Designing for Shared Situation Awareness in Rail Transport Control – Applications for Automatic Train Operations

Author

Tom Kolkman

S1997718

Supervisors

Dr. S. Borsci

Dr. F. Yildirim

University of Twente

MSc Human Factors & Engineering Psychology

In collaboration with ProRail B.V.

Dr. J. Lo

Abstract

This thesis will discuss the use of a User-Centred Design approach to design an interface for Automatic Train Operations, Grade of Automation Level 2 (ATO GoA2), for the Dutch railway traffic management system. The aim is to create an interface that integrates ATO functionalities into the current Traffic Management System whilst supporting the shared situation awareness between railway traffic controllers and rail dispatchers. The present work provides an introduction to situation awareness, shared situation awareness and the importance of these constructs within railway traffic control. A systematic literature review is performed in accordance with the PRISMA guidelines. This systematic literature is aimed at finding suitable literature which provides design guidelines for supporting (shared) situation awareness within the context of (railway) traffic control. Outcomes of the systematic literature review include the Ecological Interface Design (EID), Human Centered Design (HCD) and User Centred Design (UCD). The work continues the prototyping process with the UCD process and proceeds to create the first prototype using the user stories provided by ProRail which are part of the ongoing ATO project. These user stories guided the first iteration of the prototype, which was evaluated by means of a focus group, and further refined to create the second iteration. The present work ends by discussing the final iteration and outcomes on shared situation awareness, as well as the merits of using UCD and potential benefits of combining a UCD and EID.

Introduction

With the ever-increasing urbanization of the Western world and the population becoming denser than ever, demand for novel technologies in the transport sector is inevitable. Projections have shown that the number of kilometres travelled by passengers by train will increase by up to 45% between 2014 and 2040 in the Netherlands (Ministry of Infrastructure and Environment, 2017). However, physical rail infrastructure will not grow in a similar trend, meaning there is a need for more efficient use of the existing infrastructure. This need for more efficient use of rail infrastructure is exacerbated by the goal of a more sustainable railway industry. In order to support the goal of a more sustainable and efficient rail infrastructure, multiple solutions are currently in development. These include the European Rail Traffic Management System (ERTMS), the switch to 3 kV for railway power supplies and an improved Traffic Management System (Beheerplan ProRail 2022-2023). However, one solution currently in development at ProRail is Automatic Train Operations (ATO). For this thesis, the ATO system will be considered to run on a Grade of Automation 2 (GoA2). This entails that, while there will still be a train driver on board, the ATO system will take care of acceleration and braking, providing a speed profile that is optimal for energy efficiency, punctuality, safety and maintaining optimal distance to other trains. (Poulus, van Kempen & van Meijeren, 2018). Other tasks such as operation in case of a disruption or accident, monitoring of the environment, and closing of the doors will still need to be performed manually by onboard personnel (Lagay & Adell, 2018). Furthermore, safety functionalities such as collision prevention at stops and ATO system overrides in case of emergencies are handled by the European Traffic Control System (ETCS). ETCS is currently in development as part of ERTMS and has been defined as a prerequisite for the implementation of ATO (Poulus, van Kempen & van Meijeren, 2018, Lagay & Adell, 2018). Specific functions and responsibilities of this system, however, fall outside the scope of this paper.

Implementation of the ATO system in rail traffic control means that a range of new functionalities and information will be added to the workstations of both railway traffic controllers and rail dispatchers. To clarify: railway traffic controllers are operators who directly interact with the safety systems of a designated area (i.e., signals and switches), train drivers, and other direct stakeholders of the rail infrastructure. Rail dispatchers, on the other hand, maintain an overview of a larger area, control impactful decisions such as cancellations of trains, and communicate with operators at different levels of control, both local and national. Currently, it is yet to be determined how ATO will be integrated into the current

Traffic Management System (TMS). The design of new systems for control rooms poses the challenge of introducing new risks with potentially catastrophic consequences, especially when working with safety-critical systems such as railway TMS (Noyes, Bransby, Collis & Schmid, 2001). One notable past study has shown that 88% of accidents in commercial airlines had lapses in situation awareness as a cause of human error (Endsley, 1995).

Situation awareness (SA) has been defined as “The perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future. “(Endsley, 1988). Endsley (1988) posits that SA is comprised of three levels:

- (Level 1) The perception of critical stimuli within an individual’s environment,
- (Level 2) the comprehension of the base stimuli within these surroundings and
- (Level 3) creating a projection of future events and states of the system based on mental models the individual has.

This particular model has been selected due to a review by Stanton, Chambers and Pigott (2001), which states that the three-level model by Endsley (1988) is still the most developed when compared to other models of situation awareness.

Problems in maintaining adequate SA, such as described in the study by Endsley (1995), are not merely limited to aviation but are responsible for human error in complex systems of differing domains (Salvendy & Karwowski, 2021). Therefore, system changes need to be carefully considered, and ensuring proper SA is maintained can significantly decrease the margin for human error (Endsley, 1995; Sandom, Collis & Schmid, 2001; Endsley, Bolstad & Jones, 2003).

Despite having its origins in the aviation industry, researchers have argued that the concept of SA may also be useful for system design for supervision in land-based industries (Kaber & Endsley, 1997). This statement is based on the notion that operators pursue multiple goals simultaneously while having multiple tasks of differing importance compete for the operators' attention and that operators work under conditions that induce time stress and where they have negative consequences associated with lacking performance (Kaber & Endsley, 1997). Furthermore, a lack of SA has been argued to be a cause of poor human supervisory control due to several potential scenarios including: 1) failure to detect important cues regarding system state. 2) failure to understand task responsibilities as they are divided amongst the team and 3) failure to communicate with other operators and teams (Stanton et al, 2001).

Translating the aforementioned constructs to a team setting, they share commonalities with the contributing factors of shared situation awareness (Endsley, Bolté & Jones, 2003). Shared situation awareness has been defined as "*the degree to which team members have the same SA on shared SA requirements"* (Endsley & Jones, 1997). The contributing factors for shared SA include shared mechanisms such as mental models and processes, shared devices, displays and environments, and shared SA requirements, i.e., overlap or compatibility of information within the team (Endsley, Bolté & Jones, 2003).

In the present work in collaboration with ProRail – the Dutch government organization responsible for the maintenance and extension of the national railway network infrastructure, the allocation of rail capacity, and controlling rail traffic – we will attempt to design the ATO functionalities to optimally support (shared) situation awareness for rail traffic controllers and rail dispatchers. This includes engaging in conversations with these professionals to see what their information needs are and how these can be implemented in the existing systems whilst also supporting (shared) SA. To achieve this goal, we will benefit from the previous work done by ProRail in terms of user stories, scenarios, and requirements for the ATO interface. Interface The user stories have been prepared as part of an ongoing ATO project at ProRail and were provided utilizing an operational concept for the ATO system. User stories, at this stage, were still conceptual and required further refinement which was performed during this thesis.

An Important distinction to make is the difference between the ATO Trackside system and the ATO Onboard system. ATO Trackside will be part of the system which traffic controllers and dispatchers use to control the tracks and ensure safe and consistent execution of the train schedule. ATO Onboard will be the system which is implemented inside of the train and is responsible for driving the train following the plan that it is sent, as well as providing a feedback loop to the ATO Trackside regarding its current location, speed and delay amongst other things.

The design of the functionalities and integration into the current TMS will be based on evidence forthcoming from a systematic literature review centred around the concept of shared SA for the design of systems in (traffic) control rooms. In an attempt to integrate the ATO Trackside functionalities in the current TMS, screenshots were used from the latest simulations of the traffic control program used by ProRail. These screenshots served as the baseline from which the prototype was made. The systematic literature review has been performed following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Page et al., 2020). The PRISMA framework has been used in this paper to ensure transparency in the systematic literature review process as well as enabling reproducibility for future research.

The work was divided into three main phases. Based on the literature review (Phase 1) insights we extrapolated principles that were used to drive our first design of a mock-up ATO interface also supported by the available user stories and requirements (Phase 2), finally we evaluated qualitatively the concept of the ATO interface and produced a redesign (Phase 3).

Phase 1. Systematic Literature Review and design principles

Search strategy

Scopus and Web of Science databases were used to retrieve journal and conference articles published in the last 13 years (2010-2023) concerning SA and rail traffic control. A complete list of the keywords used for the review can be found in Appendix A.

Inclusion criteria were listed as follows:

- The article provides principles for interface design in order to support shared situation awareness or situation awareness.
- The article provides insights into interface design for railway management or traffic management.
- Published in 2010 or later.
- Written in English or Dutch
- Articles and Conference papers

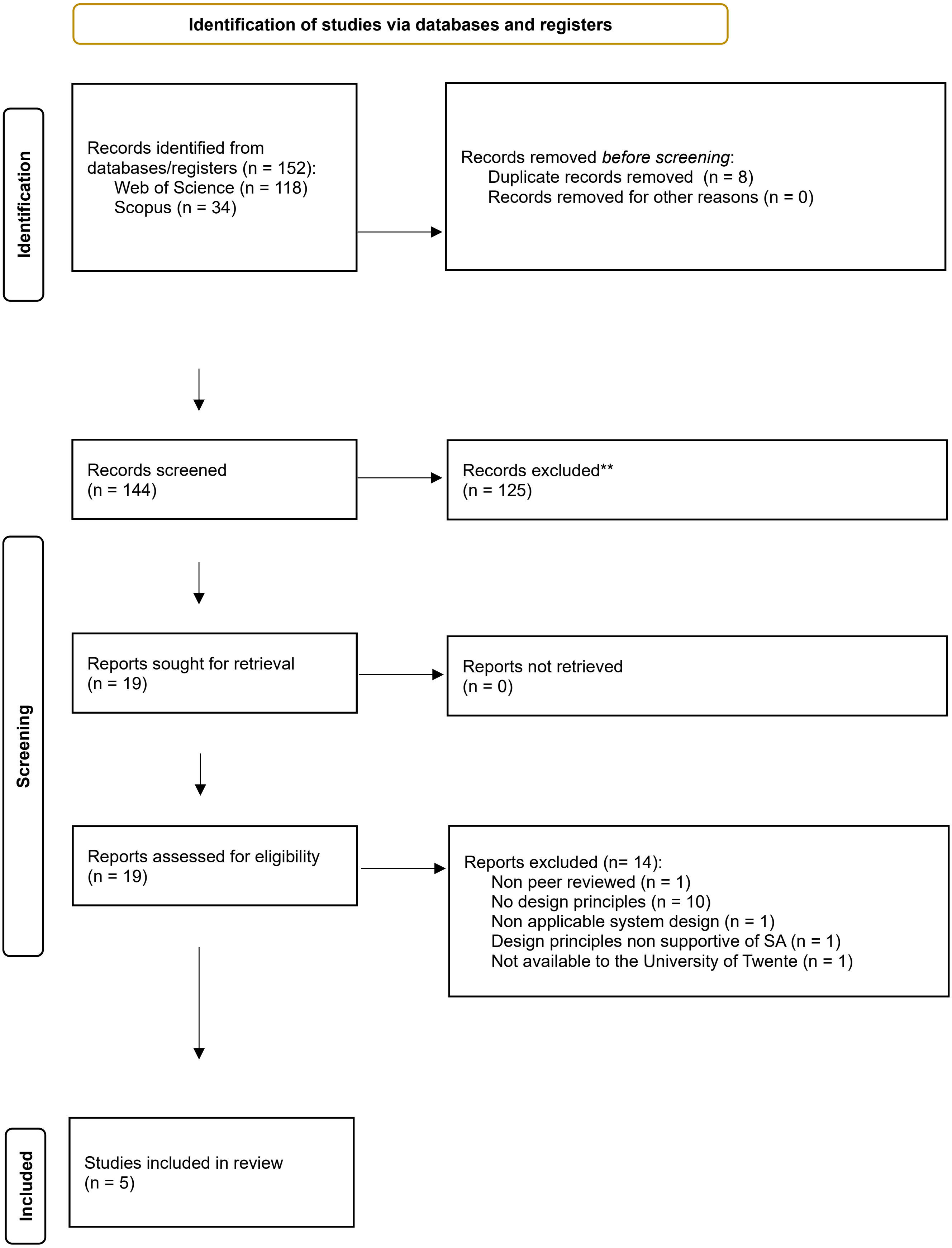
Exclusion criteria were listed as follows:

- The article does not provide principles for design in order to support shared situation awareness or situation awareness.
- System design is not applicable to the context.
- Non-peer reviewed
- Not available through the University of Twente

Initially, using the search terms provided in Appendix A, studies of potential interest were sought. These studies were first screened for duplicates, after which each study was assessed by its title and abstract using the aforementioned inclusion and exclusion criteria. During this process, a total of 125 studies were excluded. Consequently, the 19 remaining studies were assessed by means of a full-text review. Finally, a full-text review yielded a total of 5 studies that were included in this systematic literature review (Figure 1; Table 1).

Figure 1

PRISMA Flowchart



Note. The number of studies identified using search terms (Appendix A), screened, sought for retrieval and ultimately included.

The qualitative analysis of the items included in the review provided the following results. Two articles, namely by Ellerbroek, Visser, van Dam, Mulder and van Paassen (2011) and Ibrahim, Higgins and Bruce (2014) suggested that to support operators' shared SA it is necessary to adopt the Ecological Interface Design (EID) process. Both papers applied the EID process for traffic controllers working in aviation, elaborating on how to utilize the EID in that setting which can provide examples on how to make use of EID in railway traffic control.

Furthermore, Kearney, Wen-Chin and Lin (2016) and Kearney, Li, Yu and Braithwaite (2019) investigated different modalities of alarms for aviation control room operators. Their research supports the use of semantic alarms over acoustic alarms, including measures of SA of the operators. This research provides insight into the modalities that are to be used when designing for situation awareness support in a control room setting.

Finally, the study by van Doorn, Horváth and Rusák (2021) investigated the effects of different types of interfaces, created using the User-Centred Design (UCD) approach, on SA. These interfaces were divided into three categories based on the colour schemes, features implemented and level of automated support.

Results systematic literature review

The Ecological Interface Design (EID) as employed by Ellerbroek et al. (2011) provides an interesting perspective, as it focuses on visualizing possibilities and constraints within a given situation for operators. This visualization of possibilities and constraints is done by creating an abstraction hierarchy of the tasks in question, which forms the foundation of the EID. Within this design principle lies an emphasis on the cognitive interaction between operators, the system, and the environment in which they operate. Aimed at supporting SA by visualizing constraints and potential solutions, rather than providing direct resolutions to a conflict, EID exploits the use of level 1 SA, the perception of critical stimuli, and level 2 SA, the understanding of critical stimuli (Ibrahim et al., 2014). Similarly, Ibrahim et al. (2014) employed the EID process to develop a collision avoidance display for mental workload and SA support. Both studies reported positive influences of the EID process on the final product concerning the support of SA for aviation control operators. main merits of an EID lie with the abstraction hierarchy which it requires. An abstraction hierarchy, in the current setting, is composed of all physical affordances available to operators and the associated purposes of these affordances. This includes functional purpose, abstract functions, generalized functions, physical functions and physical forms (Lau et al., 2008). Access to the information provided by an abstraction hierarchy allows for an in-depth analysis of the tasks performed by operators and the critical affordances required to perform these tasks.

Other insights concerning alert systems were provided by Kearney, Wen-Chin and Lin (2016) and Kearney, Li, Yu and Braithwaite (2019). Both these studies used a Human-Centred Design (HCD) approach, directly involving their end-users in the design process and assessment of iterations. In their investigations, the influence of semantic versus acoustic alarm modalities was tested regarding situation awareness, conflict detection and conflict resolution. They posited that the use of the same acoustic alarm, a simple beeping noise, for different alerts had the potential to induce a misjudgement of the situation or a complete disregard of the alert altogether. Both studies concluded that, despite the effectiveness of acoustic alarms in gaining an operator's attention, the intrusiveness of acoustic alarms creates unwanted effects such as distraction from the current task and potentially startling the operator. Therefore, semantic alarms are more desirable as they more effectively focus the attention of the operator toward the task, as well as eliminate unwanted effects. These findings are also concurrent with the current interface design of systems for railway controllers and dispatchers at ProRail, whose only acoustic alarm is used for a dedicated phone when documented communication is necessary with personnel in- or outside of the control centre.

Finally, a study conducted by van Doorn, Horváth and Rusák (2021) investigated the effects of different interface designs for implementing new functionalities in an existing system. The interface designs in this study were categorized as coherent, integrated and context-dependent adaptable user interfaces. To briefly summarize these different interfaces: a coherent UI implemented the same use of colours, buttons, and menu structures as well as interactions such as double-clicking in the new functionalities as they were used in the original system. The integrated UI implemented extra colours, highlighting functionalities, a more elaborate information display as well as new interactions with the aim of improving quality of life within the system. Finally, the context-dependent adaptable UI was based on the integrated UI with an additional three extra features: it was able to show relevant locations in an extra area of the focus map, it automatically showed available alternative routes in case of obstructions and it showed traffic prognoses when a traffic intensity limit was exceeded. Results from this study by van Doorn et al. (2021) showed that the automated support, such as showing available alternative routes in case of obstruction, provided by the context-dependent adaptable UI increased the accuracy of answers provided by operators concerning questions relating to Level 3 SA, the prediction of future states of the system. The careful selection of automated features was paramount in this study, and could only be achieved through a thorough understanding of the work field in combination with close collaboration with expert personnel, in line with UCD (ChaiOne, n.d.). Whilst the features did not necessarily provide very rich information, they stimulated pro-active behaviour such as seeking early contact with operators to assess a situation and showed significant positive effects for time on task and speed of communication. These findings suggest that automated task support, implemented in the form of simple features, can significantly improve operator performance. This was seen in both task and communication efficiency, as well as the effective support of level 3 situation awareness by providing potential courses of action and outcomes. Due to the favourable findings of van Doorn et al. (2021) and the time constraints which did not allow for the creation of an abstraction hierarchy, the UCD approach was followed for this thesis and will be used in Phase 2 to guide the design process.

Table 1

Summary of the literature research findings including article author, article title and identified design principle

Author	Article Title	Design Principle
Ellerbroek, Visser, van Dam, Mulder & van Paassen (2011)	Design of an airborne three-dimensional separation assistance display	Ecological Interface Design
Ibrahim, Higgins & Bruce (2014)	Evaluation of a collision avoidance display to support pilots' mental workload in a free flight environment	Ecological Interface Design
Kearney, Wen-Chin & Lin (2016)	The impact of alerting design on air traffic controllers’ response to conflict detection and resolution	Human-Centred Design
Kearney, Li, Yu & Braithwaite (2019)	The impact of alerting designs on air traffic controller’s eye	Human-Centred Design

	movement patterns and situation awareness	
Van Doorn, Horváth & Rusák (2021)	Effects of coherent, integrated, and context-dependent adaptable user interfaces on operators' situation awareness, performance, and workload	Coherent, Integrated and Context-Dependent Interface Design (based on User-Centred Design)

Phase 2. The requirements to design a GUI which supports (shared) situation awareness

P2. Goals

To attain the goal of designing a user interface which supports (shared) situation awareness, the first iteration focussed primarily on gaining a deeper understanding of the tasks that accompany the first implementation of the ATO system for traffic controllers. The second iteration focussed more on practical feedback from traffic controllers and rail dispatchers and their direct wishes which came from a more elaborate explanation of ATO and what changes ATO implementation would make in their tasks. These wishes, accompanied by a deeper understanding of the tasks performed and what stimuli traffic controllers and rail dispatchers used for their situation awareness, formed the foundation for the second iteration.

P2. Materials

The primary component guiding the design was the user stories provided by ProRail, which are part of the ongoing internal ATO project. These user stories went through multiple reviews with operational experts, traffic controllers, traffic dispatchers as well as other parties involved in the ATO project. Enterprise Architect was used to organize all user stories and order them in terms of functionalities. In order to create the prototype, screenshots of the simulated TMS were used which were edited using Pixlr (Appendix C). The screens, including the new ATO functionalities, were then imported into Figma to create a low level of interactivity to give stakeholders an overview of the final product.

P2. Theoretical approach

This thesis has based its design process on the User-Centred Design approach based on the favourable findings of van Doorn et al. (2021) using this method in a traffic control setting. The UCD approach consists of the following key phases:

1. Research phase: During this phase, an explicit understanding of the users, their tasks and their environment is consolidated. This is done through interviews and contextual inquiry.
2. Concept phase: The concept phase consists of ideating low-fidelity prototypes and mock-ups used to get feedback from the users. The main aim of this phase is to understand the target users' needs better and refine the system requirements for later phases.
3. Design phase: Here, the design evolves to more complex prototypes used to refine the users' needs and wishes. The designs created in this phase can also be used to evaluate how well the users' needs and project scope are being met.
4. Development phase: Following the consolidation of designs in the design phase, the next step involves the implementation of a well-researched solution. During the development phase, data is acquired to assess the effectiveness of a design in meeting user needs by means of usability testing. Findings of the development phase can potentially be used to create further iterations and make adjustments.
5. Launch phase: Finally, the product is fully implemented for the target group and is no longer considered a prototype. One important note is that the design process does not halt at the launch phase. Further improvements can still be made based on the feedback of the users.

The present work mainly focuses on the Research and Concept phases of the UCD process (ChaiOne, n.d.; Chammas, Quaresma, & Mont'Alvão, 2015).

P2. Composition of Initial Requirements for the design

Design of the first iteration started with the assessment of the user stories which were provided by ProRail in their operational concept for ATO GoA2. User stories for ATO Trackside were formulated as personal wishes by railway traffic controllers and dispatchers. After the selection of the relevant user stories for the scope of this thesis, they were translated into functional requirements. The user stories have been translated into functional requirements by paraphrasing the user stories from a personal wish of traffic controllers and dispatchers to an objective functionality within the system. An example of this would be "As traffic controller and as a dispatcher, I want to be able to see which trains currently run on the ATO system and which routes support ERTMS and ATO" which was translated to "The system needs to indicate which trains support ATO and which routes support ERTMS and ATO". The functional requirements in turn have been combined into functionality groups which fit in the current Traffic Management System by grouping them based on categories such as “ATO/ERTMS Information”, “Travel Speed and Location” and “Traffic Control”. To maintain traceability, all user stories and system requirements were organised using Enterprise Architect (Appendix B).

The aforementioned functionality groups, i.e. ATO/ERTMS Information, were discussed with the personnel whom developed the operational concept to produce the initial set of requirements for the design. For the purpose of scoping, all functionalities which were not set for implementation in the 1st or 2nd stage of ATO deployment were saved for future developments. Furthermore, all backend functionalities such as automatic conflict detection and resolution for the execution of the traffic plan were also deemed outside the scope of this thesis.

Based on the requirements we defined out of the user stories, the operational concept and relevant user stories were refined once more in collaboration with stakeholders of the ATO project consisting of system design experts, train drivers, incident response forces, traffic controllers and operational experts in the field of traffic control (Table 1). Ultimately, this led to the production of the first iteration of the prototype for the traffic controllers only, as they formed the priority group within the ATO project for ProRail (Appendix C). One example of an implemented feature here was based on the user story “As traffic controller and as a dispatcher, I want to be able to see which trains currently run on the ATO system and which routes support ERTMS and ATO”. This feature was implemented in the system as seen in Appendix C by means of a highlight feature which would change the colour of the tracks that supported ERTMS and trains that supported ATO. Once completed, expert personnel was asked to review the implemented functionalities for relevance, usability and presentation, which provided information for the second iteration.

Phase 3. Evaluation of the GUI

P3. Methods

For the evaluation of the first iteration of the prototype, a focus group consisting of 3 operational experts, a railway traffic controller and a rail dispatcher was used. During the focus group, participants were provided with the individual user stories and the prototype in which these user stories were implemented (Table 2, Appendix C). Each functionality was then evaluated on basis of necessity and usability by means of conversation. This eventually led to a brainstorming session, in which the most important outtakes are displayed in Table 2.

Following the focus group outcomes, the functionalities implemented in the initial design were either removed, altered, or maintained as is.

P3. Participants

Participants in this phase consisted of three operational experts, a railway dispatcher and a railway traffic controller. Professional experience in the field of traffic control were in the range of 4-30 years ($M = 14.6$, $SD = 11.08$). The sample consisted of 40% females and 60% males ($N = 5$).

P3. Evaluation

The first iteration designed by the main researcher of the present work was qualitatively assessed by a focus group of 5 persons consisting of operational experts, a railway traffic controller and a rail dispatcher. Comments given by the focus group indicated that one particular functionality was redundant, as it arose from a misunderstanding within the initial user stories (Table 2). This was therefore removed entirely in the second iteration. Furthermore, it appeared that in the case of rail dispatchers, certain pieces of information, as provided by ATO, were already present in their systems. Outcomes of the focus group indicated that for railway traffic controllers, they only wished to see certain types of information which related to connectivity to a train. Other information, such as the braking capacity or faulty states of the ATO Onboard system was undesirable. This seemed to be primarily due to both traffic controllers and rail dispatchers wanting to keep their situation awareness focused on the aspects of traffic control which they can directly influence. Therefore, information that was related to matters outside of their control was deemed undesirable as it would unnecessarily increase workload. This led to, once again, further refinement of the system requirements as there appeared to still be some lacking insights regarding what was truly necessary for traffic controllers and dispatchers to perform their tasks with the implementation of ATO, and what operational changes the implementation of ATO would entail.

Table 2

Focus group feedback on functionalities implemented in the 1st iteration

Functionality/User Story	Comments	Rate of agreement	Outcome

F1: Overview of faulty states of ATO OnBoard systems	P3: "If I'm not mistaken, as a traffic controller, you can't really do anything with it if you know whether a train is, say ATO Engaged, or ready, or any other state, right?" P1: "As far as I know, no. In my understanding, I set the path for the train, same as I normally would but when it comes to driving the train, it doesn't make too much difference in that sense whether it is driving on ATO or driven by a train driver."	100%	Functionality was removed
F2: ATO connectivity status indicator, both in text and on track visualization	P1: "Seems useful, but we generally work using a "no news is good news" kind of way. So I don't want to know whether something is sending. I just want to see whether it's connected, or not. That way I know if I have to act or not."	100%	Functionality remained but with minor changes to only show whether ATO Trackside and ATO Onboard are communicating properly or not
F3: Highlighting of ATO capable trains and ERTMS tracks through a button	P4: "…… ATO trains will be visible if they are driving using ATO, otherwise it's not relevant to know anyway, since it's either being driven by ATO or manually by the train driver	100%	Functionality was removed

	so there's no need to highlight it any extra." P5: "ERTMS tracks already appear different on the traffic controllers' screens, so highlighting seems redundant." P1: "I would still like to be able to see if a train is driving using ATO, because that should still have an impact on the delays. Maybe that the plan also calculates this in my overview, so with what delay it expects to arrive at a stop?" P2: "Yes, that's something I would like to see too, because right now it just takes a measured delay at a certain point, and just throws that over the entire plan as if nothing is going to change, when usually, it is [going to change]".		
US1: As a traffic controller and rail dispatcher, I want to be able to update a train's	P1: "Adding a separate function to update Journey Profiles outside of the current plan would	100%	Moved to back-end. The updates of Journey Profiles will be done through a

Journey Profile if needed	complicate things unnecessarily" P2: "Agreed, especially if we're going to be working with both ATO and non-ATO trains. If we have to learn two different working methods for the different trains, that would only make things more difficult."		translation of the current planning system to the ATO system to prevent an unnecessary increase in workload
US2: As traffic controller I want to see if a train had a stop which failed on a positional level	P3: "This would mean that there is either an issue, such as a severe disturbance or the ATO system has disengaged for a different reason. In either case, the ATO system would be disengaged, the train would be manually driven and the train driver would be contacted." P1: "If the ATO system is disengaged anyway, and the stop isn't in any irregular place. It's not just sitting in the middle of nowhere but just overshot its goal at the station by half a meter, it doesn't matter much. And if it's somewhere it shouldn't	100%	As far as the current understanding goes, this user story goes outside of the scope of the ATO system as it disengages in both potential scenarios.

		be, I would just handle it according to my protocol."

Note. F = Functionality, US = User Story. Functionalities had already been implemented in the presented prototype, whereas User Stories required further clarification from expert personnel P1 = Traffic controller, P2 = Rail dispatcher, P3, P4, P5 = Operational experts.
All decisions were made unanimously.

P3. Evaluation outcomes

Due to the scope of the thesis and the functionalities set for implementation in the initial phases of the ATO project, traffic controllers' and rail dispatchers' needs appeared to be met by the following functions. Namely, both groups wished to be able to see when and if a train was being driven using the ATO system, primarily because the ATO system provides dynamic feedback on the estimated arrival time for the following stops (Table 2). It is assumed that the ATO system drives a train more efficiently and consistently than a human driver can by constantly calculating the maximum speed it can maintain (within the current restraints) to arrive at its stops in a timely fashion. Furthermore, traffic controllers would like to see certain train characteristics fed back to the ATO Trackside system by the ATO Onboard system. These include if the train has explicitly not received updates that were sent by traffic controllers, such as changes in the plan, the weight and speed of the train, and its current driving mode. In this context, the driving mode could be ATO driven or manually driven.

It was also uncovered that a number of system requirements which, at face value, appeared to involve the front-end of the application were better implemented as a back-end feature. These requirements were primarily related to communications between the ATO Trackside and ATO Onboard systems. This is due to the fact that the ATO systems communicate through information packages called "Journey Profiles", which are constructed differently than the current plan used by traffic controllers and dispatchers. It was deemed an unnecessary increase in workload to make personnel manually update these Journey Profiles. Therefore, a functionality for the back-end of the system was conceptualized which would translate the elements that compose a Journey Profile into the plan as it is currently used by traffic controllers and dispatchers.

Moreover, a user story relating to an ATO train missing stops was clarified where, in the scenario that an ATO train would greatly miss a stop. In this case, it was decided that the ATO system should disengage and driving should be continued manually by the train driver. This would also show up on the displays of the traffic controller, but due to the nature of the incident, this would not have any operational differences compared to the current situation.

Finally, the feedback provided by the traffic controller, dispatcher and operational experts was implemented in a second iteration of the system which is currently ready for evaluation. Changes from the first iteration included several cuts in the information presented to traffic controllers and the dismissal of functionality that would highlight trains currently driving under ATO and tracks which operated using ERTMS (Table 2). After deliberation, all decisions made and changes that were suggested were agreed upon unanimously. These decisions resulted in the second iteration of the prototype for railway traffic controllers and the initial prototype for railway dispatchers (Appendix D, Appendix E)

Overall Discussion

The initial literature review has shown that whilst each design approach (UCD, HCD and EID) holds its individual merits, the present work benefitted the most from the UCD. Implementation of the UCD approach for shared situation awareness has provided several interesting insights. Firstly, it appears that the main components which construe the shared situation awareness between traffic controllers and dispatchers are the shared SA requirements, i.e., overlapping and compatible information, and the shared mental models with regard to perceiving, interpreting and acting upon traffic delays and disturbances (Endsley et al., 2003). An important shared mental model that both traffic controllers and dispatchers mentioned during interviews is how they extrapolate and make assumptions about delays based on the information that the current system provides. Whereas currently both groups will pre-emptively anticipate what the delay of a train will be for the upcoming stops based on experience, implementation of the ATO system will eliminate any potential discrepancies between these assumptions as it dynamically calculates the delays for upcoming stops and feeds this back to both traffic controllers and dispatchers. This overlap in information, or shared SA requirements, ensures that actions will be undertaken consistently and reduces the margin for human error (Endsley, 1995). Furthermore, both groups will be informed which trains are ATO driven so they can adjust their expectations accordingly. Shared situation awareness is further supported by providing traffic controllers and dispatchers access to train-specific information such as a more exact location (contrary to the schematic representation currently used), current speed of the train and other characteristics such as whether it transports passengers or cargo. These shared SA requirements can be used to assess the priority in which trains may be contacted in case of a disturbance or emergency where an area-wide halt of traffic is not condoned or necessary, further facilitating shared situation awareness between railway traffic controllers and railway dispatchers (Endsley et al., 2003).

The second iteration generated during the design process facilitates all of the above-mentioned possibilities for improvements. The deliberations of traffic controllers and rail dispatchers have also been taken into account to minimize the amount of increased workload. This was mostly achieved by maintaining the same structure for information presentation and, with regard to new information, staying consistent with stimuli that they currently use for their mental models. The use of already used (shared) mental models and integrating automated features such as the dynamic adaptation of delays is also in line with the context-dependent interface design as seen in van Doorn et al. (2021). It is assumed that, whilst dispatchers have already had access to parts of this information before, traffic controllers will experience a small learning curve when adjusting their actions based on this information, it will ultimately be beneficial to the safety of railway traffic. More extensive testing is, however, still necessary to confirm this assumption.

Conclusion

The UCD can provide important insights when designing for shared situation awareness. The consistent involvement of users throughout the process by means of interviews, iterative designs and evaluation of the impact of changes ensures that mental models currently in place are used or built upon without hindering situation awareness. It is important to mention that the use of EID may hold similar merits as it builds upon an abstraction hierarchy which can consolidate both physical and mental affordances for traffic control.

The present work suggests that UCD could be a good compromise when the time constraints do not allow for the extensive process of creating and testing an abstraction hierarchy. Ideally, a combination of the EID and UCD would be employed in future works. This would allow for a critical assessment of the safety implications of implementing new features into a traffic management system. Furthermore, the use of abstraction hierarchies when creating requirements for safety-critical complex socio-technical systems has already been used effectively to support situation awareness (Hwang & Yoon, 2020)

The present work highlights the potential benefits of using a UCD approach for safety-critical environments such as land-based traffic rooms. The merits of the UCD include the ability to rapidly create new iterations with the involvement of users, potentially catching mistakes in the design at an early stage and being able to resolve these with the feedback of users and operational experts. However, as previously mentioned, the potential value of using

EID should not be disregarded, as the abstraction hierarchy which is necessary for the EID process can provide in-depth knowledge of the system and interactions between individual users and the system itself.

Limitations

In its current state, the prototype we developed implemented the most important facets required for the first deployments of ATO. Both traffic controllers and rail dispatchers have access to their shared SA requirements such as overlap in knowledge and interface with regards to what trains are currently operating using ATO, and consistent updates regarding the delays of ATO trains. The shared SA requirements also further facilitate the shared SA mental models traffic controllers and rail dispatchers have with regards to conflict resolution and adjusting schedules in the event of delays. Furthermore, the information presentation remained consistent with their current systems and was minimally changed to accommodate ATO functionalities and the increase in information that accompanied ATO. It is assumed that the consistency between stimuli will minimize the disruptions caused in Level 1 SA (perception), which in turn should support Level 2 and Level 3 SA. This assumption, however, requires further testing and evaluation with experts.

Due to the time-consuming process of refining the operational concept and user stories, many changes were made in the starting phases of the design process. Constant adaptations to the user stories led to the system requirements also evolving over time. This caused the eventual interface design to take longer than initially expected, leading to only two iterations being created. Further interviews regarding the second iteration will be needed to assess whether user needs are being met and what future adjustments need to be made. Ultimately, the ATO GoA2 system is still in its infancy. This means that the operational concept is still being refined and system requirements will most likely change as well, either as part of the private project held by ProRail, or as subject of the Europe's Rail project.

As previously mentioned, this thesis focussed its design process primarily on the Research and Concept phase of the UCD process. Future research into a shared SA supporting UI for ATO GoA2 may use this thesis as a foundation for continuation in the Concept phase. However, as previously mentioned, the support that Ecological Interface Design may provide should not be neglected. An important future step may be to create an abstraction hierarchy of railway traffic control as a means of mapping out the domain and creating a foundation for future research in, for example, the impact of changes in user interfaces on operator workload.

References

5 stages of user-centered design thinking. ChaiOne. (n.d.). https://www.chaione.com/blog/5-stages-user-centric-design-thinking

Beheerplan ProRail 2022-2023. Platform open overheidsinformatie. (n.d.). Retrieved April 28, 2023, from https://open.overheid.nl/Details/ronl-492428f4-47dd-4d7e-9bc4-55ab44d70db5/1?hit=14&count=50&organisatie=mnre1130&text=2023

Chammas, A., Quaresma, M., & Mont'Alvão, C. (2015). A closer look on the user centred design. *Procedia Manufacturing*, *3*, 5397–5404. https://doi.org/10.1016/j.promfg.2015.07.656

Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., Shamseer, L., Tetzlaff, J. M., Akl, E. A., Brennan, S. E., Chou, R., Glanville, J., Grimshaw, J. M., Hróbjartsson, A., Lalu, M. M., Li, T., Loder, E. W., Mayo-Wilson, E., McDonald, S., … Moher, D. (2021). The prisma 2020 statement: an updated guideline for reporting systematic reviews. *Journal of Clinical Epidemiology*, *134*, 178–189. https://doi.org/10.1016/j.jclinepi.2021.03.001

Cooke, N. J., Gorman, J. C., Myers, C. W., & Duran, J. L. (2013). Interactive Team Cognition. *Cognitive Science*, 37(2), 255-285.

van Doorn, E., Horváth, I., & Rusák, Z. (2021). Effects of coherent, integrated, and context-dependent adaptable user interfaces on operators' situation awareness, performance, and workload. *Cognition, Technology & Work, 23*(3), 403-418. doi:10.1007/s10111-020-00642-z

Ellerbroek, J., Visser, M., Dam, S., Mulder, M., & Van Paassen, M. M. (2011). Design of an Airborne Three-Dimensional Separation Assistance Display. *IEEE Transactions on Systems Man and Cybernetics - Part A Systems and Humans, 41*, 863-875. doi:10.1109/TSMCA.2010.2093890

Endsley, M. R. (1988). Design and Evaluation for Situation Awareness Enhancement. *32*(2), 97-101. Doi:10.1177/154193128803200221

Endsley, M.R. (1995). A taxonomy of situation awareness errors. In R. Fuller, N. Johnston, & N. McDonald (Eds.) *Human factors in aviation operations* (pp. 287-292). Aldershot: Avebury Aviation, Ashgate.

Endsley, M. R., Bolté, B. & Jones, D. G. (2003). *Designing for Situation Awareness*. New York, NY: Taylor & Francis Group

Endsley, M. R., Bolstad, C. A., Jones, D. G., & Riley, J. M. (2003). Situation Awareness Oriented Design: From User's Cognitive Requirements to Creating Effective Supporting Technologies. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 47*(3), 268-272. Doi:10.1177/154193120304700304

Endsley, M. R. & Jones, W. M. (1997). *Situation Awareness, Information Dominance, and Information Warfare*. United States Air Force Armstrong Laboratory Technical Report 97-01.

Hwang, G. H., & Yoon, W. C. (2020). A new approach to requirement development for a common operational picture to support distributed situation awareness. *Safety Science, 125*. doi:10.1016/j.ssci.2019.104569

Ibrahim, Y., Higgins, P., & Bruce, P. (2014). *Evaluation of a collision avoidance display to support pilots' mental workload in a free flight environment.* Paper presented at the IEEE International Conference on Industrial Engineering and Engineering Management.

Kaber, D. B., & Endsley, M. R. (1997). Out-of-the-loop performance problems and the use of intermediate levels of automation for improved control system functioning and safety. *16*(3), 126-131. Doi:https://doi.org/10.1002/prs.680160304

Kearney, P., Li, W.-C., & Lin, J. J. H. (2016). The impact of alerting design on air traffic controllers' response to conflict detection and resolution. *International Journal of Industrial Ergonomics, 56*, 51-58. doi:10.1016/j.ergon.2016.09.002

Kearney, P., Li, W.-C., Yu, C.-S., & Braithwaite, G. (2019). The impact of alerting designs on air traffic controller's eye movement patterns and situation awareness. *Ergonomics, 62*(2), 305-318. doi:10.1080/00140139.2018.1493151

Poulus, R., van Kempen, E., & van Meijeren, J. (2018, July). *Prorail*. Retrieved March 28, 2023, from https://www.prorail.nl/siteassets/homepage/nieuws/documenten/18-0057-tno-white-paper-prorail-4.pdf

Ministery of Infrastructure and the Enivornment. (2017). Nationale Markt – en Capaciteitsanalyse 2017.

Noyes, J., Bransby, M., Collis, L., & Schmid, F. (2001). In *People in control: Human factors in control room design* (pp. 273–275). Essay, Institution of Electrical Engineers.

Salvendy, G., & Karwowski, W. (2021). Handbook of human factors and ergonomics (Fifth). Wiley. https://doi.org/10.1002/9781119636113

Lagay, R., & Adell, G. M. (2018, 15-17 Oct. 2018). *The Autonomous Train: a game changer for the railways industry.* Paper presented at the 2018 16th International Conference on Intelligent Transportation Systems Telecommunications (ITST).

Lau, N., Veland, Ø., Kwok, J., Jamieson, G., Burns, C., Braseth, A., & Welch, R. (2008). Ecological Interface Design in the Nuclear Domain: An Application to the Secondary Subsystems of a Boiling Water Reactor Plant Simulator. *IEEE Transactions on Nuclear Science, 55*. doi:10.1109/TNS.2008.2005979

Sandom, C., Collis, L., & Schmid, F. (2001). In *People in control: Human factors in control room design* (pp. 51-67). Essay, Institution of Electrical Engineers.

Stanton, N. A., Chambers, P. R. G., & Piggott, J. (2001). Situational awareness and safety. *Safety Science, 39*(3), 189-204. Doi:10.1016/S0925-7535(01)00010-8

Stanton, N. A., Stewart, R., Harris, D., Houghton, R. J., Baber, C., McMaster, R., Salmon, P. Hoyle, G, Walker, G. Young, M. S., Linsell, M, Dymott, R., & Green, D. (2006). Distributed situation awareness in dynamic systems: theoretical development and application of an ergonomics methodology. Ergonomics, 49(12-13), 1288-1311.

Appendix

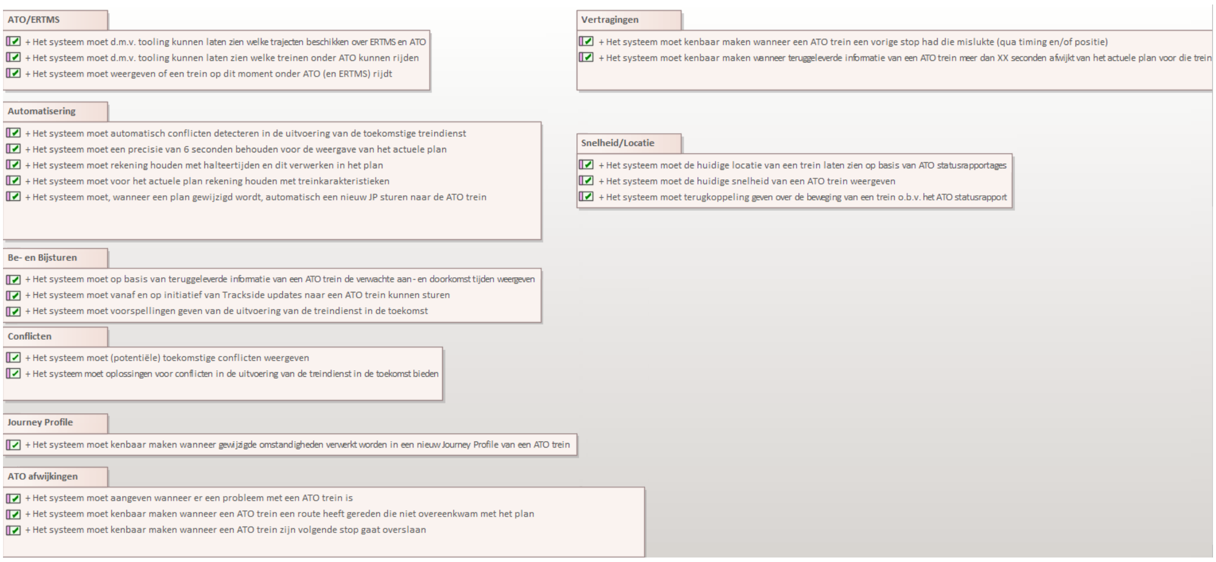
Appendix A – Search terms individually and as used with Boolean operators

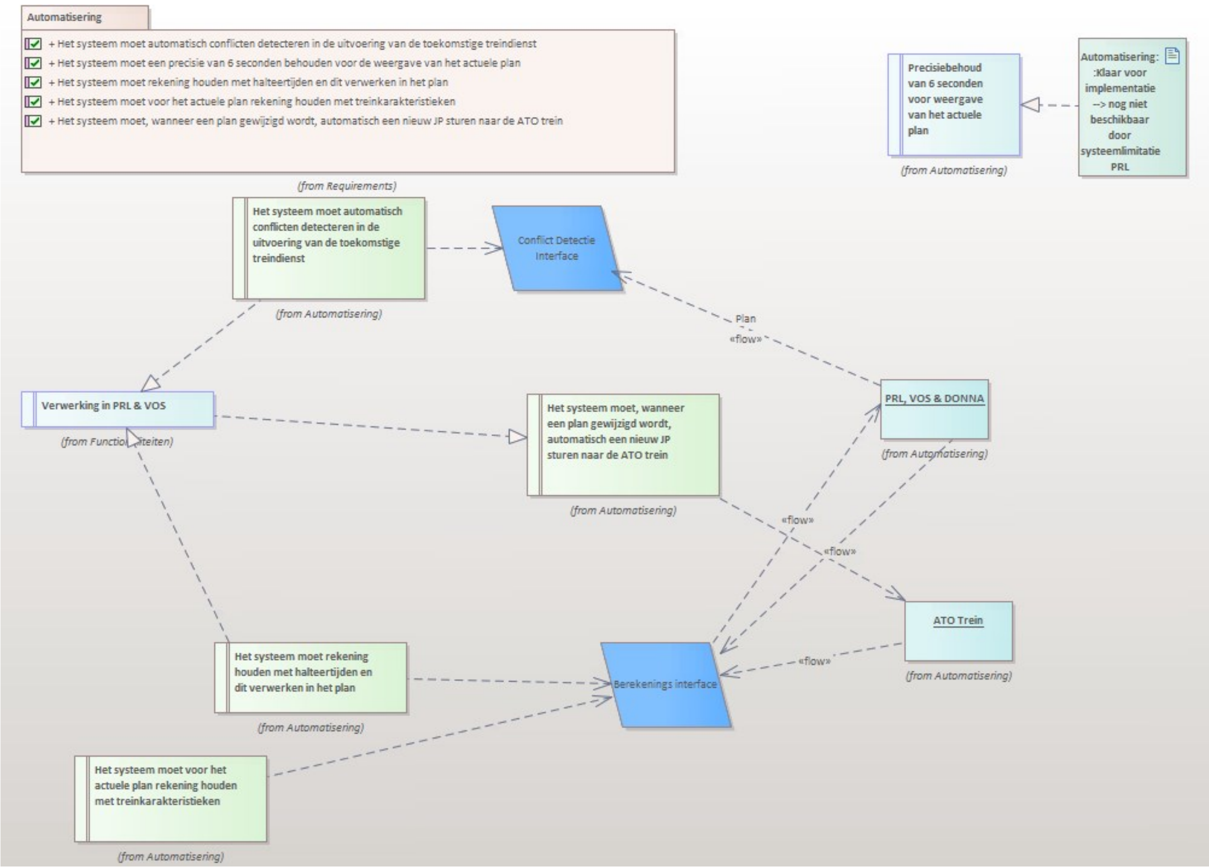
- Situation awareness
- SA
- Shared situation awareness
- Shared SA
- Distributed situation awareness
- Distributed SA
- Shared cognition
- Distributed decision making
- Rail traffic control
- Railway traffic control
- Train traffic control
- Traffic control
- Train control automation
- Train control system
- Train dispatching

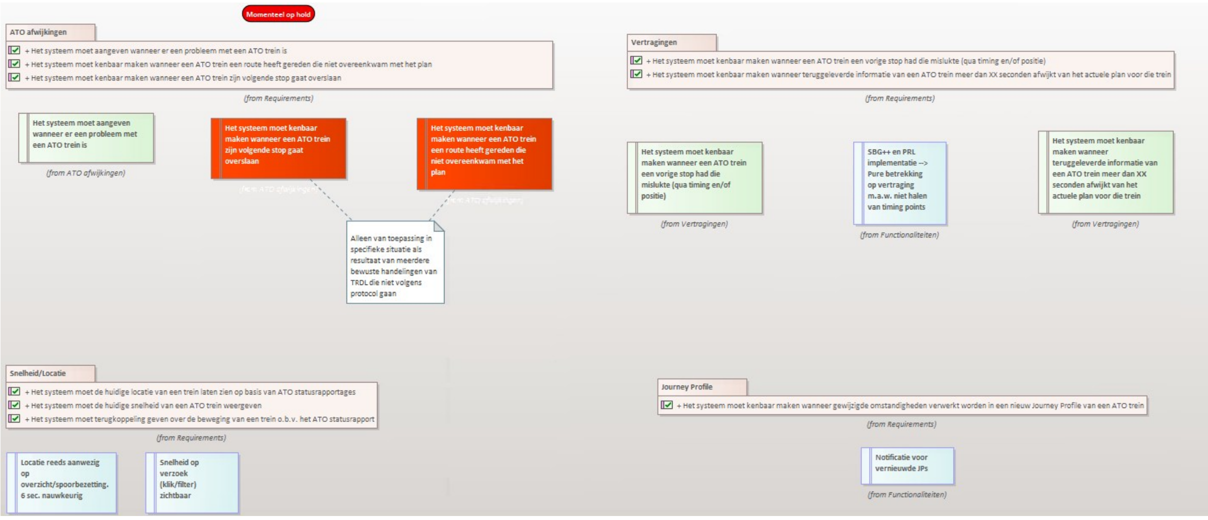
- Traffic management system
- TMS
- Mental workload
- Rail transport sector
- Railway industry
- Automatic train operation
- ATO
- GoA2
- Design

- ("shared situation awareness" OR "shared SA" OR “distributed situation awareness” OR “distributed SA” OR “shared cognition” OR “distributed decision making”) AND ("rail traffic control" OR "railway traffic control" OR "train traffic control" OR “traffic control”) AND (“design”)
- ("train control automation" OR "train control system" OR "train dispatching" OR “traffic management system” OR “TMS”) AND ("situation awareness" OR "SA" OR "mental workload" OR “shared situation awareness” OR “shared cognition” OR “distributed decision making”) AND (“design”)
- ("rail transport sector" OR "railway industry") AND ("shared situation awareness" OR "SA" OR "mental workload" OR “situation awareness” OR “shared cognition” OR “distributed decision making” OR “team cognition”) AND (“design”)
- ("automatic train operation" OR "ATO" OR "GoA2") AND ("rail traffic control" OR "railway traffic control" OR "train traffic control") AND (“design”)

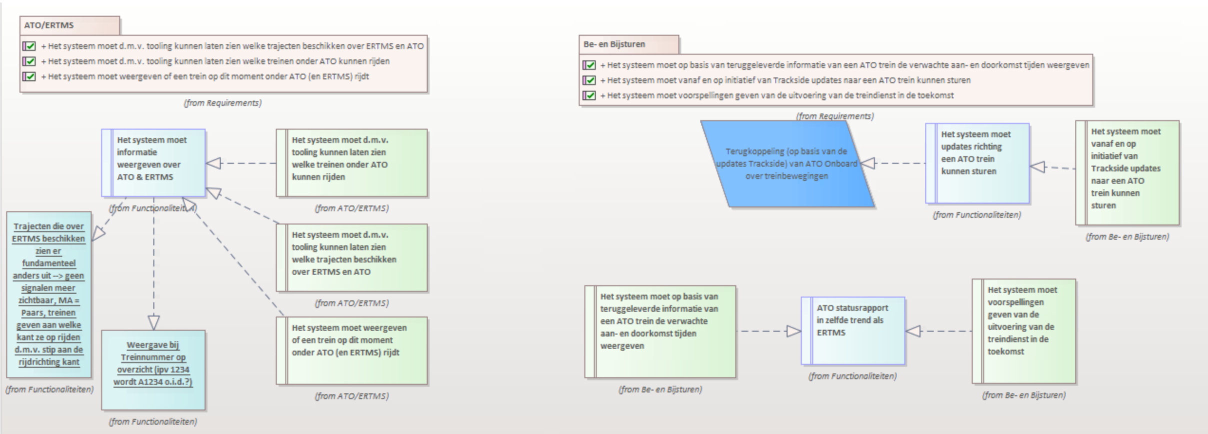
Appendix B – Enterprise Architect material





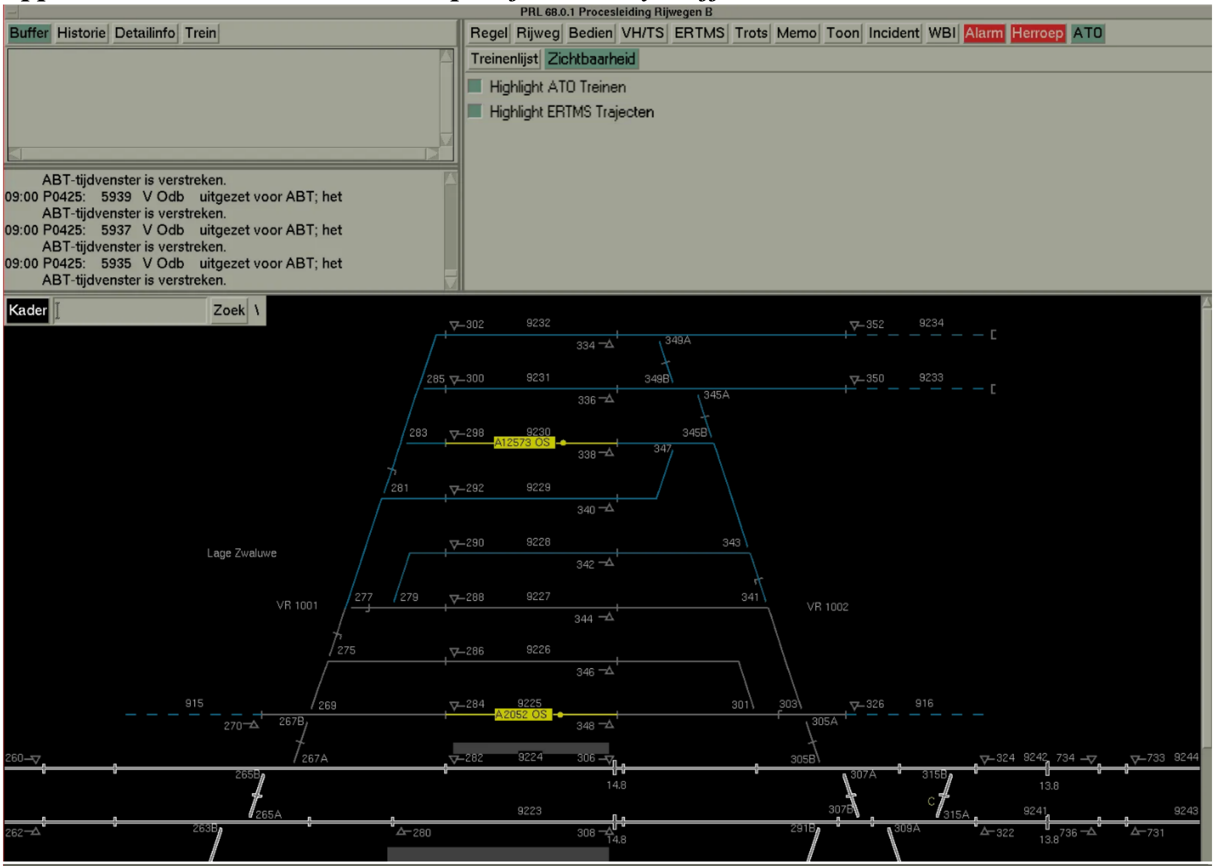


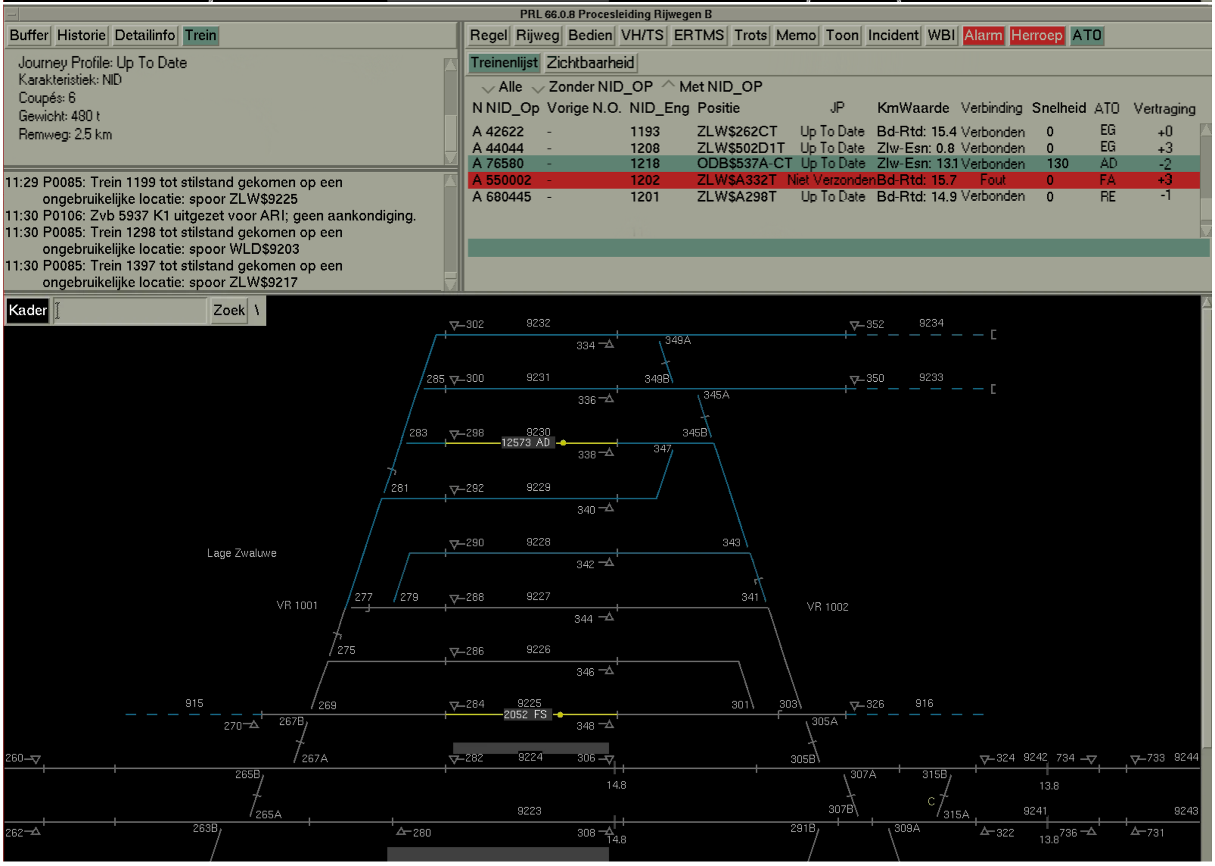
Momenteel op hold
ATO afwijkingen
+ Het systeem moet aangeven wanneer er een probleem met een ATO trein is
+ Het systeem moet kenbaar maken wanneer een ATO trein een route heeft gereden die niet overeenkwam met het plan
+ Het systeem moet kenbaar maken wanneer een ATO trein zijn volgende stop gaat overslaan
(from Requirements)
Het systeem moet aangeven wanneer er een probleem met een ATO trein is
(from ATO afwijkingen)
Het systeem moet kenbaar maken wanneer een ATO trein zijn volgende stop gaat overslaan
Het systeem moet kenbaar maken wanneer een ATO trein een route heeft gereden die niet overeenkwam met het plan
Alleen van toepassing in specifieke situatie als resultaat van meerdere bewuste handelingen van TRDL die niet volgens protocol gaan
Vertragingen
+ Het systeem moet kenbaar maken wanneer een ATO trein een vorige stop had die mislukte (qua timing en/of positie)
+ Het systeem moet kenbaar maken wanneer teruggeleverde informatie van een ATO trein meer dan XX seconden afwijkt van het actuele plan voor die trein
(from Requirements)
Het systeem moet kenbaar maken wanneer een ATO trein een vorige stop had die mislukte (qua timing en/of positie)
(from Vertragingen)
SBG++ en PRL implementatie --> Pure betrekking op vertraging m.a.w. niet halen van timing points
(from Functionaliteiten)
Het systeem moet kenbaar maken wanneer teruggeleverde informatie van een ATO trein meer dan XX seconden afwijkt van het actuele plan voor die trein
(from Vertragingen)
Snelheid/Locatie
+ Het systeem moet de huidige locatie van een trein laten zien op basis van ATO statusrapportages
+ Het systeem moet de huidige snelheid van een ATO trein weergeven
+ Het systeem moet terugkoppeling geven over de beweging van een trein o.b.v. het ATO statusrapport
(from Requirements)
Locatie reeds aanwezig op overzicht/spoorbezetting. 6 sec. nauwkeurig
Snelheid op verzoek (klik/filter) zichtbaar
Journey Profile
+ Het systeem moet kenbaar maken wanneer gewijzigde omstandigheden verwerkt worden in een nieuw Journey Profile van een ATO trein
(from Requirements)
Notificatie voor vernieuwde JPs
(from Functionaliteiten)



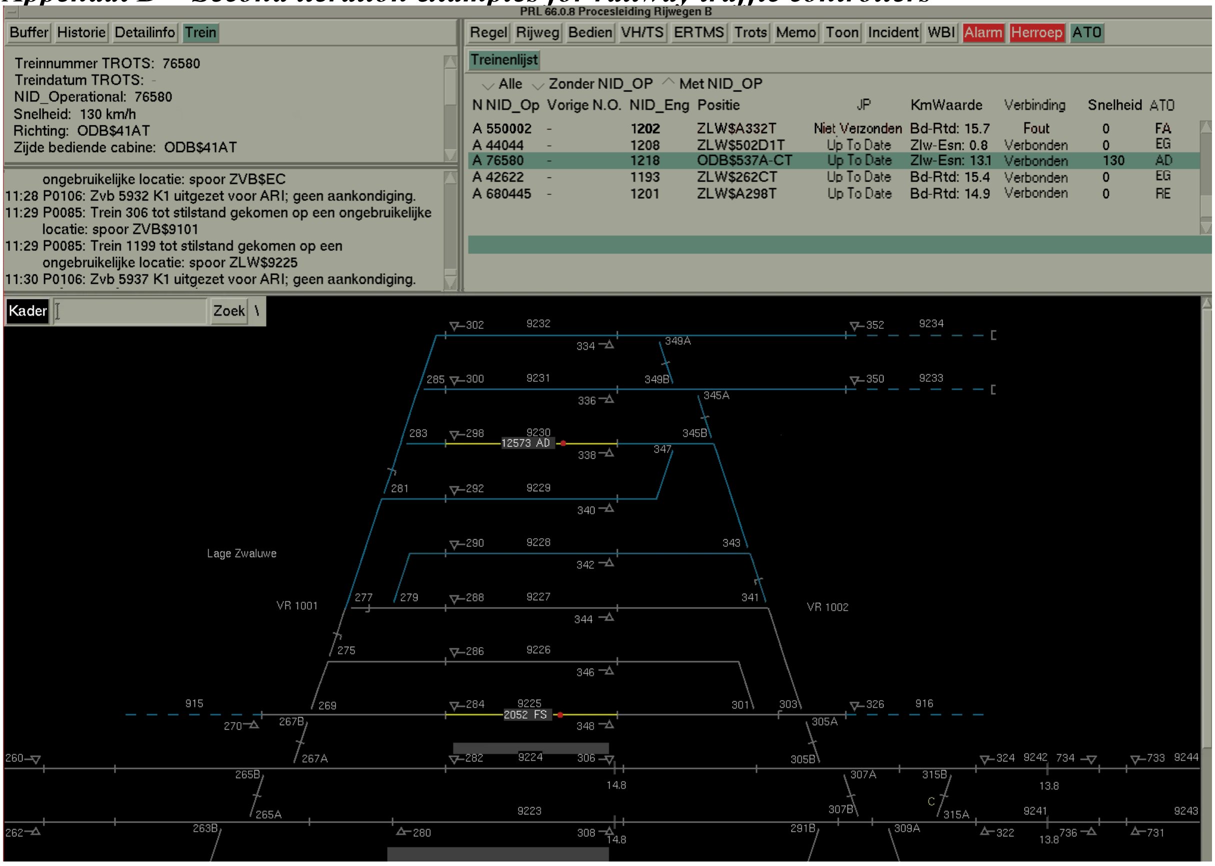
ATO/ERTMS
+ Het systeem moet d.m.v. tooling kunnen laten zien welke trajecten beschikken over ERTMS en ATO
+ Het systeem moet d.m.v. tooling kunnen laten zien welke treinen onder ATO kunnen rijden
+ Het systeem moet weergeven of een trein op dit moment onder ATO (en ERTMS) rijdt
(from Requirements)
Het systeem moet informatie weergeven over ATO & ERTMS
(from Functionaliteiten)
Het systeem moet d.m.v. tooling kunnen laten zien welke treinen onder ATO kunnen rijden
(from ATO/ERTMS)
Het systeem moet d.m.v. tooling kunnen laten zien welke trajecten beschikken over ERTMS en ATO
(from ATO/ERTMS)
Het systeem moet weergeven of een trein op dit moment onder ATO (en ERTMS) rijdt
(from ATO/ERTMS)
Trajecten die over ERTMS beschikken zien er fundamenteel anders uit --> geen signalen meer zichtbaar, MA = Paars, treinen geven aan welke kant ze op rijden d.m.v. stip aan de rijdrichting kant
(from Functionaliteiten)
Weergave bij Treinnummer op overzicht (ipv 1234 wordt A1234 o.i.d.?)
(from Functionaliteiten)
Be- en Bijsturen
+ Het systeem moet op basis van teruggeleverde informatie van een ATO trein de verwachte aan- en doorkomst tijden weergeven
+ Het systeem moet vanaf en op initiatief van Trackside updates naar een ATO trein kunnen sturen
+ Het systeem moet voorspellingen geven van de uitvoering van de treindienst in de toekomst
(from Requirements)
Terugkoppeling (op basis van de updates Trackside) van ATO Onboard over treinbewegingen
Het systeem moet updates richting een ATO trein kunnen sturen
(from Functionaliteiten)
Het systeem moet vanaf en op initiatief van Trackside updates naar een ATO trein kunnen sturen
(from Be- en Bijsturen)
Het systeem moet op basis van teruggeleverde informatie van een ATO trein de verwachte aan- en doorkomst tijden weergeven
(from Be- en Bijsturen)
ATO statusrapport in zelfde trend als ERTMS
(from Functionaliteiten)
Het systeem moet voorspellingen geven van de uitvoering van de treindienst in de toekomst
(from Be- en Bijsturen)

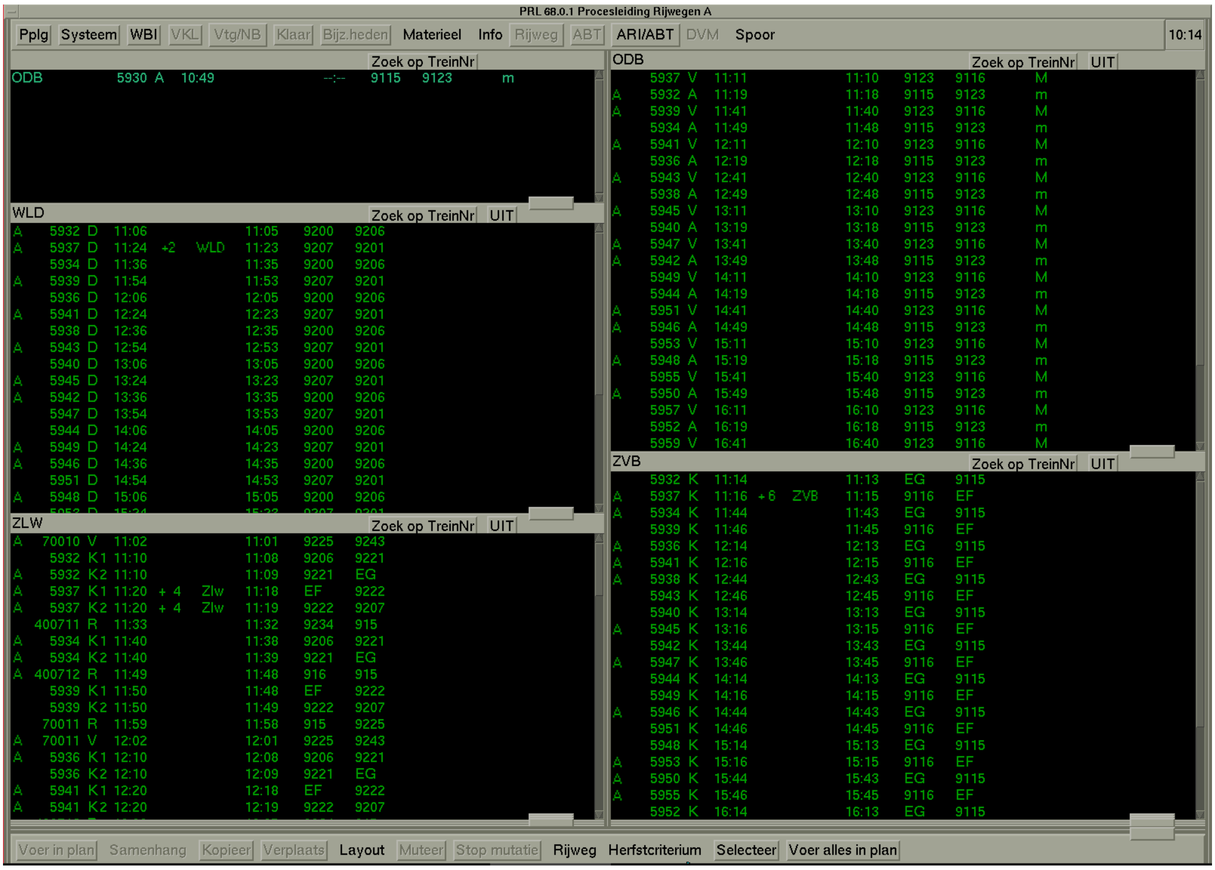
Appendix C – First iteration examples for railway traffic controllers





Appendix D – Second iteration examples for railway traffic controllers





Appendix E – Initial prototype example for railway dispatcher