation of an SBD process or a process in which simulation facilitates a design process. These are the ‘multiple worlds’ framework of Fumarola, a cross paradigm framework of Robinson and a modelling approach for collaborative design sessions by den Hengst et al. (Fumarola, 2011c; den Hengst et al., 2007 & Robinson, 2001). These approaches will be discussed and are alternatives for the design process to be drawn up for the design process at Ctw.

Multiple Worlds

Fumarola performed research on the use of simulations within SE and concluded that the hard systems thinking of SE should be adjusted in order to benefit more from simulation and to integrate soft and hard system thinking like the Soft System Methodology (SSM) (Checkland, 1981). SSM is a multi-methodological approach, which combines the soft and hard systems thinking; "Whereas hard systems approaches assumes a system that is perceived equally by all actors, soft systems approaches discuss systems as a human's view on reality, hence a human construct used for understanding. In contrast with hard systems thinking, SSM does not focus on the solution, rather on a learning process actors go through while dealing with the problem situation." (Fumarola, 2011c p.46).

Fumarola has constructed a framework for an SBD process and serve as a base for the design process in which a multi-actor group aims for mutual understanding and agreement through simulation. This method is named 'multiple worlds' (figure 2).

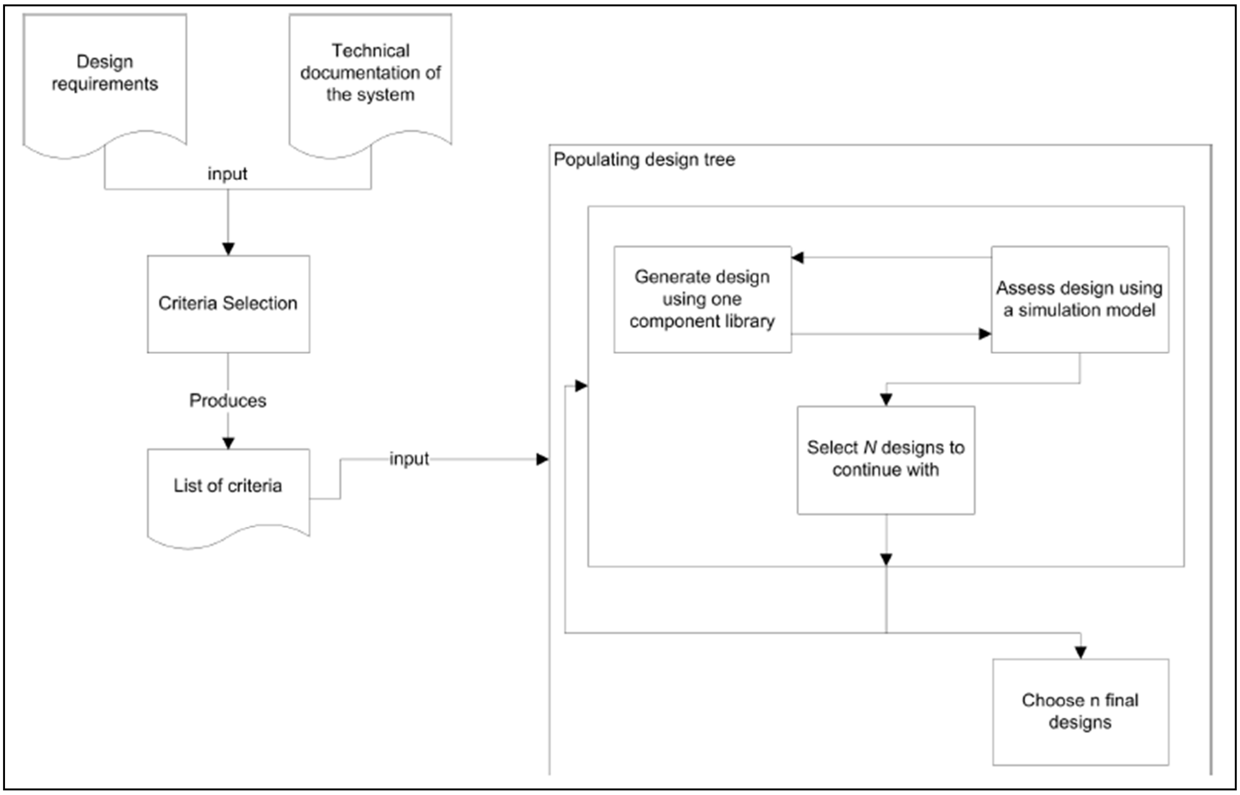

Figure 2: Multiple worlds design method for SBD (Fumarola, 2011c)

The first step in this design process is to retrieve information about the system to be designed and the environment in which the system has to perform. The program of requirements and the retrieved information are the starting point to set up criteria to which the design has to address. From there on the modelling of the system starts and through iterated design steps the design gets more and more detailed. Starting with a high aggregated simulation in each next design step more detailed simulations are made for design alternatives. To complete a design round each actor assesses the different alternatives on his individual and on collective criteria. Finally the choice will be made on the best design alternative among all actors (Fumarola 2011c & Huang et al. 2012). Using this framework as a guideline for the design process, steered by simulation of each design alternative, results in an iterative design process.

Reflection on this design approach brings the conclusion that the process creates a lot of communication and insight of actors in their systems and systems of other actors resulting in a better design result. However, as already been discussed in the previous section and in the introduction, simulation is time-consuming and needs a lot of effort by actors to participate, especially because of the intensive use of simulation in the design steps.

A cross paradigm framework

Robinson argues as well the need for a combination of hard system and soft system principles. Although he argues that simulation, especially discrete event simulation, is hardly used as a soft OR approach he performed research in which simulation is used as a soft OR technique. He concludes that simulation can be used as a very effective technique to facilitate decision making processes (Robinson, 2011). The process and steps to combine these two paradigms by the technique of simulation have been summarized in a framework (figure 3).

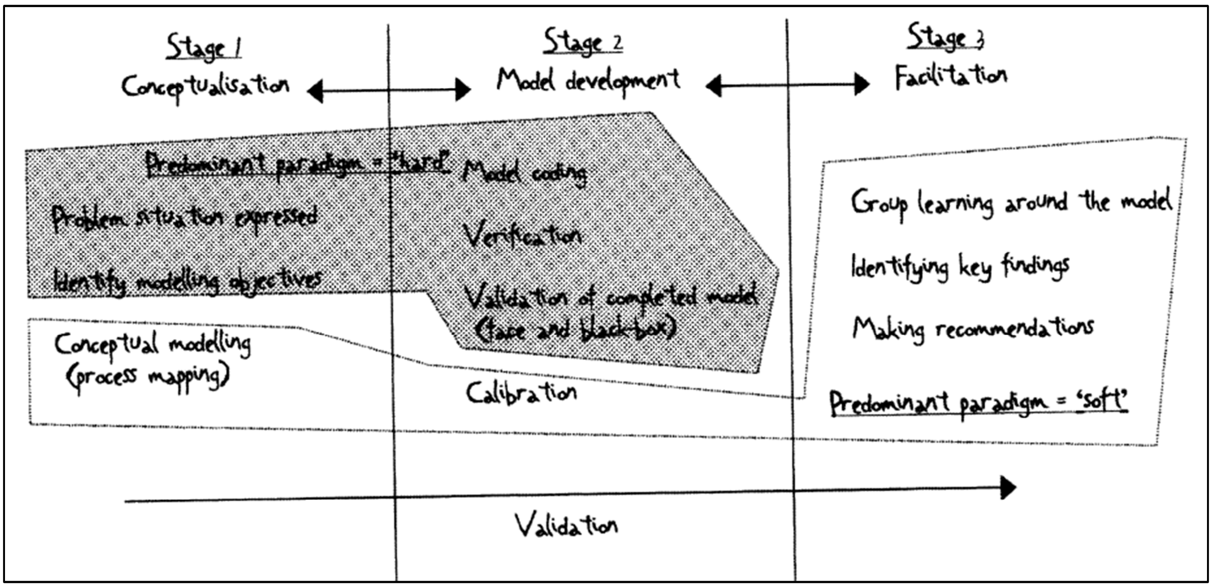

Figure 3: Cross paradigm framework for design process (Robinson, 2001)

In the figure the two paradigms of hard and soft system thinking are visualized in the two separate streams. As can be concluded form the figure especially the hard system thinking is aimed at the problem delineation and model development, which is combined with the conceptual modelling and calibration steps from the soft systems thinking stream. In the third stage only the soft system paradigm is present because this includes the final design process in which actors interact and negotiate on a final design. A quote from Robinson underpins this conclusion: "What it shows is a tendency to move from the 'hard' OR paradigm to the 'soft' OR paradigm as the study progressed. This may seem counterintuitive, in that 'soft' OR is normally associated with problem structuring, and 'hard' OR with problem solving, suggesting a movement from 'soft' to 'hard' during the lifecycle of a study" (Robinson, 2011 p.914)

The framework clearly distinct 3 stages in the design process; conceptualization, model development and facilitation of the design/decision making process. As can be concluded form the research performed by Robinson, the framework describes quite a linear design process on the first hand. However, there is definitely a need for iteration to verify and validate the design stages as discussed by Robinson (2001, p 913); "The double arrows aim to demonstrate that this is not a linear process, but that there is a need to iterate between the stages, and indeed the sub processes". The iteration is represented by the double arrows between the 3 stages as shown in the framework and a continuous validation is necessary and integrated in the framework by the arrow at the bottom of the figure. To conclude, the approach drawn up by Robinson does succeed in the integration of hard and soft system paradigm and is a suitable approach in complex design processes. However, the iterative character of the design process to be followed does not follow clearly form the framework and can cause a very structured design process with too less attention for mutual agreement and validation between actors..

Modelling approach in a collaborative design session

Den Hengst et al. performed a research in which they used the framework of de Vreede to structure a collaborative design process, in which simulation is used as a soft OR method to connect the soft and hard principles of the system to be designed (den Hengst et al., 2007). The framework is designed by de Vreede et al. and can be used in collaborative design sessions supported by simulation. The framework is illustrated in figure 4.

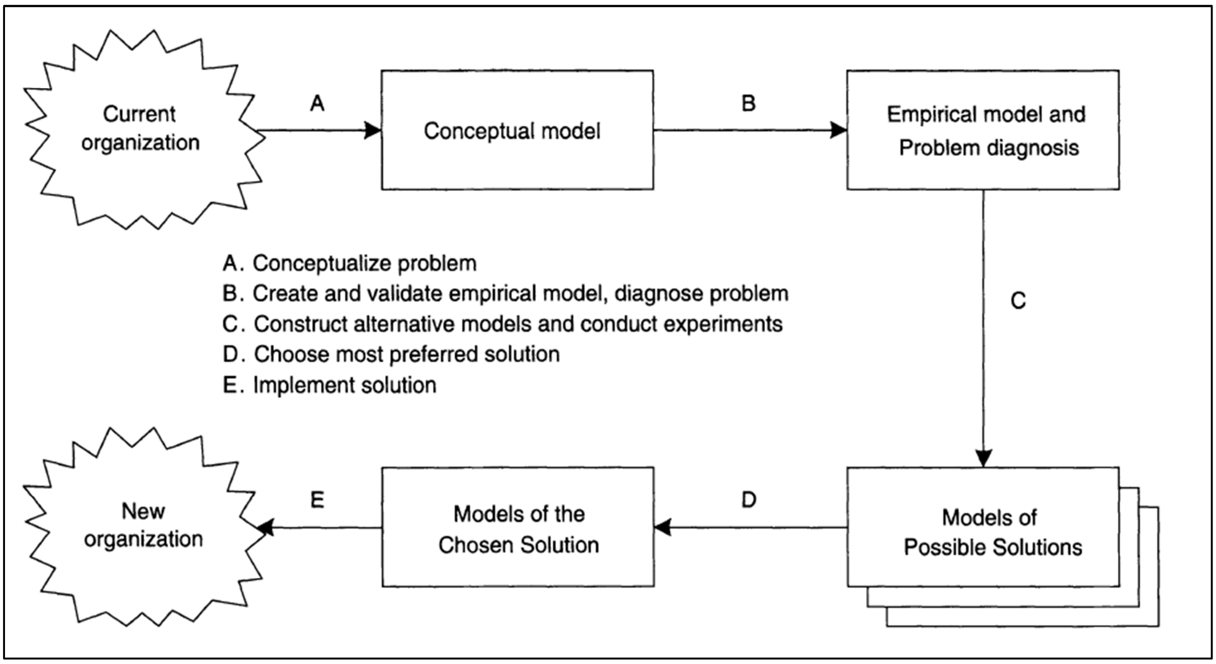

Figure 4: Modelling approach in collaborative design sessions (Vreede et al., 1996)

From the framework illustrated there can be identified 6 main steps, which are translated in the research of den Hengst et al. into 6 steps for a design process supported by a simulation model (den Hengst et al., 2007);

1. Define the problem and develop a simulation model to diagnose it
2. Validation of the simulation model in a group session and establish the conceptual model of the system to be addressed
3. Construct of collaborative design process, first discussion on alternative solutions and create an empirical model in group session

4. Validation of simulation results on all alternative solutions in group session
5. Adoption of the simulation model and analysis of outcomes for most promising alternatives in group session
6. Choosing the best alternative to point on the company's direction in the future (implementation of solution)

Within the design steps as described by den Hengst et al. there was much attention for the validation and verification of the results of design steps. In each of the design steps there was much attention for the collaborative group work, as well as the group wise validation of the simulation model. A remark to this collaboration was the absence of managers in the beginning of the project. As a conclusion from the research of den Hengst et al. the validation of the simulation model and the design alternatives within all steps in the design approach is a time consuming activity and not always effective. As den Hengst et al. conclude; "The most meaningful validations took place when model results were shown to operational staff " & "The first and second validation session did not add much value to the process…" (den Hengst et al. 2007, p 677).

2.2.2 Tools to draw up the design process

The different frameworks to be used as discussed in the previous section should be materialized to make the design processes explicit. Which design step will be taken on which moment, under presence of which actors and what are the rules of the game in these design steps should be drawn up to structure the design process and get valuable design steps. For drafting the explicit process design there are just a very few guidelines or frameworks to be found.

Mainly de Bruijn et al. describe a thorough guideline for drawing up a good design process. They summarized this guideline in a framework, which is elaborated on in appendix IX (Bruijn et al. 2010). Besides this guideline a description of process management in design sessions is set up by Jorvig (Jorvig, 2005). Furthermore no clear guidelines and/or theories on how to draw up or manage a design process have been found. In next section the guideline of de Bruijn et al. and of Jorvig will be discussed.

Framework the Bruijn et al.

The framework developed by the Bruijn et al. provides a very detailed guideline for drawing up a process design, in this case for the design process of a shunting plan at the marshalling yard Ctw. The description of the framework given in one sentence by the authors is; 'activities for making a process design'. The guideline proposes clear steps and activities which can be summarized into;

- Explore the problem
- Make an actor scan
- Couple problems and issues of actors
- Initiate the agenda by discussion on dilemmas
- Order the process design for in depth discussion between particular actors
- Set up rules of the game on aspects like time duration, accuracy of the output of the process, which actors are involved in which session, is the process confidential, what are the organic and decision making rules and what is the budget for the design process
- Test the process design

- Staffing and participation of actors, which will be the representative and should there be consent among actors on representatives of others

A detailed description of this guideline is given in appendix IX.

Guideline by Jorvig: managing your design process

Jorvig emphasizes the importance of a process leader in managing design processes. He poses that there should be an individual which independently from the content of the design should keep track of the design process and securing the procedural decisions. “The “Design Process Leader” is an individual on the design team that is responsible for managing all aspect of the design process. He or she is responsible for all the decisions as to how the design will be completed” (Jorvig, 2005 p. 6). Jorvig continues his argument by listing a set of skills which the process leader should possess.

It can be concluded from the paper by Jorvig that the guideline provides just a set of elements which the process design should include. As already mentioned the most important element to create a structured and valuable design process is a process leader. This process leader is deemed to be responsible for a list of activities, which is added in appendix X.

This guideline thereby just gives a set of elements to include in the process design, but advice on how to draw up and include these elements is lacking. When the framework of de Bruijn et al. is compared with the guideline drafted by Jorvig it can be concluded the first to be the most expedient in order to materialize the process design.

2.2.3 Design process at reference case Watergraafsmeer

Recently a similar design case as to the design case on Ctw has been finished at the marshalling yard Watergraafsmeer (Wgm). In the design for a new shunting plan at Wgm there has been used a design approach in which some simulation has been developed to support the design process. Therefore this case lends itself well to verify problems with this design approach and confirm whether or not these are the same as marked by Fumarola et al., den Hengst et al. and Robinson. Moreover this can give a validation of the problems acknowledged using SBD. It is even more interesting to analyse this case to have reference material during the design experiment for a new shunting plan at Ctw.

At Wgm there was an urgent need for a shunting plan because this was a requirement to continue with reorganization of key functions in the shunting process (Ouali, 2012). This requirement was imposed by the Employees Council (EC) of NedTrain and aimed to simplify the activities to be performed by the traffic controller. Detailed requirements for the shunting plan were not specified by the EC, just that the train movements on Wgm should be planned and each train movement should be made explicit. On Wgm they have the fortunate circumstances of no extra train arrivals (EBKs), which makes it more easy to develop a shunting plan. First of all the design process will be discussed, followed by some problems encountered during this process according to simulation and visualization used.

Design process of shunting plan Wgm

The design process walked through has been analysed with the project leader at Wgm. From an interview it can be concluded the design process consisted of 3 main steps or stages (Wieten, 2012);

1. Defining program of requirements and criteria

2. Designing first concept of shunting plan in cooperation with Process Control Logistics(PCL) and in dialogue with the department of local logistics planning in Utrecht (BLP)
3. Final design of shunting plan and implementation

During the first stage the PCL of Wgm was consulted to support in drafting the program of requirements. No other actors were involved, since the project leader had been employed before at one the most important actors responsible for the local logistics planning (BLP). Therefore this actor was not consulted in the first stage of the design process, because all criteria to be aware of were already known.
Within the second stage there has been started by drawing up a concept shunting plan in cooperation with the PCL of Wgm. Each arriving train as planned on the amendment sheet of BLP has been scheduled and planned for shunting movements to service facilities. Each train movement has been written in an excel template, as well as the planned service and maintenance for this train. The same procedure was used for the departure of trains, of which the departure time and track was given by BLP and the shunting movements had to be planned to comply with this. However, this led to some conflicts of train movements and inefficiencies. Therefore the arrival/departure time and track had to be adjusted slightly to be able to create a conflict free and efficient shunting plan. The adjustments of the input and output, the arrival/departure time and track, had to be verified and validated with BLP.
In the final stage of this design process the results of the verification and validation steps were taken into account and a satisfying design for all actors has been made by the project leader. Of this final design a simulation model has been developed, to validate whether or not this design was free of conflicting train movements.

It can be concluded the design process was clearly divided in 3 steps or stages, each with verification and validation. Despite of the conclusion that the design process was not an SBD, simulation was clearly used for the verification and validation of the final design. Visualization of the concept design plan in excel was used in consultation with other actors. Problems encountered with the simulation and visualization are discussed in next paragraph.

Simulation and visualization

A simulation has been used for the evaluation and validation of the final design for the shunting plan at Wgm. The train service on the marshalling yard was visualized by a dynamic overview of the occupancy and train movements on a graphical visualization of the marshalling yard (figure 5). The simulation brought good insight in the behaviour of the system by operation according to the shunting plan as designed, but was not used as a communication and visualization tool towards all critical actors. Just the responsible actor for the processes on Wgm, the PCL, was facilitated by this simulation.

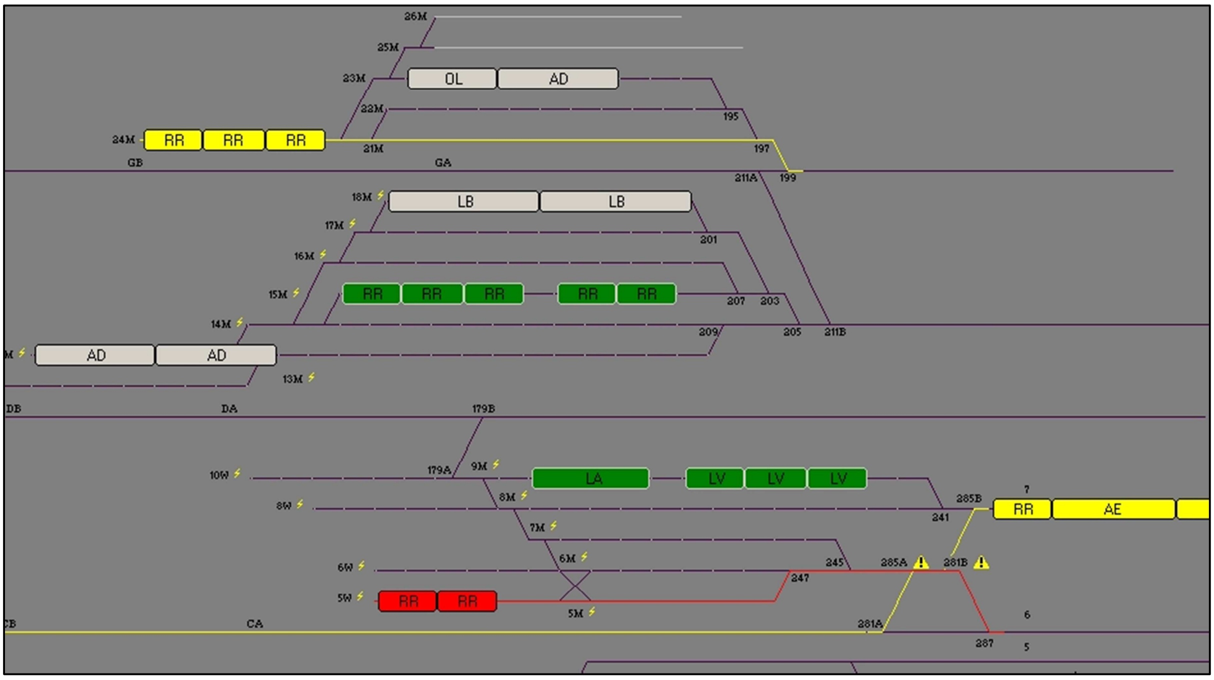

Figure 5: Visualization of train movements and occupancy on a marshalling yard

The visualization of the shunting plan during the second and final stage of the design process was simply drafted in an excel template for the communication and evaluation with critical actors. Using the excel template the same problem arose as encountered in the scientific articles; lack of multi-perspective visualization leading to misunderstanding and misinterpretation of the designed system. Therefore extra explanation was required towards the critical actors, to understand what the effects of the shunting plan were on their systems and KPIs(Wieten, 2012). An example of this template is attached in appendix XI.

Misunderstanding and interpretation mainly arose because of the designation and visualization of the tracks. An excel template does not give a good insight in the lay-out of the marshalling yard and its occupancy and train movements, which are important for critical actors to understand the system and its behaviour. The simulation as shown in figure 5 is now used by the process controllers on Watergraafsmeer, but would have been of great support as an evaluation and communication tool in the second step of the design process, because it does visualize the system from actors perspectives (Ouali, 2012).

In the next section multi-perspective visualization will be discussed, in order to provide alternatives for a multiple perspective visualization to resolve problems encountered in several researches as described in the introduction and section 2.1 as well as during the design process of Wgm.

2.3 Multi-perspective visualization

Visualization is very important for people to gain knowledge about a system, to reason about this system and to learn faster about the behaviour of this system (Yao Li 2004). As Fumarola and Tekinay already discussed there is an urgent need for a multi-perspective visualization in SBD (section 1.1 & 2.1). In the current situation not every actor can learn and reason optimally about the system to be designed because the visualization just provides a single perspective of the system.

The tool of visualization is therefore very important to understand, learn and reason on systems and its performance. It helps solving problems or understanding complex systems which otherwise would not have been resolved or understood (Winston, n.d.). It will make it even a better tool if every actor involved in a discussion is able to fully understand the system and its performance by a visualization from his specific perspective. Simulation is an abstraction of the reality and by visualization of this simulation the systems' performance is shown as it would be in reality (Han et al. 2012). If the visualization of the simulation is not from the right perspective for a particular actor, misinterpretation and misunderstanding can occur (Han et al. 2012 & Huang et al. 2012).

In the case of Wgm there was a misunderstanding between involved actors which led to time consuming explanation and a disturbed design process for a shunting plan. The actors could not understand the new processes from the excel template easily and a conversion to their system or another way to visualize the system was necessary (Wieten, 2012).

Including multiple perspectives within SBD project can foresee the problems acknowledged and also give solution to the problems encountered with the simulation used in the case of Watergraafsmeer. For each critical actor there should be a specific visualization, so shared understanding of the system and its performance is created among critical actors within the design process resulting in an effective design.

For the visualization of simulations there are numerous alternatives. Recent developments in simulation are 3D visualizations of the system to be studied. 3D visualizations are found to give a more realistic output of the simulation model, by which actors understand and interpret the system and its behaviour even better than with a 2D visualization (Han et al. 2012). Examples of simulation packages with the possibility for 3D visualization are for example Simio, Arena, FlexSim and AnyLogic of which FlexSim is concluded to be the most capable software package (Bijl & Boer, 2011). Moreover, developments in the game engine industry make it possible to build visualizations of a simulation model with standard game components. With the use of a game engine there are more possibilities, for example to rewind a simulation, stop the simulation and click on entities to check performance and state, plus the visualization can be distributed over the internet or other network, so it can be run on other locations (Bijl & Boer, 2011).

But besides graphical, realistic and real time representations of the system to be studied, visualizations of KPIs are found to be very useful by the interpretation and understanding of the system and supports the discussion between actors in the design processes; "KPIs help streamline the discussion between several actors" & "Quantitative comparison of alternatives helps collaboration between different actors" (Huang et al. 2012, p. 7).

So, at least for each single actor the effect of alternative designs on his KPIs should be made clear to arouse the discussion between actors on the design for a new system. Besides that the actors should be familiar with the visualization of the system to be studied, in this case the marshalling yard Ctw. Otherwise misinterpretation and misunderstanding can lead to dissatisfied design results as concluded in previous sections. If actors understand the system and its behaviour, also system elements which are not directly related to these actors, the level of shared understanding can be increased. The possibilities to choose between the type of visualizations (2D or 3D) and software package or game engine to use are limited. The Arena software package was available for free and I had already experience using this package. Therefore this package, which is a student version, is used and just has the possibility for a 2D visualization.

Whether or not the proposed solution of multi-perspective visualization contributes to a higher level of shared understanding and a better design result will be examined in the design experiment for a new shunting plan at Cartesiusweg. In the next section the construct and way to assess the level of shared understanding will be elaborated. In chapter 4 the visualizations for each critical actor will be composed.

2.4 Construct of shared understanding

Simulation-based Design aims for the creation of shared understanding within multi-actor design projects (Fumarola 2011c & Robinson 2001). Therefor this method is chosen to cope with the challenges of design projects in multi-actor environments (Piirainen 2009). The definition and meaning of shared understanding will be discussed, followed by the assessment method for measuring the level of shared understanding.

2.4.1 Definition of shared understanding

Shared Understanding (SU) is a conjoined term for the mutual knowledge, beliefs and assumptions by a group of actors. The amount of overlap in understanding and concepts of the particular system of study among actors can be seen as the level of SU (Mulder et al. 2002). Different actors state that the creation of SU will lead to a better performance of business processes within a multi-actor environment (Bondar et al. 2012 & Zhao et al. 2009). As Mulder denotes; '..shared understanding facilitates working and interacting effectively and efficiently. Interacting effectively and efficiently is possible when the group members use the same symbols and assign the same meanings to those symbols in their interaction processes.' (Mulder, 1999 p. 1).

During interaction, also during design processes, actors should have SU on different aspects; the content, the process and on other actors (Mulder, 1999). Together, this overall SU is important in interaction processes like for example a design process.

Through interaction between actors the SU is affected. During interaction actors exchange information which can be used to create SU. Therefore SU is not on a fixed level, but is always on-going through the interactions between actors (Mulder, 1999). The relation related interaction is about who is communicating messages and in what way. Messages from different persons can be the same, but the interpretation by others can differ a lot because of non-verbal behaviour. Interaction about the content should frame the problem so all group members have the same meaning of the problem and the problem area, 'what' are they working on. The third aspect is the process related understanding, for which actors should have the same way of communication, structure of interaction (protocols) and understanding of roles within an actor field. Actors should have a SU on how to work together (Mulder, 1999).

In literature there are a lot of alternative designations for shared understanding or terms with corresponding meaning (Nofi, 2000); Common Understanding, Team Shared Awareness, Distributed Cognition, Distributed Understanding, Group Situational Awareness, Shared Cognition, Shared Visualization, Team Awareness & Coherent Tactical Picture. All of these concepts still differ a bit from shared understanding and therefore assessment methods or findings within the field of study of these concepts cannot be used. The concept of Shared Situational Awareness comes closest to shared understanding, but only contains the observations and experiences of actors within a certain environment and the meaning which actors attach to these observations (Bolstad et al. 2005, Saner et al. 2009 & Nofi, 2000).

2.4.2 Assessment of shared understanding

In order to draw objective conclusions on the enhancement of SU, insight in the level of SU should be created. In other words, the level of SU should be measured.

Mulder has developed a quantitative assessment tool for the measurement of SU. However, this tool is not validated thoroughly (Mulder, 1999). In search for an objective assessment tool which already is tested and validated in several cases there was no result. Tools used in the corresponding theory on Shared Situational Awareness strengthened the conclusion that this theory is not applicable in the research on the enhancement of shared understanding.

The assessment model developed by Mulder can be consulted in appendix X. For the pre-tests and post-tests within the experiment this instrument has to be adjusted to the native language of the participants.

The data generated by these tests can be configured in the same way as Mulder & Swaak did, by defining the mean level of shared understanding before and after a meeting or design session, plus the mean level of improved shared understanding perceived by the actors (Mulder et al. 2002). These levels are assessed by the assessment tool in appendix XII.

2.5 Conclusion

Simulation-Based Design is a very good method to use in the design for a shunting plan at Ctw. There are three main design processes to be distinguished, which have to be drawn up using process design tools of de Bruijn et al. Which main design process to use, or which components to use from the frameworks identified will be discussed in chapter 4.

The problems identified according to the single perspective simulation are also recognized in a similar design case on the marshalling yard Wgm. The opportunity within the design assignment of Ctw is to test whether or not the addition of multi-perspective visualization can resolve the problems identified and create a higher level of shared understanding. Not just the visualization of the system and its behaviour seems to be of great importance, but also the insight in KPIs is for actors very important to discuss on in a design process. The test for an increase of shared understanding can be performed by the assessment tool of Mulder, which measures the level of shared understanding on 3 aspects (Mulder, 1999). However this tool is not thoroughly validated it will be used because there is no alternative tool. Quite similar theories like Shared Situational Awareness are studied, but concluded to be not appropriate to use within this research and the purpose to measure the level of shared understanding.

In the next chapter the design case used for the experiment will be explained. The design process to be followed for this design assignment will be formed according to the framework of Bruijn et al. (appendix IX) and will find its origin in the frameworks of Fumarola, Robinson en den Hengst. Furthermore the design process should be aligned with the design process of Watergraafsmeer to be able to verify the results and give a grounded comparison with the new approach including different perspectives of visualization. The detailed process design for the design process to be facilitated will be drawn up within chapter 4.

3. Background case study marshalling yard Ctw

In this chapter the environment in which the case study has been performed will be described. First of all a thorough description of the marshalling yard Ctw and its processes will be given, followed by an actor analysis on involved actors with the processes on this marshalling yard and the problems to be expected in the future situation.

3.1 Lay-out marshalling yard Ctw

The marshalling yard Ctw is located between 2 of the 4 main corridors of the rail network junction Utrecht (figure 6). These are the corridors to Amsterdam and to Rotterdam/Den Haag. NedTrain has one of its service locations on this marshalling yard, which is part of the SC.

Figure 6: Location marshalling yard Ctw in between the corridors

On this marshalling yard trains of NSR run out on a planned basis for simple service maintenance and EBKs arrive for special maintenance jobs. No other train service operators have capacity on this yard, so only trains of NSR will be shunted on this yard. In figure 3 the lay out of the marshalling yard is illustrated. In appendix 7 there is a more detailed description of the lay out.

On this service location 24 hours a day, Monday till Sunday, service jobs and small maintenance jobs can be executed and technical inspections are performed. In the near future, starting October 2013, more maintenance orders can be serviced because of the construction of a new Technical Centre (TC) according to the new strategy of NedTrain as already discussed in section 1.3 (NedTrain, 2012 & Busstra, 2012).

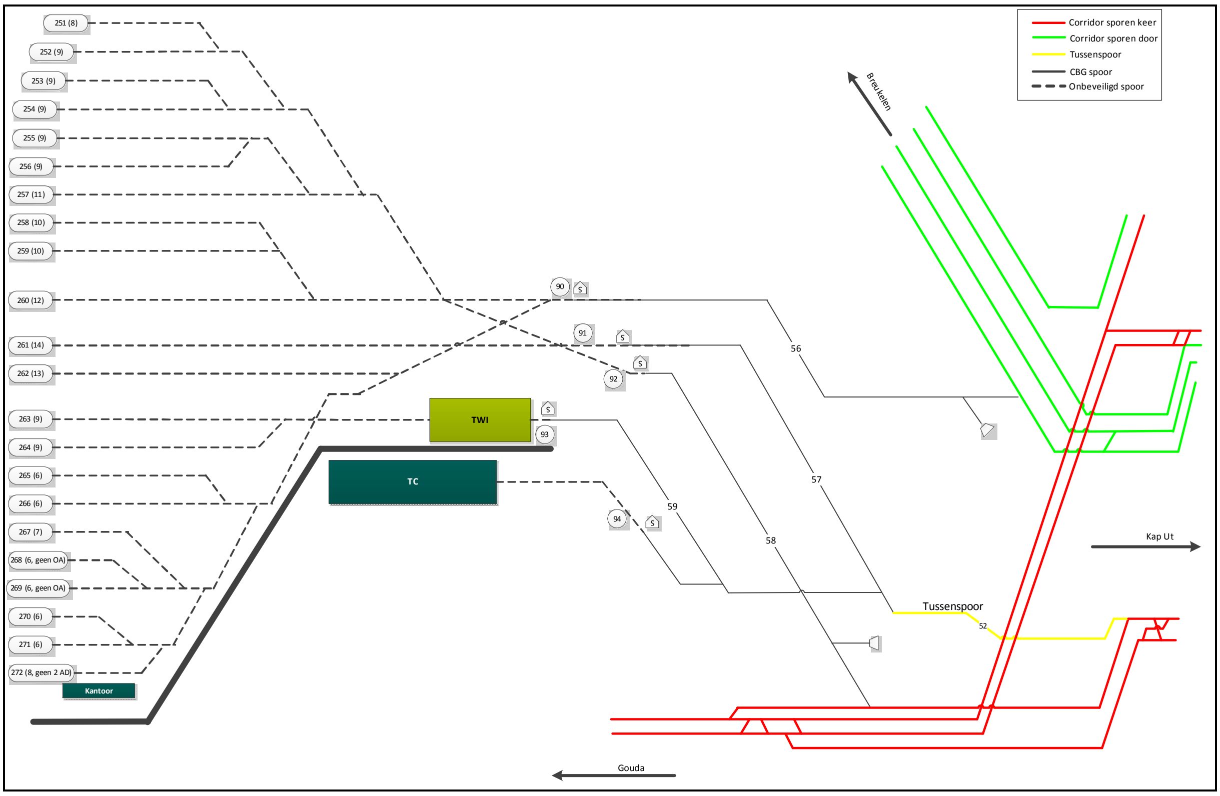

Figure 7: Lay-out marshalling yard Ctw

The main characteristics of this marshalling yard are:

- Parking capacity of 192 cars
- 3 main access tracks, of which mainly track 57/91 is used
- 22 parking tracks for Nederlandse Spoorwegen Reizigers (NSR) (appendix 6).
- 1 track for the Train Wash Installation
- 1 track with a High Service Platform (HSP) and Service Pit (SP)
- 3 tracks dedicated to parking capacity for contractor material
- No secured railway tracks behind S-sign. In figure 3 this is shown by the dotted lines. In these sections the Process Coordinator Logistics (PCL) is in control.

Due to the fact that just 1 track is accessible for the arriving and departing trains, the marshalling yard can be seen as a bottle of which the access track is the bottleneck. In figure 7 this is the yellow track. Connection of other tracks to the green and red tracks are not used usually, because train movements on these tracks can influence the train service directly (Budding, 2012).

3.2 Service facilities

There are several maintenance facilities on the marshalling yard to support the service process in the SC. The main service facilities are:

Train Wash Installation (TWI)

For each type of train this installation can wash the train externally. The TWI has an unfortunate location in the marshalling yard, which causes inaccessibility of 10 of the 22 parking tracks due to the fixation of the railway switch in front of the TWI in case this is in operation. Moreover, due to this unhandy location the TWI is not directly accessible from 12 of the 22 parking tracks. This results in more shunting movements. Besides the bad accessibility each movement through the TWI has to be communicated and requested by the rail traffic control of ProRail (VL).

High Service Platform (HSP) and Service Pit (SP)

The dead end track at the bottom of the marshalling yard is facilitated with 2 pit facilities and 2 high service platforms (track 94). With these facilities a wide range of small corrective maintenance can be serviced, like air leakage and replacement of worn pantographs. This facility track is also badly accessible, since trains have to be shunted on to a secured track whereupon they can turn and access the particular track for the HSP and SP. When the construction of the new TC is started the HSP will be replaced to track 272. The SP will be out of order during construction of the TC.

Anti-icing facility

As a result of the 'winterharde' measures after the crisis situations during heavy snowfall and extreme low temperatures, the anti-icing installation is developed. On several locations throughout the country this facility is tested. This facility consists of a large semi-open container in which trains are sprayed with anti-icing chemicals (Glycol) from the bottom side, so no ice will be frosted on the trains which can cause mechanical and infrastructural defects. This installation is located on track 58.

22 Inspection and internal cleaning tracks

All parking tracks meet requirements to perform technical inspections, small corrective maintenance jobs (Storing Niet Defect SND), internal cleaning and graffiti removal. The capacity of cars to park on these tracks can be consulted in appendix 6.

Technical Centre (December 2013)

In section 1.4 the strategy for the development of the TC is introduced. In December 2013 the facility has to be in operation and will be built on the existing track 94 with the HSP and SP facility. Within this centre also a HSP and a 120m long SP will be facilitated. Same problems according to accessibility are expected as with the current HSP facility.

3.3 Current shunting process

The shunting process on Ctw can be divided into 2 main parts (Budding, 2012). The first part consists of the incoming and departing trains on Ctw. The second part consists of shunting movements of trains from a parking track to another parking track to combine with another train or to be moved to a maintenance facility.

Incoming and departing trains

Trains arriving at the marshalling yard are under control of Railway Control Centre of ProRail, in next section VL ProRail. Up to the S-sign the railway is secured and monitored by this actor. Behind the S-sign the PCL of the marshalling yard takes control and allocates the train to a particular parking track or service facility. When trains are serviced on this particular track or service facility the train is shunted back to the station of Utrecht, which is indicated with the term 'Ut kap'. Appendix 7 shows the processes during the incoming and departing trains.

Process shunting

In case a train is located on a parking track but has to be serviced on for example the track with the HSP, the train has to be shunted to this particular track. Because the train also runs on secured track, crossing the S-sign, the VL of ProRail has to be contacted to get permission. For the process in which trains have to be shunted between the parking tracks and service facilities there has to be made a special process scheme. A special name is chosen for these activities; process shunting. In appendix VIII the SADT diagram shows the process of 'process shunting' more in detail.

3.4 Service process NedTrain in current SC Ctw

In the current situation several types of trains are regularly serviced on the marshalling yard Ctw. In the planned and also unplanned situation these type of trains have a fixed variety. First the different type of trains will be discussed whereupon the main service jobs on these trains are given.

3.4.1 Type of trains

NedTrain B.V. its main customer is NSR, but also rolling stock of NS Hispeed and other operators on rail networks are serviced. On the marshalling yard Ctw just a few type of trains are to be serviced of NSR in the planned situation (Table 1). In the unplanned situation mainly the same type of trains are to be serviced (Hakkert, 2012).

Table 1: Type of trains arriving at the marshalling yard Ctw

Sprinter Light Train (SLT)	Verlengd InterRegio Materieel (VIRM)	InterCity Materieel (ICM)
		

3.4.2 Service jobs

Within the SC Ctw a large variety of service jobs can be serviced. The main service jobs provided are technical inspections, internal cleaning, external washing and replacement of pantographs. Besides that a numerous amount of small corrective maintenance is provided, which can be divided into Storing Niet Defect (SND) and Storing Wel Defect (SWD). In section 4.4 all these type of service jobs are specified, including the service facility to be used and the mean lead time for this service job. This also varies between the different types of trains.

3.5 Actor analysis

In this section an overview of actors involved in the system of the marshalling yard Ctw is given. A thorough actor analysis is included in appendix 3. In this appendix a detailed overview of actors values, interests, goals and problem perceptions is given, as well as the criticality of actors and relations between them (Enserink et al. 2008). The information is gathered by multiple interviews with these stakeholders, in which for each stakeholder group it is aimed to consult more than 1 individual. By consulting two or more individuals for each actor it is tried to get a more objective view on all involved actors. An overview of interviews with involved actors is given in appendix 3.

As a starting point the entire information and material flow in case of planned and unplanned maintenance jobs is mapped, appendix 2. From these diagrams all involved actors are identified and thereafter interviewed. For each actor a short overview of their role, interest and responsibilities is given in next sections, resulting in a set of actors which are critical to involve in the design process.

3.5.1. Actor roles, interests and responsibilities

A short description of each involved actor within the shunting process at the marshalling yard Ctw is given in the following paragraphs. A more structured description can be consulted in table 1 of appendix 3.

NedTrain B.V.

NedTrain is a large maintenance and overhaul provider for rail rolling stock. It is a subsidiary of the Dutch Railway company NS, which is at the same time the main client for all kinds of maintenance and overhaul. The company is divided into 2 main parts, the Service Company (SC) and the Maintenance Company (MC). Within the SC just very small maintenance jobs are serviced plus several safety checks. In its MC larger maintenance jobs are serviced up to complete overhaul of trains. Management of NedTrain wants to improve its overall performance, especially on the lead time of maintenance jobs in the MC. The main goals of the company is to provide high reliable maintenance jobs, make profit and extend its activities so its main value ‘continuous business’ can be safeguarded. By transferring some smaller maintenance jobs to the SC it is planned to increase quality and decrease lead time of maintenance jobs. A first start with the new strategy is the development of a new Technical Centre in Utrecht on the marshalling yard Ctw. However, problems with the accessibility of this new TC are expected, which will undermine the intended effect of this new strategy. The demand for a well-supported design for shunting processes is very high (Busstra, 2012).

NSR Logistic Product Design (NSR-LPD)

This actor is responsible for the logistic planning of trains within the train service of the NS. Its goal is to plan enough coaches in trains, which is also the right type of coach. This actor has a lot of power to reserve capacity on the marshalling yard Ctw for NS rolling stock and the final decision for allocation of trains on the long term planning. Therefore it is a critical actor to involve in the design process for a new shunting plan, especially on the long term.

Bureau Locale Planning (BLP)

Logistic planning up to 36 hours before execution is performed by BLP. They receive the yearly plans of NSR-LPD and plan train movements for shunting trains as well as for the passenger train service. They deliver a detailed plan, including exact arrival and departure times and infrastructure paths. BLP makes a yearly plan, however due to last moment maintenance on the railway infrastructure and special demands of NSR-LPD adjustments just a week or even less before operation are made by BLP. Its value is a reliable outflow of trains on Ctw and therefore its demand in the current situation is a more robust process on Ctw.

ProRail Jaarplanning

Actor which allocates train paths for passenger and freight train services. It is important for this actor that there do not arise conflicts between train operators about the allocation. Moreover during the execution of the train service they have to prevent for conflicting train movements, especially between passenger trains and shunted trains or freight trains. Because this actor is only involved to check whether plans of BLP and NSR-LPD are free of conflicts and mistakes, this actor was not critical in the design process for a new shunting process on Ctw.

Verkeersleiding ProRail (VL)

VL is the railway traffic management actor, which controls all railway tracks, switches and traffic lights on the Dutch railway network. Each major junction on this network has its own VL station. In this case the VL Utrecht was the involved actor, which aims for a high safety and punctuality on the network. Late Order Application (LOA) therefore has to be permitted by the VL, which can cause safety issues and conflicts of other train movements on the junction Utrecht. In the current situation LOAs are permitted if possible, but sometimes are refused and postponed for some while. Clear agreements and better collaboration is seen as the way to deal with capacity problems and LOAs.

NedTrain Jaarplanning

This department of NedTrain is responsible for the capacity requests for maintenance facility tracks on marshalling yards. Each year this actor has to negotiate with ProRail Jaarplanning and NSR-LPD for storage capacity on Ctw, as well as for the conservation or extension of maintenance facility tracks. For the processes on Ctw this actor has not a high influence. This actor facilitates the tracks on which maintenance can be serviced, but does not concern about the processes itself. A more structured or planned shunting process is extremely welcome, since this actor thinks this will lead to a higher capacity for short term storage of trains on the current infrastructure.

Process Coordinator Logistics (PCL)

The PCL controls the train movements on the marshalling yard Ctw, plans maintenance jobs and steers the maintenance staff. All trains should be serviced before the time of departure, which means the moment at which the trains will be used again for the train service. Therefore its goal is to allocate the trains to an appropriate track and schedule the maintenance jobs as good as possible. However, due to a lack of a structured shunting plan, often trains are parked in a way not all maintenance jobs can be fulfilled and trains leave without being washed for example. Also shunting movements on secured tracks have to be made too much, for which VL has to give permission. Delay and insufficient maintenance jobs are the result. A shunting plan can help to avoid situations in which trains are parked on the wrong track afterwards, resulting in less shunting movements and sufficient maintenance jobs. Within the system of the marshalling yard the PCL is one of the most critical actors and was therefore involved in the design process.

Materieel Beheer NedTrain (MBN)

MBN has to take care of all maintenance jobs which should be serviced to each and every single train. They have to schedule a specific train in a certain train service, so this train will end at a marshalling yard where the specific maintenance job can be serviced. Especially in case of an unplanned maintenance request MBN is an important actor in order to recover trains as fast as possible. For each defect or check-up every train has a Q-norm, days in which the defect should be resolved or a maintenance job or check has to be serviced. In the current situation on Ctw delays occur and even maintenance jobs are not serviced at all sometimes, which causes a higher distraction of trains or a higher recidivism rate of trains under maintenance. A higher efficiency and punctuality of services on the Ctw are also for MBN evident to fulfil its goals.

Landelijk Bijsturing Centrum (LBC)

The circulation of trains and personnel is planned a long time before operation. However some small incidents, like a delay or defect train, disturb the train service enormously. Train personnel cannot be assigned to its planned train service. The LBC has to organize other trains and personnel to keep the train service running. Because some problems within the train service have wide spread influence on the entire network, a nationwide control centre gives direction to organize activities to restore the train service. It is important to have enough train material which can be used in case of a disturbance and also the marshalling yards should be accessible and have enough capacity to park trains temporarily. Inefficient processes on Ctw can lead to either too less parking capacity and/or no capacity to service maintenance on the short term.

Regionaal Bijsturing Centrum (RBC)

The RBC is the representation of the LBC but is focused on one region. In this case the RBC Utrecht played a very important role in situations with a disturbance in the train service. Their main value with the marshalling yard is to have enough capacity to park trains and service defects on trains on a short term. The RBC plays an important role in case an extra train movement has to be facilitated from somewhere on the railway network to Ctw. In these kind of situations it determines the arrivals on the marshalling yard.

Train Driver

This actor group belongs to a department of NSR in general. It has to follow up commands of the PCL and the RBC, to shunt trains to and from the marshalling yard or on the marshalling yard. Within the shunting process the train driver is important because he has to shunt the trains. However, he has weak resources to bring his point forward and is extremely replaceable. Therefore it was not a critical actor in the design process for a new shunting process.

Cleaning contractor (HAGO)

The internal cleaning of trains is subcontracted to HAGO. This actor receives orders from the PCL and has to fulfil them within a certain time period. This actor is not critical to the processes on the marshalling yard Ctw and is replaceable by another contractor.

Passengers

NSR-LPD designs the train service on the customer's needs and wishes. The passengers are the end consumers of the train service and can influence this design by travelling with the train or not, or over a specific route. For the processes on the marshalling yard the value for the passenger is that the distraction rate of trains is minimal, so trains have the maximum amount of trains and thereby seats for its passengers/customers. However, the passenger has no or weak resources to have influence on this process, but does have this on the entire train service for which it can decide to use it or not. Therefore this actor group is not involved within the design process.

3.5.2 Formal map of actors

From previous section it can be concluded some actors are very important and some have less influence and are therefore not critically involved. The relations between these actors are mapped in a formal map which is illustrated in figure 8. From this figure and the actor criticality table in appendix 4 the next actors are considered to be important within the design process for a new shunting plan on the marshalling yard Ctw.

- NedTrain B.V.
- PCL Ctw
- MBN
- VL ProRail
- RBC
- BLP

Within figure 8 the relations between the actors in the actor environment have been visualized. The actors with just arrows leading to them do not have much influence within the entire actor environment and have been left out of scope in the further research. These are the actors HAGO and train drivers. From the same figure it can be concluded that the actors RBC, VL ProRail, MBN, NedTrain B.V., PCL Ctw and BLP are central actors in the actor environment. Other actors ProRail Jaarplanning and NedTrain Jaarplanning are also an important actor according to the formal map, however from the actor criticality index in appendix 3 these actors are concluded to be not critical. That is why the 6 actors above were involved in in the remainder of this study.

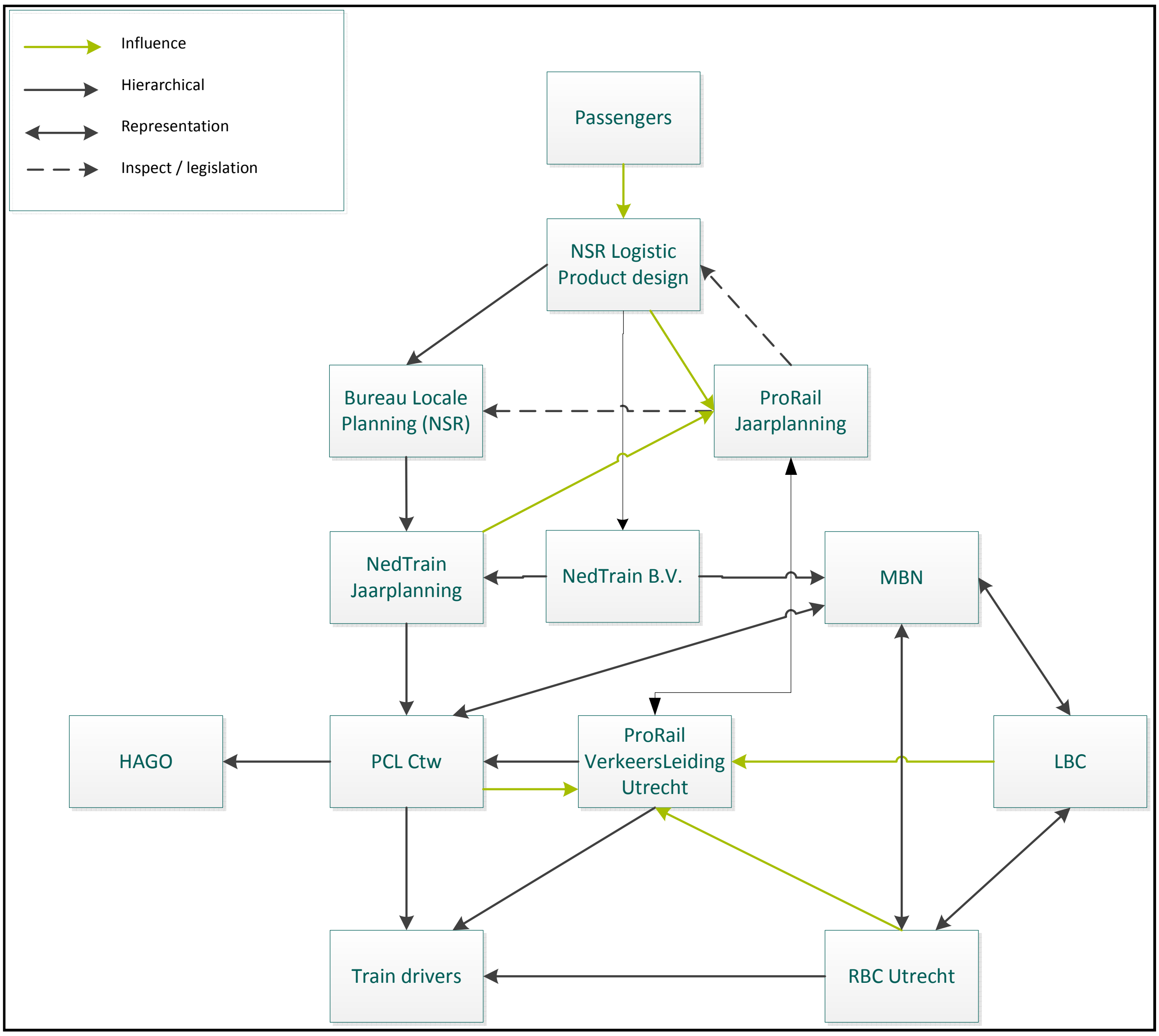

Figure 8: Formal map actor environment marshalling yard Ctw

3.6 Current problem situation

On the marshalling yard of Ctw trains have the ability to be maintained on the SP and HSP. In the current situation the shunting movement from the parking tracks to the SP and HSP is not possible during the entire day. Trains to and from Ctw all have to cross the middle-track, which is the yellow track in figure 7. If trains have to be shunted from the parking track towards the SP and HSP facility they first have to be shunted onto the middle-track and subsequently be shunted to the SP and HSP facility. This shunting movement is illustrated in figure 9.

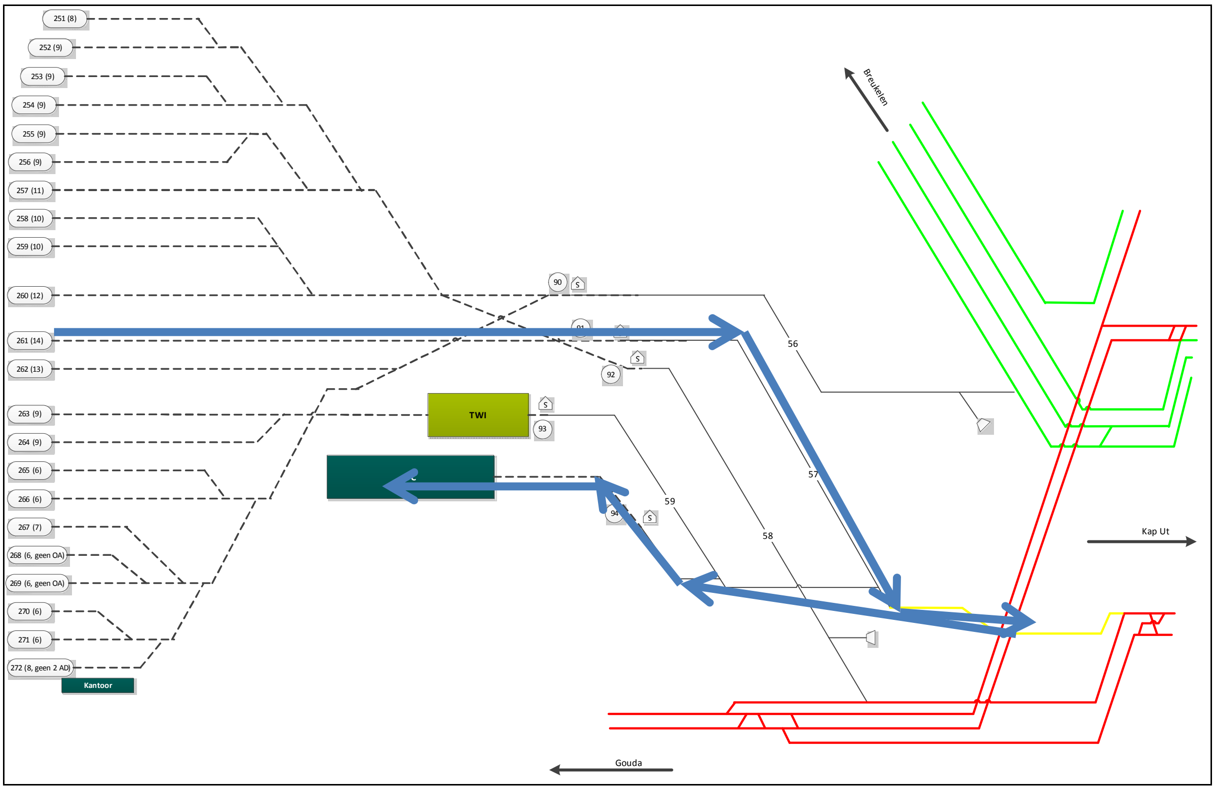

Figure 9: Shunting movement from a parking track to the TC, called saw-movement.

The 'saw-movement' as they call the shunting movement as illustrated in above figure takes in total 20 minutes. In this period no other trains can be shunted on the middle-track, since there are also safety regulations on the time interval between up-following train movements. The middle-track therefor is used for 20 minutes (Budding, 2012 & Holsappel, 2012). Incoming and departing trains have priority. This creates the problem that the 'saw- movement' cannot be executed during periods in which the middle-track is used at least every 20 minutes. In figure 10 the train movements on the middle-track are visualized. It can be concluded that on average the saw-movement cannot be executed in the periods 23.00-02.00 and 04.00-07.00. This is confirmed in several interviews with the PCLs (Budding, 2012; Holsappel, 2012 & Wrede, 2012).

Due to this limitation of these shunting movements trains sometimes have to wait for their service on the parking track. This affects the punctuality, because some trains are not serviced before their departure time and cannot depart without being serviced.

In the future situation more trains have to be maintained within the TC. On average one EBK will arrive on Ctw each day. The maintenance jobs on these trains take even more time, so trains which are in a circulation but have to be serviced within the TC should even wait longer or the risk they got a delay becomes larger.

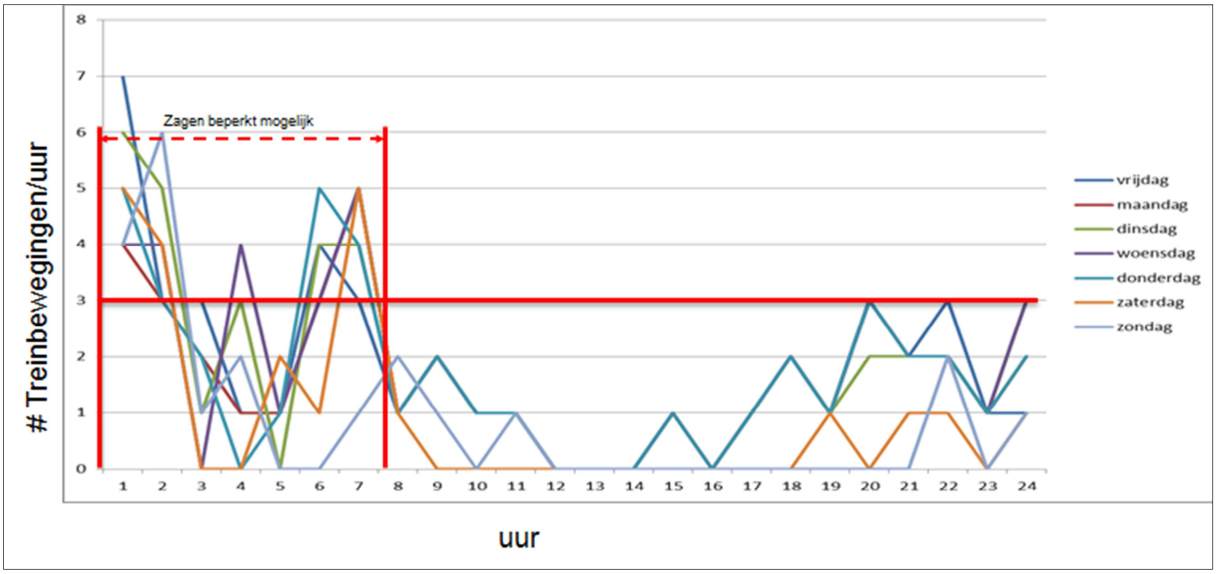

Figure 10: Number of train movements on the middle-track each hour

3.7 Conclusions

From the actor analysis it is concluded almost all actors perceive a problem with the processes on the marshalling yard Ctw. However, these problem perceptions do not align with each other but remarkable the problem solutions do align in most cases. Almost all actors had the idea that with a more structured shunting process, problems within the current situation could be mitigated.

During interviews all actors were very cooperative and open for all kind of questions. From this interviews it became clear all critical actors as named in previous section are willing to cooperate in a design workshop for a more structured shunting process design. This is because they thought through cooperation and because of their mutual dependencies, a jointly design process can lead to; a win-win situation, in which the punctuality of maintenance service and fleet availability can increase, lead-times decrease and less LOAs or conflicting train movements lead to a safer process.

The main problem in the current processes on Ctw is the occupation of the middle-track. Trains which have to be shunted from one of the parking tracks to the TC will claim the middle-track for 20 minutes. This time of period is not available during peak hours and therefore trains from the parking tracks cannot be shunted towards the TC. This causes unnecessary delay and the risk for a decrease on punctuality and material availability.

4. Experimental design

In order to get answers on the research questions an experiment has been conducted within the design case of NedTrain. This experiment was part of the entire Simulation-Based Design process as will be discussed in the first section of this chapter. The experiment, in which critical actors involved with the logistic processes on Ctw participated in a design workshop, has been used to generate information on the scientific and practical research questions. In order to draw valid conclusions from this design workshop 3 tools have been used, which will be discussed in the second section. In collaboration with the critical actors several alternative solutions have been designed to solve the problems with the logistics process on Ctw, which are discussed during the design workshop. These alternative solutions will be discussed in the third section. The design workshop, which is the centre point in this research, will be elaborated in section 4, including the supportive tool of a simulation model with multi-perspective visualization and a detailed description of the process design of this design workshop.

4.1 Process design for SBD process of shunting plan

As concluded in the previous chapter a select group of actors participated in the design process for a shunting plan at the marshalling yard of Ctw. For the design of the design process the constraints from the environment in which the design had to be produced were very determinative. First of all the fundament of the overall design process will be discussed, consisting of a composition of the frameworks for an SBD-process as discussed in the second chapter.

As already mentioned in section 2.2.3 the design process for a shunting plan at Ctw had to align with the design process at Wgm in order to be able to give a good reflection on the improvement by adding multi-perspective visualizations in a simulation. From the study on the design process at Wgm the design approach of Fumarola as well as the one of den Hengst et al. could be recognized (figure 2 and 3). The first step in the design process at Wgm can be compared to the first steps in the design approach of Fumarola, in which requirements and criteria for the design to be made are drawn up. In the case of Wgm the process continued with a first design round together with one of the important actors in play, which does also align with the approach of Fumarola. However, from that moment on in the design process, simulation was used as a validation tool and has not been used as a design tool by all participating actors. In the final round of the design process there was much attention for validation and verification among different actors, which is a key element in the approach of den Hengst et al. 3.

As can be concluded from the comparison of the design process at Wgm and the approaches in theory, both the approaches of Fumarola and den Hengst et al. both can be recognized in the Wgm case. For the design process to be drawn up in the case of Ctw the same approach has been followed because of two reasons; using the same design approach the added value of multi-perspective visualization can be recognized more easily and secondly, the approach turned out to be successful at Wgm (Wieten, 2012). In figure 11 the fundament for the design process is visualized.

The opportunities to interactively involve participants in the design process and to create several design rounds were limited in the design case on Ctw. Time and human resource constraints limited the opportunities for multiple design sessions. The group of participants could be brought together for maximally 3 hours and the meeting could be facilitated one-off. Due to this constraints the ability to perform multiple design rounds in which interactively the design for a shunting plan is drawn up was impossible. The validation rounds introduced in the framework of den Hengst et al. have been integrated in the design process and together with the main components of Fumarola a specific design process for this case was composed which is in accordance with the design process at Wgm.

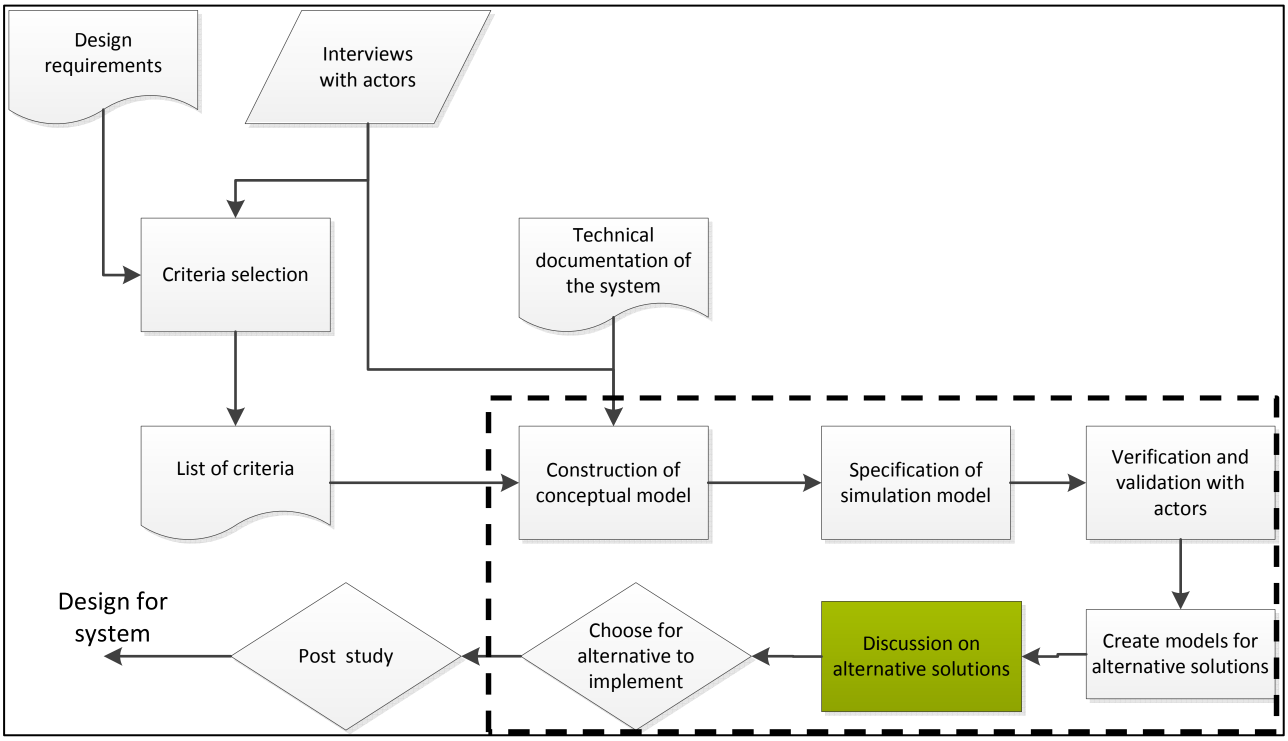

Figure 11: Adapted framework for the SBD process in the experiment

The dotted line within figure 11 encloses the part of the design process which is executed by the design workshop. Within section 4.4 this workshop is discussed in detail. The steps upfront the design workshop are already discussed in previous sections of chapter 3. As already mentioned within this design workshop the answers on several research questions were tried to be found.

For the answers on the scientific research questions three different tools have been used to draw valid conclusions and are discussed in next section. Using a pre-test and post-test on the level of SU the enhancement of the SU was tried to be identified. With an observer of the reference case Wgm the additional value of multi-perspective visualizations was identified. Moreover a post-survey on the influence of multi-perspective visualizations among the participants has been performed to strengthen conclusions on the enhancement of SU by this new approach.

4.2 Measuring enhancement of shared understanding

Three different tools have been used to identify the enhancement of shared understanding and the influence of multiple perspectives within the simulation. Each of them will be explained in more detail in the next paragraphs.

4.2.1 Pre-test and post-test

To identify whether or not the addition of multi-perspective visualization creates a higher shared understanding all participants have been asked to fill out a pre-test and post-test, according to the test on shared understanding of Mulder (appendix XII). Because the participants are all Dutch native speakers, the questionnaire was translated. Besides that the questionnaire was adjusted for the pre-test, since the questionnaire of Mulder contains questions according to the level of SU and the improvement of SU. The questions according to the improvement of SU could only be answered in the post-test. In both questionnaires the construct of SU was divided into the 3 aspects of SU as discussed in section 2.4; process, content and social relation. For each of these aspects a question was posed on the individual understanding and on the perceived shared understanding among other actors. The translated versions of the questionnaires can be consulted in appendix XV.

The moment on which the tests had to be filled in was very important. In the very first minutes of the meeting the participants have filled out the questionnaire because the enhancement of SU can be processed by interaction between actors from the first minute (Mulder, 1999). Therefor the first thing to do after a very short description of the workshop was to let the participants fill out the pre-test.

For the post-test the main conclusions of the workshop were clear and discussions were closed. This was just before the workshop ended. The results of these test can be consulted in section 5.2. Using this pre-test and post-test the influence of multi-perspective visualizations on the enhancement of SU could not be measured. Therefore a post-survey has been developed to identify the influence of the multiple visualizations on the enhancement of SU.

4.2.2 Reference case

As already mentioned in previous sections, shared understanding can emerge due to interaction between actors. In order to get insight in which part of the enhanced SU was created by the addition of multiple perspectives, the case has been compared with the case of Wgm. Therefore the setup of the design process in the case Ctw aligns with the design process at Wgm, to be able to draw a good comparison on both cases and the influence of multiple perspectives within the simulation.

In order to generate information on this subject the project manager for the design of a shunting plan at Wgm was invited to observe the design process during the workshop. By observing the process in which multi-perspective visualizations supported the design process the project manager could experience what the added value was of those perspectives in the creation of SU. During an interview with the project manager of Wgm after the design workshop was finished the influence on the enhancement of SU by the multi-perspective visualization has been examined. The observer was asked to focus on the following aspects/questions during the workshop:

- On which type of visualizations are the discussions based?
- Is the argumentation of actors better or more convincing by the use of multiple visualizations?
- Does multiple visualizations make the discussion more complex or just more simple?
- Is there more or less resistance during the discussions?

During the interview a few days after the workshop took place the observer was interviewed on her observations during the workshop and reaction on the aspects/questions she had to focus on. The discussions on which the observer had to focus were based on the proposals for alternative solutions. These alternative solutions are discussed in next section. The results of the observations are given in section 5.3.

Since the observations on the workshop were just from a single person, an extra post study on the influence of multi-perspective visualizations on the enhancement of SU has been executed to strengthen the conclusions of this research. The post-survey is discussed briefly in next paragraph.

4.2.3 Post-survey on influence of multiple visualization on enhancement of SU

This survey included propositions of the effect of multi-perspective visualizations on the enhancement of shared understanding. The questions can be consulted within appendix 16. The questions adopted within the survey were based on the questionnaire of Mulder. In the survey 2 different propositions have been formulated for each of the questions on which Mulder measures SU; process, content and relations (section 2.5). The propositions have been formulated in a positive and negative way for each question from the pre-test and post-test in order to avoid suggestive questioning (Tilly, 2008). The order in which the propositions were presented was random, so negative and positive propositions were mixed. The results of this post-survey are discussed in section 5.4.

4.3 Alternative solutions for shunting plan

Within the design workshop several solutions have been discussed to solve the problems according to the logistic process on Ctw as discussed in section 3.6. During interviews with all involved actors, solution alternatives for the logistic problems on Ctw have been found. These alternative solutions could be implemented in the shunting plan in order to improve the logistic process on the marshalling yard Ctw. For each alternative an explanation is given.

1. **Facultative paths from the parking tracks to the TC and vice versa**

The limited opportunities during peak hours on the middle-track cause unnecessary delay for trains to be serviced or maintained within the TC. In order to create the possibility to shunt trains from the parking tracks to the TC during peak hours, more time intervals should be created on the middle-track. By defining facultative paths each hour to and from the TC over the middle-track the TC will be accessible during the entire day.

2. **Facultative paths before and after the middle-track is under maintenance**

In the near future the accessing track to Ctw will be under maintenance during several days for a time period of about 5 hours. This maintenance planning is still very questionable, but a mitigating measure for the accessibility of the TC during these maintenance is proposed. The proposed solution is to create the opportunity to shunt trains just before and right after the middle-track is out of operation.

3. **Include process shunting within a new shunting plan**

In the current situation shunting movements to the service facilities are limited, especially to the TWI. By defining facultative train movements to the service facilities more trains can be serviced. In the shunting plan these process shunting movements have to be planned between the arriving and departing trains to and from the parking tracks.

4. Claim parking track for EBKs

During meetings with MBN the wish for a special parking track, just for trains which have to be maintained in the TC, is discussed. The direct effect is a loss of parking capacity, which is for some actors a big loss. The idea is to park EBKs always on the same track, to have a kind of stock for maintenance and the TC can be fed if it is operational, starting point 24 hours a day (NedTrain, 2012). MBN has the fear that trains to be maintained get 'locked' between other trains on the parking track, and thereby are less accessible to shunt to the TC.

5. Parking track for EBKs on another shunting yard in Utrecht

This alternative solution is suggested during meetings with the logistic manager of Ctw. He is not pleased with alternative 4 because of the loss of parking capacity. Another shunting yard in the region of Utrecht has several parking tracks, which can also be used for EBKs. From this shunting yard every hour there is a facultative path to cross the junction Utrecht and thereby arrive in the TC.
This alternative is out of the delineation of the simulation model and cannot be analysed because of that.

6. Collaboration between BLP and PCL to plan arrivals and departures on Ctw

The BLP plans all trains to and from Ctw, but does not take into account the process on the shunting yard they create as an effect of this pattern. In almost all interviews actors indicate this collaboration as a starting point for the improvement of the logistic processes on Ctw. With the development of the shunting plan in the near future, this collaboration is considered to be crucial by several actors.

BLP plans the trains to the S-sign, but if they plan these trains on to the parking track the processes on Ctw can be streamlined according to some actors. This alternative is not to be tested in the simulation model, but the workshop brings the ideal opportunity to start the discussion on the collaboration between BLP and the PCL of Ctw.

These 6 solution alternatives for the logistic problem on the marshalling yard Ctw have been discussed during the design workshop. This design workshop is explained in next section.

4.4 The design workshop

In the design workshop the critical actors have been involved as presented in section 3.5.2. The preparations and execution of the design workshop were part of the entire design process for a shunting plan. As already illustrated within figure 11 the substantive steps towards the workshop are illustrated once more in figure 12.

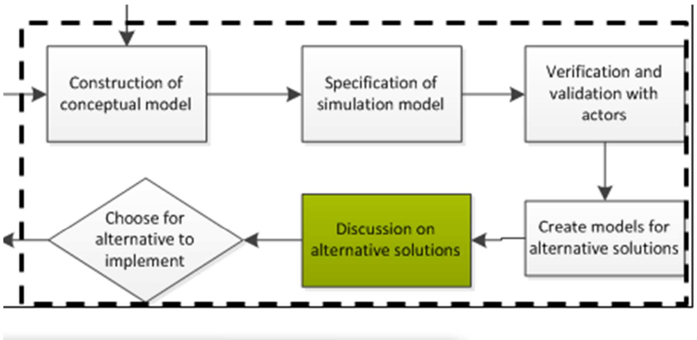

Figure 12: Steps for the design workshop within the whole SBD process

The design workshop was used as a tool to determine which alternative solution is viable and supported by all actors. Besides that the workshop was used to execute an experiment to draw conclusions on a few scientific research questions. The scientific research questions which have been examined during the design workshop are:

5. Do actors experience a higher shared understanding after they went through the design process with the support of a simulation model and the addition of a multi-perspective visualization?

6. Do actors experience a higher shared understanding and improvement of the design process using a simulation model with multi-perspective visualization instead of a design process with a single perspective visualization?

7. Does multi-perspective visualization help to resolve dilemmas during a decision making process?

Answers on these scientific questions have been examined using the tools as discussed in the previous section 4.2.

Within the workshop a few tools have been used to support the design process during the workshop. These were the multiple visualizations on which the effect on the enhancement of SU is examined. These visualizations have been established by information from a simulation model. Within the next section the simulation model will be explained, followed by the illustration and composition of the multi-perspective visualization used in the design workshop. In the third paragraph the design workshop will be discussed, in which a detailed process design illustrates the several design rounds and dilemmas which were expected to arise.

4.4.1 Discrete Event Simulation model

In order to provide the participants of the design workshop with multiple visualizations, data on KPIs should be gathered. By the development of a discrete event simulation model for the marshalling yard Ctw and its' processes, the systems' behaviour and performance could be made explicit. The model objective will be discussed in the next paragraph, followed by the data and information gathering for the development of the simulation model. Subsequently the modelling technique used is discussed in the third paragraph, followed by the conceptualization, specification, verification and validation in subsequent paragraphs. In the last paragraph of this section the adjustments to the simulation model to simulate the system with the implementation of a particular solution alternative are explained.

Model objective

The simulation model has functioned as an information generation tool, to support the discussion among critical actors in the decision making process. The model generated a set of output information of the current situation and under certain alternatives. The visualizations were separated into the number of perspectives of the participating actors, as discussed in the second chapter. The goal of the model was to produce for each actor a good insight in the behaviour and performance of the system, from its familiar perspective. In this way problems like misinterpretation were mitigated and actors could increase their shared understanding by observing the output of other actors KPIs and system's behaviour.

Using the model for each actor the most optimal alternative could be defined. However, because there had to be a conjoined decision on the design for a shunting plan the main goal of the model was to provide insight and information on the behaviour of the system under different circumstances and using different alternatives, visualized for each actor.

Data & Information

Information on the main underlying structure of the system on the marshalling yard Ctw as has been modelled is gathered by interviews with PCLs. The way in which the trains are currently shunted on the marshalling yard onto the parking tracks or to the maintenance facilities is not documented internally at NedTrain. In the daily operation the PCL defines which train has to be shunted to its particular parking track or maintenance facility. The way in which he defines this is just according to his own knowledge and experience. No standard protocol or shunting plan exists, which makes the operation out on the marshalling yard very vulnerable for the particular PCL in control.

Information on the train arrivals and the departure times could be consulted in the planning documents of BLP. In appendix 18 the arrival and departure schedule for Monday is included as an example. Information on the number of EBKs and lead times for the maintenance jobs have been collected during interviews with the PCL on Ctw and with the project manager of the TC (Budding, 2012; Wrede, 2012, Dijk, 2013 & Busstra 2013).

Modelling technique

The modelling technique of discrete event simulation has been chosen for the case study on the design for a shunting plan on the marshalling yard Ctw. Robinson (2001) and Fumarola (2011c) point out that discrete event simulation is an ideal modelling technique for systems to be analysed from a hard and soft system perspective, and are therefore very suitable to use within an SBD process. Besides that the underlying system of the marshalling yard is of a discrete character, since all trains arrive, depart and are serviced on a certain moment in time. A lot of research studies on SBD have been executed by the use of the discrete event simulation technique, like Cho & Eppinger (2005), Fumarola et al. (2011) and Bohlin et al. (2012).

For the construction of a discrete event simulation model there were multiple software packages to use. Within this project the software package Arena has been used because I had experience using this program and the student version was free of charge. This student version could only be used for research purposes and therefore NedTrain did not have the ability to use the software package for own use. Arena is only used for the analysis of the system on Ctw and to generate information to draw up multi-perspective visualizations for the particular case of a design for a shunting plan at Ctw.

Conceptual design

The characteristics of the system of the marshalling yard Ctw have been analysed using several techniques. In appendices VII, XIII & XIV the detailed analysis can be consulted.

Information on the current processes and system of the marshalling yard Ctw is gathered using the Unified Modelling Language (UML), Structured Analysis and Design Technique (SADT) and a flow chart. These techniques generated a good insight in the objects within the system of Ctw and the way in which the system functions.

In appendix XIII the UML of all objects and their relations are specified. For the objects 'train' and 'service job' an extra explanation is given in table 2 and 3. On the service location Ctw normally just 3 different type of trains arrive. These type of trains have each a specific indication code and differ in the number of cars. The number of cars are an important characteristic for the system of Ctw, since the parking tracks have a specific capacity based on standard car units (appendix VI).

Table 2: Specification of different train types arriving on Ctw

Train type	Indication	Nr of cars	Image
VIRM 4	AD	4	
VIRM 6	OA	6	
ICM 3	OH	3	
ICM 4	OC	4	
SLT 4	LE	4	
SLT 6	LC	6	

Trains arriving on the marshalling yard each have to be maintained. A train can have a simple technical inspection (B) or a thorough inspection (A) and always needs to be cleaned internally. Some trains have to be washed externally in the Train Wash Installation (TWI) or the pantograph has to be substituted. Some small maintenance jobs can be serviced on the parking track (Storing Niet Defect SND) and more serious jobs are serviced on the HSP (Storing Wel Defect, SWD). In table 3 all the maintenance jobs serviced on Ctw are listed, including the recurrence and lead time of these jobs.

Table 3: Specification of service jobs on different type of trains

Service job	Service facility	Recurrence	AD	OA	OH	OC	LE	LC
A Inspection	Parking track	1 in 5 days (SLT 1 in 2 days)	48	60	61	64	45	51
B Inspection	Parking track	1 in 2 days	11	14	8	11	19	21
Internal cleaning	Parking track	Always						
External washing	TWI	25%	30	40	30	40	25	30
Replacement pantograph	HSP	3% - 10%	45	45	45	45	45	45
SND	Parking track	Always	15-60	15-60	15-60	15-60	15-60	15-60
SWD	HSP	Unplanned	60-480	60-480	60-480	60-480	60-480	60-480
EBK	TC	Unplanned	120-900	120-900	120-900	120-900	120-900	120-900

Using the analysis technique of SADT the processes on Ctw have been structured and could be decomposed to a very detailed level. For each process the input, output, control and support has been specified according to the method of SADT (Verbraeck & Valentin, 2006)(figure 13).

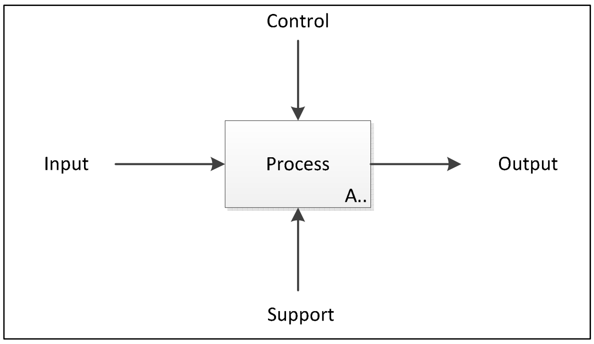

Figure 13: Illustration of Structured Analysis and Design Technique

For the first level the process on Ctw is illustrated in figure 14. Trains which arrive on Ctw have to be shunted to its particular parking track, which is indicated by process A1. On the parking track or maintenance facility the train can be serviced for a variety of service jobs as specified in table 2 and indicated by the process A2. The time of arrival and departure for planned trains can be consulted in TRAVEK, a supportive ICT tool for train movements and locations. For the third main process (A3) this is a determinative control element. At the time of departure trains are shunted to the train station of Utrecht, indicated by 'Ut kap' (A4). Especially for the second process in this figure, servicing of the trains, more decompositions are given in appendix VII.

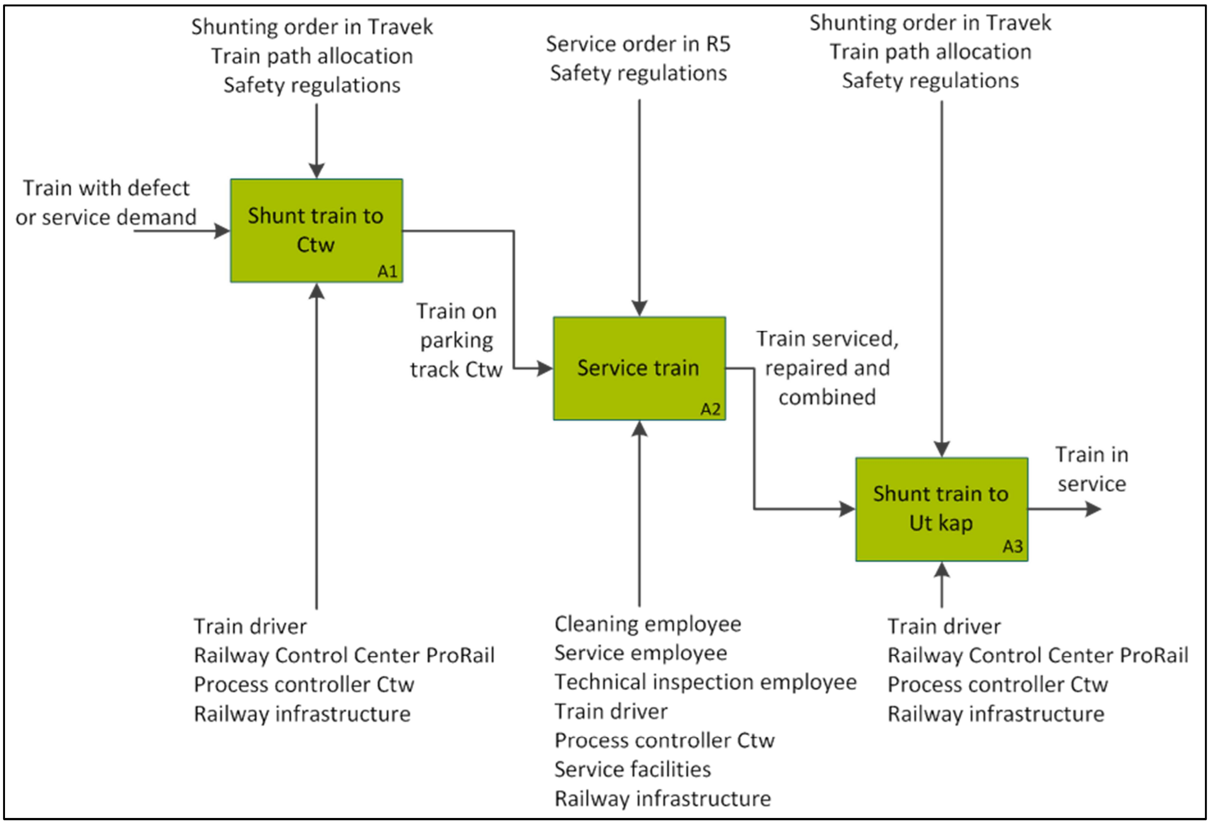

Figure 14: First decomposition level SADT for process of Ctw

Delineation

The simulation model included the processes on the marshalling yard Ctw of arrival and departure of trains, shunting movements towards maintenance facilities and the maintenance jobs itself.

SND maintenance jobs were not included in the model, because these jobs do not have to be fulfilled before the train can depart and can be serviced on their standard parking track. Also the anti-icing facility was not included in the model, especially because this facility was out of order during the research.

Train driver capacity is not included in the model. In an interview with the manager logistics it is concluded to have sufficient capacity of train drivers on the marshalling yard itself. The capacity of mechanics and cleaning crew is included in the model, since this can have an effect on the lead times of maintenance jobs and in the end the actual departure time of trains.

In the model trains only arrived and departed on the middle-track and continue onto track 57 (figure 7). In the daily process on Ctw just this single track is used. There are some alternative tracks, however due to safety regulations these can only be used in a crisis situation or in case track 57 is out of order.

The process on Ctw is very dependent on a lot of circumstances. The model was developed for two main situations, the winter and summer situation. Extreme situations are not included in the model, because there are too many dependencies which can change the arrival pattern or nature of the maintenance jobs. For two standard situations, the winter and summer, a simulation model has been specified for the system as it is now and in the future situation with the TC.

Costs and material linked with the processes on Ctw have not been included in the model. Just the logistic process and resources to facilitate the logistic process and maintenance jobs were included.

Systems assumptions

Due to a lack of information assumptions have been made as the information was necessary to construct the model. The next assumptions have been made:

- 3% of the train arrivals in the summer are disapproved during a technical inspection. All of them first have to be serviced on the HSP before they can depart from Ctw. In the winter period this is 10% of the trains.
- In the future situation with the TC, the small service jobs which now are executed on the SP and HSP will be serviced in the TC.
- There are sufficient train drivers available to support the train movements on the marshalling yard. It is assumed the marshalling yard is always in operation.
- An EBK will arrive on a random time at Ctw and can directly be serviced if the train is not a combination of several train units or the TC is not occupied. Otherwise the train has to be parked on a parking track.
- When an EBK is serviced in the TC the train will leave the marshalling yard directly.
- The model will use standard times for the overpass of rail sections on the marshalling yard, table 4.
- The lead time for maintenance jobs on EBKs in the future situation with the TC on Ctw are assumed to be at least 2 hours, median 8 hours and maximum 15 hours.
- Lead time for service jobs in the current and future situation are assumed to be at least 1 hour, average 3 hours and maximally 8 hours.

Table 4: Overpass times between rail sections on Ctw in minutes

	Tussenspoor	S-bord	Opstelspoor	Wasmachine	Putspoor
Tussenspoor	-	2			4 or 15**
S-bord	2		2		
Opstelspoor		2		25/30/40*	
Wasmachine			25/30/40*		
Putspoor	4				

***Depending on train length (3/4/6 train units)**

**** Saw-movement takes 15 minutes**

KPIs

The model has been developed for the support of the design workshop for a new shunting plan at Ctw. With information on different KPIs the different visualizations have been made. Therefor information on KPIs of the participants had to be part of the output of the model. The participants and their main KPIs are included in table 5.

Table 5: KPIs of critical actors involved which are participant in the design workshop

Participant	KPIs
Logistic Manager Ctw	Lead time EBKs and nr of trains washed
PCL Ctw	Delay of departing trains and occupancy of parking tracks
MBN	Lead time EBKs and nr of trains washed
BLP	Occupancy of parking tracks and punctuality
RBC	Punctuality and delay of departing trains
VL ProRail	Usage of middle-track and punctuality of departure

Model constructs

Entity: The 'train' is the entity which runs through the model. The creation of these entities is according to the amendment sheet of January 2013, in which the trains to and from Ctw are planned. This sheet was adjusted and characteristics for each train are added in the same sheet. In the model these characteristics have been read. The characteristics added to each entity are:

- Time of arrival
- Time of departure
- Type of train
- Need to wash

Resources: All the tracks on Ctw have been modelled as a resource. To be shunted over a particular track it has to be available. If the track is available it is seized by the entity and released when it has reached the next rail section or its final parking track. For the parking tracks the capacity of the resource is based on the amount of cars which can be parked on the parking track (appendix VI).
The service facilities included within the model are also modelled as a resource, as can be concluded from figure 14.

Time units: All time units specified in the model are in minutes.

Data analysis

The amendment sheet of January has been used for the input of the model. For the availability of the resource middle-track an analysis is performed (section 3.5). It turns out to be slightly available for train movements from the parking tracks towards TC in the time periods 22.00 – 02.00 and 04.00 – 08.00 (Budding, 2012 & Wrede, 2012). This is because of the arriving and departing trains on the middle-track (section 3.5).

For the lead times of service jobs on trains the information from PCLs has been used (table 3). In the future situation with a TC on the marshalling yard of Ctw the lead times for service jobs will increase. Which jobs there will be performed in the future situation was not known jet. An assumption for the lead times is tried to be made on current lead times in the maintenance company at Leidschendam. However, this is a MC, which means that trains are out of service for a longer time of period on a planned basis. These lead times were therefore not representative to make a good estimation on lead times for service jobs in the TC. An assumption had to be made and is based on several interviews (Hessel, 2013 & Busstra, 2012). The distribution of lead times for service jobs in the TC are assumed to be at least 2 hours, on average 8 hours and up to 15 hours maximally.

Model reductions

In case a train has a delay in its maintenance process, trains can be exchanged if there is enough capacity of back-up trains. This is hard to predict whether or not this is possible and what the effect will be on the process on Ctw. Therefore this option has not been included in the model.

Besides that some trains arrive in combination on Ctw and have to leave in combination with the same or with another train. Within the model these trains are not physically combined, but are assigned with the same arrival and/or departure time.

Run setup

The model has run for a week, with the input file of the amendment sheet and additional characteristics of trains. The base time units were minutes.

Verification and Validation

For the verification and validation methods the steps as identified by Verbraeck & Valentin (2006) have been followed. For the verification of the simulation model 3 methods were used; structured scan, input verification and structural verification. Validation of the model is performed by expert validation. Data on KPIs and the performance of the processes on Ctw are not reported and therefore the experience and knowledge of critical involved actors has been used to validate the behaviour and output of the simulation model. For the validation of the model all actors involved in the design workshop have been consulted to validate the model on their KPIs.

With the verification technique of structured scan each step or process in the simulation model has been checked on flaws. Each building block in the model has been checked on designation, set number, settings according to time units and link to the next building block. Using the technique of Input verification all numbers set in the model have been checked. The structural verification checks whether or not entities run through the model and do not remain in a queue or process. In the model 186 trains are created according to the amendment sheet of January. In the output sheet also 186 trains have left the marshalling yard. No train remains in the model.

All critical actors involved within the system of Ctw and who joined the design workshop validated the model on behaviour and output a-synchronously. The actors were consulted during the week before the design workshop took place. The simulation model has been run for several times and the actors had the possibility to ask questions on the visualizations, behaviour and output of the model. For each actor the focus was on his own KPI(s), with which he/she has a lot of experience. The conclusion of the validation meetings was clear, all actors were convinced of the quality and representativeness of the simulation model. Besides that the visualizations for the KPIs were experienced as clear. The scores on KPIs on which the actors have validated the model are shown in table 6.

Table 6: Performance of the system on KPIs within the current situation

KPI	Summer	Winter
Average lead time EBK	142 min	153 min
Maximum lead time EBK	397 min	397 min
Average departure delay	24 min	37 min
Punctuality	71,2%	69,6%
Utilization middle-track	402	430
Nr of trains washed	18 out of 49	18 out of 49
Maximum occupancy parking tracks	59%	59%

Adjustments to model for alternative solutions

For the alternative solution 1 to 4 the simulation model has been adjusted. The adjustments are specified for each alternative model:

1. Within the model the availability of the resource ‘saw-movement’ has been adjusted and made available during 24 hours a day.
2. In the alternative model including the maintenance periods for the middle-track, the resource of ‘saw-movement’ is available once before the middle-track gets out of order and right after the middle-track is back in operation.
3. In the simulation model the availability of shunting movements to and from the TWI have been made available for a longer period each day. Just on the peak hours for arrivals and departures this shunting movement is not available. An implication can occur in case trains are serviced in the TWI and according to the current arrival and departure plan other train movements have to be made. In the real situation the pattern of arrivals and departures should have been adjusted, but for this simulation not possible since another pattern for arrivals and departures takes months to develop in collaboration with BLP.
4. Within the model EBKs have been directed to one appointed parking track, if they do not have the opportunity to directly enter the TC. Other trains do not have the opportunity to be parked on this track anymore. The parking track chosen to claim as a parking track for just EBKs is 251.

4.4.2 Multi-perspective visualizations

From section 2.3 it can be concluded there is a wide variety of visualizations for actors perspectives. A distinction between the visualization of the actual behaviour of the system and the performance of the system on KPIs has been made to give the participants of the workshop an entire set of information to base their discussion on. Both types of visualizations are illustrated in next paragraphs.

Visualization of system’s behaviour

The behaviour of the system has been visualized by the representation of the lay-out of Ctw and hereon the train movements were animated. To clarify the occupancy of the shunting yard, for each parking track a bar has been added to visualize the occupancy on this particular track to quickly get an insight in the occupancy of the shunting yard. The date and time were visualized to let the participants experience the behaviour on real time basis. Moreover signals were built in for the usage of particular tracks on the marshalling yard or the ability to use a service facility. In figure 15 the animation of the behaviour of Ctw, including the occupancy of parking tracks and signals is illustrated.

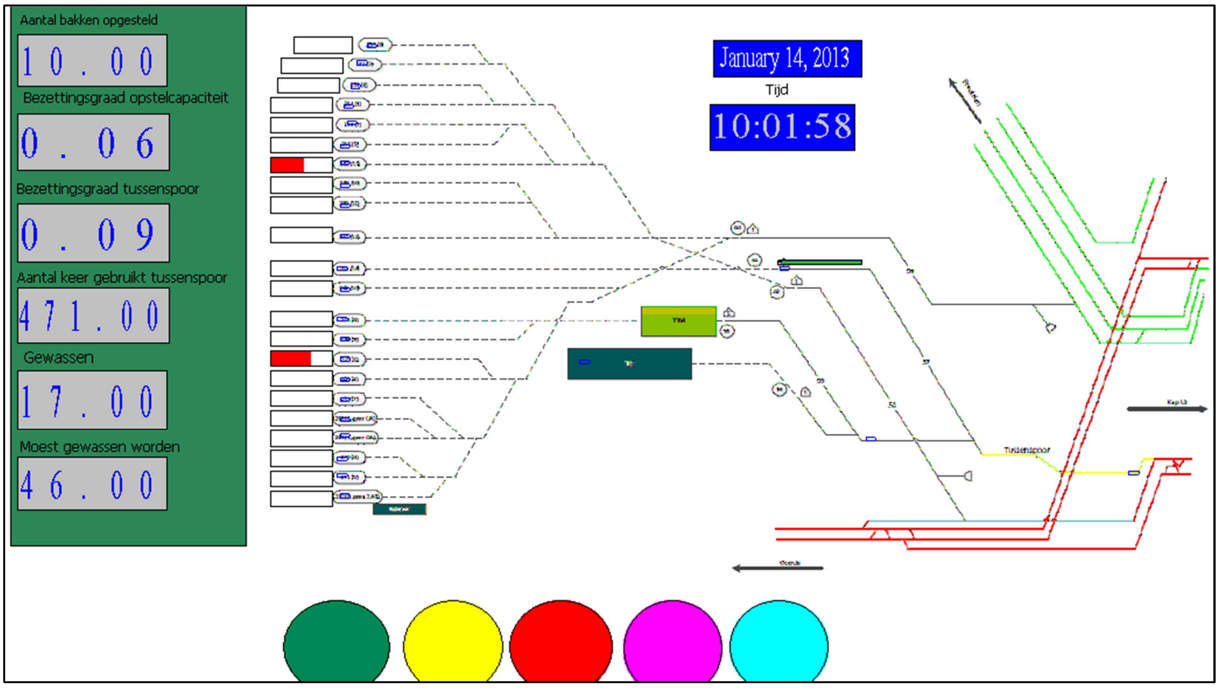

Figure 15: Visualization of system's behavior by animation in software package Arena

Visualization of system's performance - KPIs

Below figures illustrate the visualization of the performance of the system for a particular KPI (table 6). For the KPI 'occupancy rate on middle-track' the performance is already visualized within the animation as illustrated in figure 15. This also applies for the KPI 'nr of trains washed'.

In figure 16 the performance on the KPI departure delay is visualized. For each departing train the delay has been measured. For the actors PCL Ctw and RBC this is (one of) their most important KPIs. Within figure 16 the performance within the future situation and in case the alternative was implemented is visualized.

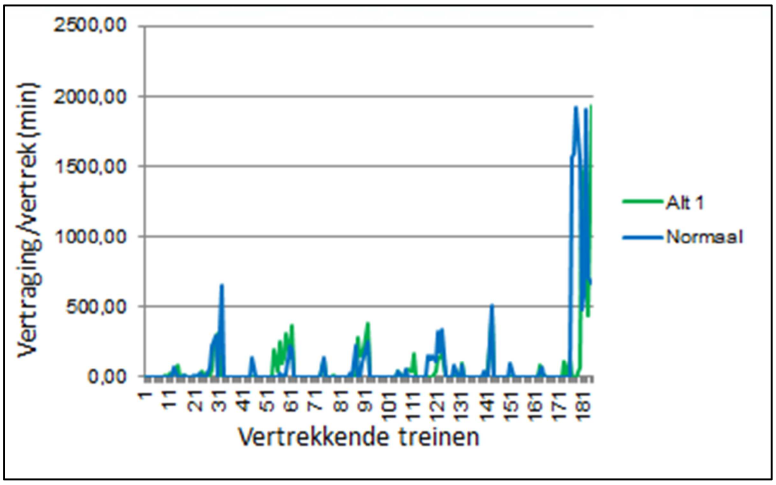

Figure 16: Visualization of KPI departure delay for each departing train

In figure 17 below the lead time for EBKs is visualized. For the actors Logistic Manager and MBN this is the most important KPI. The blue line illustrates the performance of the system in the future situation without any solution implemented, and the green line with a particular alternative solution implemented. In this case alternative 1. By visualizing the lead time in a graph figure the difference between the lead time becomes very clear.

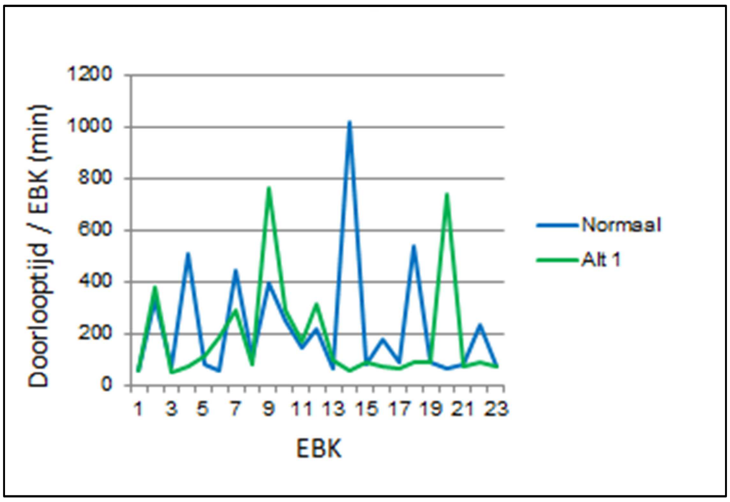

Figure 17: Visualization of KPI lead time of EBK

In figure 18 just the delayed trains are selected and ordered on their amount of delay. The PCL Ctw and RBC could use this figure to reflect on the system's performance on the KPI 'delay of departures'.

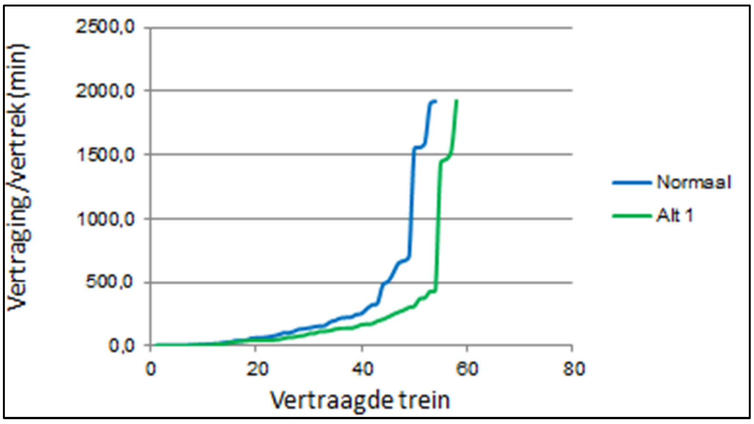

Figure 18: Visualization of KPI departure delay for each delayed departure train

For the comparison between the different situations the visualization of numbers give actors more easily insight in the improvement of system's performance (Huang et al. 2012). A table with the two main KPIs for most actors has been included to complete the set of visualizations. This visualization is illustrated in the figure 19 below.

Gemiddelde doorlooptijd EBK	224 / 185 min
Maximale doorlooptijd	1019 / 760 min
Punctualiteit vertrek	70,7% / 67,4 %
Gem. Vertraging vertrek	90 / 68 min

Figure 19: Visualization of KPIs in numbers

4.4.3 Detailed process design for the design workshop

For the design workshop the critical actors involved within the system of Ctw were invited (section 3.5). Within this workshop it is expected dilemmas to arise between the alternative solutions and effects on KPIs of involved actors. To structure the design workshop and resolve possible dilemmas a process design has been drawn up. This process design for the workshop is illustrated in figure 20. The coloured hexagons indicate the different actors involved. For each of the rounds particular actors were invited in the discussion, especially for the discussions on alternative solutions in which dilemmas were expected to occur and tried to be resolved.

Using the framework of De Bruijn et al (appendix IX) each round in the workshop has been operationalized. For each round of discussion on alternatives (rounds 4 to 9 in figure 20) the involved actors, the purpose of the alternative, expected dilemmas, used visualizations, and expected progress are discussed in the next paragraphs. An hypothesis is given for each of the discussion rounds, to reflect on in the next chapter and get an answer on the question whether or not multiple visualizations help to resolve dilemmas in a design process. Observing the behaviour and influence of the information from the visualizations will give answer to the hypothesis that multi-perspective visualization is an extra help to resolve dilemmas. The entire workshop has been filmed, to investigate whether or not these hypotheses are correct for the dilemmas which can occur during rounds 4 to 9 within the design workshop. The observer from the reference case Wgm has been consulted to validate these conclusions. In section 5.1 the results of the workshop are discussed and within section 5.5 conclusions on the hypotheses are given.

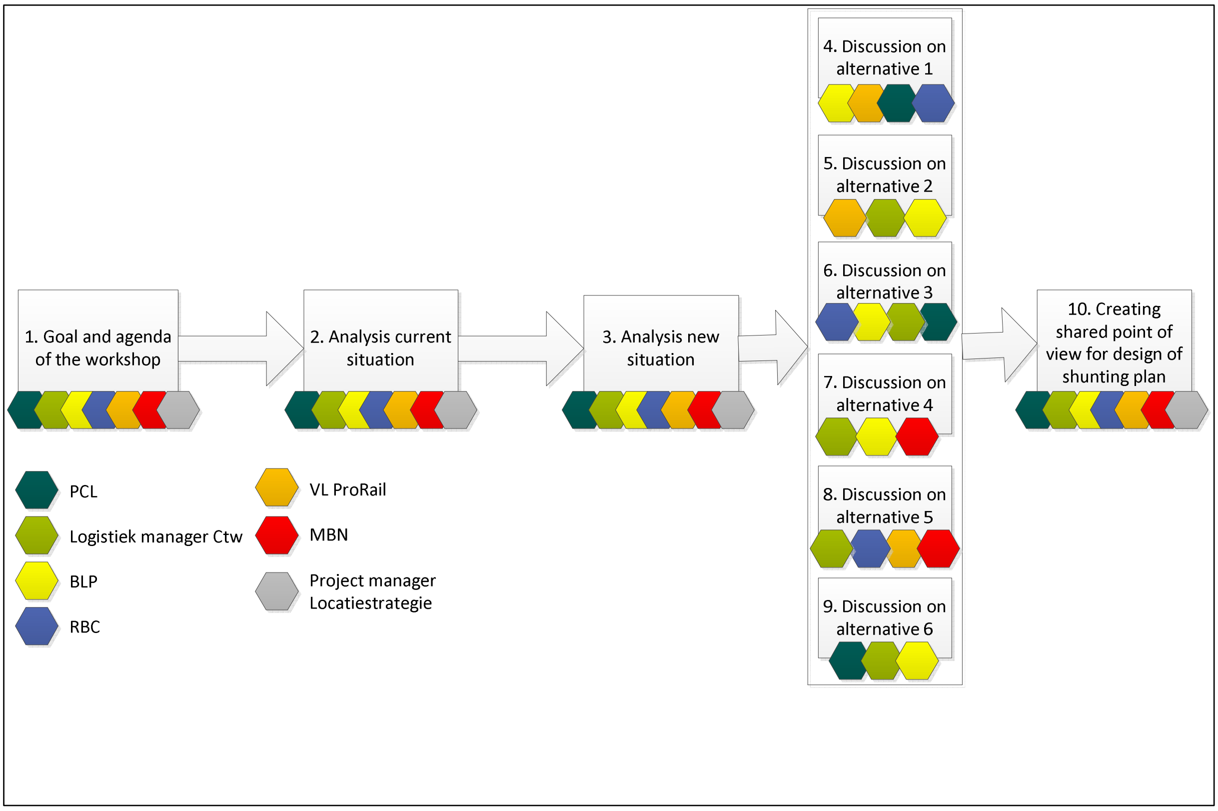

Figure 20: Process design for design workshop

1. Goal and agenda of the workshop

All critical actors have been involved within this round. According to De Bruijn et al. it is very important to communicate the goal of the workshop to all actors, to let them participate and perform optimally, to set the scope and finally reach the goal of the workshop (De Bruijn et al.). Therefore the goal and the agenda for the workshop itself were communicated in the first round of the workshop. Also the rules of the game were communicated, so participants know how to behave during the workshop. The rules according to all rounds in this workshop were:

- No actor has a dominant position
- Discussion is be open for involved actors as indicated in figure 20. Other actors are not allowed to react unless they are asked to participate in the discussion.
- The discussion is just aimed at the logistics process. Discussion on for example the location of the TC or maintenance jobs to fulfil within the TC are not to be discussed in the workshop for the shunting plan at Ctw.

2. Analysis current situation

During the second round the characteristics and performance of the current system and logistic processes on Ctw have been discussed on the basis of a presentation by the facilitator. Within this round all actors were involved and had the opportunity to ask questions. The goal of this round was to create shared understanding on the current processes on Ctw among all actors.

3. Analysis new situation

In the new situation, December 2013, the TC is constructed and in operation on Ctw. The EBK trains on Ctw which have to be maintained in the TC have impact on the logistic processes and performance of the service process on the marshalling yard Ctw. All actors have been informed about the technical characteristics and bottlenecks of the new situation and the impact on the performance of the system were presented by the facilitator. The goal of this round was to create shared understanding on the impact of the new situation on the shunting yard Ctw. During this round all actors had the opportunity to ask questions or react on the numbers and figures.

4. Discussion on alternative 1: facultative paths on middle-track

Purpose of alternative: Increase availability for saw-movements on the middle-track.

Actors involved: BLP, VL ProRail, PCL and RBC.

Dilemma: The accessibility of the TC can increase by the implementation of this alternative. As a result the material availability can increase and the average delay of departure is expected to decrease. However, the occupancy of the middle-track is expected to be a discussion point, because the flexibility and safety on the middle-track can be disadvantaged.

Important visualizations: Occupancy of the middle-track, animation of Ctw, lead-time EBKs and average departure delay.

Hypothesis on expected progress: The discussion is based on the KPIs for all involved actors and come to a consensus on the implementation of this alternative.

5. Discussion on alternative 2: Availability of saw movement before and after decommissioning of middle-track

Purpose of alternative: Increase availability for saw-movement on the middle-track.

Actors involved: VL ProRail, Logistics manager Ctw and BLP.

Dilemma: By the reservation of half an hour before and after an out-of service period for middle-track to shunt trains, this time period is shortened to execute maintenance by ProRail. A shorter time period to shunt trains to/from Ctw for BLP can be one of the results either. The accessibility of TC can increase, which can have as a result a shorter lead time for EBKs and a decrease of the average departure delay.

Important visualizations: Occupancy of middle-track, average departure delay and lead time of EBKs.

Hypothesis on expected progress: BLP and ProRail get insight in the importance for the availability of a saw-movement before and after a decommissioning period and thereby permit the reservation of the middle-track for a saw-movement before and after a decommissioning period.

6. Discussion on alternative 3: Adapt process shunting in shunting plan

Purpose of alternative: Increase shunting movements to maintenance facilities to streamline process shunting.

Actors involved: RBC, BLP, Logistics manager Ctw, PCL.

Dilemma: The lead times for service jobs can decrease, but the shunting process can become inflexible due to the planned shunting movements. The average departure delay, punctuality can be vulnerable for this more inflexible shunting process. For the punctuality, quality of the service process and material availability a dilemma can arise.

Important visualizations: KPIs on number of trains washed, departure delay, punctuality, lead time EBKS and the animation of Ctw.

Hypothesis on expected progress: Actors come to consensus on the implementation of the alternative.

7. Discussion on alternative 4: Claim parking track for EBKs

Purpose of alternative: More easy to park an EBK and afterwards shunt a train towards the TC to decrease the lead time for EBKs.

Actors involved: BLP, Logistics manager Ctw, MBN.

Dilemma: Direct loss of parking capacity of 8 cars makes the planning of BLP more complex, shunting movements can be vulnerable for the particular parking track, but a more easy working process for the TC can be created.

Important visualizations: KPIs on lead time EBKs, punctuality and average departure delay

Hypothesis on expected progress: MBN recognizes problem situation for BLP and Logistic manager Ctw based on the visualizations and get rid of his wish for a parking track for EBKs.

8. Discussion on alternative 5: Parking track for EBKs on another shunting yard in Utrecht

Purpose of alternative: Avoid saw-movements from parking tracks of Ctw to TC, but shunt EBKs directly to the TC from another marshalling yard in Utrecht.

Actors involved: Logistics manager Ctw, RBC, VL ProRail, MBN.

Dilemma: More shunting movements will be executed on the junction Utrecht, which already is utilized maximally. Safety and punctuality risks for ProRail can create a dilemma with the decrease of lead time of EBKs by avoiding the saw-movement. The work load for RBC can increase by implementation of this alternative.

Important visualizations: No, is out of scope of the simulation model.

Hypothesis on expected progress: A more blurred discussion, in which actors argumentations are more questioned by other actors.

9. Discussion on alternative 6: Collaboration between BLP and PCL

Purpose of alternative: Decrease shunting movements to combine trains during the night by planning the train combinations in collaboration.

Actors involved: BLP, PCL and Logistics manager Ctw.

Dilemma: Human resource capacity for collaboration of both actors.

Important visualizations: No, cannot be tested using the simulation model.

Hypothesis on expected progress: Discussion on the substance of the collaboration. Animation of the processes on Ctw during the discussion on the current situation can help to identify the need for collaboration.

10. Creating shared point of view for design of shunting plan

Within the final round of the design workshop the outcomes of all discussions on dilemmas have been summarized. All actors were asked to give their consent on these conclusions. The facilitator gave a short summary of the discussion on each alternative and all actors were asked subsequently whether or not they had comments or additions to the conclusions derived by the facilitator.

The setting of the design workshop is illustrated by a photo in figure 21. On the left screen the animation run to visualize system's behaviour. On the right screen a presentation was walked through with the visualizations on KPIs as discussed in section 4.3.

Figure 21: Setting of design workshop – Utrecht, 27 February 2013

5. Results of design workshop

For both the scientific experiment considering the enhancement of shared understanding through the addition of multiple perspectives and on the practical research the results are given in this chapter. The results are directly evaluated, to be able to draw conclusions in the next chapter. First of all the substantive results of the discussions on the solution alternatives are given. The results of the 3 evaluation studies, pre-test and post-test, observations and post-survey are given in paragraph 2, 3 and 4. The results on the hypothesis of the dilemma resolving during the discussion are discussed in paragraph 5. A short analysis on the meaning of the results of this case study for other SBD processes will be given in the final paragraph of this chapter, the generalisation of the results.

5.1 Discussion on alternatives solutions

During the design workshop the solution alternatives have been discussed. During these discussions the multiple visualizations were a great support. The simulation model provided output on the specified KPIs as already discussed in section 4.4.1. The results on these KPIs will be illustrated within the next paragraphs. For all results on the KPIs 'lead time of EBKs' and 'departure delay' statistical tests have been executed, to test whether or not the implementation of a specific alternative lead to a significant improvement or deterioration. For these tests a paired t-test (student t-test) has been used and a significance level of 95% has been applied. In case the increase or decrease on a specific KPI is tested to be significant, the number within the table is indicated with an asterisk (*).

5.1.1. Current situation vs. future situation

The current situation in which there is no TC yet and the future situation from the end of 2013 on, in which the TC is in operation have been simulated and discussed during the workshop. The results on different KPIs are given in table 7.

Table 7: Results on KPIs of the system's performance within the current and future situation

KPI	Current situation	Future situation (with TC)
Average lead time EBK (min)	142	224
Maximum lead time EBK (min)	397	1019
Departure punctuality	71,2%	70,7%
Average departure delay (min)	24	90*
Nr of trains washed	18 / 49	18 / 49
Times of middle-track used	402	440

Using the statistical method of paired t-test the difference between the average lead time EBK and average departure delay has been tested whether this difference is significant or not. The average departure delay increase in the future situation is significant, but the average lead time increase for EBKs is not.

5.1.2. Conclusion on alternative solutions

For each alternative solution the outcomes from the model and substantive discussion will be illustrated in next sections.

Alternative 1: Facultative paths on the middle-track

Table 8: Results on KPIs of system's performance with implementation of alternative 1

KPI	Future situation	Alternative 1
Average lead time EBK (min)	224	185
Maximum lead time EBK (min)	1019	760
Departure punctuality	70,7%	67,4%
Average departure delay (min)	90	68
Nr of trains washed	18 / 49	18/49
Times of middle-track used	440	435

For the average lead time for EBKs and departure delay the average do not differ significantly (table 8). The conclusion of the discussion between the critical actors is clear. This alternative can improve the problem situation, however a footnote is pronounced according to the feasibility for implementation of this alternative. The average lead time for EBKs will decrease as well as the departure delay and number of times the middle-track is used, which are all benefits of this alternative. ProRail did not want to implement facultative paths, which led the discussion to an adjustment of the alternative. The common thought for this alternative was to create a time window on the middle-track in which no trains arrive or depart. In this time window of 20 minutes the shunting movement from a parking track to the TC can be executed.
However, in the current planning this time window can be created, but it is not a solution which is future proof if more trains will arrive on Ctw.

Alternative 2: Facultative paths before and after the middle-track is under maintenance

Table 9: Results on KPIs of system's performance during decommissioning periods of the middle-track with implementation of alternative 2

KPI	Future situation with middle-track under maintenance	Alternative 2
Average lead time EBK (min)	235	215
Maximum lead time EBK (min)	910	910
Departure punctuality	70,1%	73,4%
Average departure delay (min)	73	60
Nr of trains washed	18 / 49	18/49
Times of middle-track used	440	388

For this alternative the average lead time for EBKs and departure delay do not differ significantly (table 9). During the discussion it became clear the time period and regularity for the middle-track to be out of order is not clear yet. Discussion on possible solutions would not lead to any benefits according to the participants. That is why the discussion was closed very quickly and no further conclusions for this alternative can be made.

Alternative 3: Include process shunting within a new shunting plan

Table 10: Results on KPIs of system's performance with implementation of alternative 3

KPI	Future situation	Alternative 3
Average lead time EBK (min)	224	316
Maximum lead time EBK (min)	1019	1176
Departure punctuality	70,7%	67,9%
Average departure delay (min)	90	40*
Nr of trains washed	18 / 49	34/49
Times of middle-track used	440	434

According to the statistical test the average delay decreases significantly. The increase of the average lead time for EBKs is not significant (table 10).

During the discussion mainly 2 actors were quite enthusiastic about the number of trains washed and decrease of average departure delay, the Manager Logistics and the PCL. For the other actors the decrease of the punctuality and increase of lead time resulted in a long discussion which led to the conclusion that process shunting frustrates the processes on Ctw in case there is an unplanned situation. The PCL should plan shunting movements to the TWI better himself in order to wash a higher number of trains. Most of the actors did not see the advantage for the implementation of this alternative.

Alternative 4: Claim parking track for EBKs

Table 11: Results on KPIs of system's performance with implementation of alternative 4

KPI	Future situation	Alternative 4
Average lead time EBK (min)	224	250
Maximum lead time EBK (min)	1019	910
Departure punctuality	70,7%	65,8%
Average departure delay (min)	90	71
Nr of trains washed	18 / 49	18/49
Times of middle-track used	440	434

For both the average lead time of EBKs and the average departure delay the statistical test was not significant (table 11).

During the discussion only the representative of MBN was in favour of this alternative solution. All other participants were less enthusiastic and found support in the numbers presented in table 11. The final conclusion of the discussion on the alternative was clear, this will just foresee in the demand of MBN and will slightly improve the maximum lead time. Loss of direct parking capacity and the decrease of the punctuality were the main reason for actors to not agree on the implementation of this alternative.

Alternative 5: Parking track for EBKs on another shunting yard in Utrecht

For this alternative it was not possible to test the impact on actors KPIs using the simulation model, because the alternative solution affects a part of the infrastructure outside the scope of the model. However, during the discussion it became clear this alternative solution brings several negative side effects. The main bottleneck for this solution is the extra capacity for train drivers required for shunting movements from other shunting yards in and around Utrecht. These train drivers are not available and therefor trains from another shunting yard cannot be shunted to the TC on Ctw. Besides that the possibilities to shunt a train from another shunting yard to Ctw are limited. All actors agreed that this alternative does not improve the problem situation.

Alternative 6: Collaboration between BLP and PCL to plan arrivals and departures on Ctw

A very enthusiastic reaction of all actors arose when the alternative for a collaboration between BLP and PCL was introduced. The impact of this alternative on the KPIs could not be analysed using the simulation model, since the planned arrivals and departures will change and the way in which trains will be allocated to a parking track will be defined upfront.
According to all actors this alternative is the starting point for the improvement of the shunting processes on Ctw. Alternative 1, which is the other alternative on which all actors agreed on a positive implementation, is subordinated to this alternative. Alternative 1, a time window in which no trains arrive or depart so the middle-track can be used for shunting movements, can be implemented if the collaboration is set.

Together with the post-test on the level of Shared Understanding, which will be discussed in section 5.4, the participants of the workshop were asked to rank the alternatives on feasibility and preference. In table 12 the order for alternative solutions on the degree of effectiveness and feasibility perceived by the participants is given. In appendix 19 the calculations for this order can be consulted.

Table 12: Alternatives ordered by preference.

Order	Alternative
1	6: Collaboration between BLP and PCL
2	1: Create time window to shunt train from a parking track to the TC during peak hours
3	3: Adopt process shunting in shunting plan
4	4: Claim parking capacity on Ctw for EBKs
5	2: Create opportunity to shunt towards TC right before/after closure of middle-track.
6	5: Park EBKs on other shunting yards and shunt to Ctw if TC is free

5.2 Pre-test and post-test on SU

In the very first beginning of the workshop the pre-test questionnaire has been filled out by the participants (appendix 15). Right after the design workshop ended the participants filled out the post-test (appendix 15). Within these tests the scores on the degree of shared understanding could vary between 1 and 6. The scores on additional questions within the post-test for each aspect of SU on the perceived improvement of SU could vary on a 7-point Likert scale, as discussed in section 4.2.1. The results of the pre-test and post-test are shown in table 13.

Table 13: Results of the pre-test and post-test on the level of SU

Question	Pre-test	Post-test	Wilcoxon test (p-value)	Perceived improvement
Content 1	4,71	5,43	0,025*	5,57
Content 2	3	5	0,027*	5,43
Social Relation 3	3,43	5,29	0,016*	5,43
Social relation 4	3,29	5	0,016*	5,71
Process 5	3,57	4,89	0,066	5,14
Process 6	3,43	4,43	0,053	5

* Asymp. Sig. level of 95%
N = 7

The pre-test and post-test are compared in order to test the hypothesis that through the workshop with the multi-perspective visualization the SU is enhanced significantly. The results on the pre-test and post-test have analysed and a first conclusion is that the scores of the post-test on all aspects of SU are higher. This is strengthened by the scores of the additional question in the post-test because all scores on the perceived improvement of SU is higher than 4 (neutral).

The statistical Wilcoxon-test has been performed to test whether or not the scores on the post-test are significant of a higher level. This is a nonparametric test which tests whether or not 2 related sample tests differ from each other (Vocht, 2004). A student t-test cannot be used because the sample size is not large enough, less than 30 (Vocht, 2004).

From the second right column in table 13 it can be concluded that with a confidence interval of 95% the first 4 questions on SU are scored significantly higher. Therefor on the aspects ‘content’ and ‘social relation’ the workshop with the multi-perspective visualization has led to a significant higher SU. For the questions on the process aspect of SU the results are not significant, but could have been if the sample size was larger and a student t-test have had been executed.

From the average scores in table 13 it is concluded there already is a moderate level of SU. In the reflection chapter possible influences on this score due to the project setup will be discussed.

5.3 Observations by reference case

The project manager for the design of a shunting plan at Wgm has been involved as an observer during the workshop (section 4.2.2). This senior planner is consulted a few days after the design workshop for an interview to reflect on the added value of multi-perspective visualizations within an SBD process (Wieten, 2013).

During a two-hour meeting the project manager was interviewed which led to the following conclusions.

Multi-perspective visualizations do enhance shared understanding

The overall workshop did enhance the SU enormously. The multi-perspective visualizations are definitely an added value and have increased the SU more than if the workshop was organized without the multi-perspective visualizations. Especially the completion of the entire set of information which is necessary for the substantive discussion on impacts of alternative solutions is of great importance.

Discussions are based on multiple perspectives of KPIs

The different type of visualizations have created far more insight in the system and its behaviour under different circumstances. Within the substantive discussions on the alternative solutions the focus was on the visualization of the different KPIs. Actors used the figures and numbers in their argumentation which led to very transparent discussions. The result was a very orderly discussion, in which no discussion on numbers used in actors argumentation arose.

Discussions are already discussed for a greater part

Due to the visualization of actors perspectives all participants could already estimate other actors reaction on a specific solution. As an effect participants already did some assumptions about actors opinions of an alternative solution. The discussion was ‘beaten flat’ already for a greater part. Through this, the substantive discussions were more on the details of the solution alternative than as a discussion on a high level between the preferences of different actors.

The effectiveness of the different visualizations depend on the point of discussion

Wieten did a remarkable statement that the different kinds of visualization had different functions. For the understanding of the behaviour of the system and the problem situation the animation of the train movements on the visualized marshalling yard of Ctw was very effective. During the substantive discussions the animation was hardly used anymore but participants focused on the visualizations of the different KPIs. “For the imaging of the system and its behaviour the animation was excellent, but for the discussion on the alternative solutions the participants often referred to visualizations on KPIs”(Wieten, 2013).

5.4 Post-survey on influence of multiple visualization on SU-enhancement

The test on the enhancement of SU is positive, however it should be tested if the addition of multi-perspective visualization had a significant influence on this enhancement. This is examined using the observer from the reference case Wgm as already discussed in section 5.6 and with a survey.

The participants are consulted once more after the design workshop in order to strengthen the conclusion whether or not the multi-perspective visualization was of a significant influence on the enhancement of the SU. For each of the aspects of SU two propositions are included in the survey, a negative and a positive proposition on the influence of multi-perspective visualization on the enhancement of SU. The participants could answer on a 7-point Likert scale, varying from totally disagree (1) to totally agree (7). In appendix 16 the survey can be consulted. The results of the individual scores can be consulted in appendix 20.

The results of the survey on the influence on SU of multi-perspective visualization are given in table 14. Using a nonparametric Wilcoxon test the hypothesis could be tested whether or not multi-perspective visualization does have a significant influence on the enhancement of SU. This type of test is used because of the small amount of 6 respondents. The positive and negative propositions from the survey on each aspect of SU are compared and tested whether or not the positive proposition are significant higher than the negative proposition. In right column of table 14 the results of the Wilcoxon test are shown.

Table 14: Results of post-survey

Aspect	Positive proposition	Negative proposition	Wilcoxon Test (p-value)
Content 1	5.8	1.7	0,026*
Content 2	5.3	1.8	0,024*
Social relation 1	5.0	2.5	0,068
Social relation 2	5.7	2.5	0,027*
Process 1	4.7	2.3	0,027*
Process 2	4.7	2.8	0,074
Overall enhancement of SU	5.8	2.3	0,041*
* Asymp. Sig. level of 95% N = 6			

From table 14 the first conclusion can be drawn that the participants on average agree with the positive propositions and disagree with the negative propositions since the average score is less than 4. Especially on the proposition of the overall enhancement of SU it can be concluded there is a serious influence of the multi-perspective visualization on the enhanced shared understanding.

From the results of the nonparametric test it can be concluded that the influence of multi-perspective visualization on the enhancement of SU is significant. With a confidence interval of 95% the multi-perspective visualization has a significant influence on 4 of the 6 aspects of SU. Moreover, it can be concluded the participants experienced the multi-perspective visualizations of a significant influence on the overall enhanced SU, on which a separate question was posed (table 14).

The scores on the propositions are recalculated to draw more stronger conclusions from the survey. Therefor the scores on the negative propositions are recalculated (8 – score on negative proposition). The average scores on each aspect for the negative and positive propositions have been averaged. By merging the aspects for each construct of SU the average score on the particular construct could be calculated. The average scores on the 3 aspects of SU are shown in table 15.

Tabel 15: Recalculated results of post-survey

Aspect of SU		Scores post-survey		Average score	Average score on aspect
Content	Content 1	Pos.	5.83	6.08	5.92
		Neg.	6.33		
	Content 2	Pos.	5.33	5.75	
		Neg.	6.17		
Process	Process 1	Pos.	5.00	5.25	5.42
		Neg.	5.50		
	Process 2	Pos.	5.67	5.58	
		Neg.	5.50		
Social Relation	Social Relation 1	Pos.	4.67	5.17	5.04
		Neg.	5.67		
	Social Relation 2	Pos.	4.67	4.92	
		Neg.	5.17		
Overall	Overall	Pos.	5.83	5.75	5.75
		Neg.	5.67		

The average scores on the three aspect of SU indicate that the influence of the addition of multi-perspective visualization on the enhancement of SU is substantial , since the scores are between 5.04 and 5.92 out of 7. The propositions on the overall enhancement of SU has an average score of 5.75. This score does indicate even more that the influence of the addition of multi-perspective visualization on the enhancement of SU is substantial.

5.5 Dilemma resolving

For the discussion rounds on the 6 different alternatives, for which the hypothesis are established in section 4.1.3, the actual discussion process will be discussed in this section. Comparing the actual process in each round, studied by the film of the entire workshop, the hypothesis can be adopted or rejected.

Round 4: Discussion on alternative 1

Hypothesis: Actors come to a consensus on the implementation of this alternative by a discussion based on scores on KPIs.

Observation: The kernel of the discussion, the dilemma for involved actors, was resolved very quickly. Actors got insight in the effects of the implementation of the alternative and all agree this is a serious alternative which should be implemented to improve the logistical process on Ctw. The visualization of the impact on actors KPIs was used several times, to underpin actors arguments. The actors agreed on the elaboration of this alternative and the discussion on the details of this alternative continued. In this discussion the VL of ProRail stated a few requirements on the implementation of the alternative. All actors agreed on these requirements.

Conclusion: Actors do come to a conclusion very quickly, with the support of the visualizations on KPIs.

Round 5: Discussion on alternative 2

Hypothesis: BLP and ProRail get insight in the importance for the availability of a saw-movement before and after a decommissioning period and thereby permit the reservation of the middle-track for a saw-movement before and after a decommissioning period.

Observation: The main subject of discussion were the assumptions for the decommissioning period of the middle-track for maintenance. Because there is a lot of uncertainty about the planning of decommissioning periods actors did not discuss on the alternative solution and its impact. They did not consider the discussion on the alternative to be useful.

Conclusion: No conclusions can be drawn from the discussion on this alternative, since actors considered this discussion as not useful.

Round 6: Discussion on alternative 3

Hypothesis: Actors come to consensus whether or not to implement a shunting plan including process shunting.

Observation: Actors are convinced by the performance of the system, since the number of trains washed increased enormously. However, the PCL and RBC were very reticent about the implementation of a marshalling plan including process shunting. They consider such a shunting plan as a risk for the flexibility of the processes on Ctw. The project manager explained the functionality of a shunting plan including all movements to service facilities. However, the insight given by the project manager of Wgm and the positive performance did not lead to a consensus on this alternative.

Conclusion: Actors did not come to a consensus on the implementation of this alternative. They did agree on the usefulness of this alternative considering the performance of the service facilities.

Round 7: Discussion on alternative 4

Hypothesis: MBN recognizes the problem situation for BLP and Logistic manager Ctw based on the visualizations and get rid of his wish for a parking track for EBKs.

Observation: During the discussion the representative of MBN did encounter the other side of this alternative. The discussion was closed very fast, the actor of MBN did try to explain once more why he had the wish for a parking track but directly referred to the negative impact on other actors KPIs.

Conclusion: MBN recognizes the problem for other actors by the analysis of the KPIs of other actors and exclude the implementation of this alternative.

Round 8: Discussion on alternative 5

Hypothesis: A more blurred discussion arises, in which actors argumentations are more questioned by other actors because there is a lack of information on KPIs and systems' behaviour.

Observation: A lot of qualitative argumentations are used by the participants. The subjects of the argumentations differed a lot from the previous discussions and due to the increased number of arguments the discussion leads for a longer time. In reaction on others argumentation they do not refer to their KPIs. In the end actors agree with each other this alternative to be ineffective. The occupancy on the junction Utrecht is known by all actors and the accessibility of other marshalling yards too. They all agree that this alternative will not improve the problem situation.

Conclusion: The discussion is more blurred and is time consuming. At the end they do agree to not implement this alternative.

Round 9: Discussion on alternative 6

Hypothesis: Discussion on the substance of the collaboration. Animation of the processes on Ctw during the discussion on the current situation can help to identify the need for collaboration.

Observation: Actors do not even start a discussion on the question whether or not to implement this alternative solution. It should be implemented, as first. The way in which the collaboration should be formed is discussed, but did not lead to a clear answer. The PCL of Ctw should take the initiative according to the actors present.

Conclusion: No discussion whether or not to implement the alternative, it should be implemented, as first! The substance of the collaboration is discussed but no clear outcome is generated.

5.6 Generalisation of the results

The results of the case study, in which the design workshop had a prominent role, are clear and promising for the execution of SBD projects in the future. Within this section the results of the case study are evaluated and justified, in order to generalize the results and identify what these results mean for the SBD approach within other design projects. Therefor first of all the case will be typified very briefly again. Reflecting the results on the characteristics of the case, a more general conclusion of the experiment is tried to be drawn.

Case characteristics

The design case at NedTrain, for a new shunting process design at the marshalling yard is a very specific design project. The environment in which the design of a shunting process design had to be implemented was a marshalling yard, on which only NedTrain services trains for NSR. On this marshalling yard the logistic processes on Ctw are controlled locally by the PCL, which has to cooperate with the regional railway control centre of ProRail. The shunting process to be designed is specifically for the marshalling yard, which is an outlying part of the railway network. Critical actors involved within the design process were all actors which are closely related to the processes on the railway network and were departments of a larger company like NedTrain, NS and ProRail. Thereby all actors involved have a background with logistic processes, know the typology used within the sector and can communicate very easily with each other. Since there were a lot of different actors involved the interests and stakes were very divergent.

For the next levels of generalization the results of this case study will be reflected.

Similar cases

At NedTrain another 3 TCs are planned to be developed in the next few years. The locations of these TCs will be all on marshalling yards; Zwolle, Nijmegen and Den Haag. The technical system, logistic processes and actor environment of these design projects are similar to the design case of Ctw. For these locations other train operators also have their trains serviced by NedTrain, so more actors will be involved. However these actors will be of the same type as the departments of NSR within the case study on Ctw. Therefore the SBD approach including multi-perspective visualization is expected to have the same impact and results as within the design for a new shunting process at Ctw.

SBD project on logistic processes on the railway network

The type of problem seems to be the same, as well as for the technical system on a particular part of the railway network. However, logistic processes on the main railway sections are to deal with other actors involved and the logistic processes will be of a different nature. The technical environment will differ, as well as the location and thereby the critical involved actors will be different. The SBD approach including multi-perspective visualization is expected to be successful in these kind of design projects, however the type of visualizations and approach of the design project should be adjusted, to fit with the technical and actor environment. Since the involved actors will be within the railway sector mainly, the communication is not expected to be a problem. By the use of the SBD approach including the multi-perspective visualization the results are expected to be in line with the results of the case study on Ctw, but adjustments to the type of visualizations and maybe the type of simulation should be made.

SBD projects overall

In every other design project other than for logistic processes on the railway network the technical and actor environment will differ a lot. The field of actors can be enormously varied, in which actors from environmental organizations, government, engineering companies and financial institutions can be involved. Because of the different backgrounds of these organizations the SU upfront the design project will be very low and the opportunity to be increased by an SBD process including multi-perspective visualization is enormous. However, it is expected the use of SBD including multi-perspective visualization to be challenging, since it is hard to have an successful workshop with these varied group of actors, just because they have entire different backgrounds. Other type of visualizations will be required and the introduction of actors with the methodology of SBD including the orientation of actors within the field of the design project will be time consuming. A design workshop as used within the case study on Ctw needs actors to be informed about the type of communication, culture and background of the system to be designed on all different levels, technical, environmental, financial etcetera. The SBD process will need a lot more preparation, need other type of visualizations and maybe even another type of simulation software. Despite of it will need a lot of effort to prepare for an SBD process, but the results on the level of SU and the quality of design are expected to be great. Especially in a very diverse design environment the opportunity to enhance the level of SU by the addition of multiple perspective visualization is expected to be enormous.

6. Conclusions and recommendations

The conclusions and recommendations for the scientific and practical research will be discussed separately.

6.1 Use of multi-perspective visualizations within an SBD process

First of all the conclusions to be drawn from the case study will be discussed. These results were generated within a very typical design case. The results and conclusions from this case study will be used to draw more general conclusions on the use of multi-perspective visualization within a Simulation-Based Design (SBD) process.

Fumarola et al. and den Hengst et al. provide the most suitable approaches for an SBD process. Fumarola strives to make the SBD process as interactive as possible, where den Hengst et al. focusses on the involvement of all kind of actors for the validation of design artefacts. A combination of these approaches has been used for the design project for a new shunting process at the marshalling yard Cartesiusweg (Ctw), so that it could be reflected on the reference case Watergraafsmeer (Wgm) and be executed within the limitations of the case Ctw.

Although the approaches of Fumarola et al. and den Hengst et al. for an SBD process are proved to be very suitable design approaches in literature, the addition of multi-perspective visualization can lead to a higher level of Shared Understanding (SU) and more satisfactory design results. For the addition of multiple perspective visualizations two main types of visualizations are found to be most important; the visualization of KPIs and the visualization of actual behaviour of the system. Visualizations of KPIs are important to include because discussions are based on KPIs. Moreover an animation is important to include for the shared understanding on systems' behaviour and understanding of the problem situation as stated in section 2.3. For the case of Ctw for each involved actor his main KPI has been visualized. Moreover the actual processes on the marshalling yard, the shunting movements of the trains have been animated to visualize the actual behaviour of the system of Ctw.

Three different tools have been used to measure the level of SU and the effect hereon by the addition of multi-perspective visualization. By a quantitative pre-test and post-test it is concluded the level of SU to be increased significantly. The scores on the level of SU on different aspects as discussed in section 2.4 are for 4 out of the 6 aspects significant higher in the post-test. From the interview with an observer during the design workshop it has been indicated that the multi-perspective visualizations do have a clear influence on the enhancement of SU. This conclusion is strengthened by the results of the post-survey, in which all participants strongly affirm the conclusion that the multi-perspective visualization enhance the level of SU. The scores of the survey indicate significantly that the addition has a positive influence on the enhancement of SU.

For the shared understanding on systems behaviour and the problems in the current and future situation the animation of the marshalling yard was very important, as the observer of the workshop reflected. On the other hand the substantive discussion is primary based on the visualizations of KPIs. Reflecting on the workshop with the observer and together with the quantitative test it is concluded that the design process including the different visualizations on actors perspectives is experienced to be more effective than a design process with a single perspective visualization.

Furthermore from the observations during the workshop it can be concluded that the multi-perspective visualizations do help to resolve dilemmas within a multi-actor design process. Especially visualizations on KPIs are very effective and even already close a greater part of the discussion.

On the basis of the research results a final answer can be given on the main research question:

To what extent does the addition of multi-perspective visualization contribute to an enhanced shared understanding in the multi-actor simulation-based design process for a logistic process design on a marshalling yard?

By the addition of multi-perspective visualization the shared understanding can be increased significantly. By adding multiple visualizations on actors' KPIs and on systems' behaviour the discussions are more effective, dilemmas are resolved more easily and a joint decision on a final design for a shunting process design has been made. The influence by the addition of multi-perspective visualization on the level of SU can be concluded to be substantial.

The results of the research on the influence of multi-perspective visualization on the enhancement of SU have been tested significantly. The extent of the influence can just be estimated qualitatively by the observer of the reference case and can be deducted from the scores of the post-survey. The average scores of the post-survey indicate the participants strongly agree with the propositions that the addition of multi-perspective visualization enhanced their SU. Further quantitative research should be performed on the extent of influence of multi-perspective visualization, in order to strengthen the conclusion that multi-perspective visualization within an SBD process is very important and quantify the extent of the substantial influence on the enhancement of SU.

The design case for a shunting plan at Ctw was very specific. Typical for this case was the type of activities on a specific section of the railway network, the marshalling yard Ctw. Besides that the location of the marshalling yard itself within the railway network, type of actors involved and the motivation to design a new shunting plan were typical for this case.

As can be concluded from the design workshop and the use of the SBD method it is perceived to be a very effective design approach for the case of Ctw, in which a technical complex problem within a large actor environment had to be solved. The addition of multi-perspective visualization has a positive effect on the enhancement of SU and resolved dilemmas during the discussions on alternative solutions. The addition is expected to be very effective for design projects similar to the case of Ctw. At NedTrain 3 more TCs will be built the coming few years. For these projects in which also a new design for the logistic processes will be made on a marshalling yard the approach of SBD including multi-perspective visualization is expected to enhance the level of SU and helps to solve dilemmas during the discussion on alternative solutions. The same type of actors will be involved facing the same design objective. Since the same type of actors will be involved and the same type of system will be subject of analysis, the same visualizations can be used and are expected to contribute to an enhanced SU and effective design result.

Other design projects for logistic processes on the railway network, other than for a shunting process design, can certainly benefit from the addition of multiple perspective visualization to the methodology of SBD. It is expected to increase the level of SU and thereby increase the quality of design. However, since the design case will differ on more aspects, the type of visualization and the SBD approach to use should be adjusted to fit with the environment of the particular design case.

For the design of technical complex systems within a complex actor environment the effect of including multi-perspective visualization in the SBD approach is expected to be enormous on the enhancement of SU. Especially in a very diverse actor field the addition of multiple perspectives within the visualization in an SBD process can enhance the level of SU. Since design projects for logistic processes on the railway network include very specific actors, which are all dedicated to the railway sector, are probably more easy to start since all actors are familiar with the design environment. The SBD approach in other sectors or even over multiple sectors will need more preliminary preparation, in which actors are all introduced with each other and the different systems in which the design has to be fit. The environment of the design project requires different type of visualizations and another process approach of the SBD design process.

The conclusions are based on just a single case study. To strengthen these conclusions multiple case studies should be performed. The approach used in this research study is experienced to be very successful and is recommended to adopt in future case studies. Similar cases but also totally different cases should be performed, to identify the effect of multi-perspective visualization in all kind of SBD projects.

6.2 Design for shunting plan Ctw

The main bottleneck within the logistic system on the marshalling yard Ctw is the occupancy of the middle-track. All arriving and departing trains drive on this track and besides those movements this track is used for the shunting movement from a parking track to the TC. During peak hours, in which the train service ends or starts (23.00-02.00 & 04.00 – 07.00) the occupancy of the middle-track is very high, which limits the ability to shunt a train to the TC.

This can cause unnecessary waiting time for trains to be serviced within the TC, with a result these trains get a delay, the punctuality decreases and there are less trains available for the train service. For the concept of the new-to-build TC it is of great importance to improve the accessibility of the TC, in order to service trains as fast as possible and keep up the business case for the TC project.

In first instance the solution to get the TC accessible, also during peak hours, is tried to be found within the logistic processes. Six different alternatives have been developed in collaboration with different actors. In a design workshop for a shunting plan at Ctw, in which the accessibility of the TC could be warranted, the main conclusion was that a collaboration between BLP and the PCL on Ctw must be seen as a starting point to improve the logistic process.

Just a single alternative is concluded to be viable and is supported by all actors. The planned arrivals and departures on the middle-track should be organized in a way that there is the opportunity for a shunting movement from the parking track to the TC. Creating a time window of at least 20 minutes during the peak hours on the middle-track is the only alternative to be implemented. The robustness of this alternative on the long term is questionable. Therefore a study on infrastructural adjustments to increase the accessibility of the TC from the parking tracks is executed, although it was not part of this research originally. This study is illustrated in the discussion chapter.

From the additional research study no feasible solutions have been found on the adjustments of the railway infrastructure. The most feasible solution to create, in collaboration between BLP and PCL, is a structural time window of 20 minutes during peak hours on the middle-track. In this way trains from a parking track to the TC do not have to wait the entire period of peak hours but can be shunted on a shorter term to the TC. However, this solution is not robust enough on the longer term and therefore a list of requirements and desires is composed, in order to avoid the shunting movement from the parking tracks to the TC (appendix 17). The logistic process is expected to be good enough if those requirements are fulfilled and even improve if the wishes are carried out.

7. Discussion

The method of Simulation-Based Design (SBD) has been well praised in literature. Within this research this method is examined and completed with multi-perspective visualization. This chapter discusses the usefulness of the methodology. Besides that the first design workshop did not lead to a satisfactory solution for the logistic problems on Ctw. Therefore a second workshop has been executed to identify whether or not adjustments to the infrastructure could lead to a robust process on the long term. The proceedings of the second workshop will be discussed as well in the second section of this chapter.

7.1 The SBD approach

The SBD approach including multi-perspective visualization has shown to be very successful for the design project for a new shunting plan at the marshalling yard Ctw. This approach is experienced to deliver for a good design result supported by all involved actors in this research case. The addition of multi-perspective visualization as proposed by Fumarola had a very positive effect on the enhancement of Shared Understanding (SU) among all participants.

As Mulder (1999) denote that SU is very important to end with a satisfactory design result supported by all actors this can be confirmed by the design results of this case study. Due to the interaction between involved actors and by visualization of KPIs and the actual behaviour of the system the SU was enhanced significantly. The design result is satisfactory and supported by all actors.

Fumarola indicated that a more interactive design approach would even enhance SU and the quality of the design more (Fumarola, 2011b). This seems to be very logic, however the feasibility is doubtful. As experienced in the design for a new shunting plan at Ctw it is extremely difficult to involve all critical actors within the design sessions. Since the actor environment was complex a lot of actors had to participate in the design workshop. Bringing together 8 actors, from different companies or departments needs a lot of effort. The 3-hour workshop has fulfilled its goal and was very useful. Making the design process more interactive by letting the participants design and simulate needs far more effort. Actors have to become familiar with the simulation package and in the beginning with the entire system they are working with. This will cost a lot of time and effort for each actor, which will not be available in most cases. I would definitely follow the proposition that a more interactive design session will lead to even a better design result, however it seems impossible to me to involve all critical actors in a more interactive design workshop.

The value of a supported design and a higher SU among critical actors created by the SBD approach including the multi-perspective visualization will definitely loan the efforts and costs. However, in this case study the costs were limited since the visualizations were very simple and the simulation software was free of use. Costs for the purchase of a simulation package and creation of visualizations can lead to quite an investment. The results and effects of using an SBD approach including the multi-perspective visualization will definitely be of great value, but may not be profitable for just a single design project.

In general I think SU is very important in large and complex design problems. Whatever design approach to use, the creation of SU among critical actors should be prominent. It is not directly the design method leading to a very fruitful design result, but more the involvement of critical actors, the communication between them and thereby the creation of SU that makes a design project more successful. The SBD approach is a very appropriate method to involve actors, start the communication between them and end with a satisfactory and supported design result.

7.2 Second design workshop

A second design workshop has been organized because the first design workshop in which participants form different disciplines participated led to the discussion on the infrastructural lay-out of Ctw because the solution for the logistical problem could not be found within the logistic process. Besides that the observer from the reference case Wgm noticed that it could have been important to involve an actor for the planning of logistical process in Utrecht on the longer term.

Therefore a post study has been performed on the possibilities to adjust the infrastructure and design of the TC and involve an actor which focusses on the logistic processes in Utrecht on the longer term (NSR-LPD). A detailed report of the entire study is included in appendix 17. Because this research report was for NedTrain only it is written in Dutch.

A short substantive summary of this research will be discussed within this chapter.

7.2.1 Study on infrastructural adjustments

From the design workshop it is concluded that a robust solution for the logistical problems according to the middle-track and shunting movements from the parking tracks to the TC cannot be found. Therefor a post study is performed, to identify whether or not adjustments to the infrastructure and redesign of the TC can create a robust solution for the future.

The main research question for this post study is:

Can adjustments to the infrastructure on the marshalling yard of Ctw improve logistic processes on Ctw in the future?

7.2.2 Research activities

Together with several actors the possibilities for the adjustment of the infrastructure on Ctw have been identified. The opportunities to adjust the infrastructure on Ctw are limited because of the following reasons:

- ProRail does not allow crossings on a marshalling yard
- The TWI should be accessible by road on which a middle size truck can drive
- The open area for extra parking tracks or adjustment to the existing infrastructure is tight

Together with a supervisor of NedTrain an alternative solution is drawn up, taking into account the limitations for infrastructural adjustments. The design is visualized in figure 22. The design of the TC should be adjusted, to create the entrance at the backside. The connecting track to the TC should be connected to the lower parking tracks on Ctw. The road to the TWI can be rerouted along the backside of the TC. With these adjustments the following advantages are expected:

- The TC will be accessible from parking tracks, so shunting movements over the middle-track are not necessary
- The shunting movements to the TC can be executed on own territory, so no LOAs have to be requested by ProRail
- The opportunity to shunt a train towards the TC from a parking track is possible 24/7.

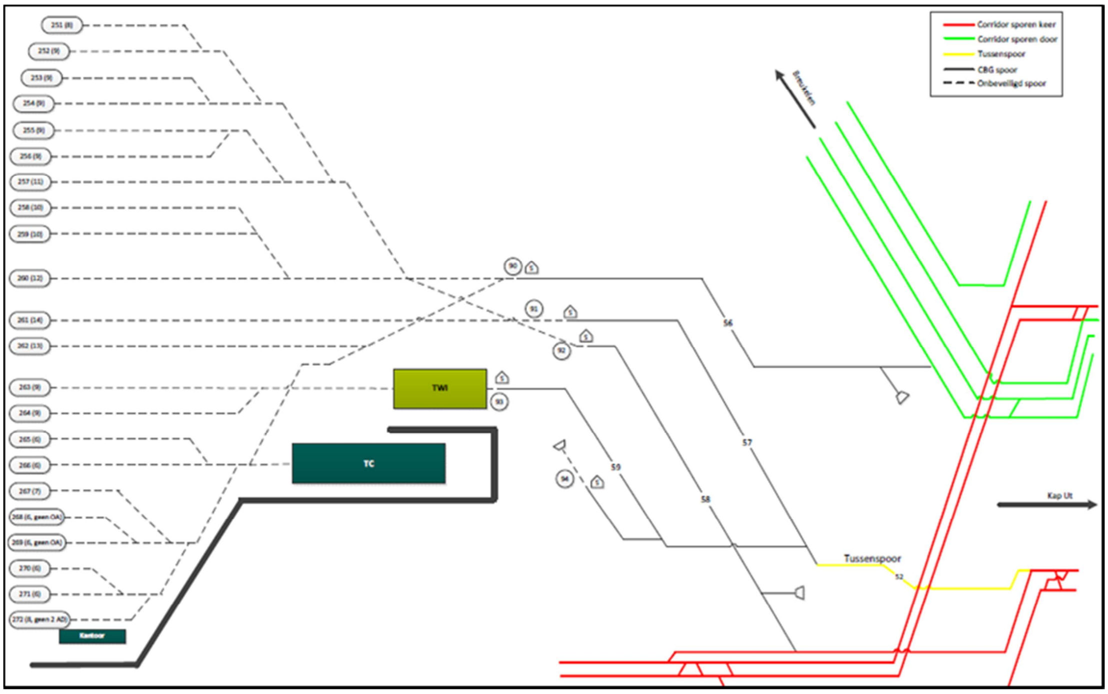

Figure 22: Alternative design for infrastructural lay-out of Ctw

The alternative design has been discussed with a steering committee for the development of TCs. Their reaction was positive and therefore an additional workshop has been organized to discuss the alternative with critical actors. Due to the positive experiences of a workshop in which critical actors are involved a special workshop is held for the discussion on this new alternative.

7.2.3 Second workshop

Within the second workshop on the discussion of the infrastructural adjustments other actors than within the first workshop are involved since it does not influence the logistic processes on the junction Utrecht. Therefore the actors RBC, BLP, VL ProRail and MBN have not been involved. As a result of the recommendation to involve a long term planner a representative of NSR-LPD is invited. The actors involved within the workshop are:

- NSR-LPD
- PCL Ctw
- Manager Logistics Ctw
- Project Manager TC

During the workshop the alternative for re-design of the TC and adjustments on the infrastructure have been discussed. A first notice, which directly swept the viability of the alternative, is the fact that the problem on the middle-track will be shifted to the cross-switch on the marshalling yard itself. The additional track which has to be constructed to/from the TC can only be connected to the lowest parking track on Ctw, track 272. In that case, this track can only be used as a shunting track, which causes direct parking capacity. Within the workshop NSR-LPD did the promise to collaborate and relinquish the track to improve the logistic process on Ctw.

However, continuing the discussion during the workshop a very determinative notion has been made. The problem on the middle-track according to the high occupancy which limits the possibilities to shunt trains to the TC will also rise by implementation of this alternative. To shunt trains from a parking track to the TC in the proposed situation, they always have to be shunted over the cross-switch. The same problem will occur according to the middle-track, since all trains arriving and departing on Ctw will drive on this cross-switch. During peak hours the possibilities to shunt a train from a parking track to the TC will have the same limitations.

From the second workshop and the post study on the accessibility of the TC it can be concluded that redesign of the TC and adjustments to the infrastructure do not improve the accessibility of the TC and logistic process on Ctw.

7.2.4 Conclusion

At a first sight the alternative in which the TC is accessible directly from the parking tracks, so shunting movements on the middle-track, was promising. However, during a second workshop it has been concluded the problems according to the occupancy of the middle-track will be shifted to the cross-switch at the entrance of the parking tracks. Costs and time delay to adjust the design of the TC and the infrastructure on the marshalling yard do not weigh up to the benefits of this alternative. Therefore it is recommended to retain on the conclusions and recommendations of the first design workshop, section 6.2.

8. Reflections

This chapter aims to discuss the lessons learned during the research, exemplify important choices within this research and reflects on methods used, validity of the results and personal experiences from the past six months.

◊

The use of Simulation-Based Design methodology within a technically complex and multi-actor environment is experienced to be a very appropriate method. I think the method of SBD without the addition of multiple perspectives in the simulation would have been of great support already to solve the problems according the logistic process on the marshalling yard Ctw. The addition of multiple perspectives is definitely of great value for the design process and its outcomes.

Not just for the design of a shunting plan but for a wide variety of design problems this method can be completed with multi-perspective visualization. For the design of an artefact for a technically complex problem and especially within a complex actor environment the addition of multi-perspective visualization, so that each involved actor can perceive the performance and behaviour of the system in his own way, will contribute to the enhancement of SU and in the end a satisfactory and supported design result. So, not just for the design of a shunting plan, but for the design of any system this design approach is expected to be very useful. However, the type of simulation and visualizations should be adopted to the characteristics of the actors involved.

◊

The cooperation of all involved actors was for the SBD process of great importance. The possibilities I got to interview and consult actors were extraordinary. Without the openness and willingness to cooperate of all different actors this research would not have been a success as it is now. It costs a lot of efforts to consult and plan interviews with all different actors, collect all the information, data and experiences of the experts in the field of the logistic process according to the marshalling yard Ctw. However, I can conclude the efforts have led to a very good end result of this thesis project, for the scientific contribution and the great help for NedTrain as well.

For similar design projects, in the railway sector but also in other fields of study, the SBD approach including the multi-perspective visualization can be useful. However, as already discussed this approach is vulnerable for actor participation. Therefore the use of the SBD approach, using multi-perspective visualization will only be of great result in case all actors are open and motivated to participate in the SBD process.

◊

The SBD approach followed during the research brought a very clear structure and guideline in the design project. The scientific research objective is completely fulfilled. However, the measurement on the enhancement of SU did not identify the entire enhanced SU. I think actors' SU on the problems and system of the logistic process on Ctw was already enhanced during interviews and consultations upfront the design workshop, in which the basic level of SU has been measured. Therefore I suppose the enhancement of SU during the entire SBD process for a new design of the logistic process on Ctw is even larger as identified during the design workshop.

The identification of the influence of multi-perspective visualization on the enhancement of SU and on resolving dilemmas has been performed in a good way. Using 3 different tools to identify the enhancement of SU is scientifically a strong approach already. However, it would have been even stronger if there were measurements on the enhancement of SU during the SBD process at the reference case Wgm. In that case the enhancement during the SBD process at Ctw could have been compared with the enhancement of SU within the case of Wgm. The same applies for resolving the dilemmas arising during the design process. The conclusions on hypothesis would have been stronger if there was reference material of the reference case on resolving dilemmas. This gap is tried to mitigate by involving the project manager of the Wgm case as an observer.

Besides the lack of a more useful reference case the tool of Mulder can be criticized (Mulder, 1999). The tool of Mulder used for the measurement of the level of SU has not been validated thoroughly. This case study has shown the results of these tests to align with the reactions of the observer from the reference case Wgm and the results of the post-survey. Therefore I think the validity of the tool of Mulder is enlarged by the application during this case study.

◊

The output of the simulation model has been used to draw up the visualizations during the design workshop. Not all the improvements or deterioration on KPIs are tested significant. The participants have not been informed about the significance of the results on KPIs. It could have been of minor influence on the discussion followed on the visualizations. However, the final conclusion for the practical research questions would not have been different I suppose. It would not have been a difference for the outcomes of the results on the scientific research questions and objective, the enhancement of SU through multi-perspective visualization.

◊

During the design workshop the discussions did not burst out very quickly and spontaneously. I had to ask a first question to a specific actor to start the discussion. After the first reaction was given on my question the discussion ignited. During a reflection with my supervisor of NedTrain and with the observer of the reference case Wgm we came to the conclusion that actors needed some processing time, to absorb the amount of information and form an opinion about an alternative to implement. Giving actors a lot of information, in different formats, make actors do not directly respond on the shown performance and behaviour of the system.

In future design projects, using the SBD approach including multi-perspective visualization actors should get the time to create their opinion and prepare for a strong argumentation.

◊

The objective of the practical research for NedTrain has been fulfilled more than expected, especially by the additional study performed as discussed in the chapter 7 and appendix 17. However, the biggest effort of the research performed at NedTrain is the start of a collaboration between some departments of the 3 main organizations involved; NedTrain, ProRail and NSR. When I started my research 'the door' to the other actors or even departments seemed to be closed. By taking the initiative and with an enthusiastic attitude all actors were willing to cooperate. Bringing the actors together is the best result of the practical research. The discussions on alternative solutions for the logistic process was useful, but the insight they got about the added value of collaborative design or decision making lead to permanent collaboration between NedTrain, ProRail and NS.

NedTrain has planned 3 more TCs to build in the next years. The design approach used is experienced to be very effective and successful and therefore for the other locations the same design approach will be followed.

◊

During my thesis project at NedTrain I have learned a lot on working in a large organization and on a project within a multi-actor environment. Especially the experiences of working in an multi-actor environment are enormous. Networking, communication with all kind of personalities and ensuring the research to be comprehensive was challenging. Since the research project was complex, a lot of actors involved, also from other organisations, I have a lot of lessons learned on the networking and communication skills. One of the most important lessons learned to highlight is to be aware of not making assumptions on a person's knowledge. In a few situations I assumed the other person to have particular knowledge, so I already continued the conversation or discussion. This led to a less pleasant conversation, because persons become uncomfortable in situations in which they are thought to know of but do not know actually. Setting up the communication on the right level, using the right terms and not making assumptions of person's knowledge is one of the best personal lessons learned.

Another important lesson learned in communication with other persons is to be open minded, even more than I was used to. During the very pleasant and useful supervision meetings with especially Rens Kortmann and Marten Busstra I experienced the effectiveness of an even larger open mind. In conversations with Rens Kortmann this led to very fruitful discussions on how to combine my scientific and practical research. Each meeting was very effective and has brought my thesis project to a higher level. During my meetings with Marten Busstra the discussions were often focussed on how to solve the problems according the logistic process. Moreover an extra coaching process on managing expectations and managing individuals or groups gave me the insight that an open mind is of great importance, to improve my own knowledge, skills and behaviour.

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Once more I would like to thank my graduation committee for their great support and inspiration for the execution of this master thesis project. Applying the knowledge from my master program SEPAM into a very practical research problem and combine it with a challenging scientific research objective was a very rewarding project. The open and critical discussions with my supervisors, together with the pleasant collaboration with all actors involved made my work for the past 6 months a great pleasure.

Bart van Zaalen

May 2013

References

Ackoff, R.L. 1979. *The future of operational research is past*. The Journal of Operational Research Society 30, pp. 93-104.

Bijl, J.L., Boer, C. A. 2011. *Advanced 3D visualization for simulation using game technology*. Proceedings of the Winter Simulation Conference 2011, pp 2810 - 2821.

Bloem, A. 2012. Interview 30-10-2012.

Bohlin, M., Gestrelius, S., Khoshniyat, F. 2012. *Evaluation of planning policies for marshalling track allocation using simulation.* Royal Institute of Technology. Stockholm. Sweden.

Bolstad, C.A., Cuevas, H.M., Gonzalez, C., Schneider, M. 2005. Modelling Shared Situation Awareness. 14th Conference on Behaviour Representation In Modelling and Simulation (BRIMS) May 16-19th 2005, Los Angeles.

Bondar, K., Katzy, B.R., Mason, R.M. 2012. *Shared understanding in networked organizations*. Proceedings of the 2012 18th International Conference on Engineering, Technology and Innovation, pp 1-11.

Bruijn de, H., Ten Heuvelhof, E., In ’t Veld, R. 2010. *Process Management –Why project management fails in complex decision making processes.* Springer: London

Bürgi, P., Roos, J. 2003. *Images of Strategy*. European Management Journal Vol. 21, No. 1, pp. 69–78.

Checkland, P.B. 1981. *Systems thinking, systems practice*. John Wiley & Sons, NJ,USA, 1981.

Cho, S.H., Eppinger, S.D. 2005. A simulation-based process model for managing complex design projects. IEEE Transactions on engineering management, Vol. 52, No. 3, August 2005, pp. 316-328.

Conklin, J. 2009. *Building Shared Understanding of Wicked Problems*. Rotman Magazine. Winter 2009, pp. 17-20.

Vreede, de G.J., Eijck, van D.T.T., Sol, H.G. (1996*). Dynamic modelling for re-engineering organizations*. Journal of Information Systems and Operational Research (INFOR) 34: 28-42.

Daalen, C. van, Verbraeck, A., Thissen, W., Bots, P. 2009. *Methods for the Modelling and Analysis of Alternatives*. Handbook of Systems Engineering and Management, 2nd edition, edited by A. P. Sage and W. B. Rouse, 1127-1169.

Ding, H., Benyoucef, L., Xie, X. 2009. *Stochastic Multi-Objective Production-Distribution Network Design Using Simulation-Based Optimization*. International Journal of Production Research 47(2):479 - 505.

Enserink, B., Koppenjan, J.F.M., Thissen, W.A.H., Kamps, D.P., Bekebrede, G. 2008. *Analyse van complexe omgevingen*. Reader course SPM2110. Faculty Technology Policy & Management, March 2008.

Fumarola, M., Huang, Y., Tekinay, C., Seck, M.D. 2010. Simulation-Based Design for Infrastructure System Simulation. Proceeding of the 2010 European Simulation and Modelling Conference. October 2010, pp 288-293.

Fumarola, M., Klofschoten, G., Verbraeck, A. & Versteegt, C. 2011. *Experimenting with the multiple worlds concept to support the design of automated container terminals*. Proceedings of the 2011 Winter Simulation Conference.

Fumarola M., Seck, M.D. & Verbraeck, A. 2011b. *Simulation-based systems design in multi-actor environments*. Intelligence-based Systems Engineering, ISRL 10, pp. 107-127.

Fumarola, M. 2011c. Multiple Worlds – A multi-actor simulation-based design method for logistcs systems.

Fumarola, M., Staalduinen van, J-P., Verbraeck, A. 2012. *A Ten-Step Design Method for Simulation Games in Logistics Management*. Journal of Computing and Information Science in Engineering. March 2012, Vol. 12.

Fumarola, M., Huang, Y., Tekinay, C. & Seck, M.D. 2012b. *Simulation-based design for infrastructure system simulation.*

Hair, F., Black, W.C., Babin B.J. & Anderson, R.E. 2010. *Multivariate Data Analysis*. 7th edition.

Halim, R.A., Seck, M.D. 2011. *The simulation-based multi-objective evolutionary optimization (SIMEON) framework.* Proceedings of the 2011 Winter Simulation Conference, pp 2839 – 2851.

Han, S.H., Al-Hussein, M., Al-Jibouri, S., Yu, H. 2012. *Automated post-simulation visualization of modular building production assembly line.* Automation in Construction 21 (2012) 229–236.

Hengst den, M., Vreede de, G.-J. & Maghnouji, R. 2007. *Using soft OR principles for collaborative Simulation: A Case study in the dutch Airline Industry*. The Journal of Operational Research Society, Vol. 58, No 5, pp 669-682.

Hevner, A.R., March, S.T., Park, J. & Ram, S. 2004. *Design science in Information Systems Research*. MIS Quarterly, Vol. 28, No. 1, pp. 75-105.

Huang, Y., Seck, M.D. & Verbraeck, A. 2010. LIBROS-II: Railway modelling with DEVS. Proceedings of the 2010 Winter Simulation Conference, pp. 2150-2160.

Huang, Y., Seck, M.D. & Fumarola, M. 2012. *A simulation-based design framework for large scale infrastructure systems design*.

Jorvig, J.R. 2005. Managing your design process. Jorvig Consulting Inc. 15 January 2005, Chandler.

Kanacilo, E.M., Verbraeck A. 2006*. Simulation services to support the control design of rail infrastructures*. Proceedings of the 2006 Winter Simulation Conference, pp. 1372-1379.

Klein, M. Sayama, H., Faratin, P., Bar-Yam, Y. 2003*. The Dynamics of Collaborative Design: Insights from Complex Systems and Negotiation Research.* Concurrent Enigineering: Research and Applications. Vol. 11 nr 3. September 2003, pp 201-209.

Kuechler, B., Vaishnavi, V. 2008. *On theory development in design science research: anatomy of a research project*. European Journal of Information Systems (2008) 17, pp. 489-504.

Mulder, I. 1999. *Understanding technology mediated interaction processes: A theoretical context*. Telematica Instituut, 1999.

Mulder, I., Swaak, J., Kessels, J. 2002. *Assessing group learning and shared understanding in technology-mediated interaction*. Educational Technology & Science 5 (1) 2002.

NedTrain, 2012. *Eindrapportage investeringsvoorstel en NCW-berekening Locatiestrategie.* Versie 1.5.

Nofi, A.A. 2000. *Defining and Measuring Shared Situational Awareness*. CNA Coorporation.

Piirianen, K., Kolfschoten, G.L., Lukosch, S. 2009. *Unraveling challenges in collaborative Design: A literature study.* CRIWG 2009, LNCS 5784, pp. 247-261.

Piirianen, K., Kolfschoten, G.L., Lukosch, S. 2010*. In search for the right tools to fix the right problem: a look into the challenge of collaborative design.* 43rd Hawaii International Conference on System Sciences. IEEE Computer Society.

Pruyt, E. 2010. *Multi-actor systems and ethics*. International transactions in operational research, 17 (4), pp. 507-520.

Robinson, S. 2001. *Soft with a hard centre: Discrete-Event Simulation in Facilitation*. The Journal of Operational Research Society, Vol 52, No. 8, pp. 905-915.

Saner, L.D., Bolstad, C.A., Gonzalez, C., Cuevas, H.M. 2009. *Measuring and Predicting Shared Situation Awareness in Teams.* Journal of Cognitive Engineering and Decision Making, Volume 3, Number 3, Fall 2009, pp. 280–308.

Simon, H.A. 1996. *The Sciences of the Artificial*. 3rd edn. MIT Press. Cambridge, Massachusetts.

Smid, B.J. & Busstra, M. 2011. *Eindrapportage Locatiestrategie: Locatiekeuze*. Versie 1.2.

Stein, J. & Louca, L. 1995. *A component-based modelling approach for system design. Theory and implementation*. Proceedings of the 1995 International Conference on Bond Graph Modelling and Simulation, pp. 109-115.

Tekinay, C., Seck, M., Fumarola, M. & Verbraeck, A. 2010*. A context-based multi-perspective modelling and simulation framework*. Proceedings of the 2010 Winter Simulation Conference, pp. 479-489.

Tilly, T.T. 2008. *Aerospace Leaders' Questioning Techniques and Their Perceived Effectiveness: A Case Study.* Pepperdine University.

Verbraeck, A., Valentin, E.C. 2006. *Discreet modelleren deel 2: Discrete modellatie*.

Vocht de, A. 2007. *Basishandboek SPSS 12 voor Windows*.

Winston, P.H. n.d. Why I am Optimistic. Ford Professor of Artificial Intelligence and Computer Science at the Massachusetts Institute of Technology. Consulted 24-12-2012. http://people.csail.mit.edu/phw/optimism.html

Xia, W. & Lee, G. 2005. *Complexity of information systems development projects: conceptualization and measurement development*. Journal of management information systems, 22 (1): p 45-83.

Yao Li, 2004. *Discovering structure of data to create multiple perspective visualization*. Massachusetts Institute of Technology.

Yin, R.K. 2003. *Case study research. Design and Methods*. Third edition. Applied Social Research Methods Series. Volume 5.

Zhao, Z., Yunfeng, W., Xiaochun, C. 2009. *The Development of Shared Understanding among IS Leadership Team: A Multiple Case Study in China*. International Conference on Information Management, Innovation Management and Industrial Engineering, 2009. Pp 356-359.

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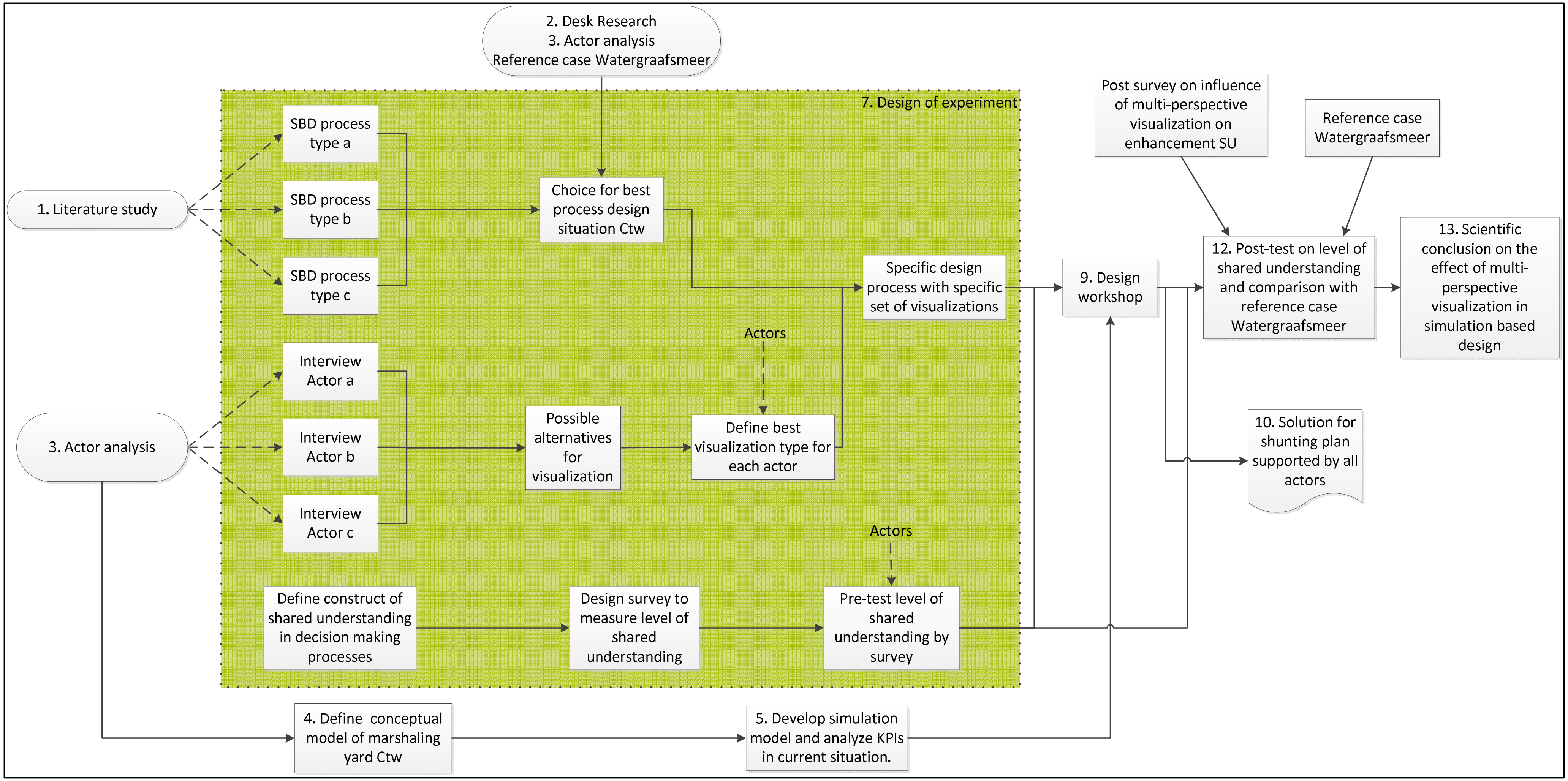
Glossary

Amendment sheet	Overview of planned arriving and departing trains on a marshalling yard
BLP	Bureau Lokale Planning
Ctw	Shunting yard Cartesiusweg
DSR	Design Science Research
EBK	Dutch abbreviation for unplanned train arrival for service or maintenance (Extra Binnenkomst)
HSP	High Service Platform
ICM	Train type: InterCity Materieel
KPI	Key Performance Indicator
LOA	Late Order Application
MBN	Materieel Bijsturing NedTrain
MC	Maintenance Company
NS	Nederlandse Spoorwegen
NSR	Nederlandse Spoorwegen Reizigers
OB	Dutch abbreviation for Maintenance Company (Onderhouds Bedrijf)
OR	Operations Research
PCL	Process Coordinator Logistics
Process shunting	Shunting movements on a marshalling yard to other parking tracks or a maintenance facility
RBC	Regionaal Bijsturings Centrum
Saw-movement	Shunting movement from or to a parking track to or from the TC, using the middle-track on Ctw as a pivot
SB	Dutch abbreviation for Service Company
SBD	Simulation-Based Design
SC	Service Company
SE	Systems Engineering
SLT	Train type: Sprinter Light Train
SND	Storing Niet Defect
SP	Service Pit
SSC	Specialized Service Company
SU	Shared Understanding
SWD	Storing Wel Defect
TC	Technical Centre
TWI	Train Wash Installation
VIRM	Train type: Verlengd InterRegio Materieel
VL	Railway traffic control centre of ProRail (Verkeersleiding)
Wgm	Shunting yard Watergraafsmeer

Appendices

I: Research project approach



II: Process description of maintenance service SB Ctw

Planned situation

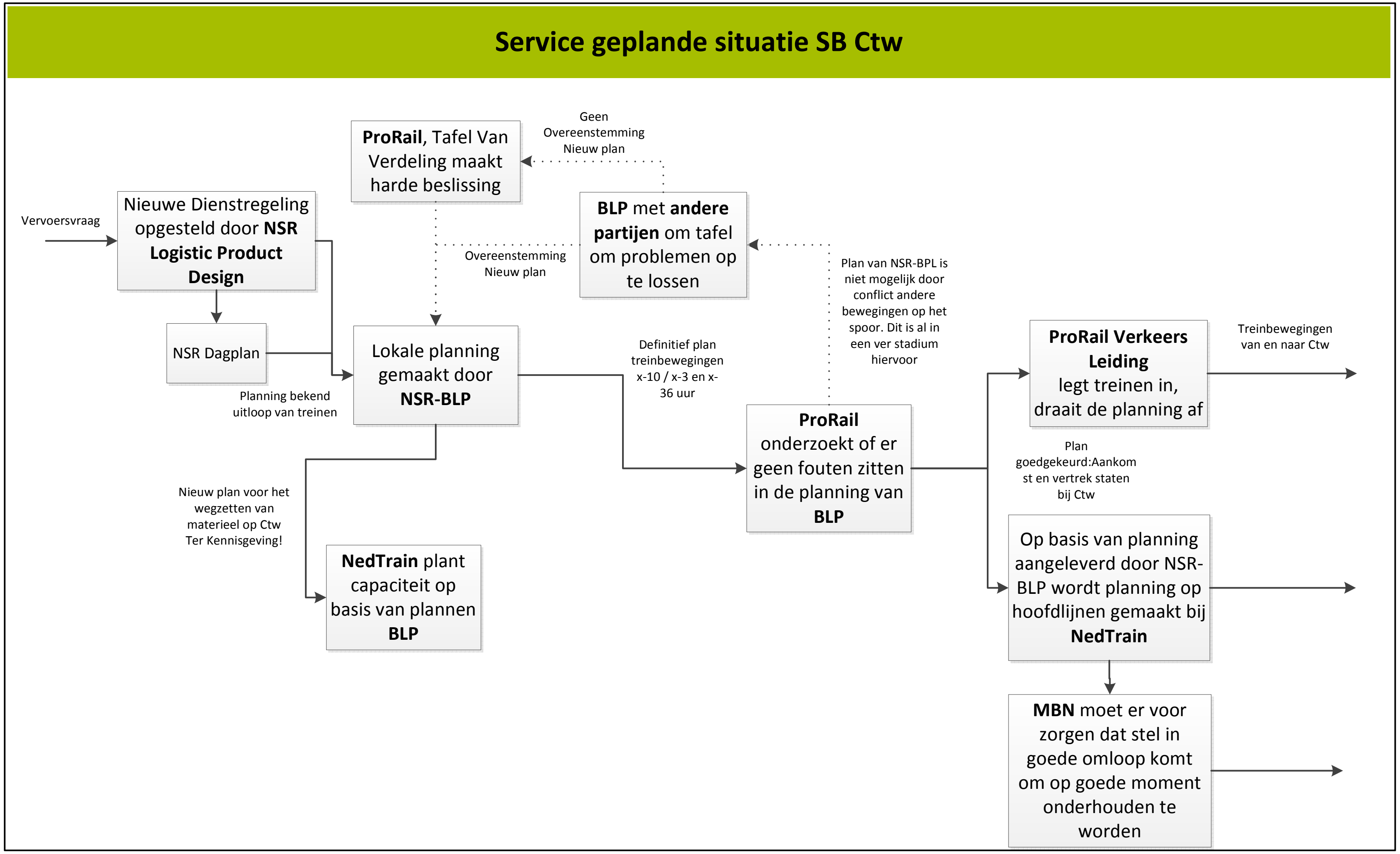


Figure 23: Process description of planned service on trains for the SB on Ctw

Unplanned situation

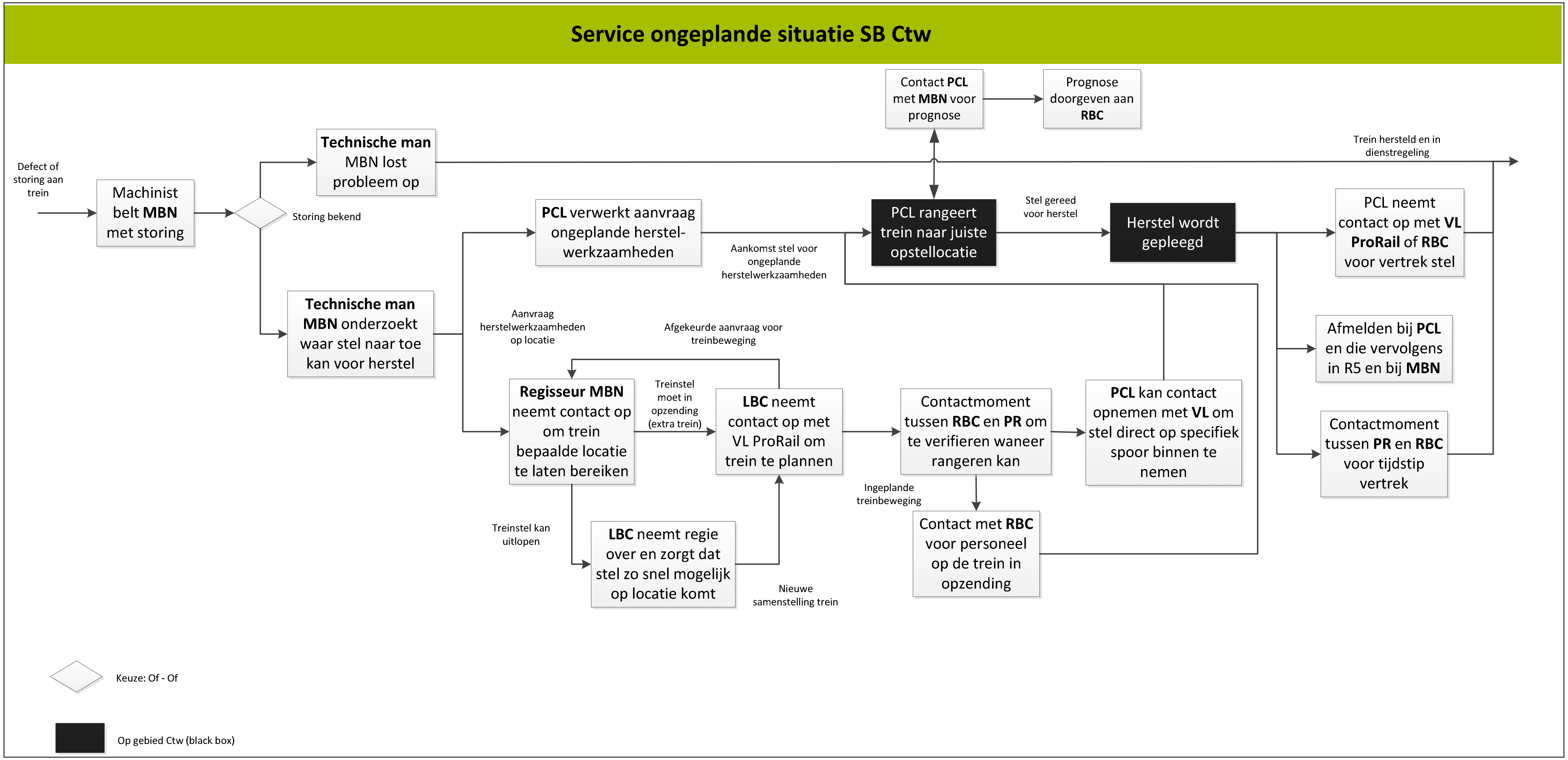


Figure 24: Process description of unplanned service on trains for the SB on Ctw

III: Actor analysis

Values, goals and problem perception

Table 16: Actor analysis on actors' values, goals and problem perceptions

Actor	Value	Goal	Problem situation	Solution directions
NedTrain B.V.	Maintenance and overhaul on rolling stock of especially NSR	High quality, reliable and safety of maintenance and overhaul service. Ensure a high train availability.	Longer lead times due to delay in maintenance service	Specialized Technical Centers
NSR Logistic Product Design (NSR – LPD)	Design for logistic planning according to developed train service and to the needs and wishes from NSR Commercie	Comply to demand for 'zitplaatskm' Minimalize trainkm Enough shunting capacity for NSR	Higher attractability due to unstructured shunting process and capacity No insight in processes on Ctw	Better alignment of train schedule, withdrawal of trains and maintenance capacity and alignment of 'opstelcapaciteit'
Bureau Locale Planning (NSR)	Planning of train movements on corridor Utrecht and planning of trains in operation	High reliable planning for withdrawal 36-hours before run out of trains	Delay in corrective and preventive maintenance results in less trains for train service operation. Last minute train movements interfere with planning of BLP	Higher reliability of maintenance jobs and a more robust planning for maintenance
Landelijk Besturings Centrum (LBC)	Available trains to keep the balance on rolling stock on the right level	Right balance of trains on key locations	Too less capacity on Ctw to park trains or too long lead times for service jobs resulting in wrong material balance	Higher reliability of maintenance jobs and a more structured way of parking trains

RBC (Regionaal Besturings Centrum	High punctuality of train service.	Minimize delay and increase punctuality.	To less trains to support for optimal train service and external factors influencing punctuality	More back up trains and a better planning to increase punctuality.
ProRail Jaarplan	Safety and right allocation of capacity on railway network	Less conflicting train movements	A lot of Late Order Application (LOA), which can lead to conflicts and less safety	More planned train movements to support the shunting process at Ctw
ProRail VerkeersLeiding (VL)	Safety and high punctuality of operational train service	Less conflicting train movements and a more robust operation of the train service	A lot of Late Order Application (LOA), which can lead to conflicts and less safety	More consulation RBC and NedTrain to avoid conflicting train movements
NedTrain Jaarplan	Perform all planned and unplanned service jobs on capacity and demand from BLP	Claim enough capacity to perform all service jobs	Some service jobs cannot be serviced due to inefficiency on the marshalling yard	More efficient utilization of capacity by using a shunting plan
MBN (Materieel Beheer NedTrain)	High availability and quality of trains in operation	Recovery of trains before q-norm has been expired. Avoid situation in which trains cannot be used due the q-norm is exceeded.	Trains are not recovered entirely and has to return on the short term to finish recovery jobs. Capacity shortage or wrong planning are assumed to be the cause	More and better collaboration MBN, PCL and RBC
PCL Ctw (procesleider)	Planning of maintenance jobs, plan and position trains on parking tracks	Optimal allocation of maintenance facilities, high rate of maintenance and punctuality of out-flow from Ctw	No structured procedure for planning and positioning of trains to be maintained leading to inefficient train movements and low maintenance rate	Shunting plan for arrival and departure of trains. 'process shunting' is to complex to be regulated by a plan

Cleaning contractor HAGO	Continuity of business. Manageable cleaning schedule of trains	Perform high quality of cleaning service and fulfil each cleaning order	Sometimes long walking distances and uncertain amount of trains to clean	Better planning of maintenance jobs, which is the internal cleaning
Passengers (customers of NSR)	High availability of trains	Have a comfortable seat	Sometimes a high distraction rate of trains so less available seats in the trains	Higher performance of the maintenance service, faster lead times
Train drivers	Manageable shunting orders, short walking distances	Shunt trains on a punctual basis, minimize delay	Train widespread over marshalling yard and extra shunting movements	Shunting plan optimization

Actor criticality

Table 17: Overview on actors' criticality

Actor	Resources	Replace ability	Importance of resources	Critical actor?
NedTrain B.V.	Is only company within the Netherlands that provides in rolling stock maintenance on large scale, so is more or less monopolist.	Low	High	Yes
NSR Logistic Product Design	Exclusive actor in logistic design	Low	Medium	Yes
Bureau Locale Planning (NSR)	Planning tools. Leading actor in train service planning up to x-36. Has critical knowledge and tools to make planning	Very low	High	Yes
LBC/MRC (Landelijk Besturings Centrum / Materieel Regel Centrum)	Has overview of material balance and personnel availability. Shunts trains to keep balance of train material throughout the country	Medium	Low	No
RBC (Regionaal Bijsturings Centrum				Yes
ProRail Jaarplanning	Exclusive right on planning of network allocation	Very low	Low	No
ProRail VerkeersLeiding (VL)	Final decision for LOA's. Final responsibility and competence in train service	Low	High	Yes

NedTrain

NedTrain Jaarplan	Lobbying for capacity during 'opstelconferentie'	Medium	Low	No
MBN (Materieel Beheer NedTrain)	Decide on moment of maintenance for trains according to q-norm Critical actor in supply of trains to be maintained	Low	High	Yes
PCL Ctw (procesleider)	Shunting process leader Makes work preparation	Low	High	Yes
Cleaning contractor HAGO	Working capacity	High	Low	No
Passengers (customers of NSR)	Choice to travel by train or other modality	Low	Low	No
Train drivers	Working capacity	Medium	Low	No

IV: Interviews involved actors

Table 18: Overview of actors interviewed and consulted

Actor	Contact person	Date
NedTrain B.V.	Marten Busstra	22-10-2012 / 7-1-2013
	Aad Bloem	24-10-2012 / 16-1-2013
	Joris van der Loo	24-10-2012 / 27-2-2013
NSR Logistic Product Design	Bob-Jan Smid	28-11-2012 / 8-3-2013
	Jaap de Ruijter	8-3-2013 / 13-3-2013
Bureau Locale Planning (NSR)	Bernard van Nee	22-11-2012 / 28 -2-2013
Landelijk Besturings Centrum (LBC)	Willem de Jager	3-12-2012
RBC (Regionaal Bijsturings Centrum	Pieter Meerveld	8 -1-2013
	Els Lieben	30-1-2013
	Brigitte Verstraaten	27-2-2013
ProRail Jaarplanning	Martijn Meegdes	12-11-2012
ProRail VerkeersLeiding (VL)	Martijn Meegdes	12-11-2012
	Ton van Diepen	27-2-2013
NedTrain Jaarplan	Cora Berlo	3-12-2012
MBN (Materieel Beheer NedTrain)	John Broeder	15-11-2012
	Erik Hessel	27-2-2013
PCL Ctw (procesleider)	Ad Budding	15-11-2012 / 27-2-2013
	Eduard Wrede	4-12-2012
	Andries Hakkert	5-12-2012
SB Watergraafsmeer	Marleen Wieten	Several
	Mohammed Ouali	6-12-2012

V: Lay-out marshalling yard Ctw

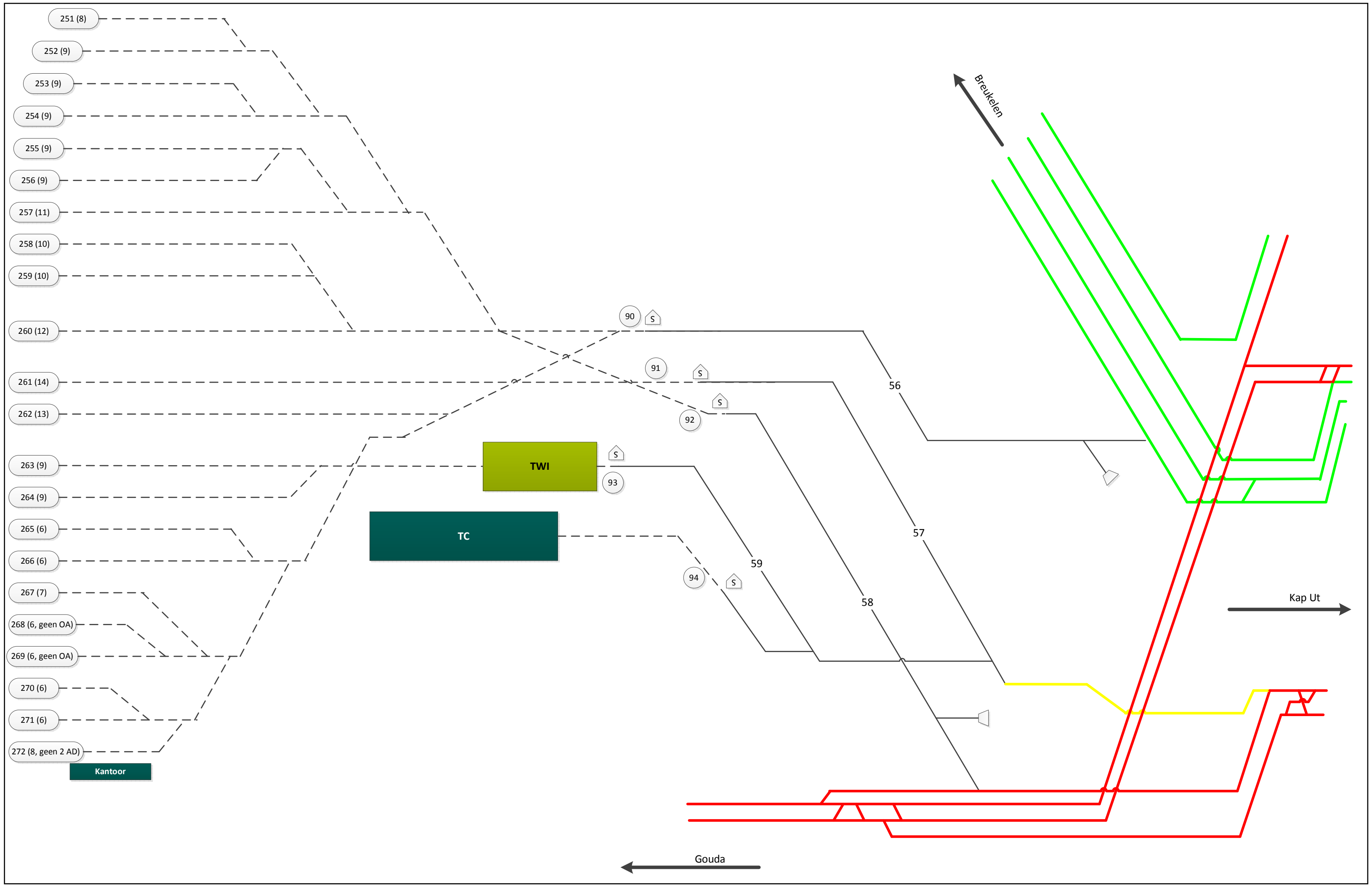


Figure 25: Schematic overview of marshalling yard Ctw

Main characteristics of the marshalling yard Ctw:

- Track 251 to 272 are parking tracks, each with a different length
- Switches on the marshalling yard which are controlled by the PCL are the 800 numbers
- Tracks 56, 57, 58 and 59 are incoming tracks. Normally only track 57 is used. Behind the S-sign on this track the number changes into a 90-number. These are the tracks under control of the PCL.
- Tracks 95, 96 and 97 are reserved for contractor material and fall outside the scope of this project
- Track 94 is the service facility with the High Service Platform and Service Pit
- Track 93 is the Train Wash Installation
- Along track 58 is the Anti-Icing Installation

Critical points in the infrastructure of Ctw:

- Normally all train movements from a 90-numbered track to a 50-numbered track has to be requested by the VL of ProRail. On track 90 there is just before the S-sign a security panel on which switch 1191A can be laid in to the buffer stop. When this switch is laid in to the buffer stop no request by the VL has to be made. This gives some room for shunting movements.
- In case the TWI is in operation the switch at the end of track 93 (866/867) is blocked from this track to one of the tracks 263 to 272. No trains can be shunted from these tracks to for example track 91, but also the other way around. It can be concluded that the TWI in operation blocks almost half of the capacity of the parking tracks.
- Track 94 is a dead-end track. Trains from and to this track have to be shunted over track 57, where it crosses tracks on which passenger trains run. This can create conflicts, in which passenger trains always have priority.

VI: Capacity of parking tracks

Table 19: Capacity of parking tracks on the marshalling yard Ctw

Track	VIRM/ICM/DDZ	SLT/Sprinter
251	8	12
252	9	13
253	9	13
254	9	13
255	9	13
256	9	13
257	11	15
258	10	14
259	10	14
260	12	16
261	14	19
262	13	17
263	9	12
264	9	12
265	6	8
266	6	8
267	7	9
268	6 (no OA)	7
269	6 (no OA)	7
270	6	8
271	6	8
272	8 (no 2 AD)	11

VII: Current process of incoming and departing trains

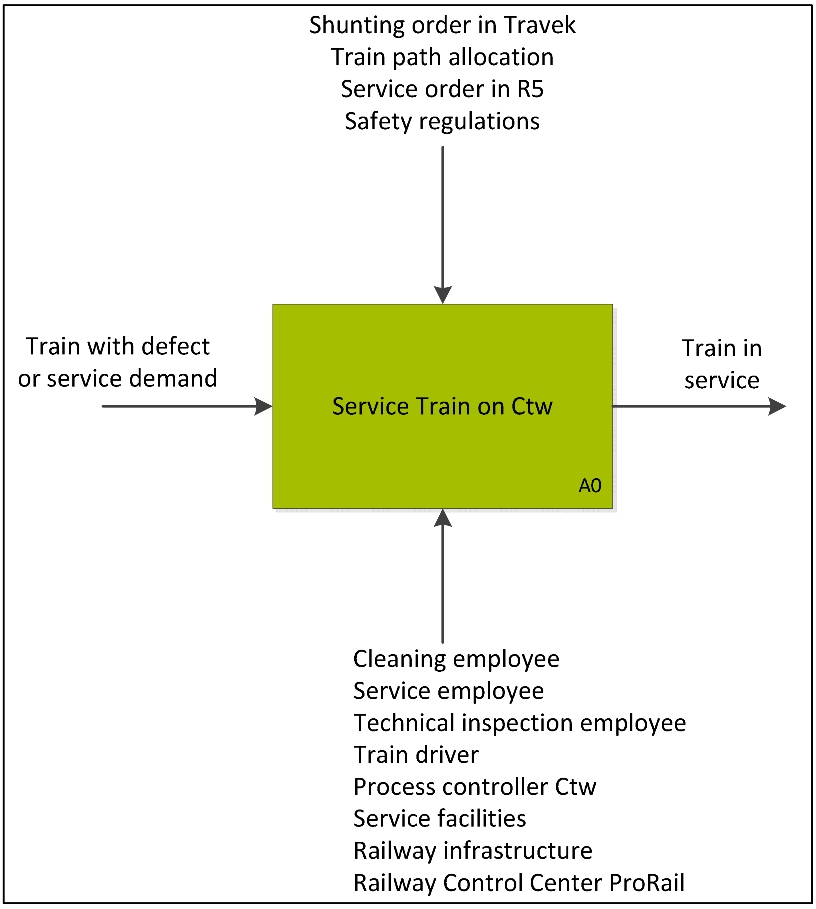


Figure 26: SADT diagram of the system on Ctw (level A0)

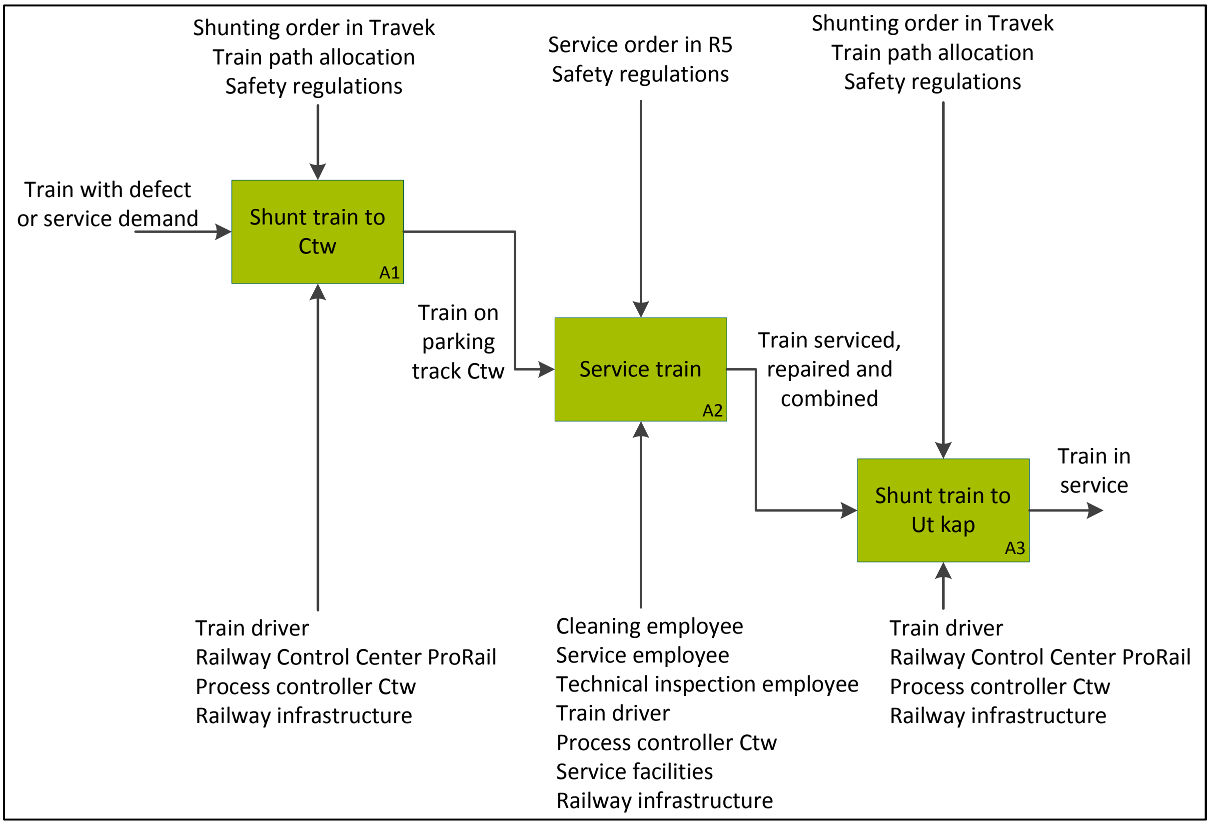


Figure 27: SADT diagram of the system on Ctw (first decomposition level)

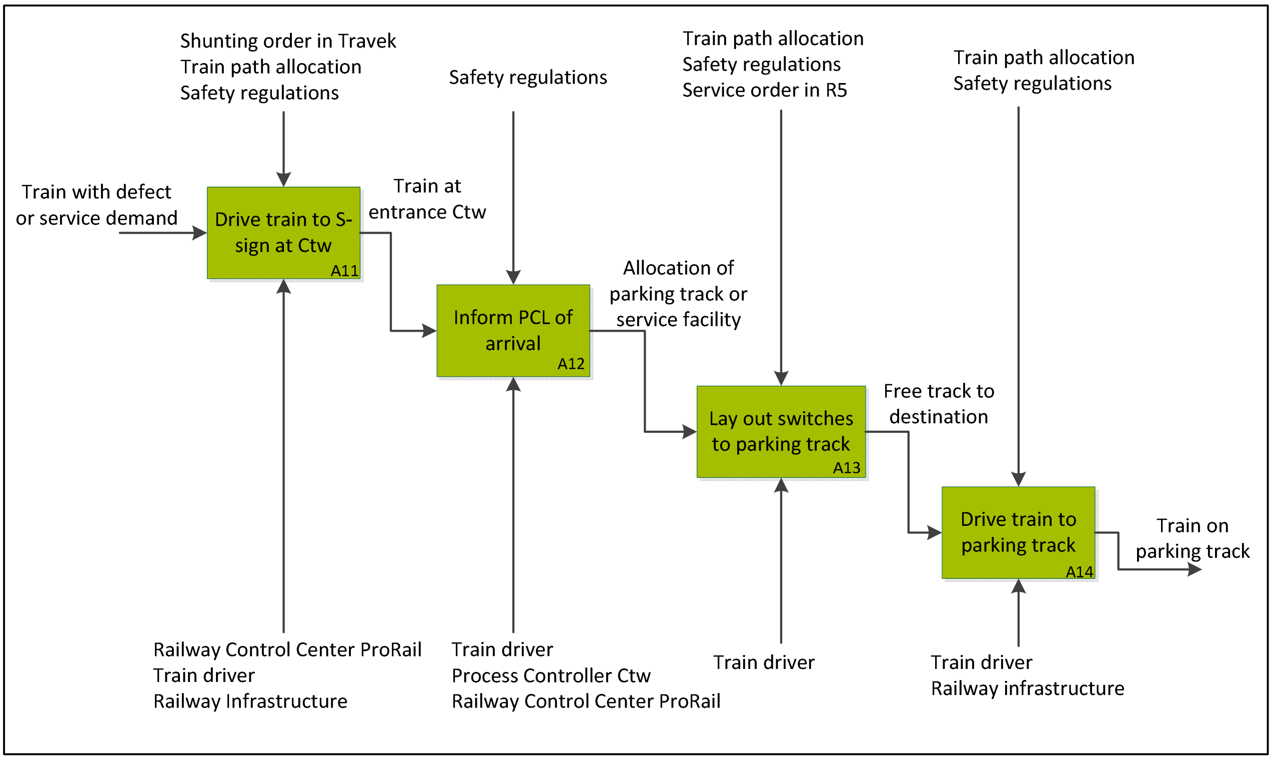


Figure 28: SADT diagram of the system on Ctw (decomposition of process A1)

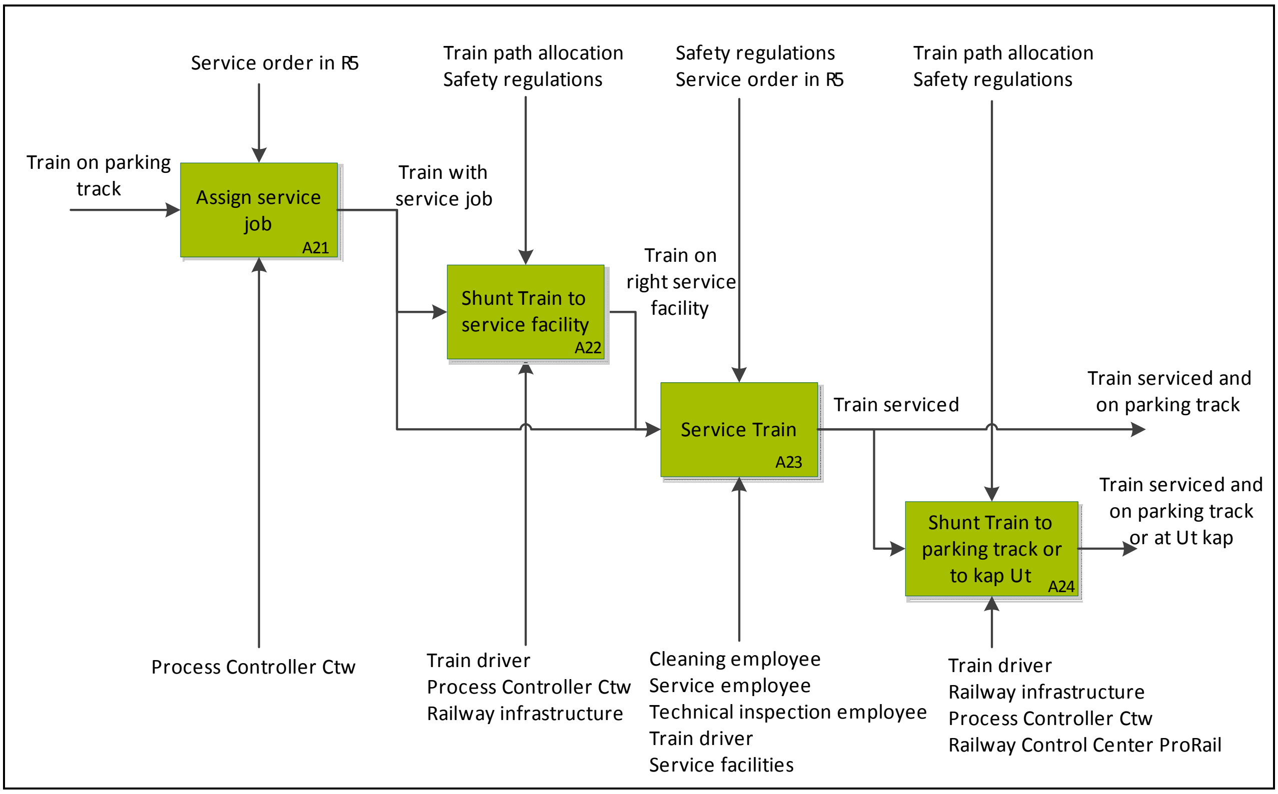


Figure 29: SADT diagram of the system on Ctw (decomposition of process A2)

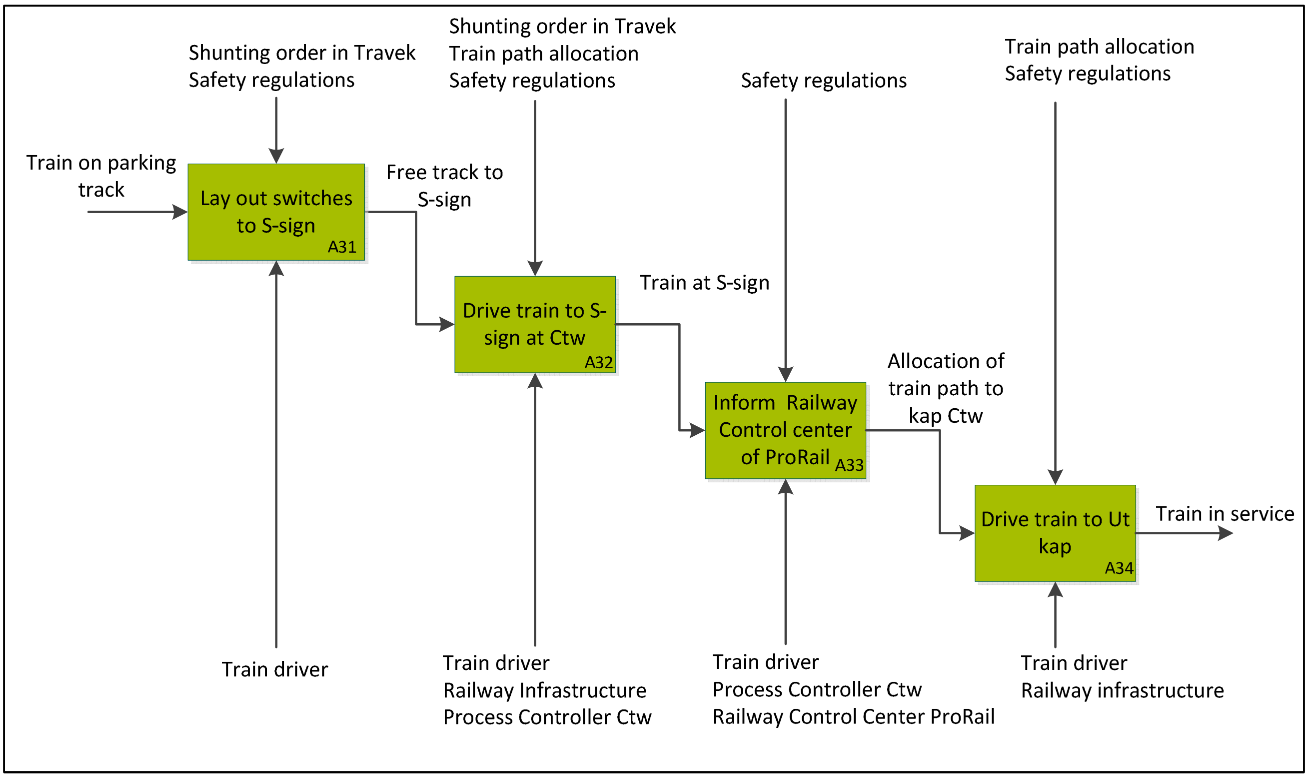


Figure 30: SADT diagram of the system on Ctw (decomposition of process A3)

VIII: Current process of process shunting

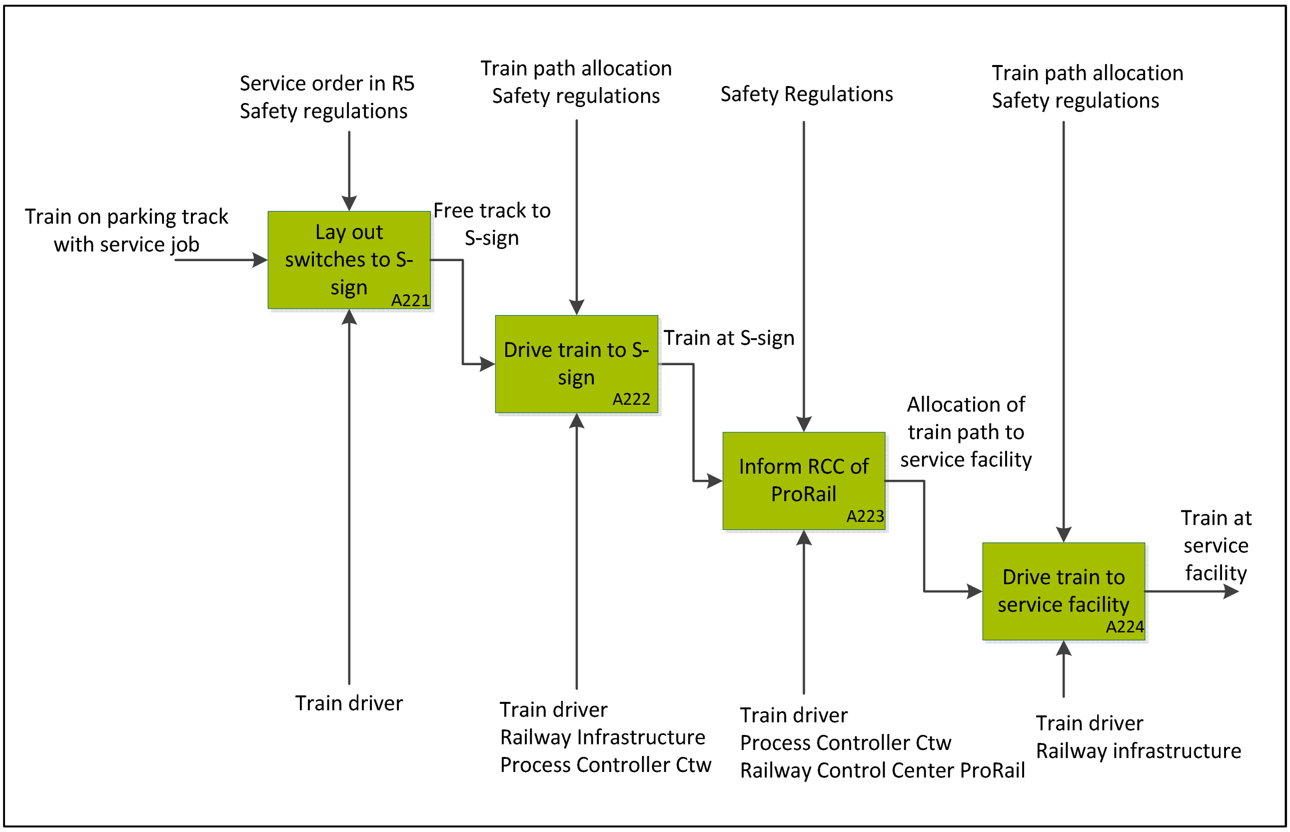


Figure 31: SADT diagram of the system on Ctw (decomposition of process A22)

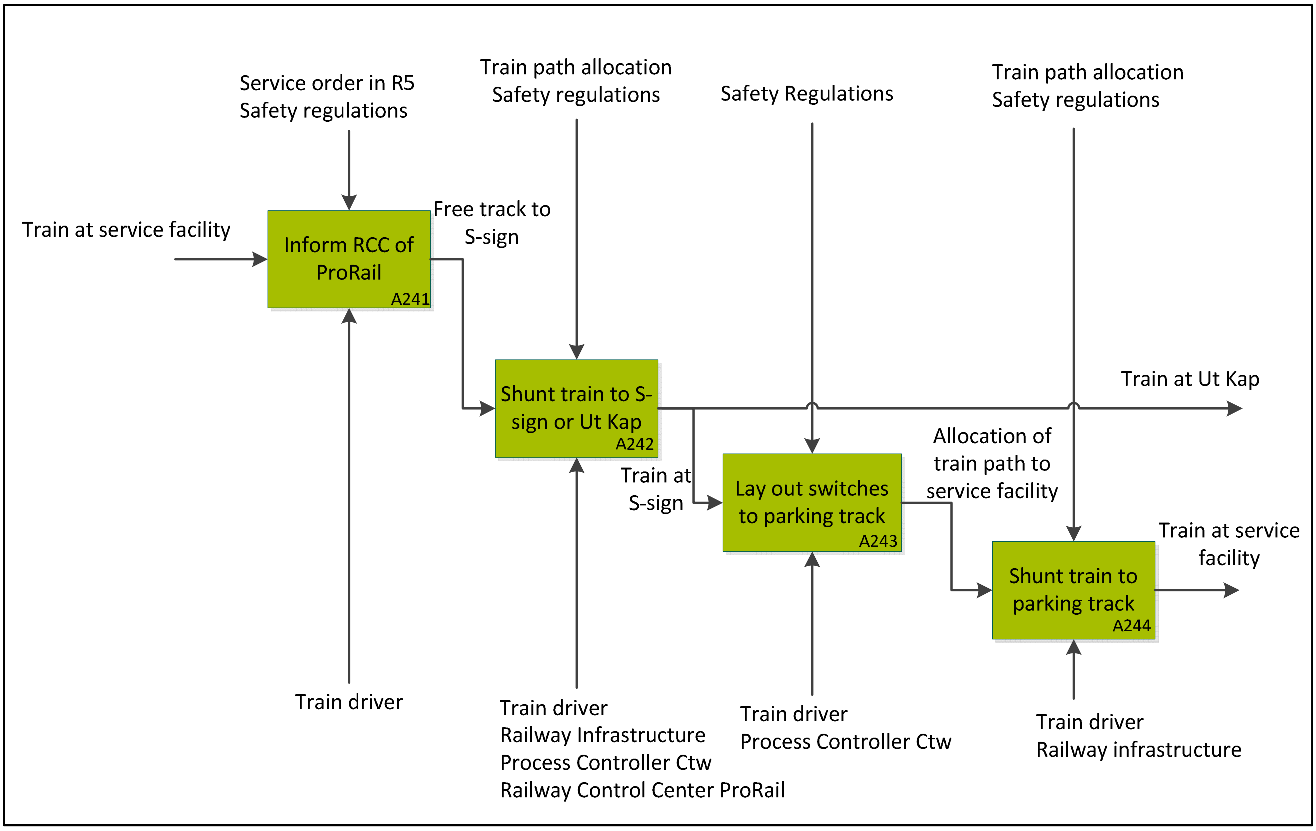
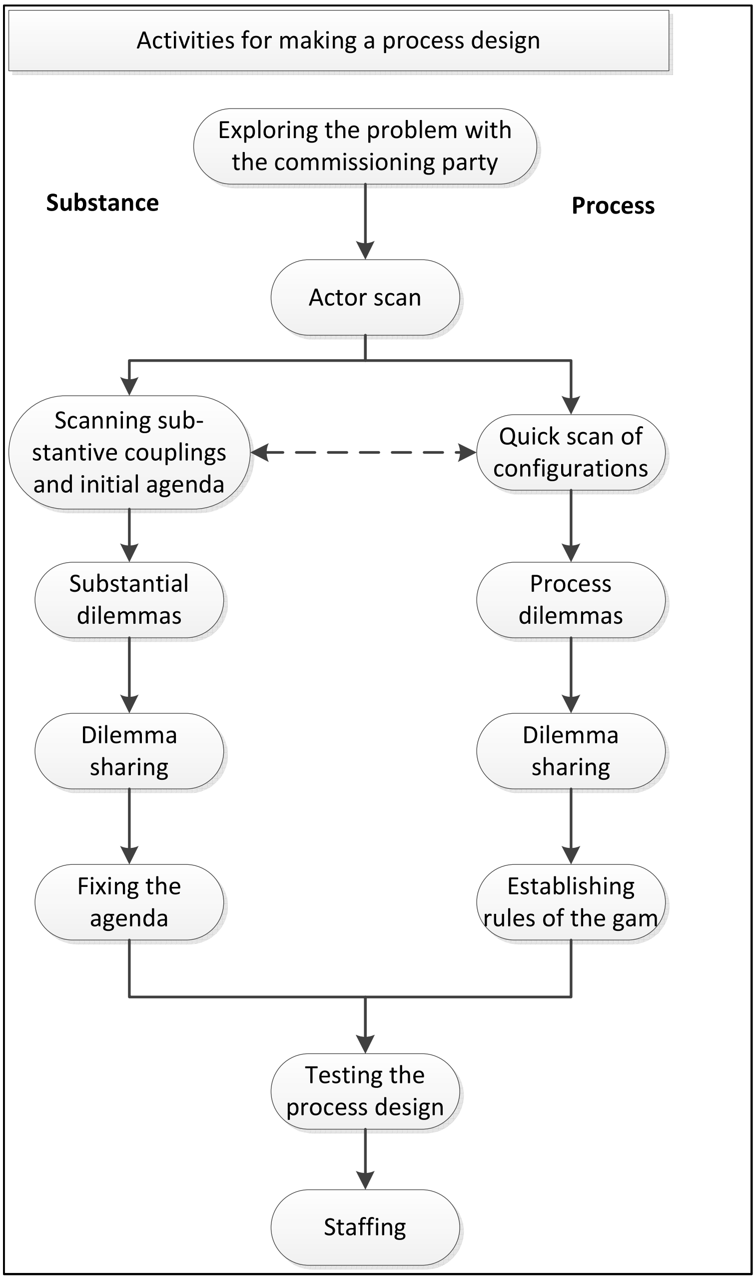


Figure 32: SADT diagram of the system on Ctw (decomposition of process A24)

IX: Activities for making a process design



Figuur 33: Guideline for process management (Bruijn et al. 2010)

Exploring the problem with the commissioning party

In collaboration with Marten Busstra the problems on the marshalling yard Ctw are mapped. As can be concluded is the main problem the process shunting movements of trains to the HSP and the TWI. In the near future a TC will replace the HSP and it is desired to be 24 hours operational. Therefore trains should be able to be shunted to the TC on platform 94. However, this is due to the complex train movements and unhandy lay out of the marshalling yard not possible during the run out of the train service. Therefore there is a request for a shunting plan, in which train movements should be made insight and the ability for movements to the TC should be included, also during peak hours.

Actor scan

Scan of relevant actors in written documents and interviews with relevant actors. During interviews new potential actors will emerge. The aim is to gain data about all important actors in the problem area, for which core values, views and interests and resources will be gathered. A thorough actor scan is performed in section 3.5 and appendix III.

Quick Scan Configurations

Interactions between actors and viewpoints are analysed. Interactions which are not intensive and viewpoints are extreme should be mitigated by coupling processes to each other so interaction between particular actors increase on issues on which they have a more average view. Besides that reframing and renaming the agenda of actors can help to start up the communication between actors.

Scanning substantive couplings and initial agenda

Mapping issues among actors and coupling these together to formulate the agenda to start the process. Researching the issues among actors and trying to couple them will generate a lot of opposite views among actors.

Substantial Dilemmas and fixing the agenda

The design and decision making process entails a lot of dilemmas which should be discussed. It is the aim to smoothen the flow of the design process by coupling substantive dilemmas and planning discussion on these issues in a certain order and over a time period so there can be dealt with. Resolving dilemmas can be done in several ways: by Synthesis, Pilot Option, Monthball Variant, Developing Options in Parallel, the Growth Model, Addressing the Underlying Question, Designing Mitigating and/or Compensating Measures.

Process Dilemmas and establishing rules of the game

For the way in which the process will be designed there arise also dilemmas. Rules of the game deal with these dilemmas. The main dilemmas are:

1. Accuracy vs. Speed of the process. Has the design process to be fast or very accurate. A very accurate design process will be time consuming and therefore the dilemma will arise on the speed of the process and its accuracy.
2. Involvement of actors. When and how will actors be involved. In case all actors are involved the design process will be time consuming and a lot of substantive dilemmas arise. Involving actors in particular phases of the design process may lead to less effort and incentive for actors to participate. The decision has to be taken on the involvement of the right set of actors on the right moments.
3. Confidentiality of the process and its outcomes. Should they be made public or just communicated to a certain set of parties.

Rules of the game thereby has to be established to create agreement on:

- Entry and exit rules: which parties will be involved and under which conditions can these parties join and leave the process.
- Decision making rules: Rules on how decisions are made, for example by consensus or majority rule.
- Organic rules: Rules on for example a steering group, which actor(s) is/are facilitating or evident in the design process, for example chairmanship.
- Planning and budget: What is the time frame and what deadlines are there for the design process. Also an estimation of costs for design activities should be made resulting in a decision on the budget.

Testing the process design

The process architect can optionally test the process design, by for example brainstorming within a prima facie test with participants about the process design or by simulation.

Staffing and participation

Which parties to involve is already been decided, but the person who is the representative of this actor should be chosen carefully. This person should be informed with the design problem and been involved in the system or environment the design should be made for. Besides that there can be the option to have consent among actors about the representatives of others. The advantage of this consent is that the risk of conflicts between actors is reduced. A last decision on participation should be made if only direct or also indirect representation is possible. In these two cases the representative is part of the actor (direct) or is asked to participate on behalf of the actor (indirect).

X: Managing design processes

Task	Design Process Leader	Technical Lead
Design Resources	X	
Design Review Procedure	X	
Power Consumption Plan		X
Simulation Validation Procedure	X	
Architectural Tradeoffs		X
Design Partitioning		X
Design Task Breakdown	X	
Design Review Content & Procedure	X	
Block Level Specifications		X
Design Flow	X	
Chip Engineering Spec		X
Back Annotation Requirements	X	
Work with CAD/CAE for new capability.	X	

Figure 34: Characteristics of a Design Process Leader (Jorvig, 2005)

XI: Shunting plan at Wgm

Aankomst te WGM					Rangeren			Reinigen	Techniek	Vertrek WGM			
Treinnummer	Ps	Vanaf	Aankomsttijd	Mat	Van	Naar	Tijd	Reinigen	Techniek	Wordt trein	Ps	Vertrektijd	Richting
77458		345	18:51	LM	345	C13	19:15	Ja		77419		6:16	345
					C13	Bult 339 via OZ	23:15		Ja				
					Bult 339	via C naar 345	5:45						
77460		345	19:21	LC	345	C13	19:15	Ja		80724		3:11	Asd
					C13	F1	23:00		Ja				
					F1	C9	2:45						
80465	A	345	19:37	AD + OA	345	Bult 339	19:45		Ja	80412	AD + OA	6:40	320
					Bult 339	C14	4:06	Ja					
					C14	320 (incl ontspor	6:00						
80775		asd	20:24	LC	C14	Bult 339	0:00	Ja		80730	A	4:06	Asd
80779		asd	21:11	LE	C14	Bult 339	0:00	Ja		80730	M	4:06	Asd
				LC+LE	Bult 339	C10	2:30		Ja				
80791		Asd	23:24	2 LBM	C11	Let op geen reiniging te Llso/Hn mogelijk			Ja	80712	2 LBM	1:11	asd
					Let op deze dient ook techniek in Wgm te krijgen, want in Hn geen capaciteit voor 80712 A evt te Llso ruimte voor								
80179		345	23:32	AD	345	C12	23:45	Ja	Indien nodig	80738	A	5:32	Asd
80701		asd	0:10	LE	C13	Wijzigen in C10		Ja	Indien nodig	74919	A	6:13	345
					C13/10	345	5:30		Ja				
80703	A+V	asd	0:24	2AD	C 12			Ja	Indien nodig	80738	V+M	5:32	Asd
80709	V	asd	1:09	LC	C 13	Wisselstraat	1:15	Ja		74919	V	6:13	345
					Wisselstraat	C13/10							
					C13/10	345	5:30		Indien nodig				
80709	A	asd	1:09	LE	C13			Ja	Indien nodig	80730	V	4:06	Asd
80711	V+A	asd	1:24	2 OC	C11			Ja	Indien nodig	80736	A+V	5:16	Asd
80715		asd	1:56	LB	C10			Ja	Indien nodig	75427		6:17	Asd

Figure 35: Visualization of shunting plan at Watergraafsmeer

XII: Instrument for assessment of shared understanding

Mulder, I. 1999.

CONTENT

How well do you understand the definition and requirements of the problem?

Very badly (1)------(2)------(3)------(4)------(5)------(6) Completely well

To what extent has your understanding of the group's definition and requirements of the problem changed since the previous meeting?

Understanding has decreased a lot (1)------(2)------(3)------(4)------(5)------(6)------(7) Understanding has increased a lot

Nothing has changed

To what extent does your group holds a shared interpretation/ understanding of the definition and requirements of the problem?

No shared understanding at all (1)------(2)------(3)------(4)------(5)------(6) Completely shared understanding

Since the previous meeting, to what extent has a common understanding of the definition and requirements of the problem emerged in your group?

There is less common understanding (1)-----(2)-----(3)-----(4)-----(5)-----(6)-----(7) there is more common understanding

Nothing has changed

SOCIAL RELATION

To what extent do you feel you know the other group members (with regard to skills, interests, the way they behave or react in different situations)?

Very badly (1)------(2)------(3)------(4)------(5)------(6) Completely well

How has the degree of how well you feel you know the other group members changed since the previous meeting?

Understanding has decreased (1)------(2)------(3)------(4)------(5)------(6)------(7) Understanding has increased

Nothing has changed

To what extent do you feel the other group members know each other?

Not at all (1)------(2)------(3)------(4)------(5)------(6) Completely

Since the previous meeting, to what extent has this common knowledge about the other group members emerged in your group?

Shared understanding has decreased (1)-----(2)-----(3)-----(4)-----(5)-----(6)-----(7) Shared understanding has increased

Nothing has changed

PROCESS

How certain are you about the nature and timing of tasks to accomplish this project?

Very uncertain (1)------(2)------(3)------(4)------(5)------(6) Completely certain

How did your degree of certainty of the nature and timing of tasks change since the previous meeting?

Understanding has decreased (1)------(2)------(3)------(4)------(5)------(6)------(7) Understanding has increased

Nothing has changed

To what extent do you feel the views of the other group members correspond with your interpretation concerning the nature and timing of tasks to carry out this project?

Do not correspond at all (1)------(2)------(3)------(4)------(5)------(6) Correspond completely

Since the previous meeting, to what extent has a common understanding of the nature and timing of tasks emerged in your group?

Shared understanding has decreased (1)-----(2)-----(3)-----(4)-----(5)-----(6)-----(7) Shared understanding has increased

Nothing has changed

Since the previous meeting, to what extent do you feel a common understanding of the project (in general terms) has emerged?

Shared understanding has decreased (1)-----(2)-----(3)-----(4)-----(5)-----(6)-----(7) Shared understanding has increased

Nothing has changed

XIII: UML diagram

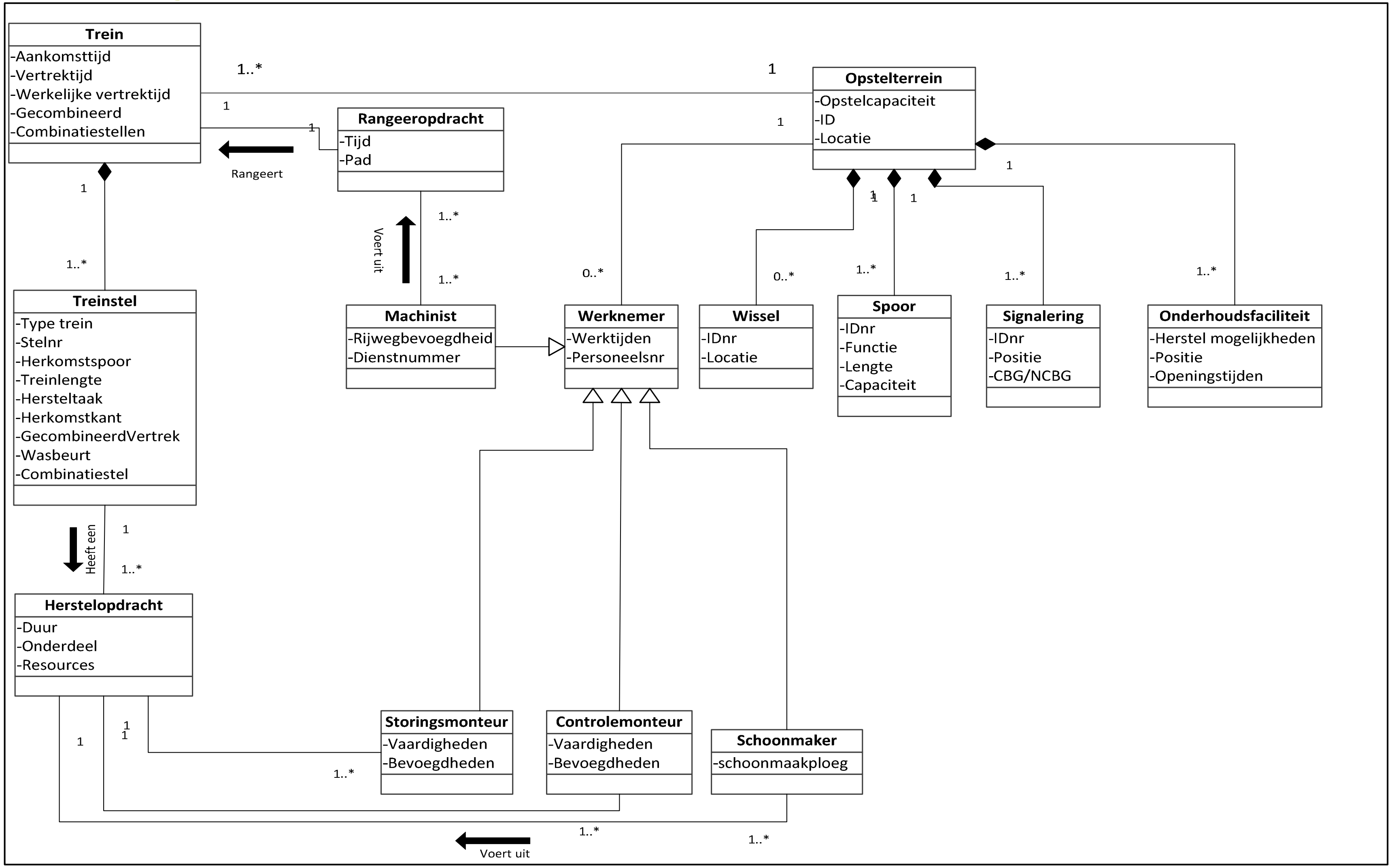


Figure 36: UML diagram of the system on marshalling yard Ctw

XIV: Flow diagrams of Ctw processes

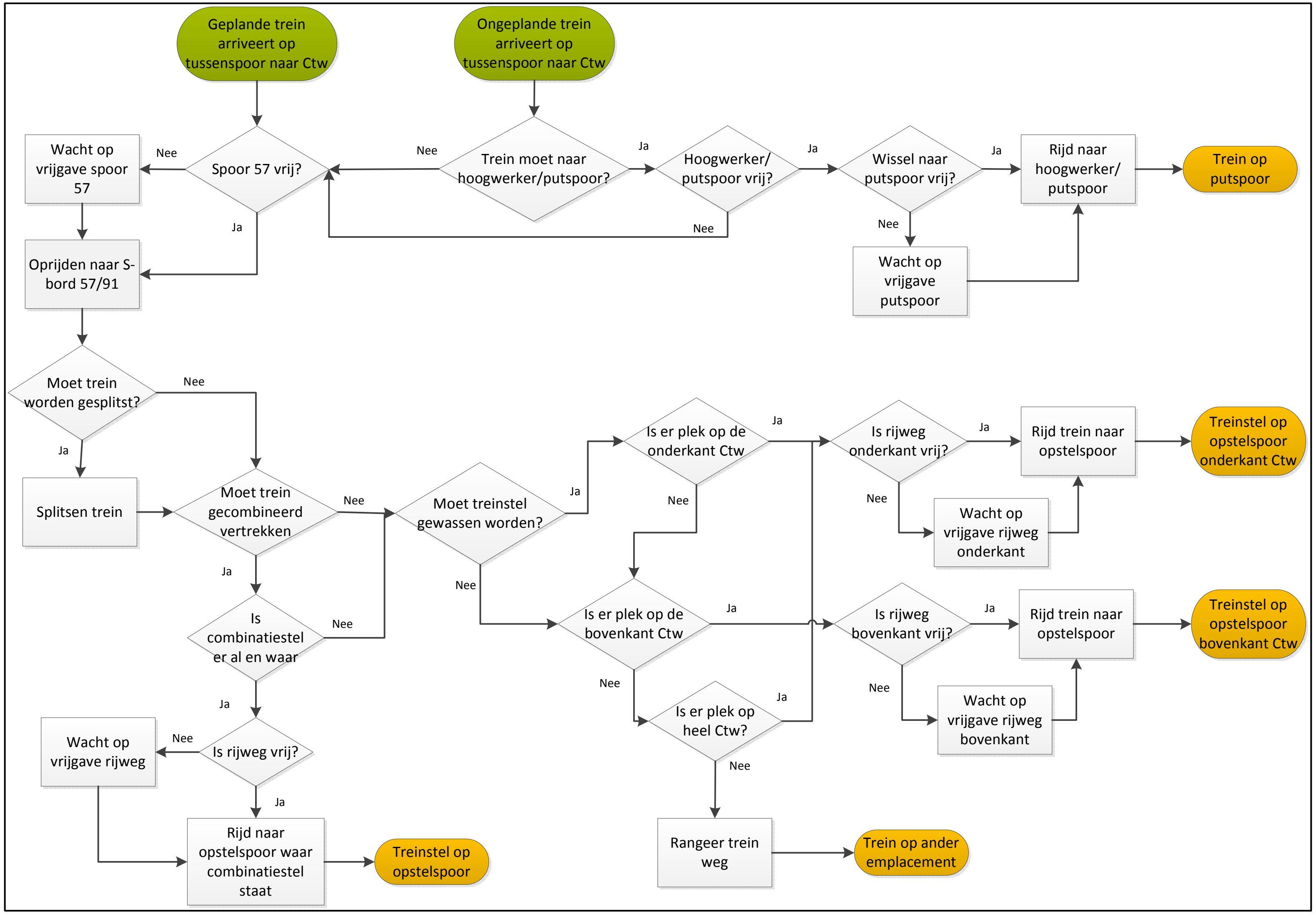


Figure 37: Flow diagram of handling process of arriving trains

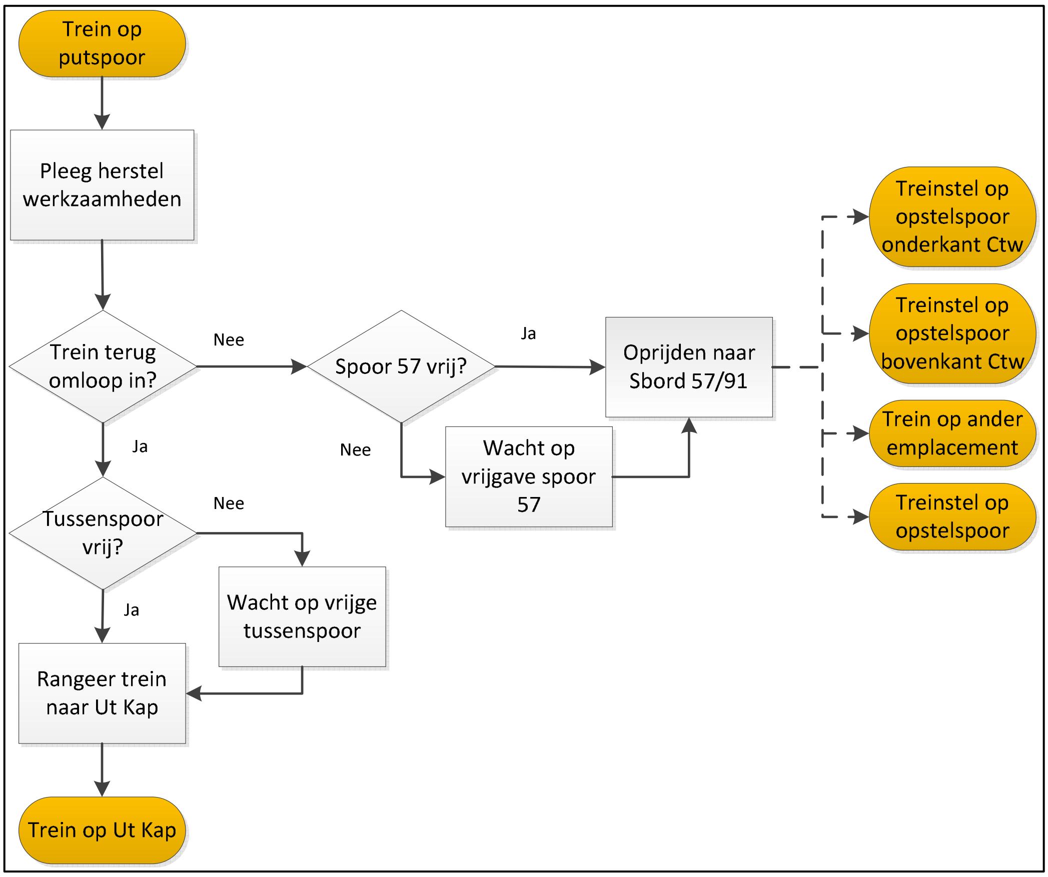


Figure 38: Flow diagram of service process

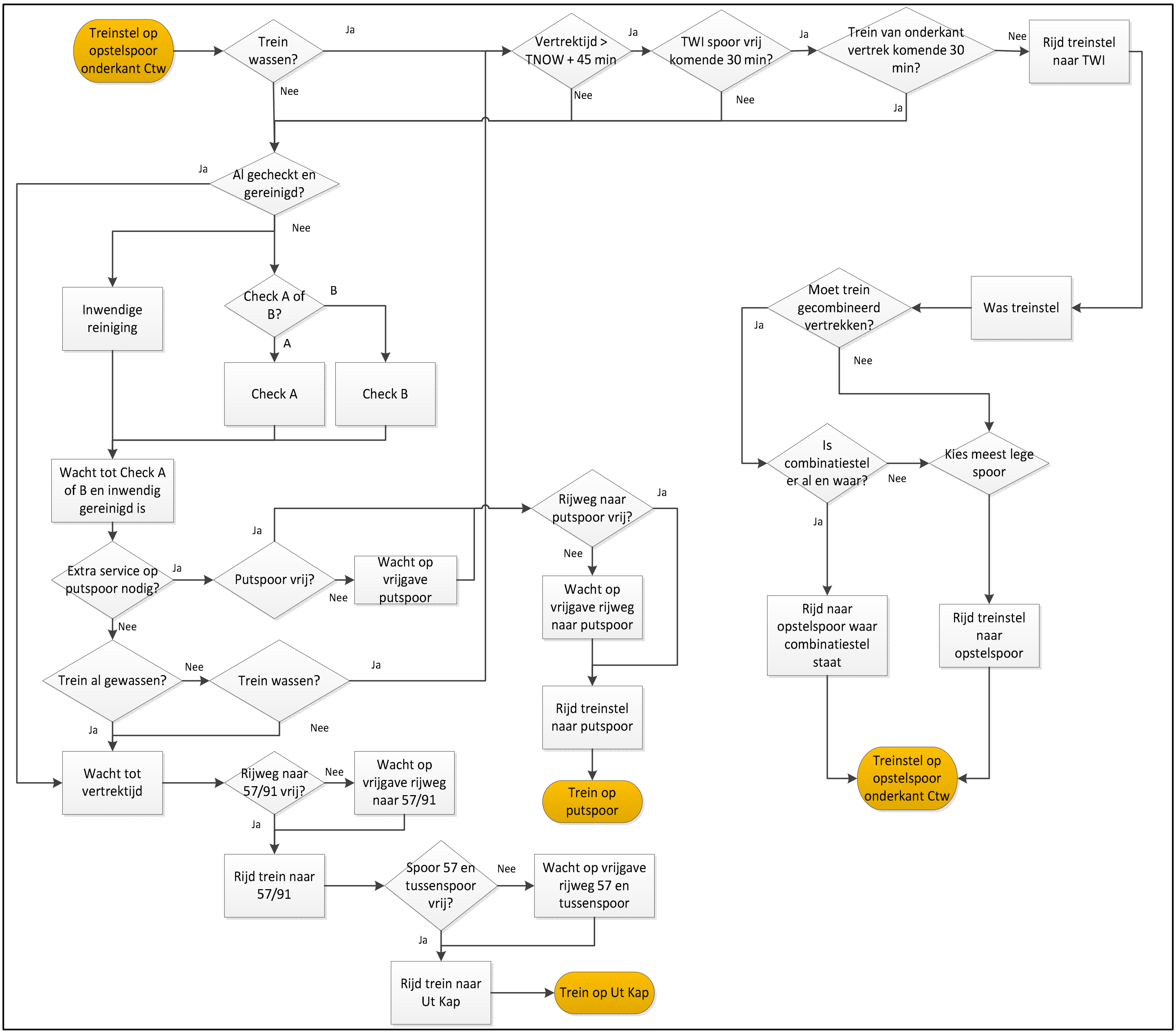


Figure 39: Flow diagram of extra servicing and departure of trains from upper part of Ctw

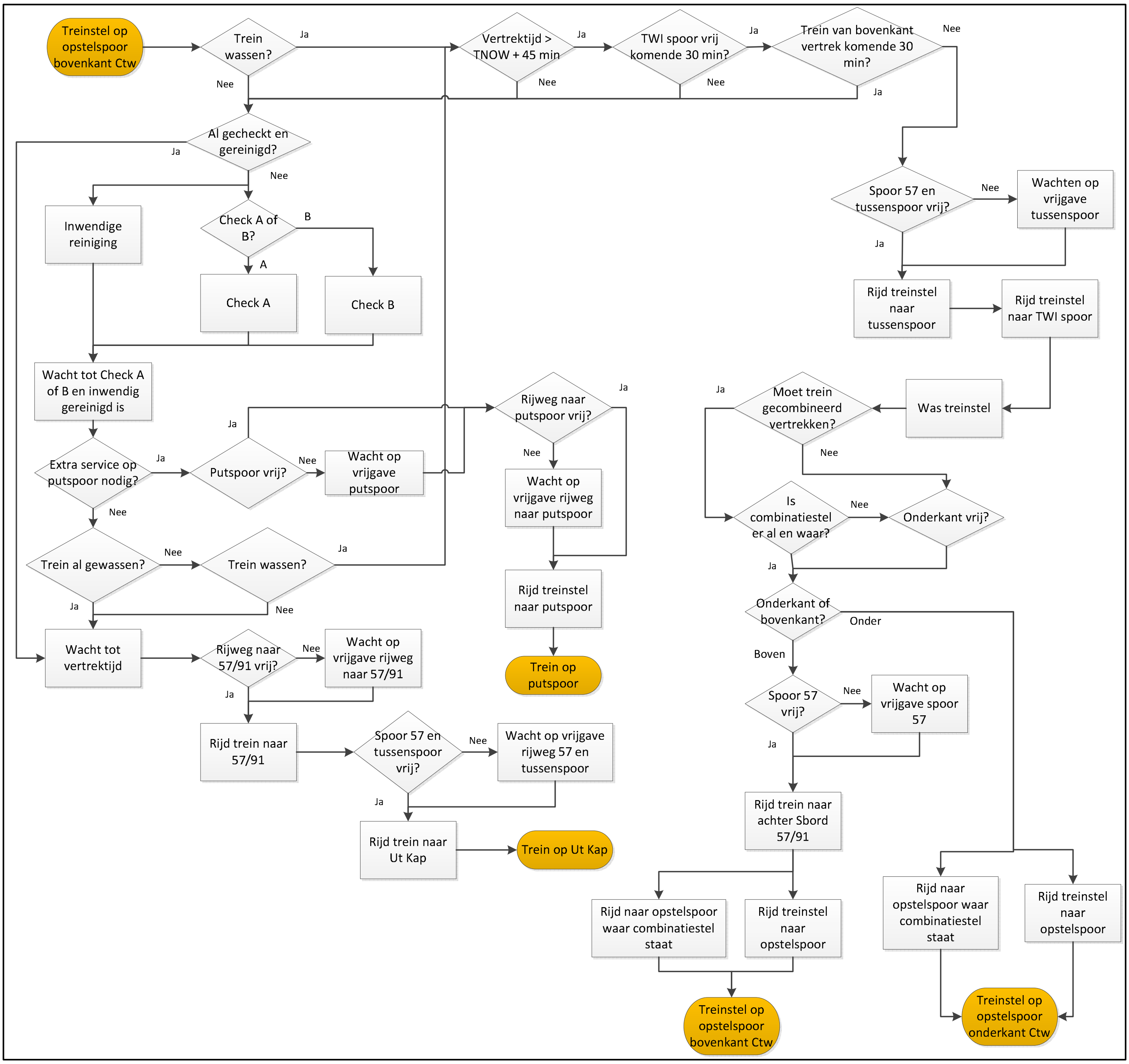


Figure 40: Flow diagram of extra servicing and departure of trains from lower part of Ctw

XV: Translated pre and post-test Shared Understanding

Vragenlijst *gedeeld begrip*

Onderwerp: logistieke problemen op Ctw en de invulling van een toekomstig rangeerplan

27 februari 2013

Versie: Vooraf

1.1 In hoeverre denk je de problemen omtrent de rangeerprocessen op Ctw en de invulling van een toekomstig rangeerplan te begrijpen?

Helemaal niet (1)------(2)------(3)------(4)------(5)------(6) Heel goed

2.1 In hoeverre denk je dat de groep op de hoogte is van de problemen omtrent de rangeerprocessen op Ctw en de invulling van een toekomstig rangeerplan?

Helemaal niet (1)------(2)------(3)------(4)------(5)------(6) Heel goed

---

3.1 In hoeverre denk je de andere partijen te kennen (m.b.t. de belangen, vaardigheden en gedrag dat ze hebben in verschillende situaties)?

Helemaal niet (1)------(2)------(3)------(4)------(5)------(6) Heel goed

4.1 In hoeverre denk je dat de andere partijen elkaar kennen (m.b.t. de belangen, vaardigheden en gedrag dat ze hebben in verschillende situaties)?

Helemaal niet (1)------(2)------(3)------(4)------(5)------(6) Heel goed

---

5.1 In hoeverre kan je inschatten wat er moet gebeuren en hoe lang dit gaat duren om de logistieke processen op en rond Ctw te verbeteren en een rangeerplan op te zetten?

Helemaal niet (1)------(2)------(3)------(4)------(5)------(6) Heel goed

6.1 In hoeverre denk je dat de visie van de andere partijen op de zaken die er moeten gebeuren en de tijd die dit gaat innemen overeenkomen met jou visie?

Helemaal niet (1)------(2)------(3)------(4)------(5)------(6) Heel goed

---

Opmerkingen:

<u>Enorm bedankt!</u>

TUDelft Delft University of Technology

Vragenlijst *gedeeld begrip*

Onderwerp logistieke problemen op Ctw en de invulling van een toekomstig rangeerplan

27 februari 2013

Versie: Achteraf

1.1 In hoeverre denk je de problemen omtrent de rangeerprocessen op Ctw en de invulling van een toekomstig rangeerplan te begrijpen?

Helemaal niet (1)------(2)------(3)------(4)------(5)------(6) Heel goed

1.2 Denk je dat je begrip betreffende de problemen omtrent de rangeerprocessen op Ctw en de invulling van een toekomstig rangeerplan beter begrijpt?

Begrip is enorm verslechterd (1)------(2)------(3)------(4)------(5)------(6)------(7) Begrip is sterk verbeterd

Niets veranderd

2.1 In hoeverre denk je dat de groep op de hoogte is van de problemen omtrent de rangeerprocessen op Ctw en de invulling van een toekomstig rangeerplan?

Helemaal niet (1)------(2)------(3)------(4)------(5)------(6) Heel goed

2.2 Is het begrip van de groep betreffende de problematiek omtrent de rangeerprocessen op Ctw en de invulling van een toekomstig rangeerplan veranderd?

Begrip is enorm verslechterd (1)------(2)------(3)------(4)------(5)------(6)------(7) Begrip is sterk verbeterd

Niets veranderd

3.1 In hoeverre denk je de andere partijen te kennen (m.b.t. de belangen, vaardigheden en gedrag dat ze hebben in verschillende situaties)?

Helemaal niet (1)------(2)------(3)------(4)------(5)------(6) Heel goed

3.2 Denk je dat je na deze sessie de belangen en het gedrag van andere partijen beter kan inschatten?

Begrip is enorm verslechterd (1)------(2)------(3)------(4)------(5)------(6)------(7) Begrip is sterk verbeterd

Niets veranderd

4.1 In hoeverre denk je dat de andere partijen elkaar kennen (m.b.t. de belangen, vaardigheden en gedrag dat ze hebben in verschillende situaties)?

Helemaal niet (1)------(2)------(3)------(4)------(5)------(6) Heel goed

4.2 Denk je dat de andere partijen elkaar beter kennen na deze sessie (m.b.t. de belangen, vaardigheden en gedrag dat ze hebben in verschillende situaties)?

Begrip is enorm verslechterd (1)------(2)------(3)------(4)------(5)------(6)------(7) Begrip is sterk verbeterd

Niets veranderd

5.1 In hoeverre kan je inschatten wat er moet gebeuren en hoe lang dit gaat duren om de logistieke processen op en rond Ctw te verbeteren en een rangeerplan op te zetten?

Helemaal niet (1)------(2)------(3)------(4)------(5)------(6) Heel goed

5.2 Denk je dat je beter kan inschatten wat er moet gebeuren en hoe lang het gaat duren om de logistieke processen op en rond Ctw te verbeteren en een rangeerplan op te zetten?

Begrip is enorm verslechterd (1)------(2)------(3)------(4)------(5)------(6)------(7) Begrip is sterk verbeterd

Niets veranderd

6.1 In hoeverre denk je dat de visie van de andere partijen op de zaken die er moeten gebeuren en de tijd die dit gaat innemen overeenkomen met jou visie?

Helemaal niet (1)------(2)------(3)------(4)------(5)------(6) Heel goed

6.2 Denk je dat de visie van de andere partijen op de zaken die er moeten gebeuren en de tijd die het gaat innemen om een rangeerplan op te stelen nu beter overeenkomen?

Begrip is enorm verslechterd (1)------(2)------(3)------(4)------(5)------(6)------(7) Begrip is sterk verbeterd

Niets veranderd

7. In vergelijking met vooraf deze sessie, in hoeverre denk je dat het algemene begrip over de logistieke problemen en hoe het rangeer plan op te stellen is veranderd

Begrip is enorm verslechterd (1)------(2)------(3)------(4)------(5)------(6)------(7) Begrip is sterk verbeterd

Niets veranderd

Opmerkingen:

Enorm bedankt!

XVI: Survey on extend of SU through multiple visualization

The survey is made in Dutch since the respondents are Dutch native speakers.

The survey is published online: *http://www.thesistools.com/web/?id=332254*

The propositions withinin the survey:

1. Het gebruik van meerdere visualisaties heeft ervoor gezorgd dat ik de problemen omtrent de rangeerprocessen op Ctw en de invulling van een toekomstig rangeerplan beter begrijp

2. Het gebruik van meerdere visualisaties heeft ervoor gezorgd dat de gehele groep bet er op de hoogte is van de problemen omtrent de rangeerprocessen op Ctw en de invulling van een toekomstig Rangeerplan

8. Het gebruik van meerdere visualisaties heeft er niet aan bijgedragen dat ik de problemen omtrent de rangeerprocessen op Ctw en de invulling van een toekomstig rangeerplan beter begrijp

3. Het gebruik van meerdere visualisaties heeft ervoor gezorgd dat ik de belangen, vaardigheden en gedrag van andere partijen bet er heb leren kennen

9. Het gebruik van meerdere visualisaties heeft er niet aan bijgedragen dat de gehele groep bet er op de hoogte is van de problemen omtrent de rangeerprocessen op Ctw en de invulling van een toekomstig rangeerplan

4. Het gebruik van meerdere visualisaties heeft ervoor gezorgd dat de andere partijen elkaar beter hebben leren kennen (m.b.t . de belangen, vaardigheden en gedrag dat ze hebben in verschillende situaties)

10. Het gebruik van meerdere visualisaties heeft er niet aan bijgedragen dat ik de belangen, vaardigheden en gedrag van andere partijen beter heb leren kennen

11. Het gebruik van meerdere visualisaties heeft er niet aan bijgedragen dat de andere partijen elkaar beter hebben leren kennen (m.b.t . de belangen, vaardigheden en gedrag dat ze hebben in verschillende situaties)

5. Het gebruik van meerdere visualisaties heeft ervoor gezorgd dat ik bet er kan inschatten wat er moet gebeuren en hoe lang dit gaat duren om de logistieke processen op en rond Ctw te verbeteren en een rangeerplan op te zetten

6. Het gebruik van meerdere visualisaties heeft ervoor gezorgd dat de visie van andere partijen op de zaken die er moet en gebeuren en de tijd die dit gaat innemen beter overeenkomen met jou visie

12. Het gebruik van meerdere visualisaties heeft er niet aan bijgedragen dat ik bet er kan inschat t en wat er moet gebeuren en hoe lang dit gaat duren om de logistieke processen op en rond Ctw te verbeteren en een rangeerplan op te zetten

7. Het gebruik van meerdere visualisaties heeft ervoor gezorgd dat het algemene begrip over de logistieke problemen en hoe het rangeer plan op te stellen is verbeterd

13. Het gebruik van meerdere visualisaties heeft er niet aan bijgedragen dat de visie van andere partijen op de zaken die er moet en gebeuren en de tijd die dit gaat innemen beter overeenkomen met jou visie

14. Het gebruik van meerdere visualisaties heeft er niet aan bijgedragen dat het algemene begrip over de logistieke problemen en hoe het rangeer plan op te stellen is verbeterd

XVII: Research report for NedTrain

2 april 2013

Onderzoeksrapport bereikbaarheid TC op Ctw

Bart van Zaalen
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Dit document beschrijft het resultaat van het onderzoek naar de bereikbaarheid van het Technisch Centrum (TC) op het opstelterrein Cartesiusweg (Ctw) te Utrecht. Aanleiding voor dit onderzoek zijn de zorgen en risico's betreffende de bereikbaarheid van het TC vanaf het opstelterrein.

Materieel vanaf het opstelterrein naar het beoogde TC moet over beveiligd gebied worden gerangeerd en conflicteert met inkomende en vertrekkende treinen. Effecten op de bereikbaarheid en doorlooptijd van EBKs op Ctw, maar ook de punctualiteit van materieel in omloop en overstand zijn onderzocht. Zelfs een herontwerp van het TC is overwogen en tijdens een workshop besproken.

Binnen het onderzoek zijn 4 deelonderzoeken uitgevoerd:

1. Analyse huidige situatie en mogelijke complicaties in toekomstige situatie met het TC op Ctw
2. Ontwerpsessie rangeerplan met kritiek betrokken partijen
3. Workshop betreffende alternatief ontwerp TC
4. Analyse materieel binnenkomst op Ctw

Het resultaat is een werkbare oplossing voor het beter bereikbaar maken en houden van het TC. De conclusies en aanbevelingen die volgen uit het integrale onderzoek zullen eerst worden benoemd. Een toelichting op deze conclusies zal worden gegeven voor elk deelonderzoek in het vervolg van dit rapport.

Context

Het TC op Ctw wordt gebouwd op het huidige putspoor (spoor 94), met de ingang aan de kapzijde (oostkant, huidige aanlooprichting). De business case is gebaseerd op 1 Extra Binnenkomst (EBK) per dag van een materieeleenheid SLT met een OB-herstelregeling. Hiervan zal de materieeleenheid SLT voornamelijk in de omloop binnenkomen op Ctw, zodat deze in de natuurlijke overstand hersteld kan worden. Een groot deel van de EBKs zal in de omloop naar Ctw worden geregeld[1]. Een klein deel zal middels een B-regeling naar Ctw worden opgezonden.

Vanuit de materieelbeschikbaarheid geredeneerd is er de wens om de herstellingen in het TC zo dicht mogelijk op het vervoersproces te laten plaatsvinden. Ingenieursbureau DHV heeft onderzoek gedaan naar de bereikbaarheid van het TC op het knooppunt Utrecht. Hieruit is gebleken dat er beperkt maar voldoende mogelijkheden zijn om van andere emplacementen over te steken naar Ctw. De mogelijkheden om vanaf het opstelterrein via beveiligd gebied om te zagen naar het TC zijn nog niet onderzocht en worden in dit document besproken.

[1] In de besluitvorming is aangenomen dat 75% van de EBKs in de omloop binnen zal komen

Conclusies en aanbevelingen

Het TC is tijdens een aantal uren per dag (23.00-02.00 en 04.00-07.00 uur) beperkt bereikbaar vanaf het opstelterrein. In deze perioden wordt het aankomst- en vertrekspoor (tussenspoor) op Ctw intensief gebruikt door de uitloop en opstart van de dienstregeling. Voor een beweging vanaf het opstelterrein naar het TC of vice vera moet er ook over dit spoor worden gerangeerd. De mogelijkheid tot rangeren naar/van het TC is dan zeer beperkt mogelijk.
Echter is uit onderzoek gebleken dat het aantal keer dat een EBK vanaf het opstelterrein naar het TC gerangeerd moet worden klein zal zijn. Stellen in omloop kleiner of gelijk aan SLT 4 + SLT 6 kunnen direct het TC in, mits deze vrij is. Alleen stellen die gecombineerd langer zijn dan een SLT 4 + SLT 6 moeten eerst worden gesplitst op het opstelterrein en vervolgens gezaagd worden naar het TC. Dit is in de huidige situatie slechts 8% van de SLT-binnenkomsten op Ctw. De overige EBKs zullen middels een extra treinbeweging naar Ctw komen. De praktijk wijst uit dat dit 90% een single stel betreft en direct het TC in kan. In bovengenoemde gevallen moet het TC wel vrij zijn, anders moet het stel alsnog eerst worden opgesteld op het opstelterrein.

De bevindingen en conclusies van alle deelonderzoeken zijn vertaald naar eisen en wensen om het TC beter te kunnen bereiken en benutten. Deze eisen en wensen zijn gericht op het ontlasten van het tussenspoor en het voorkomen van wachttijden.

Eisen:

- De hoogwerker moet definitief op spoor 272 worden geplaatst. In de huidige plannen is dat nog van tijdelijke aard wegens de bouw van het TC.
  Toelichting: Herstellingen die met gebruik van de hoogwerker uitgevoerd moeten worden komen anders in het TC terecht, waardoor een EBK een grotere kans heeft om eerst naar het opstelterrein te moeten om vervolgens terug gerangeerd te worden als het TC vrij komt. Deze beweging is mogelijk, echter tijdens een aantal uur per dag beperkt. Daarnaast lopen herstelling voor onder de hoogwerker in omloop het risico op vertraging, omdat de hoogwerker in het TC bezet is. Definitieve plaatsing van de hoogwerker op spoor 272 is daarom essentieel. Met een aparte hoogwerker worden bovendien onnodige rangeerbewegingen van het opstelterrein naar het TC vermeden.

- Inwendige reiniging van stellen moet mogelijk worden gemaakt in het TC.
  Toelichting: Een stel in omloop dat hersteld is in het TC moet anders eerst gezaagd worden naar het opstelterrein om daar intern gereinigd te worden. Deze zaagbeweging is beperkt tijdens de uitloop en opstart van de dienstregeling. Risico is dat het stel zijn omloop niet haalt als deze eerst nog naar het opstelterrein gezaagd moet worden.

- De diagnose voor de herstelling moet los staan van de herstelling zelf, deze kan op een later tijdstip worden ingepland.
  Toelichting: Herstellingen aan het EBK-stel in omloop die langer duren dan zijn natuurlijke overstand moeten doorgewisseld worden of naar het OB in Leidschendam worden geregeld. Het risico dat een herstelling langer duurt dan verwacht en het stel hierdoor zijn omloop mist wordt hierdoor kleiner. De afleverbetrouwbaarheid gaat hierdoor omhoog.

- In samenwerking met het BLP moeten de nachtoverstanden op Ctw gepland worden.

Toelichting: Plannen van nachtoverstanden in samenwerking met het BLP zorgt voor een meer overzichtelijk en rustig proces op het opstelterrein. Bovendien kan hiermee ook worden voldaan aan de eis vanuit de OR om volgens rangeerplan te werken na aanleiding van de herinrichting SB.

- Het aantal extra werkzaamheden in het TC moet worden beperkt[2].
  Toelichting: Gedurende de nacht is de kans op een EBK groot omdat EBKs in de omloop zullen binnenkomen. Extra herstellingen in het TC verrichten vergroten de kans dat het TC bezet is als er een EBK binnenkomt op Ctw. Hierdoor moet het EBK-stel eerst naar het opstelterrein en vervolgens worden gezaagd naar het TC. Deze zaagbeweging is gedurende een aantal perioden per dag beperkt mogelijk, waardoor het risico ontstaat dat het stel onnodig lang moet wachten op behandeling in het TC. Het risico dat dit stel zijn omloop mist wordt hierdoor ook groter.

Wensen:

- In samenwerking met het MBN moeten de EBKs naar het TC op Ctw zo veel mogelijk in een omloop worden geregeld waarin maximaal een SLT 4 + SLT 6 is gecombineerd. Dit kan de extra zaagbeweging voorkomen. Daarnaast kan er in samenspraak met het MBN het tijdstip van binnenkomt worden afgestemd. Het is de wens om een EBK-stel ruim voor de drukke uitloop (23.00-02.00 uur) naar binnen te regelen op Ctw, zodat er in een situatie waarin het EBK-stel eerst naar het opstelterrein moet er voldoende tijd is om de zaagbeweging te maken.
- In samenwerking met het BLP moet er getracht worden om tijdens de drukke uitloop en opstart van de dienstregeling een zaagmogelijkheid te creëren naar het TC vanaf het opstelterrein. Zo hebben stellen die toch eerst op het opstelterrein gesplitst moeten worden of wachten totdat het TC vrij de mogelijkheid om op korte termijn het TC te bereiken. Dit betekent concreet dat het aankomstspoor op Ctw voor een periode van 25 min vrijgehouden moet worden (inclusief veiligheidsnorm BLP voor treinopvolgingen).
- Versnel het rangeerproces door bijvoorbeeld het aanleggen van automatische wissel bediening. De rangeertijd van het opstelterrein naar het TC wordt daardoor verkort. Hierdoor zal er in de drukke periodes op het aankomst-/vertrekspoor vaker een ‘gat’ vallen waarin er een zaagbeweging kan plaatsvinden.
- Behoudt planmatige overstand SLT op Ctw. Hierdoor kan een EBK-stel waarvan de herstelling langer duurt dan verwacht worden doorgewisseld. Het risico dat een trein terug de omloop in gaat met een stel te weinig wordt hierdoor sterk gereduceerd.

Impact

Door te voldoen aan de genoemde eisen is de verwachting dat er een maakbaar logistiek proces op Ctw ontstaat voor het behandelen van EBK herstellingen voor SLT, zonder dat de overige processen per saldo nadelig beïnvloed worden. Materieel langer dan 170 meter zal eerst gesplitst en gerangeerd moeten worden waarvoor de logistieke mogelijkheden beperkt aanwezig zijn. Door het invullen van de eisen (en wensen) zal het aantal keer dat er gezaagd moet worden tot een minimum

[2] Voorstel extra werkzaamheden TC’s – Mette Klaversma – 13 februari 2013

kunnen worden beperkt. De belasting op het tussenspoor zal naar verwachting gemiddeld niet toenemen door het aantal zaagbewegingen vanaf het opstelterrein.

Deze conclusies en voorwaarden zijn opgesteld na individuele gesprekken met de personen in onderstaande tabel, tijdens een ontwerpsessie voor een rangeerplan op Ctw en een extra workshop t.b.v. een alternatief ontwerp voor het TC.

Gesprekken gevoerd met:

Naam	**Functie**
Marten Busstra	Projectleider Locatiestrategie (NT)
Joris van de Loo	Logistiek manager Ctw (NT)
Aad Bloem	Consultant OS (NT)
Ad Budding	Procesleider Ctw (NT)
Andries Holsappel	Procesleider Ctw (NT)
Eduard Wrede	Procesleider Ctw (NT)
Bernard van Nee	Bureau Lokale Planning (NSR)
Bob-Jan Smid	Logistiek Product Ontwerp (NSR)
Pieter Meerveld	Regionaal Bijsturing Centrum (NSR)
Marleen Wieten	Planner Wgm (NT/Yacht)
Mohammed Ouali	Planner Wgm (NT)
Cora Berlo	Capaciteitsmanager OS (NT)
Martijn Meegdes	Stafmedewerker Verkeers Leiding (ProRail)
John Broeder	Materieel Bijsturing NedTrain (NT)
Erik Hessel	Materieel Bijsturing NedTrain (NT)

Ontwerpsessie rangeerplan Ctw – 27 februari 2013:

- Marten Busstra Projectleider Locatiestrategie – Procesinrichting
- Joris van de Loo Logistiek manager Ctw
- Erik Hessel MBN
- Ad Budding Procesleider Ctw
- Ton van Diepen ProRail
- Bernard van Nee Bureau Locale Planning (NSR-BLP)
- Brigitte Verstraaten Regionaal Bijsturings Centrum NSR Ut (RBC)
- Marleen Wieten Planner Wgm
- Bart van Zaalen Afstudeerstagiair (TU Delft)

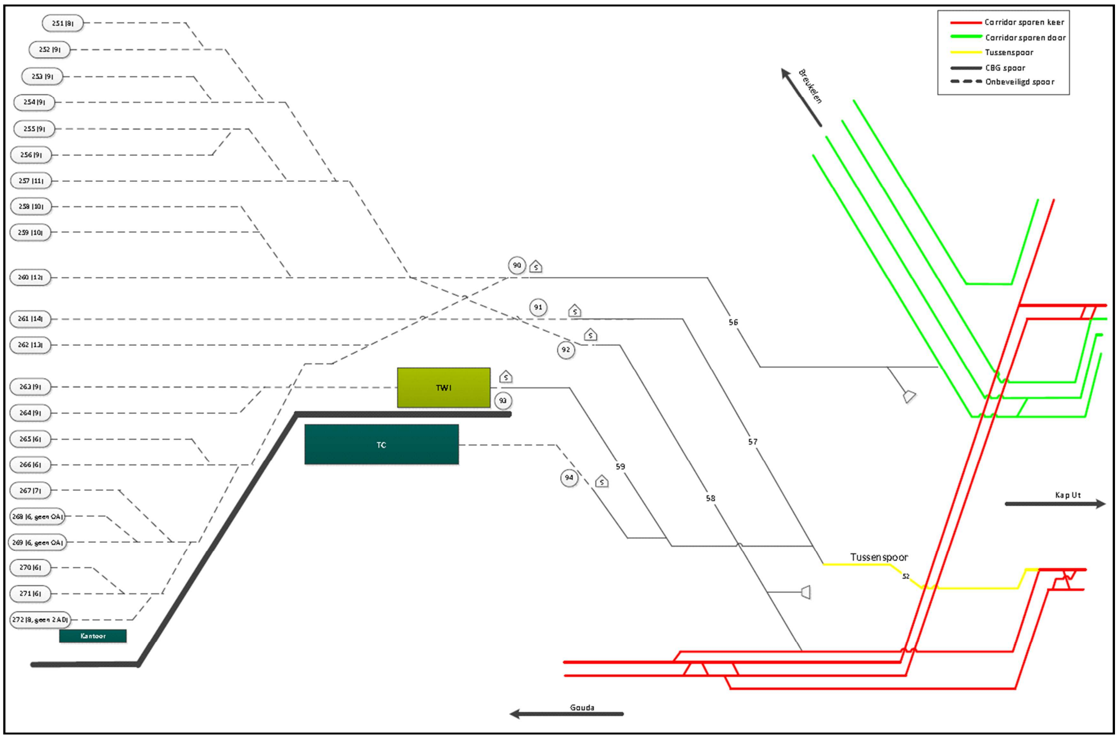
Workshop alternatief ontwerp TC – 13 maart 2013:

- Marten Busstra — Projectleider Locatiestrategie – Procesinrichting
- Albert-Jan van de Ster — Senior Consultant OS
- Arjan Vrieze — Projectleider Locatiestrategie - Bouw
- Jan-Theo Zorgdrager — Manager techniek/logistiek SB Utrecht
- Gert van Dijk — Procesleider Ctw
- Jaap de Ruijter — Logistiek Product Ontwerp (NSR)
- Aad Bloem — Consultant OS
- Bart van Zaalen — Afstudeerstagiair (TU Delft)

Toelichting deelonderzoeken

1. Analyse huidige situatie en mogelijke complicaties in de toekomstige situatie met TC op Ctw

De lay-out van Ctw zorgt ervoor dat het logistieke proces veel beperkingen kent. Het opstelterrein is alleen bereikbaar via spoor 52, loopt over in spoor 57 en komt op het gebied waar NedTrain de controle heeft op spoor 91 binnen. Onderstaande figuur is een schematische weergave, waarin Ctw is gekoppeld aan de knoop Utrecht.



Figuur 41: Schematische weergave opstelterrein Cartesiusweg (Ctw)

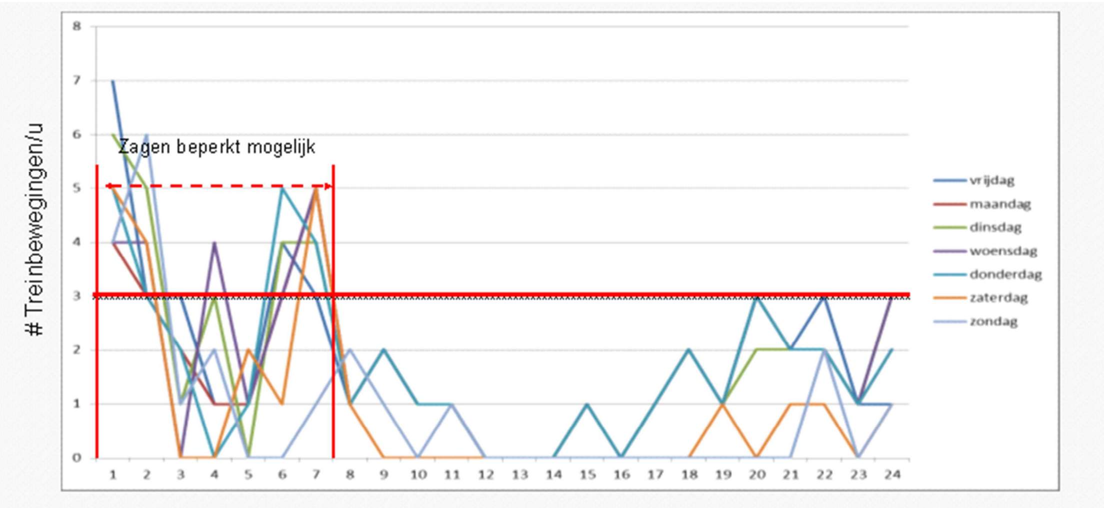
Bovenstaande figuur zal in de bijlage worden meegestuurd. De groene en rode sporen zijn de 2 corridors KEER & DOOR[3]. De aansluitingen op deze sporen van Ctw worden nauwelijks gebruikt omdat het in- of uitvoegende verkeer hier direct invloed kan hebben op de reizigerstreinen. Het risico dat het treinverkeer vertraagd raakt zorgt er voor dat alleen het tussenspoor wordt gebruikt voor de aan- en afvoer naar/van Ctw. Treinen die in omloop of middels een B-regeling naar Ctw komen worden allen over dit spoor geleid. EBKs worden dan of direct in het TC binnen genomen of moeten eerst naar het opstelterrein worden gerangeerd.

In de volgende gevallen moet een EBK eerst worden opgesteld op het opstelterrein:

- Het TC is bezet
- Gecombineerde trein langer dan een SLT 4 + SLT 6. Combinaties van VIRM of ICM 3+4 moeten altijd eerst worden gesplitst op het opstelterrein. Nadere toelichting volgt in het verslag van deelonderzoek 4.
- EBK-stel komt binnen in omloop. Hierdoor moet het stel nog worden gereinigd en wellicht worden gecombineerd op het opstelspoor voordat deze weer terug de omloop in kan.

[3] NAU nieuwsbrief nr. 1 – 15 februari 2011

In het geval een EBK eerst opgesteld wordt moet het stel vervolgens van het opstelterrein naar het TC worden gerangeerd. Een beweging van of naar het opstelterrein naar of van het TC wordt een zaagbeweging genoemd. Hierbij moet het stel volledig op het tussenspoor (spoor 52) komen om te kunnen keren. Hierbij treedt de beperking op dat dit spoor gedurende de uitloop en opstart van de dienstregeling druk bezet is (figuur 2). Omdat een zaagbeweging in zijn geheel 20 minuten duurt en er hierdoor geen ander verkeer naar en van de Ctw kan, is er een minimale periode van 20 minuten zonder verkeer op het tussenspoor (spoor 52) nodig.



Figuur 42: Aantal treinbewegingen op het tussenspoor naar/van Ctw per uur

Gemiddeld gezien is er tussen 23.00 en 02.00 uur en 04.00 en 07.00 uur zeer beperkte mogelijkheid tot zagen vanwege het drukke verkeer op het tussenspoor. Hierdoor kunnen stellen bestemd voor het TC en zich bevinden op het opstelterrein de zaagbeweging niet maken. De effecten hiervan zijn:

- Onnodig langere doorlooptijd doordat er gewacht moet worden op het zagen naar/van het TC. Als stellen in de omloop binnenkomen kunnen ze vaak pas na 02.00 uur richting het TC worden gerangeerd om vervolgens te worden hersteld. Als de herstelling niet is voltooid voor 04.00 uur dan is de kans groot dat het stel zijn omloop mist.
- Als overige herstellingen ook gaan plaatsvinden in het TC wordt het in de nachtelijke uren druk in het TC. Door de beperkte zaagmogelijkheden zal er in de nacht vaak maar 1 herstelling kunnen plaatsvinden. Stellen die terug de omloop in moeten lopen hierbij vertraging op, waardoor of de vertrekkende trein vertraging krijgt of er doorgewisseld moet worden indien mogelijk. Dit brengt risico's met zich mee betreffende de punctualiteit van vertrekkende treinen, doorlooptijd van herstellingen en mate van vertraging van stellen terug de omloop in.

Eisen die gesteld zijn om bovenstaande risico's te mitigeren:

- De diagnose voor een EBK moet los kunnen worden gekoppeld van de herstelling. Als een EBK-stel niet voldoende tijd heeft om zowel diagnose als herstelling te ondergaan moet deze na de diagnose weer terug de omloop in of doorgewisseld worden. Als er doorgewisseld kan worden of als er voldoende tijd is om te herstellen dan moet dit uiteraard gebeuren.

- De hoogwerker wordt tijdelijk op spoor 272 geplaatst. Dit moet een definitieve locatie worden voor de hoogwerker, zodat alle extra herstellingen aan materiaal die nu plaatsvinden op de hoogwerker niet in het TC terecht komen. Hierdoor is het TC vaker direct bereikbaar omdat er geen ander stel wordt hersteld. Bovendien worden zaagbewegingen over het tussenspoor met kleine defecten voor de hoogwerker voorkomen.
- Inwendige reiniging moet uitgevoerd kunnen worden in het TC. Hierdoor hoeft een hersteld stel in het TC niet eerst nog te worden gezaagd naar het opstelterrein voor reiniging. Hiermee wordt het risico op het missen van de omloop voorkomen.

2. Ontwerpsessie rangeerplan met kritiek betrokken partijen

Met de komst van een rangeerplan op Ctw, dat verplicht is gesteld door de OR naar aanleiding van de herinrichting SB, zijn er kansen om het TC beter bereikbaar te maken vanaf het opstelterrein. Voor de toekomstige situatie met de bijkomende risico's zoals toegelicht in deelonderzoek 1 zijn een aantal oplossingsalternatieven opgesteld in samenwerking met kritiek betrokken partijen. Bij het rangeerproces zijn de volgende partijen direct en kritiek betrokken:

- Procesleider Ctw (PCL)
- Manager logistiek Ctw
- Materieel Bijsturing NedTrain (MBN)
- Bureau Lokale Planning – NSR (BLP)
- Regionaal Bijsturing Centrum Utrecht (RBC)
- Verkeersleiding ProRail (VL ProRail)

Op de locatie Watergraafsmeer (Wgm) is onlangs van start gegaan met de ontwikkeling en implementatie van een rangeerplan. De projectleider hiervan, Marleen Wieten, is daarom ook betrokken in dit onderzoek.

Uit diverse gesprekken met bovenstaande partijen is geconcludeerd dat een rangeerplan de bereikbaarheid van het TC zou kunnen waarborgen. Daartoe is er een ontwerpsessie opgezet om de verschillende alternatieven die opgenomen zouden kunnen worden in een rangeerplan en de bereikbaarheid van het TC te vergroten te onderzoeken.

Er zijn 6 alternatieve oplossingen opgesteld:

1. Facultatieve 'zaagpaden' van opstelterrein naar TC
2. Zagen voor en na buitendienststelling van toegangssporen naar Ctw
3. Proces rangeren opnemen in rangeerplan
4. Claimen opstelspoor voor materieel bestemd voor TC
5. Opstelspoor voor TC op OZ
6. In en uitrangeerplan (samenwerking BLP – PCL Ctw)

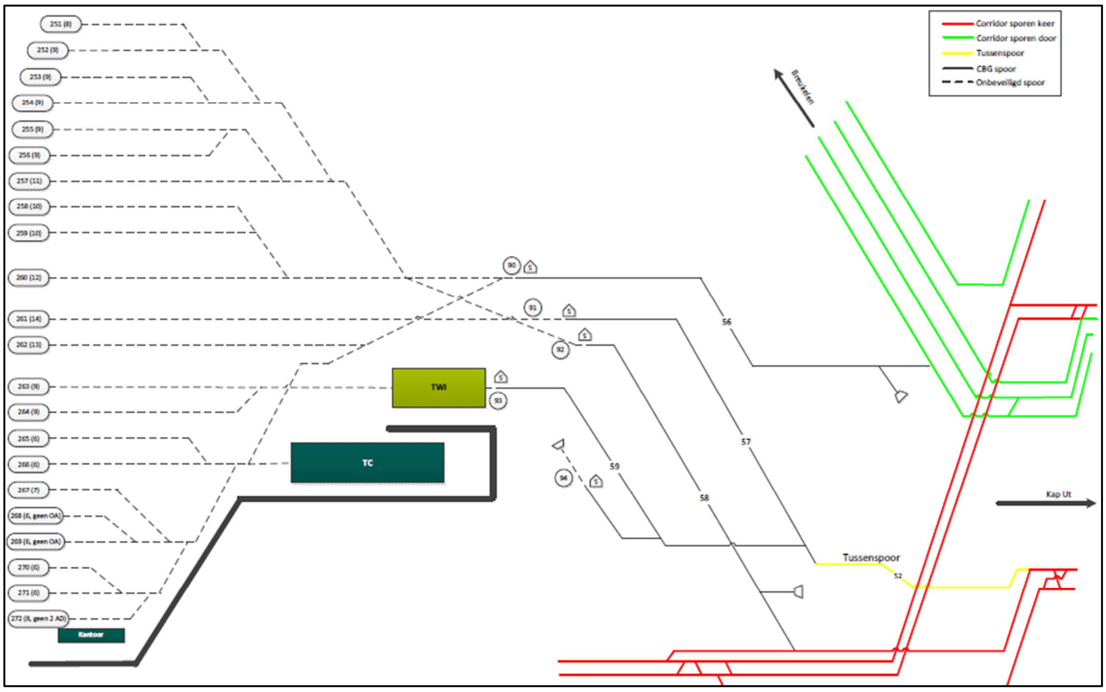
In een ontwerpsessie zijn de bovenstaande oplossingsalternatieven besproken. Hierbij is voor de alternatieven 1 t/m 4 een ondersteunend simulatiemodel ontwikkeld op basis van de huidige processen.

Uit de ontwerpsessie kan geconcludeerd worden dat alternatief 6 de basis is voor het verbeteren van de processen op Ctw. Ook zonder komst van het TC moet er een samenwerking worden opgezet tussen het BLP en de Procesleider op Ctw om de huidige processen te stroomlijnen. Daarnaast is geconcludeerd dat alternatief 1 het enige haalbare alternatief is, waarbij een facultatief pad geen mogelijkheid is, maar het creëren van ruimte op het tussenspoor eenzelfde uitwerking zou kunnen hebben. De maakbaarheid van deze oplossing op de lange termijn werd echter door alle partijen in twijfel getrokken om de volgende reden; Het creëren van een vrije periode op het tussenspoor in tijden van uitloop of opstart van de dienstregeling zorgt ervoor dat het patroon hiervan aangepast moet worden of op geplande basis een gat gevonden moet worden. Op basis van de komende wijzigingsbladen zou dat mogelijk kunnen zijn, maar bij een toename van geplande overstand op Ctw zal de mogelijkheid hiertoe sterk afnemen door een toenemend aantal treinbewegingen van en naar Ctw.

De conclusie is dat dit geen robuuste oplossing biedt op de lange termijn. Naar aanleiding van deze uitkomst is er een onderzoek gestart naar een alternatief ontwerp voor het TC, waarbij een zaagbeweging over beveiligd gebied wordt vermeden. Dit deelonderzoek wordt toegelicht onder punt 3.

3. Workshop betreffende alternatief ontwerp TC om bereikbaarheid te verbeteren

Omdat er vanuit de ontwerpsessie werd geconcludeerd dat er geen robuuste oplossing te vinden is in het logistieke proces om de bereikbaarheid van het TC vanaf het opstelterrein te vergroten op de lange termijn is er gedacht aan het omdraaien van het TC. Hierdoor wordt het TC direct toegankelijk vanaf het opstelterrein (figuur 3).



Figuur 43: Alternatief ontwerp TC met ingang aan opstelzijde

De ingang van het TC aan de andere zijde creëren heeft op het eerste oog voordelen t.o.v. het huidige ontwerp. De zaagbeweging op het tussenspoor wordt namelijk vermeden. De reden dat het TC geen doorrijspoor kan krijgen is:

1. Nieuwe overwegen op emplacementen worden door ProRail niet toegestaan i.v.m. veiligheidsrichtlijnen.
2. Het magazijn ter bevoorrading van het TC is ontworpen op de kopse kant. Herontwerp van het TC met het magazijn aan de lange zijde is niet meer mogelijk omdat het bouwproces al in gang is gezet. Bovendien is hier ook geen ruimte voor.

Een workshop is belegd om de voor- en nadelen af te wegen en de risico's voor het proces op Ctw in kaart te brengen.

De uitkomst van deze workshop leidt tot de conclusie dat een herontwerp van het TC met de ingang aan de kant van het opstelterrein geen significante voordelen oplevert t.o.v. het huidige ontwerp. De extra kosten van circa €800.000 en een vertraging van het bouwproject van 6 maanden zijn dit zeker niet waard.

Bij het omdraaien van het TC wordt het opstelspoor 272 opgeofferd om te kunnen keren naar en vanuit het TC. In overleg met Logistiek Product Ontwerp (NSR) is gebleken dat dit geen belemmering moet zijn voor de keuze het TC om te draaien. Echter zorgt het omdraaien van het TC ervoor dat alle stellen op spoor 272 moeten keren en vervolgens richting spoor 90 of 91 gerangeerd worden om uiteindelijk opgesteld te kunnen worden op een van de overige opstelsporen. Er is namelijk alleen de mogelijkheid om het TC aan te takken op het onderste spoor op Ctw (272). Hierdoor wordt het centrale punt op het opstelterrein, de wisselstraat bij het aankomstspoor 57/91 bij alle bewegingen van en naar het TC overkruist. Dit betekent impliciet dat de problemen die door het drukke verkeer ontstaan op het tussenspoor in het huidige ontwerp worden verplaatst naar het knooppunt verderop het opstelterrein. Tijdens drukke uitloop en opstart van de dienstregeling is het dus ook niet mogelijk om over dit knooppunt te kunnen zagen van een opstelspoor naar het TC en andersom. De tijd die nodig is om de zaagbeweging te maken is wel een paar minuten korter. Het structureel creëren van een periode zodat de zaagbeweging wel gemaakt kan worden is door de kortere rangeertijd wel gemakkelijker te realiseren. Echter is de situatie die ontstaat een risico voor het creëren van een robuuste oplossing om het TC beter bereikbaar te maken vanaf het opstelterrein. Het zagen vanuit het TC door de wasinstallatie naar een opstelspoor aan de onderkant van het opstelterrein is wel mogelijk, maar zorgt ervoor dat de onderkant van het opstelterrein dan tijdelijk niet bereikbaar is voor inkomend verkeer en conflicteert met het was proces.

Vervolgens is er geopperd om een analyse te doen hoe vaak het voorkomt dat een EBK binnenkomt in een omloop waarbij het eerst moet splitsen op het opstelterrein. Toelichting op dit deelonderzoek wordt gegeven onder punt 4.

De wens die er tijdens deze workshop werd uitgesproken door meerdere partijen was de aanleg van automatische wisselbediening. Hierdoor kan de rangeertijd aanzienlijk worden verkort en zullen er tijdens drukke periodes op het tussenspoor vaker vrije periodes benut kunnen worden om een zaagbeweging te maken.

4. Analyse materieel binnenkomt op Ctw

Op basis van de wijzigingsbladen december 2012 en februari 2013 zijn de aankomsten op Ctw geanalyseerd. Hierbij is onderzocht welk type materieel in welke combinatie binnenkomt volgens de geplande omloop. Het doel van dit onderzoek is het inschatten van het aantal gevallen waarin een EBK eerst naar het opstelterrein gerangeerd moet worden omdat deze te lang is om direct in het TC binnen genomen te worden.

Uit deze analyse blijkt dat 92% van de SLT stellen in een omloop binnenkomt die direct het TC in zou kunnen. Voor overig materieel kan alleen voor VIRM een conclusie worden getrokken omdat dit het enige type is dat vaak op Ctw komt. Hiervan komt gemiddeld 66% in een omloop binnen die direct het TC in zou kunnen.

Uitgaande van de GSL voor SLT materieel is van het merendeel van de EBKs die in de omloop naar Ctw komen 92% geschikt om direct in het TC binnen te komen. Van het kleinere deel EBKs die buiten de omloop naar Ctw wordt geregeld zal 90% een single stel zijn en direct het TC in kunnen. Het aantal gevallen waarin een EBK-stel door een te lange combinatie eerst naar het opstelterrein moet om gesplitst te worden is dus erg klein.

Daarnaast zouden betrokken partijen zoals het MBN er voor kunnen zorgen dat een EBK-stel in een omloop binnenkomt die maximaal een combinatie van SLT 4 + SLT 6 is. Mocht dit niet lukken dan is het moment van binnenkomst op Ctw ook van belang.

Voor stellen die in de omloop binnen worden gebracht op Ctw en bestemd zijn voor het TC zijn de volgende wensen aan deze binnenkomst:

- Materieeleenheid komt ver voor 23.00 uur binnen, zodat zaagbeweging gemaakt kan worden indien noodzakelijk
- Materieeleenheid hoeft niet in de ochtendspits weer de omloop in, doordat er met materiaal doorgewisseld kan worden
- Materieeleenheid wordt op het juiste moment naar Ctw gestuurd, zodat het TC niet bezet is
- Materieeleenheid wordt in de juiste combinatie naar Ctw gestuurd, zodat het stel in de combinatie kan worden hersteld in het TC. Dit betekent maximaal een combinatie van SLT 4 + SLT 6

Doordat het overgrote deel van de EBKs direct in het TC binnen genomen kan worden en overige herstellingen vaak plaats zullen vinden onder de hoogwerker op spoor 272, zal de belasting op het tussenspoor afnemen. De bewegingen van stellen, zowel SLT als VIRM om onder de hoogwerker te komen worden namelijk vermeden als er wordt voldaan aan de eis om de hoogwerker definitief te plaatsen op spoor 272.

Van de EBKs onder het SLT materieel zal maar 8% gezaagd moeten worden. Bij VIRM materieel is dit 34%. Doordat de bewegingen vanaf het opstelterrein naar de hoogwerker niet meer over het tussenspoor gaan zal per saldo de belasting op het tussenspoor afnemen.

XVIII: Arrival and departure sheet for the marshalling yard Ctw

Planning van de treinen 4-12-2012 21:49:29

Locatie: SUTC

Plangegevens: Maandag

Trein	Tijd	Spoor	Dgn Later	Aantal	Trein	Tijd	Spoor	Dgn Aanwezig
16018	7:58:00	le	0	1	6015	1:40:00	a	1
16020	8:28:00	lc	0	1	6063	17:10:00		0
16020	8:28:00	le	0	1	6051	14:10:00		0
16022	8:58:00	le	0	1	6065	17:40:00		0
16022	8:58:00	le	0	1	6061	16:40:00		0
16024	9:28:00	le	0	1	6015	1:40:00	v	1
16030	10:58:00	le	0	1	6067	18:10:00		0
6064	19:08:00	lc	0	1	16089	23:30:00		0
6066	19:38:00	le	0	1	6017	5:45:00	a	1
2073	19:58:00	oa	0	1	512	2:10:00	2014	1
16068	20:28:00	le	0	1	16017	5:30:00	a	1
16070	20:58:00	lc	0	1	76014	1:40:00		1
2877	21:10:00	oa	0	1	2812	5:55:00		1
2879	21:40:00	oa	0	1	2814	6:08:00		1
16078	22:55:00	le	0	1	16017	5:30:00	v	1
3587	23:59:00	oa	0	1	2012	5:50:00	3117	1
889	0:12:00	oa	1	1	2014	2:10:00		0
70576	0:12:00	oa	1	1	3117	5:50:00		0
16082	0:20:00	le	1	1	16019	6:00:00	v	0
16082	0:20:00	le	1	1	16019	6:00:00	a	0
3589	0:28:00	ad	1	1	8814	3:25:00	a	0
3089	0:28:00	ad	1	1	8814	3:25:00	v	0
9891	0:37:00	le	1	1	9810	3:35:00		0
3086	0:45:00	ad	1	1	3112	5:20:00		0
3084	0:45:00	oa	1	1	3015	5:20:00		0
16086	0:56:00	lc	1	1	6017	5:45:00	v	0
16086	0:56:00	lc	1	1	6021	6:40:00		0
76089	1:13:00	lc	1	1	6019	6:14:00		0
8893	1:20:00	ad	1	1	8812	3:55:00	v	0
8891	1:20:00	ad	1	1	8812	3:55:00	a	0
9893	1:28:00	le	1	1	981[illegible]	3:35:00		0

Figure 44: Amendment sheet of January with arrival and departure of trains

XIX: Rank order for alternative solutions on degree of feasibility and effectiveness

Table 20: Rank orders on alternative solutions by participants

Participants/ Order	1	2	3	4	5	6
1	6	6	1	1	6	6
2	1	4	3	6	1	3
3	3	1	6	3	3	1
4	4	3	2	4	2	2
5	2	2	5	5	4	4
6	5	5	4	2	5	5

Table 21: Recalculation of rank order for best alternative

Rank	1st	2nd	3rd	4th	5th	6th	Rank order
Alt 1	2x	2x	2x				2
Alt 2				3x	2x	1x	5
Alt 3		2x	3x	1x			3
Alt 4		1x		2x	2x	1x	4
Alt 5					2x	4x	6
Alt 6	4x	1x	1x				1

XX: Results survey on influence of multi-perspective visualization on SU

Table 22: Scores of participants on proposition in post-survey

Respondent	Q 1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Q13	Q14
1	5	5	2	5	2	2	4	2	3	5	4	1	4	4
1	7	6	6	6	5	4	6	2	2	2	2	2	4	2
3	6	6	5	6	4	5	6	2	2	2	4	3	2	1
4	6	5	6	6	6	5	7	1	1	2	2	2	2	2
5	5	5	6	6	5	5	6	2	1	2	1	3	2	3
6	6	5	5	5	6	7	6	1	2	2	2	3	3	2
Average score	5,8	5,3	5,0	5,7	4,7	4,7	5,8	1,7	1,8	2,5	2,5	2,3	2,8	2,3