Situation Awareness and Gamification for Driver assistance on Railways

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Problem Description

Situation Awareness and Gamification for driver assistance on Railways

Conceptualize and develop prototype of an iPad app for train drivers that enables them to obtain better situation awareness of the train traffic in their area.

Abstract

Rail companies are increasingly investing in information systems that contribute to reducing energy consumption and increasing punctuality by telling the train driver at which speed to drive. These driver advisory systems do little to make the train driver understand why the advice is given and existing research suggests that increasing the train drivers awareness of the traffic around them could have positive effects on the acceptance of the advice given by driver advisory systems, while also increasing the train drivers understanding of the current situation and projection of future state, their situational awareness.

There also seems to be room for increasing train drivers motivation to follow the advice of driver advisory systems by motivating them to be punctual. Gamification is a set of concepts that are often used with success to increase system usage and user interaction and can be a promising way of motivating train drivers

This Thesis shows that the situational awareness of train drivers can be supported by designing and prototyping a system that fills this gap in current research by visualizing live traffic. The thesis also defines a framework for constructive use of gamification targeted towards making train drivers reflect over own driving styles and motivating towards punctuality.

The scientific contributions of this thesis are:

C1 A novel framework for applying gamification to support reflection and increase train drivers intrinsic motivation to be punctual.

C2 A prototypical example of how the situational awareness of train drivers can be supported.

Sammendrag (Norwegian abstract)

Togselskaper har økende grad begynt å investere i informasjonssystemer som bidrar til redusert energibruk og en økning i punktlighet ved å gi lokføreren råd om hvilken hastighet som skal holdes. Disse førerstøttesystemene (Eng.: Driver Advisory System) gir få bidrag til å støtte lokførernes forståelse av hvorfor rådene gis. Eksisterende forskning foreslår at å øke lokførernes bevissthet på togtrafikken rundt de kan ha positive virkninger på viljen til å godta råd fra førerstøttessystemene, samtidig som det også øker lokførernes forståelse av nåværende situasjon og projeksjon av fremtidig tilstand, altså lokførernes situasjonsbevissthet.

Det synes også å være rom for å øke lokførernes motivasjon til å følge rådene fra førerstøttesystemer ved å motivere lokførerne til å være punktlige. "Gamification" (spillifisering) er et sett med konsepter som ofte har suksess i å øke bruk av systemer og brukerinteraksjon, og kan dermed være en lovende måte å øke lokførernes situasjonsbevissthet på.

Denne masteroppgaven demonsterer at lokføreres situasjonsbevissthet kan støttes ved å designe og utvikle en prototype av et system som fyller dette hullet i eksisterende forskning ved å visulisere togtrafik i sanntid. Et rammeverk for konstruktiv bruk av spillifisering rettet mot lokførere defineres. Rammeverket er rettet mot å få lokførerne til å reflektere over egen kjørestil og til å motivere for punktlighet.

De vitenskapelige bidragene til denne masteroppgaven er:

C1 Et nytt rammeverk for å bruke spillifisering til å støtte refleksjon og øke lokføreres indre motivasjon til å være punktlig.

C2 En prototype av et informasjonssystem som demonsterer hvordan lokføreres situasjonsbevissthet kan støttes gjennom visualisering av togtrafikk i sanntid.

Preface

The work with this Thesis has been performed at the Department of Computer and Information Science (IDI) at the Norwegian University of Science and Technology (NTNU), and in collaboration with SINTEF Technology and Society.

The original assignment text for this thesis was as follows:

> Conceptualize, develop prototype of an iPad app for train drivers that enables them to: 1) easily report causes of delays and operational problems and 2) obtain better situation awareness of the train traffic in their area.

Since then the assignment text has changed to the one given in the problem description. The reason for these changes were that the original first part was less scientifically interesting than the second part. Being a relatively open assignment it was also very interesting to draw in theories on gamification which also has turned into a relatively large part of this thesis, and is in the authors opinion a very interesting contribution.

While working on this thesis I have been supervised by Sobah Abbas Pettersen, and co-supervised by research scientist Andreas Landmark and research manager Andreas Seim which have both provided excellent guidance, input, and insight throughout the whole process.

Trondheim, June 17, 2014

Magnus Bae

Acknowledgements

In parallel with the work undertaken for this thesis I have also been a part of Revolve NTNU, a team of 46 students building a prototype formula race car for competing in the international Formula Student competitions. A big thanks goes out to everybody in Revolve for contributing to one of the best experiences I have had as a student.

A second big thanks goes out to my supervisors for understanding that time has been difficult to balance.

Further thanks are in order for senior research scientist Arnt-Gunnar Lium, and fellow student Magnus Krane who contributed to the workshop, and to Rimmert van der Kooij for offering valuable input in the writing process and spotting the spelling errors that slipped through.

Last, but not least; a final thank you to Domitille, who has supported me by doing the work I didn't have time to do and who is still here after being neglected for six months.

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Definitions & abbreviations

SA Situational Awareness

DAS Driver Advisory System

HMI Human Machine Interface

GPS Global Positioning Systems

TC Traffic controller

TXP Train expediter

TIOS Train Information and follow-up system ("Toginformasjons- og oppfølgingssystem")

ERTMS European Rail Traffic Management System

SIRI Service Interface for Real Time Information

API Application Programming Interface

HTTP HyperText Transfer Protocol

JSON JavaScript Object Notation

1. Introduction

Rail companies are increasingly seeking to invest in information systems that promise to reduce energy consumption and increase punctuality. Driver Advisory Systems typically use speed profiles based on train type, track height profiles, and speed restrictions to present the driver with a recommendation for speed. While such systems seem to deliver on their promises they fail to improve the interaction between train drivers and traffic controllers. There is potential for a system that allows train drivers to be aware of the traffic around them so that they can make better decisions and understand the advice given based on the actual situation.

In this Master's Thesis we show that the situational awareness of train drivers can be supported by designing and prototyping a system that fills this gap by visualizing live[1] train traffic on the rail network in real time, allowing the train driver to observe the actual traffic flow in real-time and thus acquire knowledge about the current situation and making it easier to predict future development and act upon it. The prototype is directed towards train drivers, but such a system could also prove to be beneficial for traffic controllers – allowing them to better understand the complete traffic picture.

The thesis also explores how to use gamification strategies to increase the intrinsic motivation of train drivers to be punctual and presents a framework that focuses on supporting reflection, the process of performing a retrospective analysis, understanding

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[1]Due to the difficulty in obtaining real time data the prototype uses historical data

the situation and processing what is seen into knowledge that can be applied to

The research process has been qualitative and has followed the Design Science Research Process (DSRP).

This chapter first gives a quick introduction to the problem and the theoretical frameworks applied during the work on this thesis, then introduces the research questions answered in this thesis, before giving a brief introduction of the method used, thesis scope and contribution, and finally the structure for the rest of the thesis.

1.1. Background and Motivation

Rail companies seeking to lower operation expenses and increase punctuality have in later years started to install Driver Advisory Systems (DAS) in train cabs. Driver Advisory Systems generally specialize in telling the driver at what speed to drive to arrive at the next goal at a given time, whilst these systems increase passenger comfort and reduce energy consumption they do not increase the cab drivers situational awareness (SA), or support their intrinsic motivation to be punctual.

The work on this Master's Thesis has been performed in collaboration with SINTEF's "Presis"-project ("punctual"). Presis is a project involving NSB, CargoNet, Flytoget (Airport express train), the Norwegian Institute of Transport Economics, and the Norwegian National Rail Administration (Jernbaneverket). The project aims to increase punctuality, robustness, and regularity on the Norwegian rail network. [1]

As part of a report by SINTEF [2, pp. 18-19] on Norwegian Train Expedition it is suggested that there seems to be potential for improvement if train drivers were to have a higher understanding of the traffic controllers work situation (and vice-versa). It is also suggested that increased awareness about surrounding traffic can improve traffic flow, and that systems that give the train driver suggestions about recommended speed could

contribute positively.

Tschirner et al [3, 4] found that train drivers often end up in a situation where they can only perform suboptimal. This is due to lack of information about changes to the original planned scheduling and lack of information about the current traffic situation. According to Tschirner the traffic controllers also lack information about the exact whereabouts of the trains, something which in many situations can lead to suboptimal planning.

Situation awareness is a theory focused on operator environments and their mental models. In short situation awareness is framework under which we can understand how humans and systems can perceive information and process it into a model that can be used to understand the current situation and predict the future [5]. Situation awareness is therefore at the very center of human actions. We act based on how we perceive situations, and increased understanding and projection of the current and future situation which lead to better decision-making.

Gamification is the theory of using elements, mechanics or thinking from games in non-game-related situations to increase learning, attention, motivation, or ability to solve problems [6]. By using good gamification one can increase users intrinsic motivation, although less thought through use of gamification can work too, it has a tendency to have a declining effect over time since it usually is based on extrinsic motivation (e.g. rewards).

Based on the ambitions of the "Presis"-project [1], the recommendations of SINTEF's report on Norwegian Train Expedition [2], and the findings and conclusions of Tschirner et al [4, 3] the purpose of this Master's Thesis is to prototype and test a DAS running on a tablet computer to provide train drivers with situational awareness, and to investigate how to support train drivers intrinsic motivation to be punctual.

1.2. Research questions

Given the problem definition and existing research on the area, the following research questions have been formulated:

RQ 1 How should train driver situational awareness be supported to enable better performance with regards to punctuality?

RQ 2 How can train punctuality be improved by gamifying the driver advisory system?

The goal of RQ 1 is to research how to support train drivers' situational awareness through the use of information systems, and how situational awareness can contribute to increased punctuality and a better understanding of network traffic and the work situation of train traffic controllers. Supporting train driver SA will allow the train drivers to make better decisions about their speed and adapt their driving style to the actual traffic conditions, reducing knock-on delays, wear on rail lines and rolling stock, and improving communication between train drivers and traffic controllers.

The goal of RQ 2 is to find how the concepts of gamification can be adapted to fit naturally in the context of a driver advisory system. Successfully motivating train drivers to be punctual could result in increased usage and adoption of driver advisory systems and better understanding of how their own driving style affects the traffic flow on the network.

1.3. Method

The research process used in the work on this thesis is modeled on the Design Science Research Process (DSRP) described in [7]. Design Science as a method was introduced in the 1990s through multiple separate papers [8, 9, 10], and has seen a gradual adoption by the information systems community since. However the 2006 paper by Peffers et.al is

among the first to outline a process model that is nominal and consistent with other science disciplines [7, pp. 85-87]. See Figure 2.1 on page 8 for an outline of the DSRP.

The DSRP process was chosen over the design process proposed by Endsley et.al. [5, pp. 43-62] due to both being more adapted to scientific writing, and being more flexible with regards to the process content.

1.4. Thesis Scope

The scope of this Master's Thesis is to prototype and evaluate an information system that supports the situational awareness of train drivers, and to research how the theories of gamification can be used in driver advisory system to increase driver motivation to use that system, and to increase the drivers intrinsic motivation to be punctual.

The work with RQ 1 is in large parts built upon the research performed by Tschirner et.al [4, 3], and the recommendations and findings in SINTEF's report on train expedition in Norway [2].

Existing work have already covered speed recommendation systems, but none have yet to create a system that really can provide train drivers with situation awareness in a manner that is comparable to the one held by train controllers. This thesis builds in large part on the work of Tschirner et al [3, 4] who have elicited train driver goals and recommendations for how a driver advisory system could significantly improve train drivers' situation awareness of current traffic and planning.

RQ 2 is answered by the means of a theoretical framework built on gamification theory and findings from the research process. The framework allows for constructive use of gamification directed towards train drivers by supporting retrospective analysis of own performance.

1.5. Thesis Contribution

This thesis builds upon existing research and has two main contributions:

- A novel framework for applying gamification to support reflection and increase train drivers intrinsic motivation to be punctual.

- A prototypical example of how the situational awareness of train drivers can be supported. Evaluation of the prototype also finds that it can be used as a tool for retrospective analysis of traffic situations.

1.6. Thesis Structure

The next chapter, Chapter 2 details the methodology used to find the results presented in this thesis. Chapter 3, Project Theory, gives further background and contains the significant findings from the literature study (see Chapter 2). Chapter 4, Results, presents the results from the workshop that was part of defining the project and the evaluation of the prototype system that was developed as part of the DSRP. Chapter 5, Discussion, discusses the findings, evaluates the method and defines the framework for gamification which is the answer to RQ 2. The last chapter is Conclusions and further work which sums up the contributions of this thesis and suggest possibilites for further work. The appendix section contains an interview transcript and the full summary from the workshop. The developed source code is available as a digital attachment.

2. Method

This chapter describes the method used in work on this thesis and serves to clarify how the results were obtained and thus showing how the research results presented herein is both scientifically reliable and valid. The first section gives a quick outline of the method and process. The second section outlines the goals of a solution to RQ 1 described in Chapter 1.2 on page 4. The third section outlines the goals of an answer to RQ 2. The following sections detail the method and application in the major points of the research process. The last section describes the prototype system developed in order to answer RQ 1.

As mentioned in the Introduction chapter the method followed for this research is the Design Science Research Process. Design Science is according to Hevner et al [11] a paradigm that "seeks to extend the boundaries of human and organizational capabilities by creating new and innovative artifacts". The paradigm differs from other software engineering paradigms in that the goal is rarely the artifact developed, rather the artifact is a tool to achieve understanding and knowledge of the problem domain.

2.1. Method Outline

The method used in the work on this thesis has been based on the DSRP. The DSRP can be applied in both a linear (waterfall-like) model or in an iterative fashion as has been the case

in the work on this project. Working iteratively generates a feedback-loop in which design and development are demonstrated, and the results of the demonstration are evaluated and allow for refocusing, adapting, or progressing on the work, and re-evaluating the objectives of the solution if necessary.
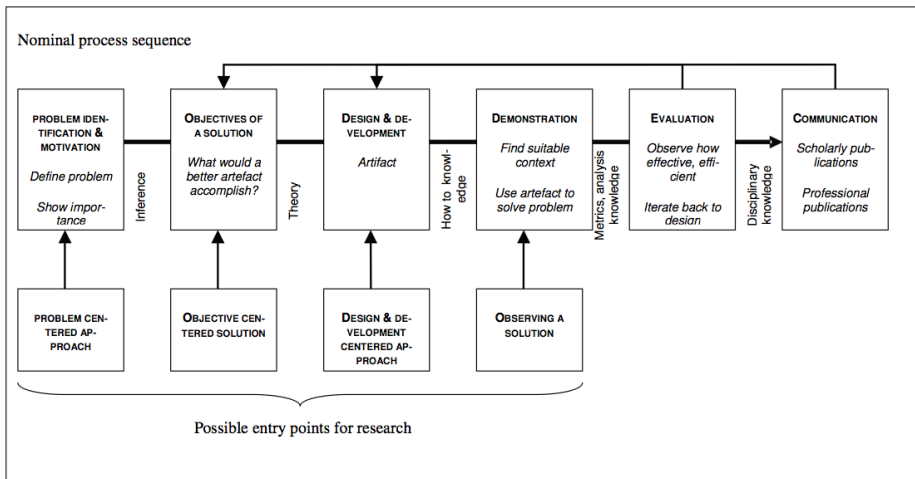
Figure 2.1.: The design science research process (DSRP) (from [7])

The main outline of the method as it was applied in the work on this thesis:

1. Literature study

2. Problem identification (workshop)

3. Design and development

4. Demonstration

5. Evaluation

6. Steps 3 through 5 were repeated in an iterative fashion

7. Case demonstration and evaluation

8. Communication (this thesis)

2.2. Entry Point for Research

The DSRP has multiple entry points for research (see Figure 2.1). Given the specifics of the assignment, the goals of the PRESIS-project and the recommendations of related research the approach for the research has been primarily design and development centered.

2.3. Goals of the Prototype

Part of this thesis is dedicated to the prototype system which was developed as a part of achieving knowledge and understanding of how to provide a solution to RQ 1 (see Chapter 1.2). To be able to assert whether or not the developed prototype is a good answer to RQ 1 some goals need to be defined. These goals are based on the results of the literature study and build on information presented in Chapter 3 on page 21.

The developed prototype shall: [1]

1. provide train drivers with information about the current traffic situation.

2. improve train drivers understanding of the current traffic situation.

3. support train drivers in making better decisions based on the current traffic situation.

4. contribute to train drivers' situation awareness.

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[1]The goals of this prototype are listed without priority, numbering provides easy referencing.

5. function in a manner which would require minimal operator interaction.

It is important to note that the prototype is not a goal of the research itself, it is being developed as a tool for performing research. Designing and developing the prototype allows for testing if it works, and through that evaluation learning about the problem to be solved. The goals of the prototype is therefore not the goals of the research itself.

2.4. Goals for Gamification Research

RQ 2 (see Chapter 1.2) asks how the use of gamification in driver advisory system can lead to increased punctuality. Based on domain knowledge and background information a theoretical framework for increasing the intrinsic motivation of train drivers to be punctual is proposed in Chapter 4 on page 52.

Any usage of gamification in a driver advisory system have to support the goals in a long run, thus usage of extrinsic motivational factors like rewards should be avoided. Use of gamification should be in the pursuit of building intrinsic motivation, and ideally support train drivers in reflecting over their own behavior and learn how to improve their own skills over time.

RQ 2 is answered by defining a framework that allows for constructive application of gamification in an information system for train drivers. The framework is defined based on information presented in the literature study, and knowledge and understanding acquired through the research process.

2.5. Literature Study

The literature researched for this study includes books on Gamification and Situation Awareness. Scholarly articles and theses have been reviewed. The searches were

mainly performed using Google Scholar. Search-phrases were mainly permutations of the following terms: Driver advisory system, DAS, train, driver, cab, information system(s), rail, situation awareness, and gamification. Google searches with similar keywords have also been used, and have provided information about commercially available information systems where no scientific articles had been published. Titles and abstracts were used to qualify the papers for further review. Reviewed and appropriate papers' references were also searched for further relevance.

Deciding on whether or not a paper is relevant will always require subjective interpretation, and some older papers have been omitted due to either being covered by the newer papers or not contributing towards the goals of this thesis. The literature used is not an exhaustive list, and was deemed as the most relevant when reviewed.

2.6. Problem Identification and Workshop

After the initial literature study and formulation of research questions a small workshop was arranged. The workshop included supervisor Sobah Abbas Pettersen, co-supervisors research scientist Andreas Landmark and research manager Andreas Seim, SINTEF senior research scientist Arnt-Gunnar Lium, and Master candidate Magnus Krane. The goal of the workshop was to elicit ideas and aid in defining the scope for both the prototype and the thesis.

Prior to the workshop the participants received some background information as well as some concept ideas and the main points for the workshop.

The workshop was arranged as follows:

- An initial introduction and "show and tell" round.

- Discussion on data sources and access.

- Discussion on scope of prototype DAS and possibility for live trials.

- Discussion of Gamification; focus, intent and data usage.

- Summary of main points.

2.7. Design, development, and demonstration

Development-wise two main strategies have been employed. Data processing software components have been developed using Test-Driven Development (TDD) to minimize the possibility that the resulting data was transformed incorrectly. Visual software components have been developed very prototypical in an effort to prototype as rapidly as possible. The resulting software is somewhat tightly coupled, but functional. Multiple branches were created to separate the code-bases for different prototypes, allowing for easy alteration of the functionality of existing sources.

Professional train drivers have limited time available for participating in research projects like this. To overcome this availability issue co-supervisor Andreas Landmark has for large parts of the process taken the role of representing train drivers during prototype demonstrations. Andreas have through several projects worked closely with train drivers and observed and interviewed them in a work environment. Working with Andreas in this fashion facilitated a more rapid prototyping process with less uncertainty than if aiming for a one or two demonstration/evaluation workshops.

The development cycle was performed iteratively. Demonstrations were performed on a close to weekly basis with development cycles running in between. Further work was either planned with input from the co-supervisors, or based on their feedback.

2.8. Pilot testing

For the final evaluation a pilot test was performed on a volunteer SINTEF research scientist with extensive experience from the railway sector. It was originally intended to perform a more extensive evaluation using a team of three to five train drivers, but this could not be done due to time constraints.

In the pilot test the prototype system was presented and introduced, and the test subject was allowed to try out the system, picking routes and dates of their own choosing. The test participant was guided through the initial testing, allowing traffic to play out, and asked to reduce time compression when interesting situations unfolded. No further guidance was given after the participant seemed to have become comfortable using the system.

After the participant had spent sufficient time with the prototype and encountered some interesting situations the participant was asked to fill out a System Usability Scale (SUS) form [12]. SUS is a proven tool that can quickly collect information on how a user experiences the usability of a system. SUS has seen extensive use and is deemed to be a well designed tool for assessing the usability of a system as experienced by users [13].

After the participant had filled out the SUS form a focused interview was performed to capture a deeper insight into how the participant had experienced the system, and get better feedback. The use of a focused interview was both because the topic was limited and because the participant was not a train driver. Assuming the participant had already warmed up there were no warm-up questions. The questions were adapted to the answers from the participant and new questions were added as needed. The interview was recorded to be able to transcribe it later and to be able to focus on following up the interview instead of transcribing directly. [14, pp. 100-128]

The following questions were prepared:

- Did the prototype contribute to your understanding of the traffic situation, and how?

- Do you think that a system which displays the traffic situation, like the one demonstrated today, or in any other manner you can think of, would contribute positively with regards to supporting you in making decisions while driving a train?

- If you were given the choice of using such a system in your daily work, would you?

- If you had to choose between a finished and polished version of such a system, or a system that tells you how fast you should drive at any given time, which would you choose?

- If you had a system that tells you how fast you should drive, would you like it to incorporate functionality like the one demonstrated today? (The participant was shown pictures of the systems described in Chapter 3.4 on page 43)

- What additional information would you like the system to display?

- Do you have any additional comments or feedback?

The results of the test case demonstration and answers to the questions were evaluated. The results are described in Chapter 4 on page 52.

2.9. Prototype Design and Development

This section describes the prototype driver advisory system that has been developed. The prototype has been developed as a part of design and development part of the DSRP process, and is considered a tool for performing research, not a goal of the research itself. This section starts out by describing the data sources used, the technology that was used in the development, and the structuring of the system components. Following this the functionality of the prototype is described.

2.9.1. Data Sources

For the prototype several historical datasets were used, including schedule and traffic information from TIOS [2], infrastructure information (station names, distance between stations, etc.), and GPS recordings from cargo trains on Dovrebanen. Datasets used in SINTEF's re-planning tool [15] were also provided in XML-format, but ultimately not used, although some support was built into the system.

The datasets used were provided as SQL-data from a MySQL database, while the XML-data was enveloped using the Service Interface for Real Time Information (SIRI) schema [16]

The GPS and TIOS datasets use different values for station names; full names and abbreviated. To be able to work seamlessly with both datasets the station names in the GPS set was replaced by the station abbreviations. The station data came from an infrastructure set containing distances between stations, information about the placement relative to the origin station (Oslo for tracks south of Trondheim, Trondheim for tracks north of Trondheim), and the name of the stretch that the segment belongs to.

2.9.2. Technology

The prototype was developed as a tablet application. Tablet computers typically run on hardware with both memory and battery constraints, thus it made little sense to have the front end process raw data from the database and instead do that processing in a separate back end. The back end fetches the data from the database and processes it as necessary to reduce the amount of processing required in the front end.

The back end developed exposes JSON [17] data to the client using a REST-API [18], this allows the front end to retrieve data using HTTP calls with parameters instructing the back end server which data to retrieve.

The back end was built using Node.js [19] and the Express web application framework [20]. Node is lightweight event loop driven framework for JavaScript powered applications. Express is web application framework for Node.js that allows for rapid creation of web applications. MySQL was used as the database management system (DBMS). For data interchange between the front and back end the JSON data interchange format was used. JSON has a much smaller overhead on transfers than XML [21], and many modern programming frameworks come with built in JSON support, including both Digia Qt and Apple Cocoa [22, 23].

The front end was realized as an iPad application written in Objective-C [24, 25]. For plotting data points in a two- dimensional coordinate system the Core Plot framework [26] was used.

2.9.3. Final prototype

The prototype consists of two parts, a server back end and an user front end. These communicate through a network or Internet connection, and the user only interacts with the front end. The front end is realized as an iPad application.

When the application is launched the user is presented with a list of routes which there exists GPS-recorded runs for, and the user needs to choose a route for playback. After choosing a route the user is presented with the available departure dates for that route (see Figure 2.2 on the facing page). After choosing one of the routes the front end starts loading in the datasets from the back end, and loads the main view.

The main view user interface consists of a view showing the route in a coordinate system, no axes are shown, and the x-axis is scaled by half to give a coordinate projection that is close to common mpa projections [27]. Stations are marked with stars, and there is a small label annotating each station with the abbreviated station name. Figure 2.3 on page 18 shows examples of the user interface.

Carrier 📶	4:37 AM	100%
5701	
5704	
5706	
5707	
5708	
5709	
5730	
5731	
5733	
5735	

Carrier 📶	4:38 AM	100%
2012-05-10	
2012-05-11	
2012-05-14	
2012-05-15	
2012-05-16	
2012-05-18	
2012-05-21	
2012-05-22	
2012-05-23	
2012-05-24	
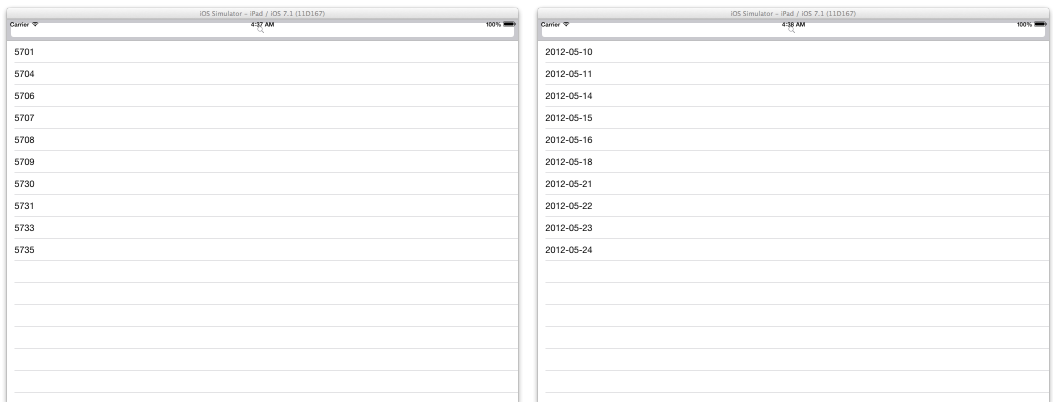
(a) The first screen allows the user to select a route for
 playback

(b) The second screen allows the user to select a date
 for playback

Figure 2.2.: The user has to select route and the actual departure date of the route before
the playback starts

Train movement is plotted on top of the track outline using different colors. The color
of the train indicates the speed of the train. The plotting of train movements is separated
by category; trains that have recorded runs, and trains that only have schedule data. The
position of trains with recorded runs is indicated by a graphic point with dynamic color
ranging from red (full stop) to green (100 km/h or more). Between 100 and 0 km/h the
color is automatically calculated based on the speed of the train. Trains with only schedule
data are plotted with a blue color when in-between stations, and with a red color while
stationary at stations. Both plot categories have a label annotating the route number of
the train next to the graphic point indicating the position of the train. The position of the
trains that only have schedule data is generated from linear interpolation of the train speed
between stations. Figure 2.4 on page 19 shows the progress of a crossing at Tretten station,
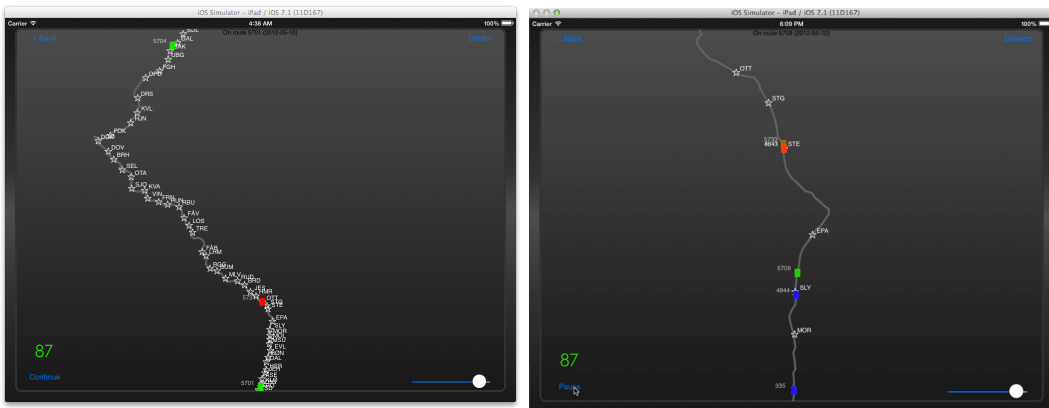
(a) Route and traffic overview when zoomed out. (b) A higher zoom levels gives a clearer view of the closest traffic. The green 5709-train is the one being tracked.

Figure 2.3.: Traffic playback in the prototype. Blue trains have their positions estimated based on a linear interpolation of speed between the stations.

one can see how the southbound train has arrived and is waiting for northbound train to pass before it starts driving again.

The choice of red and green colors to indicate speed was based on similarity with existing systems. Systems that display traffic flow commonly use red to indicate slow moving traffic, while green is fast moving traffic. In traffic situations a red light also means "stop", while a green means "go". The usage of red and green colors is unproblematic as train drivers are required to have color vision [28, 29]. Figure 2.5 on page 20 shows traffic with three GPS-recorded trains and two trains with only schedule data about to cross.

The user can scale the plot view (zoom in or out) using a pinching gesture on the screen. By default the view follows the route being tracked, a button in the upper right corner can be used to turn off the auto-tracking feature and allow the user to pan the map and zoom
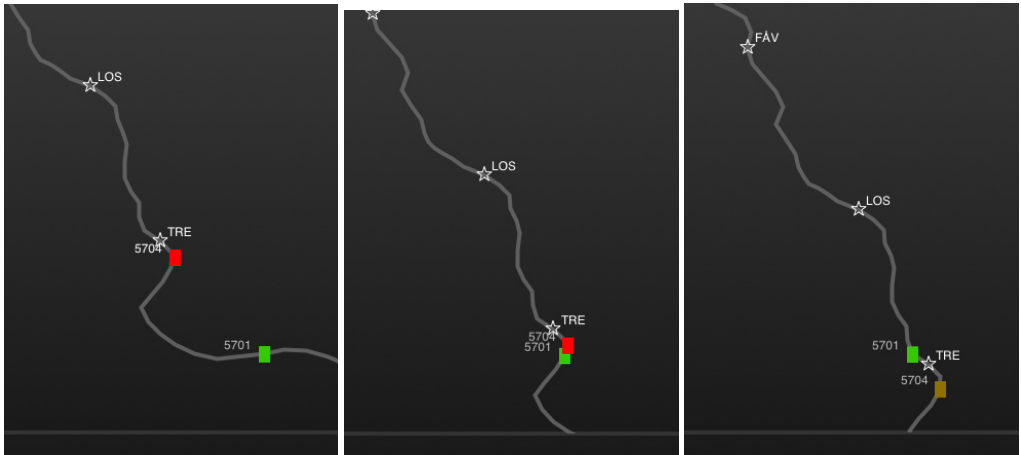
(a) Before: 5704 has arrived and is waiting for 5701

(b) During: 5701 is about to reach Tretten

(c) After: Both trains have left the station and 5704 is regaining speed, 5701 has the same speed as before the crossing.

Figure 2.4.: Two GPS recorded trains crossing at Tretten.

in on traffic further away.

The prototype also has a slider to alter the time compression, and a button to pause and resume the playback. This is practical when running with high time compression, and allows for adjusting both view, and playback speed before resuming playback - watching "frame-by-frame", or live, playback if desired (the resolution of the test datasets is approximately 0.0333 Hz – or one record every 30 seconds).

This chapter has presented the method applied to find the research results presented in this thesis. The research method followed is the Design Science Research Process and as part of this process a software prototype has been developed to gain knowledge and
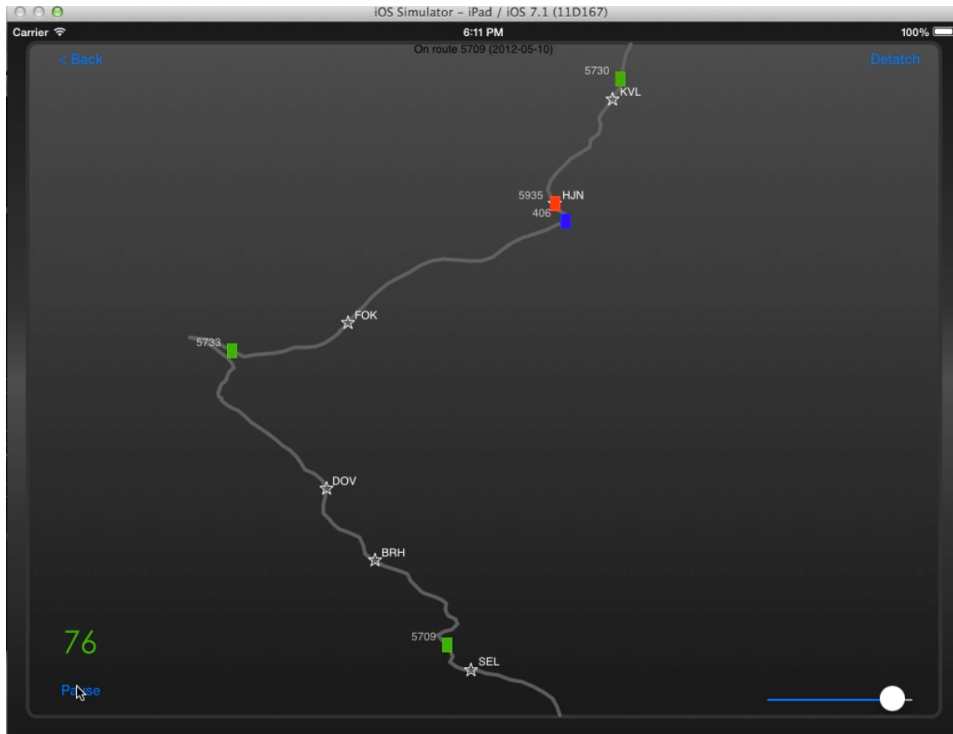
Figure 2.5.: Traffic around Dombås when tracking route 5709.

understanding of how to support train driver situational awareness. The prototype has been developed as an iPad application and uses historical data to overcome the shortcomings of the live data available. Other significant parts of the research has been a literature study, ideas elicitation workshop, and pilot testing of the prototype.

3. Project Theory

This chapter presents background information about trains, train expedition, train driving and theories that influenced the work on this thesis.

The first part introduces the logistics of trains and train expedition, as well as some of the problems that remain unsolved. The second part describes the concept of Gamification and gives examples of usage, how it is used to create motivation, increase learning or interest, and create engaging experiences. The third part introduces situational awareness and why it is important, how information systems can support situational awareness, and situational awareness in the context of railway operations such as train driving and train expedition. The second to last part introduces and discuss Driver Advisory Systems, information systems that are designed to support the driver in choosing the right speed at any given time. The last part looks at other related research.

3.1. Train Operations

Trains are one of the oldest forms of mechanized transport, and is still today one of the most energy-efficient ways of transporting goods and people over long distances. Capacity utilization on parts of the railway is high, often close to the limit of the capacity and it is important to keep the flow going as close to plan as possible to avoid congestion, delays, and logistical problems. There are two ways to decrease knock-on problems caused by

delay; either introduce more slack in the timetables or increase the punctuality of the trains by improving the planning and re-planning process, infrastructure, and technical systems. Only the latter method allows ensuring regularity without decreasing the amount of traffic [1].

Tschirner et al describes the system and the interaction between actors like this:

> Many different actors have to collaborate in order to guarantee efficient railway traffic that is safe, on time, comfortable, eco-friendly and economic. Appropriate planning is necessary: The transport company has to provide rolling stock and personnel, the traffic controllers have to solve perturbations proficiently, and the train drivers have to drive in a way, as far as the traffic plan allows, that saves energy and reduces wearing on rolling stock and infrastructure. In order to find a globally optimal solution, all actors need optimal access to information on the current traffic situation. [4]

3.1.1. Overview

Most of Norwegian rail lines are single track, meaning that trains traveling in opposite directions on the same line can only pass each other where there is a siding for one of the trains to roll onto and wait for the other train to pass. On single line parts of the network delays easily propagate onto other trains, both going in the same direction and in the opposite direction. Because of this problem train schedules are created with a bit of slack so that time can be made up, or one can drive slower and still be inside the window allowed by the timetables if the oncoming train is delayed.

Even though trains inhabit a, in theory, fully observable environment - all information is not necessarily available for every agent or actor in this complex, multi-agent environment. The environment can be both competitive and cooperative. Traffic controllers have

overviews of their part of the network and the train schedule, while the train driver has his time schedule and other information and instructions he or she has been given. Often this creates situations where the goals of a train driver (and the company they work for) is in conflict with other users of the rail network. Train drivers will have very accurate knowledge of where they are and their timetable, but not where other trains are. From the timetable they know where they are supposed to meet the other trains, but they rarely have any knowledge about whether or not the other train is still running as scheduled or if it is delayed or ahead of schedule. [3]

Traffic controllers also have limited knowledge of the real-world situations. For instance they only know which track segment a train is on, not it is exact position or speed. If train drivers do not report factors that can contribute to delays it is difficult to plan ahead as a traffic controller will not be able to realize that a train is running behind schedule until the moment where the train should have changed from one segment to another. External delay factors include slippery tracks in the winter or high passenger volumes on certain days. [3, 2]

As mentioned earlier, delays are not the only problem. Situations where the train comes in to a station[1] early and have to wait for oncoming trains can be particularly annoying and potentially confusing for passengers who do not understand the situation. If a preceding train is running off schedule a train might have to wait outside the station until the station has been cleared. [3]

The slack in the timetable will often result in propagation of slow driving. Even if the first train is within the margins of the timetable, it can cause delays for the following trains if they are following too close. This is partially caused by the traffic rules, which states that a track segment has to be clear before another train may enter that segment. Another

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[1]Please note that there are many closed stations that still acts as passing points for trains in Norway, and that these are stops are not part of the official timetable given to passengers.

contributing factor is the train driver's lack of knowledge about the current situation and what the actual ideal moment of arrival at a station is. [3, 2]

3.1.2. Train planning and expedition

Train planning is done using a "train graph" (see Figure 3.1, Figure 3.2, and Figure 3.3). The train graph is planned using computer tools, but in their day-to-day work traffic controllers work using a printed version of the train graph, noting down changes by hand. Starting out a train graph is without conflicts and has minimal waiting times, but as delays, cancellations, or advances occur — so do conflicts. This requires rescheduling and is done by the traffic controllers. They control the equipment that in turn controls the signals used to signal train drivers how to proceed. Train expediters (TXP) performs manual control of train signals in smaller areas where the signals are not automated, usually stations and goods terminals.

As mentioned in the previous section, (in Norway) track segments have to be cleared before another train can enter that same segment. To avoid having trains stopping and starting all the time, signals are in tandem; signal and pre-signal. The pre-signal signals expectations for the next signal. This allows train drivers to reduce speed, hoping that by the time they reach the next signal they don't have to stop. In many cases reducing speed is also necessary in case the next signal is a stop-signal. Even small trains require a considerable distance to stop. To improve communication traffic controllers can at any moment call a train driver, and vice-versa, but this is rarely done. Communication between train drivers and traffic controllers is often low due to traffic controllers not having enough time to perform these extra tasks. [3]

When one train is delayed it would often be wise to move the meeting point to another station, but this is rarely done [2]. Instead one train often sits stationary over a long period of time waiting for the delayed train. An example is shown in Figure 3.4. One explanation
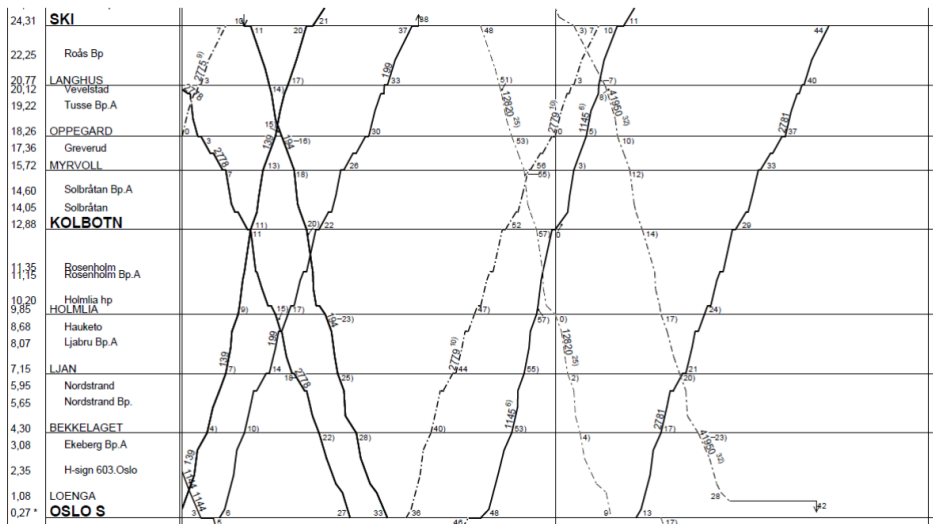
Figure 3.1.: Example of a train graph as planned.

for why this happens might be that although train controllers have complex mental models that allow them to estimate the position of a train on a segment, the models often fall short when external factors are hindering train drivers from driving at optimal speed [3], thus waiting too long to move the crossing point. Another reason the crossing points are rarely moved may be that in many cases the delay is so small that there is no point to moving the crossing, or that moving the crossing can lead to larger delays later.

There are multiple reasons why long waiting times are suboptimal. First, if a passenger train sits waiting it may cause dismay with the passengers who do not know or understand why the train is stationary. Second, cargo trains are longer and heavier than passenger trains and therefore require much more energy to start moving again and ideally one would like to avoid having them stop at all [4, p. 156], avoiding stops also means that they can get back to nominal speed much faster than after a full stop and reduces risk of damage to
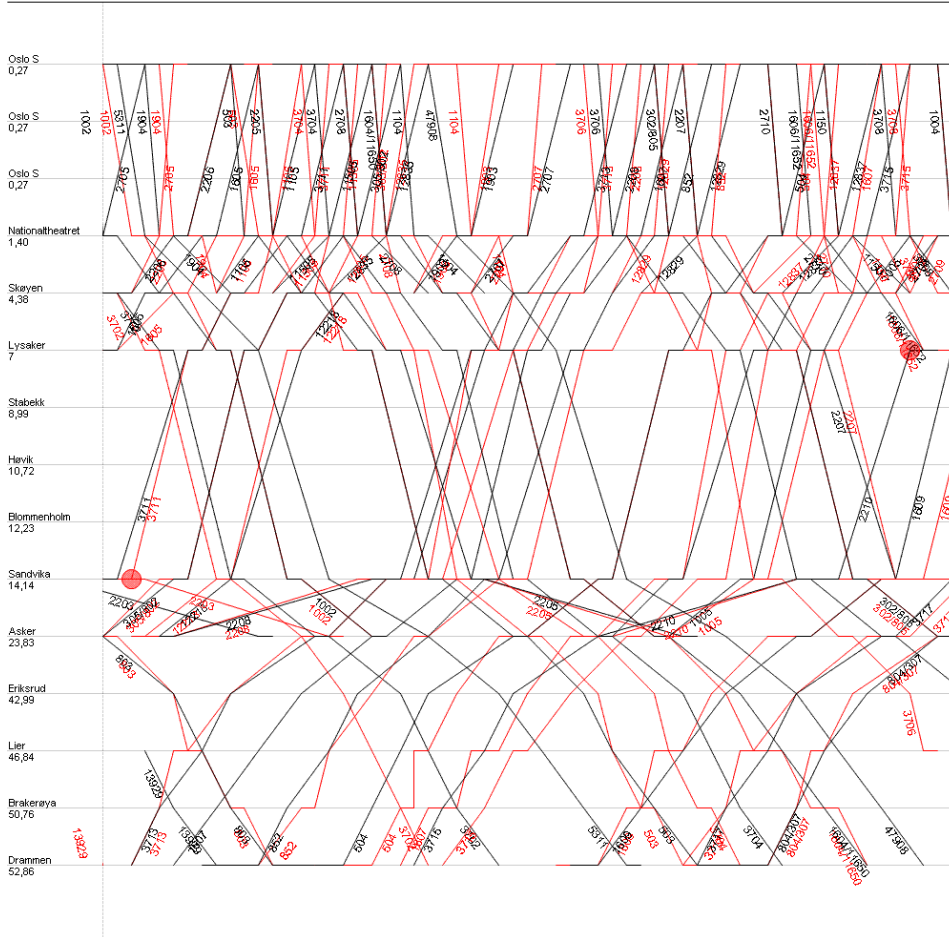
Figure 3.2.: Example of a train graph showing actual data (red lines) and the planned schedule (black lines) between Oslo S and Drammen on November 12 2013 between 0600 and 0700.
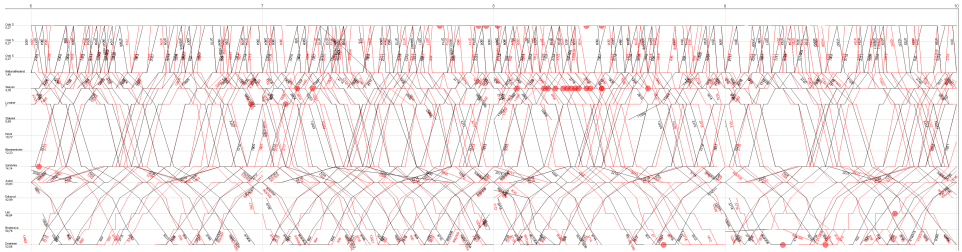
Figure 3.3.: 4 hours of train graphs between Oslo S and Drammen on November 12 2013.

infrastructure and rolling stock. However, since the priority policy is in favor of passenger trains cargo trains are often scheduled to arrive before the passenger train and wait until the passenger train has passed. [2, pp. 18-19]

Tschirner et al elicited these goals for traffic controllers [3, p. 394]:

- Maintain safety

- Maintain smooth traffic

- Minimize delays

- Efficient execution of train routes

- Optimizing the traffic plan and track usage

- High capacity utilization

3.1.3. The train driving process

Train drivers work in a highly controlled and monitored environment, yet they spend most of their work hours isolated from their colleagues. As trains are separated by large distances due to traffic rules, trains mostly meet at stations or on double line tracks at high speed.
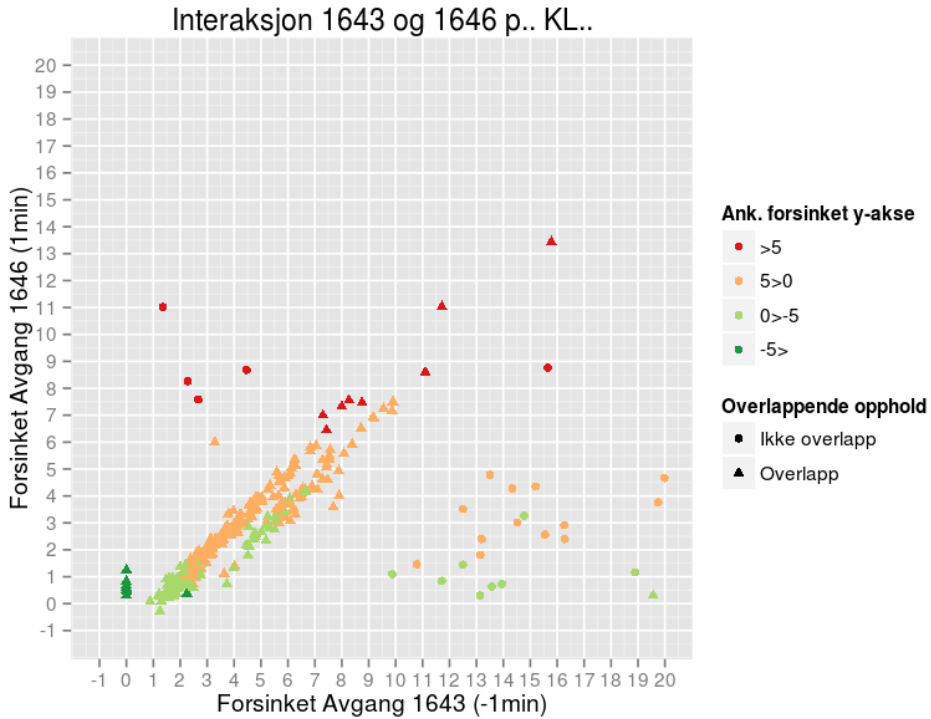
Figure 3.4.: Graph showing a correlation plot between delays on route 1646 and route 1643 (opposing directions). The plot shows that there is a positive correlation between the delays, indicating that a delay on one of the routes also causes the other route to be delayed. The plot also shows that crossing points are rarely moved, but when they are moved the trend is towards a negative correlation between delay times. Circles indicate that the trains did not pass each other at the station

All trains contain a logging device, and in case of accidents or incidents the data from this device will be examined. This results in that careful drivers often stay well within the allowed limits in fear of straying outside, thinking it is better to be on the safe side and rather arrive a bit late, than being close to the limit and be on time.

The time schedule given is the starting point, but it is difficult for train drivers to know upfront whether or not the schedule is likely to hold. Delays often propagate from other trains, and external circumstances also contribute to delays. All of these factors contribute to make it difficult for train drivers to keep a mental model of the traffic on the rail network, and it may be difficult to perceive why a traffic controller wants them to increase their speed when the schedule seems to hold fine. According to SINTEF there is some variation in how well traffic controllers and train drivers communicate. [2, p. 19]

There are also times when the train drivers are left out of the loop. One example is a situation observed in the PRESIS-project:

> A traffic controller points to a train quite a bit out from Drammen and says
> that if the train driver speeds up a bit he will be able to cross before the airport
> express train, if not he will have to wait a long time before the lines are clear.
> The controller does not follow up on this and the train keeps up the same pace
> as before and thus has to wait for a considerable amount of time at Drammen.

When asked later the traffic controller had answered that he didn't want to stress the train driver as some train drivers are glad they are not being asked to increase their speed.

Train drivers plan their driving according to the information they have, and when replanning occurs they are rarely informed and may often find themselves coasting into a station where they expected to stop and wait, but instead they receive a green light indicating for them to proceed to the next station. Tschirner et al finds that train drivers in most cases have no choice, but to act in a suboptimal manner due to lack of information.

[3]

Tschirner et al elicited these goals for train drivers [3, p. 394]:

- Maintain safety

- Punctuality

- Smooth ride/comfort

- Provide good information to passengers

- Energy saving

- Minimize wearing

- Control Workload

3.1.4. Current situation

In Norway, planning of train expedition is done using an electronic system called TIOS, which also visualizes the actual train expedition process and compares it to the planned. Although planning is done using TIOS, since traffic controllers work using a printed copy of the train graph changes normally does not get communicated back into the system [2].

Researchers at SINTEF have developed a tool to aid train traffic controllers in rescheduling trains. The system uses speed profiles and current data from TIOS to generate new train graphs automatically with focus on minimizing delay times and moving passing points as necessary. When the meeting point for passing trains are moved, the train drivers are, as before, notified by the traffic controllers or by indication of signals when arriving the original crossing point. Initial tests of the system have been successful. [15]

In January 2014 a new information system called FIDO was put into testing at Ofotbanen, and the plan is for the system to be rolled out for the whole of Norway in

October 2014 [30]. FIDO gives digital access to updated route information and route announcements for both train drivers, train personnel, train operators, and other interested parties [31]. FIDO is designed to provide information about routes, maintenance work on track, and temporary changes in the infrastructure. The information in FIDO will be maintained and updated by the traffic controllers. Since FIDO replaces the old printed schedules it requires that all cabs/train drivers are equipped with a tablet computer, or similar, to access FIDO. [32]

3.2. Gamification

Gamification can be defined as "(...) using game-based mechanics, aesthetics and game thinking to engage people, motivate action, promote learning, and solve problems" [6, p. 10] and can take many forms; from incorporating a scoring-system in an existing system, or turning a daily jog into an interactive story, to using a game board to play out a factory work-flow in an office before trying it out in practice [6, pp. 2-6].

Often gamification is being used in its simplest form, introducing rewards for certain behavior. Rewards can come in various forms; achievements, points, experience points and the ability to level up, ranking lists or score boards. Applying these forms of gamification can result in loss of intrinsic motivation, and also creates a dependency to these elements as extrinsic rewards reduce intrinsic motivation [33].

More involved and meaningful forms of gamification can involve creating avatars to learn from, tutorials or interactive guides or interactive feedback. Nicholson [33] suggests the following six concepts for meaningful gamification: Play, exposition, choice, information, engagement, and reflection.

Reflection is a critical process in learning from past experiences [34]. To get better at anything requires the ability to analyze own performance and find areas for improvement.

(NSB) Pt. 47. Dombås - Trondheim S
Søndager - fredager
Hast. 130

1 Avst. Oslo S	2 Stasjoner mv.	3 Spor	4 Til	5 Merkn.	6 Fra	7 Krysser	8 Kjører(-s) forbi
	Oslo S......................				*16.07*		
343.04	Dombås ....K+	2	*20.04*		**20.07**		
352.40	*Gardsenden Bp ....*						
361.65	Fokstua....................	2			19		
371.14	*Vålåsjø Bp..............*						
381.74	Hjerkinn	1		X	30		
393.23	Kongsvoll................	1		X	37		
407.12	Drivstua	2			48		
418.59	*Driva Bp ....*						
429.28	Oppdal	1	21.02		21.05		
441.35	Fagerhaug	2			12		
455.17	Ulsberg....................	1			21		
466.35	Berkåk....................	1		■	30		
477.31	Garli.......................	2			37		
486.60	Soknedal	1			43		
493.60	*Skjærli Bp ....*						
501.20	Støren.....................K+	1		■	55		
504.44	*Krogstad Bp...........*						
507.89	Hovin	2			22.00		
511.20	*Horg Bp ....*						
514.78	Lundamo................	2			05		
517.69	*Helgemo Bp ....*						
520.49	Ler...........................	2			09		
524.77	*Kvål Bp ....*						
528.77	Søberg.....................	1			15		
532.09	Melhus	1[1]	22.18	●	21		
537.11	Nypan......................	2			26		
541.41	Heimdal	1		■[2]	31		
544.11	*Kolstad Bp ....*						
546.44	Selsbakk..................	2			35		
548.82	*Stavne Bp ....*						
550.76	Trondheim M..........K+	7			38		
552.87	Trondheim S ....K+	2	22.43				

1. Spor 2 helligdager.
2. Reisende fra Heimdal tas ikke med.

Figure 3.5.: Excerpt of a train schedule from the service route book.

Modern technology can help this process. A golf player can videotape his or her swings and compare the video footage to other players' or earlier footage, while fighter pilots can practice in simulators - much cheaper and safer than getting shot down in an actual aircraft.

Nicholson suggests that there are three important stages to reflection: Description, analysis, and application. Description involves thinking about what actually happened

158.66	Larvik	K+	1	06:21	06:22				▲
157.20	Alfr. Andersen Mek. Verksted Og		1		06:23				
149.80	Lauve		1		06:28				
139.52	Sandefjord	K+	1	06:34	06:36				

TO-267-2013:
Midlertidig nedsatt hastighet

Strekning:	Sandefjord - Lauve
Fra - til km:	141.2 km - 142.1 km
Ny hastighet:	50 km/h
Årsak:	Ustabile sviler
Gyldig fra:	08.07.2013 - 08.07.2013

☐ Jeg kvitterer på at jeg har lest og forstått kunngjøringen

134.80	Torp		1		06:40				
128.24	Stokke		1		06:45				
121.06	Sem		1		06:49				
113.90	Tønsberg	K+	1	06:55	06:59				

Figure 3.6.: Excerpt from a train schedule in FIDO.

in an activity. Analysis is seeing the connection between own action and activity outcome. Application involves utilizing gained insight in achieving a better performance the next time the activity is performed. [33]

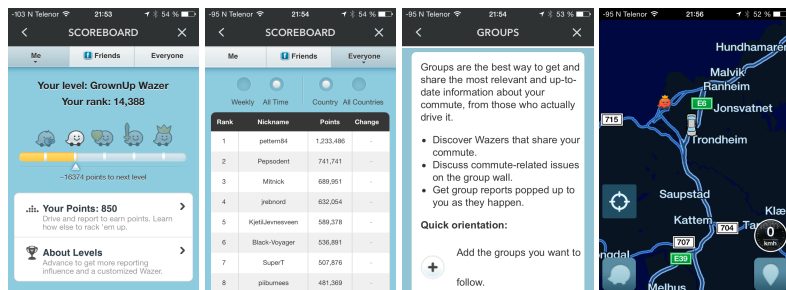## 3.2.1. Gamification in information systems

Figure 3.7.: "Waze" allows users to join groups, find people who shares their commute, edit the map, and get live updates based on other users data. Users contribute map data just by using the app while driving.

Game design elements have also been introduced into other contexts; systems which in various ways try to engage the player by giving them rewards for accomplishing tasks, or performing tasks in a certain way. One example is "Waze" which is a "community-based traffic and navigation app" [35]. Users of Waze gets points for using the application while driving, and ranking is based on points and contribution. Waze has quickly grown to become a very valued company [1]. In addition to points and ranks which are quite artificial constructs, Waze also promises to tell the user when someone finds a shorter route for their commute (or other trip) – this ought to increase motivation to use Waze. Figure 3.7 on the preceding page shows some screen captures from the Waze user interface.

In another case [37] simple gamification was tested out in an oil separation process system (see Figure 3.8 on the next page) where they tried to increase the operator performance by adding points and goals, but while the results did not show increased performance in the test group, they did show higher engagement and an altered workflow.

The process of reflection can be aided in various ways. Researchers at NTNU have for instance used Augmented Reality on an iPad to trigger reflection [38]. The system overlays recorded information on video captured by the camera in real time and uses location information to align the augmented view on top of the camera view. This use of augmented reality realizes the description part of the reflection process, while analysis is partially supported, but obviously the user needs to take in and process the information to complete the analysis on a personal level.

Opower is a US-based company that has partnered with power and utility companies in reducing their customers energy footprints. The way they have done this is by applying behavioral science and putting statistical data on the electricity bill of customers (see Figure 3.9 on page 36) to trigger reflection on own energy usage. By comparing the electricity usage of a customer to that of their neighbors Opower experienced in 2013

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[1]Google bought Waze for 966 million US dollars in 2013 [36]
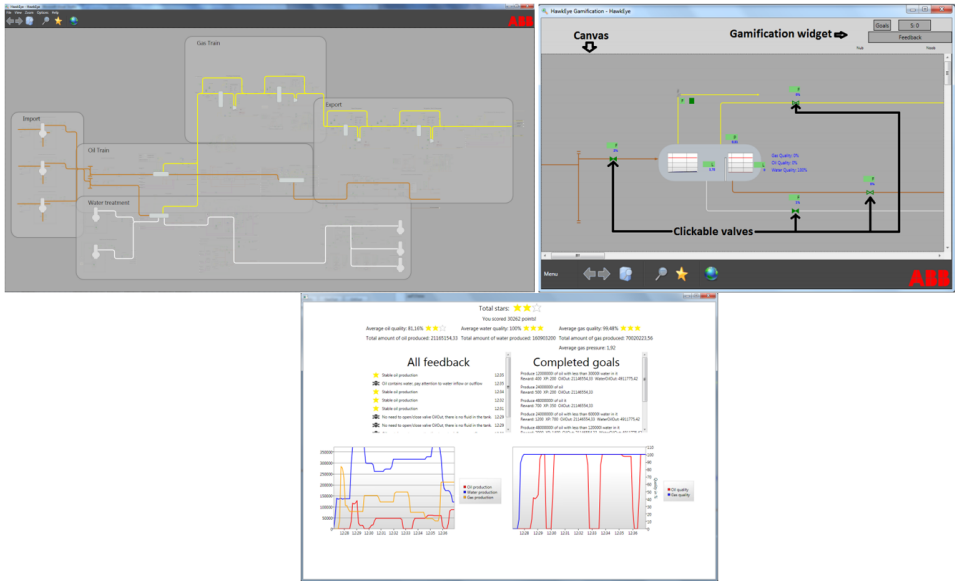
Figure 3.8.: Non-gamified HMI on the left, gamified on the right. Bottom center shows a result page from the gamified system that is shown after finishing. [37]

a 1.9 TWh reduction in consumption among their customers. The average reduction is around 2%. In addition to the graphs on the electricity bill Opower also has a portfolio of software, both for end users and for their direct customers - the power and utility companies. Opowers approach is also interesting when compared to what is commonly done in gamification. They do not utilize an absolute ranking list, but instead compares customer performance against average and "efficient" average neighbors. [40, 39]
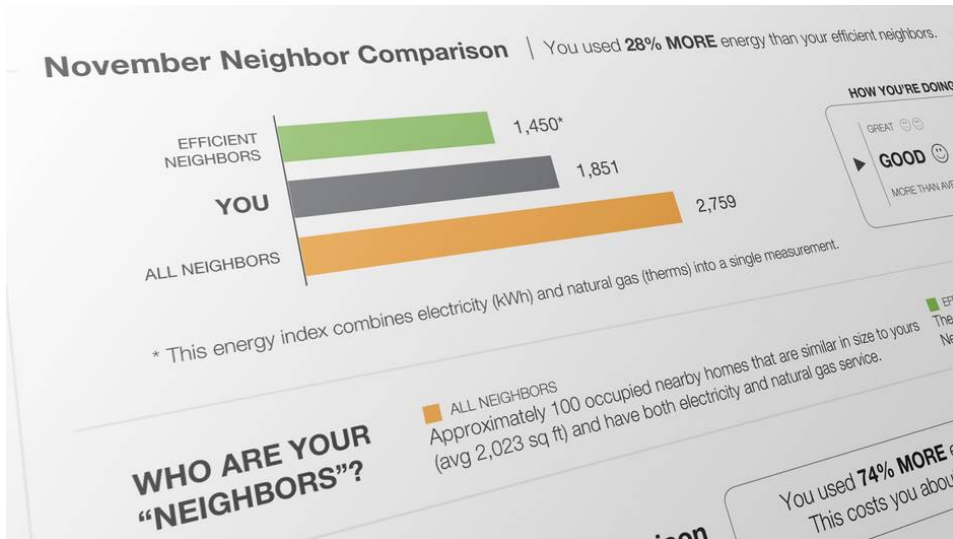
Figure 3.9.: By comparing the customer's energy footprint with their neighbors and giving smilies for efficient household Opower's customers have on average reduced consumption by 2% (image from [39])

3.3. Situational Awareness

Situation Awareness (SA) is a theory focused on operator environments and their mental models. Endsley [5] defines three levels of SA:

1. "Perception of the elements in the environment".

2. "Comprehension of the current situation".

3. "Projection of future status".

Level 1 SA is the base level. One see what is happening around one, but one does not understand the situation. If one manage to achieve level 2, one also understand what is

happening, but cannot yet understand what this will lead to. Only at level 3 SA will one be able to understand the future implications of the current situation and own responses to it.

Human short term memory is one of the most important tools for aiding situational awareness, but it is limited to seven items ($\pm$ two items) [5]. As a person becomes familiar with a type of situation that person develops a mental model that also supports situational awareness and allows that person to use less of the short term memory, or to group certain information together in a way that gives a more efficient use of memory slots. [5]

3.3.1. Examples of general SA

Achieving higher levels of SA requires the ability to process the information gathered through level 1 SA and apply a fitting mental model based on level 2 SA. For most daily tasks achieving some amount of level 3 SA is quite easy: If one is stuck in traffic on the way home from work then one perceives the amount of cars around as high, and also know from experience that the speed is slower than usual. With this level 1 SA information one can then compare that to previous experiences. Having experienced similar situations before a mental model is already developed and will automatically be used to project what this does to the travel time, and thus arrival time. Figure 3.10 on the next page shows how situational awareness is an integral part to decision making, and how the feedback on actions performed goes back into creating better mental models that can help achieve higher levels of SA.

On the other hand – if one was stuck in traffic en-route to an important business meeting in an unknown area this mental model would not be nearly as good. Projecting how much delay to expect becomes much more difficult, and one would have to use aids such as a map and mathematics to try to calculate the increase in travel time. This simple example shows how much value there is in experience and well-formed mental models.
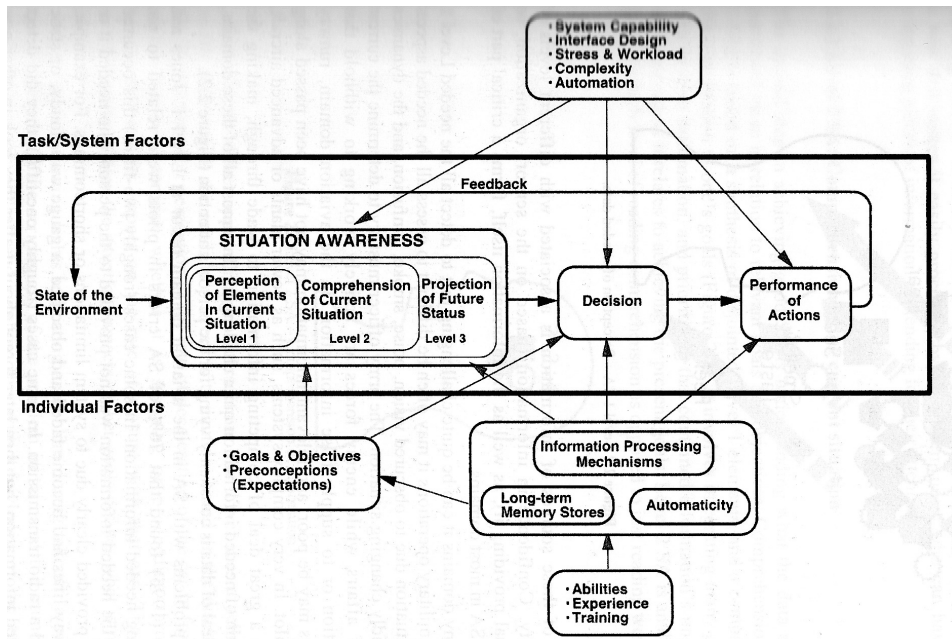
Figure 3.10.: The model shows how situation awareness is an integral part of decision making. The model also shows other factors that contribute to decision making, and how the decision process can lead to better situation awareness in the future. From [5]

Sometimes more than one actor needs to have a "common ground" - a mutual understanding of the situation - this is called shared situation awareness [5, p. 196]. High levels of shared SA allows actors to understand each other and the situation easily, while low levels can cause communication issues and makes successful collaboration difficult.

3.3.2. Situational Awareness Systems

Computer systems can easily attain what we refer to as level 1 SA, but that in itself does not necessarily support human SA. To support human SA the software system has to be designed with the human limitations in mind. Creating a design that supports the goals of the users often means not having a technological approach (e.g. displaying raw data sources – see Figure 3.11) to the system. Examples of this can be combining multiple data sources into a view that easily visualizes significant information and thereby reducing the users mental workload. [5]
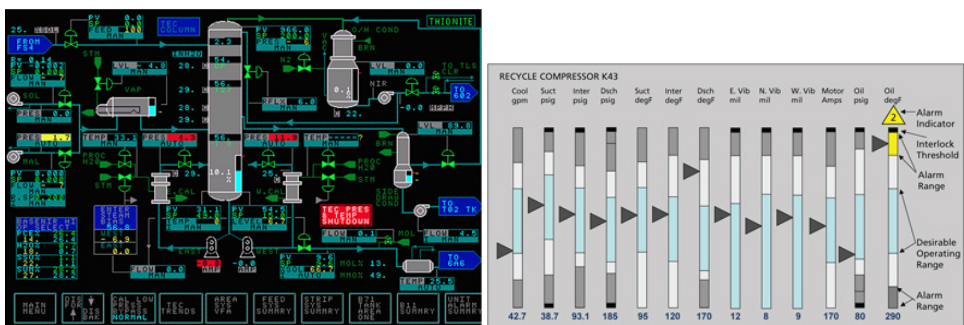
Figure 3.11.: A well designed system can reduce operator training and their mental workload, as well as making it very easy to see if any control or operational parameters are abnormal. The system on the right shows thresholds for normal operation, and also which thresholds generates a warning. [41]

A simple example that illustrates SA is a GPS navigation unit. Imagine the display showing the current coordinates (latitude and longitude), elevation and angle of direction as numbers, next to a map showing the current grid, but not the placement and angle on it, clearly this is not something the users would find very helpful, and it definitely would not support SA. The way the navigation unit transforms this GPS data by superimposing the

route and a small marker on the map, then pointing the marker or the map in the direction of travel — that is supporting situational awareness. The navigation unit creates a mentally affordable way to create models of unknown areas, and as a bonus gives information about the planned route and visualizes it in the context of the surrounding area.

Looking back to the earlier example of being stuck in traffic, modern GPS navigation units often have access to traffic information, broadcast via radio or downloaded from a cellular Internet connection. Traffic updates allow them to show where to expect queues, roadwork, or traffic accidents. They also have the capability to recalculate routes, and update the estimated time of arrival based on both actual and expected conditions. Compare this to guessing how much queue is in front of one and trying to recalculate one's own travel time based on distances and best guesses. The navigation unit clearly provides an equal or better amount of level 3 SA with a fraction of the mental workload required through manual processes.

3.3.3. SA for vehicle operators

There exists a multitude of systems designed to support operator SA. SA systems range from the speedometer in a car (level 1 SA), to Heads-up-Displays in fighter planes. These systems are in place to ensure the operator meets their goals. Car drivers wish to obey the speed limit[1], while fighter pilots have quite more complex goals like avoiding observation, gunfire, and missiles while completing their mission objectives.

Another example of a system that gives the operator SA is GPS navigation units which makes it easier for a car driver to perceive their immediate environment and make assumptions about their trip. Operators of ordinary aircraft also have systems that contribute to their situational awareness, one example is the Instrument Landing System

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[1]Assuming that car drivers in general want to keep their driving licenses and not get ticketed for speeding

(ILS) that indicates the trajectory towards the runway during descent.

Characteristically SA systems provide the operators with information about their environment that they cannot perceive using their own senses. Better systems can convey complex information with lower mental workload for the user. As an example, both cars and airplanes are equipped with speed indicators, but a car have less instruments that require the operators surveillance and attention. The aircraft operator have to spend a considerably higher amount of time looking after the instruments and making sure that everything is within operational limits and that they are flying level in the right direction at the correct speed. Figure 3.12 shows an example of an aircraft display that supports level 2 SA by combining multiple data sources in one view that allows the pilot to gather whether or not the speed is good in relation to the planes attitude.
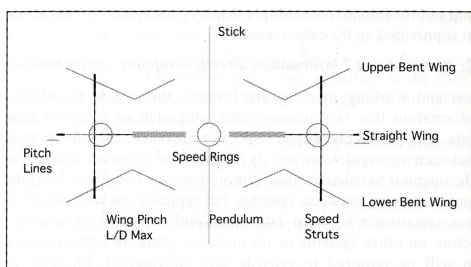
Figure 3.12.: The Oz concept shows integration of several data sources in a view that gives level 2 SA and allows the pilot to spend more time attending to other tasks than making sure the aircraft's operational parameters are sound. From [5, p. 84]

3.3.4. SA in trains

In general most of the train driver's SA is coming from their own mental models, observations, and knowledge. Perception of the environment in form of signals, observation of own speed and other traffic combined with knowledge about the route. Very few information systems have tried to give the driver increased SA.

One system that fits in the SA category is the Dutch system "RouteLint". RouteLint provides train drivers with the signal situation on the track segments ahead of the train, indicating if they are blocked or free (thus, indicating the traffic situation ahead of the train). Testing has shown positive result, but with energy savings at only around 3%. The system supports level 1 SA.

Figure 3.13.: The RouteLint user interface. [42]

Information systems in trains have commonly been used for other purposes than increasing the driver's SA. See 3.4 for more about systems designed to assist train drivers in choosing the right speed.

3.4. Driver Advisory Systems

In the past decade several projects have sought to optimize train driver behavior through the development of information systems that provide the train driver with either information about traffic, or giving driving advice such as recommended speed. These Driver Advisory Systems (DAS) could be utilized to increase the train drivers SA, in turn aiding them to operate with minimal disturbance to other trains, reducing energy consumption and increasing punctuality [43]. Figure 3.14 on the next page shows an example of how typical DAS can look like in a train cab.

As part of SINTEF's "Presis" project there is a plan to test one or more driver advisory systems in collaboration with NSB, which in turn can be connected to TIOS and automatically receive this information and notify the driver of any changes in scheduling and automatically adjust the speed advice given to the driver. One of the main advantages of driver advisory systems are that they, if followed, can get the train to meeting points and stations precisely within a very small time window.DAS systems can be configured manually or automatically with information from other systems. Using DAS systems results in less variance between different drivers, and reduces power usage by giving smoother driving with less acceleration and braking, which also increases passenger comfort and reduces wear on material and infrastructure.

Although driver advisory systems seemingly reduce operator workload by telling the train driver which speed to hold, removing the need to work out this through the use of mental models, it is hard to argue that they give any considerable contributions to the SA of

Figure 3.14.: An example of a Driver Advisory System mounted in a train cab (the extra screen on the right side.). Picture from [44]

the driver. The mental workload on the driver in using a DAS system is clearly dependent on how the user interface is realized and information is visualized. Existing DAS systems do not contribute to the understanding or perception of the traffic situation.

3.4.1. Existing systems

There are a number of driver advisory systems, some are commercially available and some are not. This section first introduces two systems that are not available on the commercial market, before presenting several systems that are.

3.4.1.1. FARE

The Swiss system "FARE" displays driving advice based on calculations using real-time updated schedules. The system gives advice for increasing, reducing or keeping the current speed. The system gives advice, but does not support SA.[4]

3.4.1.2. CATO

In Sweden a system named "CATO" has been developed and tested. CATO displays target points, speed limits, and the height profile, as well as advice on driving speed to reach the target points within the time-frames given by the schedule. In the same manner as "FARE", CATO does not do much to support SA [4], although one can argue that level 1 SA is supported through providing height profiles and target points. Figure 3.15 on page 47 and Figure 3.16 shows the graphical user interface and system architecture of the CATO system.

3.4.1.3. EDAS

Italian producer FAR Systems have created a DAS named "EDAS". The system consists of many components (see Figure 3.17 on page 49), and has an easy to read cab display (see Figure 3.18 on page 49) that shows the last and next stations, as well as expected arrival time, and delay or advance on schedule. EDAS does not give speed recommendations, but recommendations about energy usage or time [45, pp. 3]. In that manner EDAS seem to provide better support for SA than other existing systems.

3.4.1.4. Energymiser

TTG Transportation is the Australian company behind Energymiser, a product which they claim have achieved up to 23% reduction in energy consumption, as well as increased

on-time arrivals. The system displays elevation profile, speed, speed restrictions, track curvature, and target with estimated arrival time (see Figure 3.19 on page 50).

Energymiser does not integrate as much with the train's control system as EDAS, and focuses more on the administrative aspects of being able to look up speed profiles, and generate performance reports and benchmarks (see Figure 3.20 on page 50. In terms of SA Energymiser provides some information about the upcoming terrain and the outline of the rail network. Experienced train drivers will most likely have knowledge about the areas they frequent, and this is mostly valuable for drivers who do not know the areas well.

3.4.1.5. Greenspeed

Greenspeed has been adopted by Danish Railways (DSB) and was developed by the Danish company Cubris. Being used by DSB since 2012 the system has, according to Cubris[1], proved to be economical both with regards to energy savings and increased precision. [47]

Greenspeed supports being integrated with traffic managements systems and train traffic controllers' re-planning can therefore automatically be updated in the DAS and effectuated by the driver in near real time [44]. In terms of SA the Greenspeed user interface makes it easy to compare your speed to the speed limit and to the recommended speed (see Figure 3.21 on page 51. It is also easy to see if you are behind or in front of the schedule, but this feature is not as prominent as in EDAS.

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[1]No official data has been posted
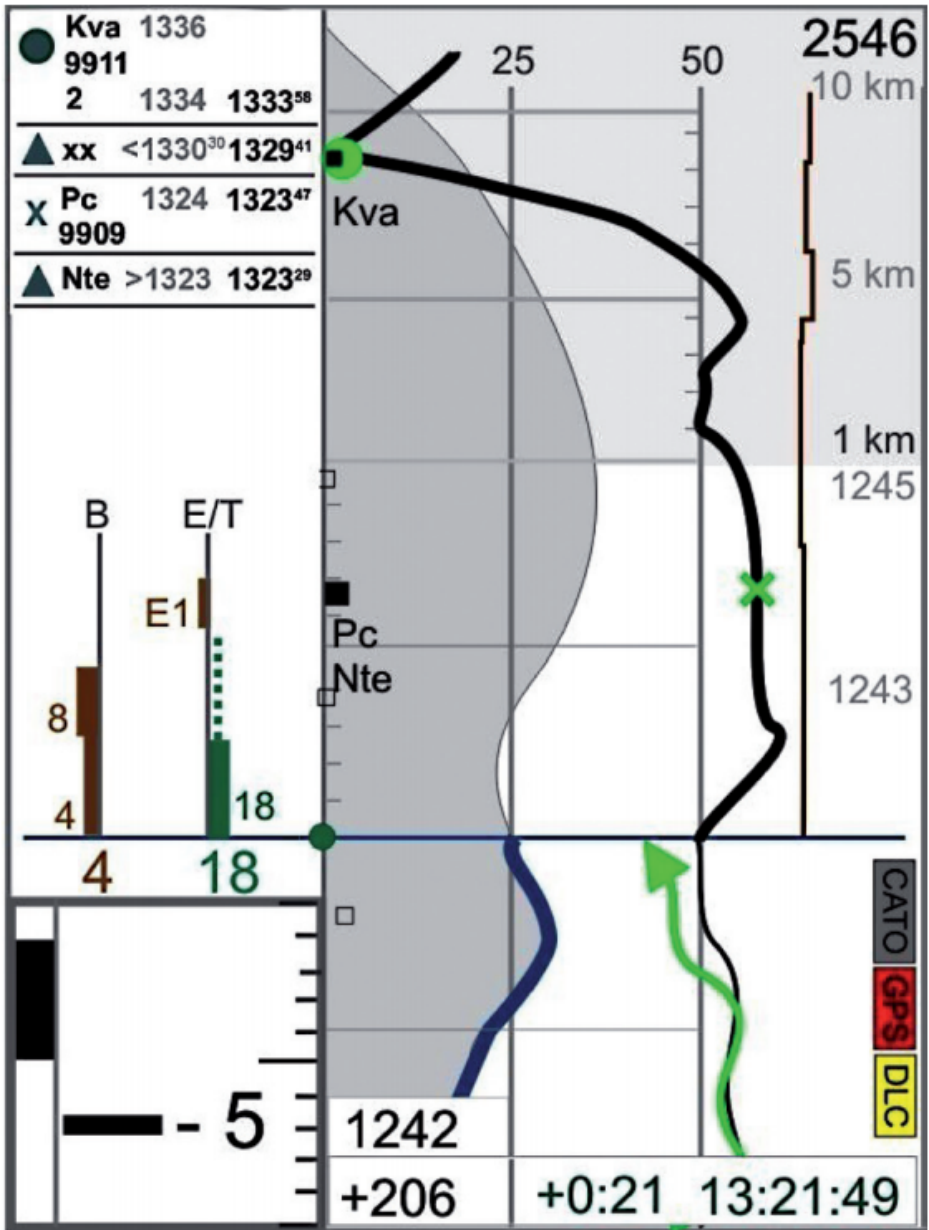
Figure 3.15.: The CATO user interface. The system provides height profiles, speed graphs and target points for the driver to reach within a limited time window. (from [43])
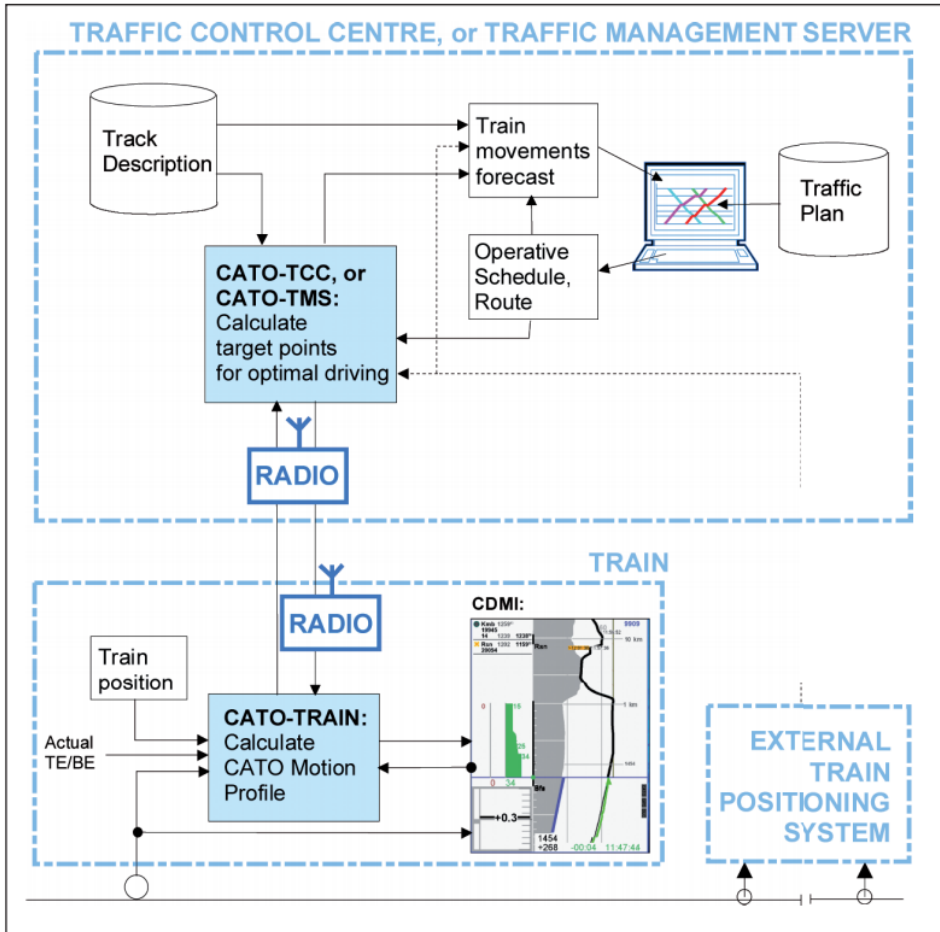
Figure 3.16.: An overview of the CATO system architecture. (from [43])
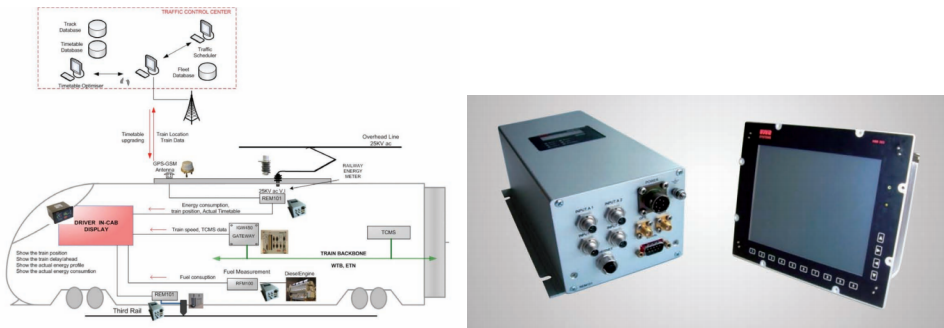
Figure 3.17.: An overview of the EDAS in-train system components on the left, and the EDAS in-cab components on the right. Images from [45]

Figure 3.18.: A screenshot of the EDAS user interface (from [45])
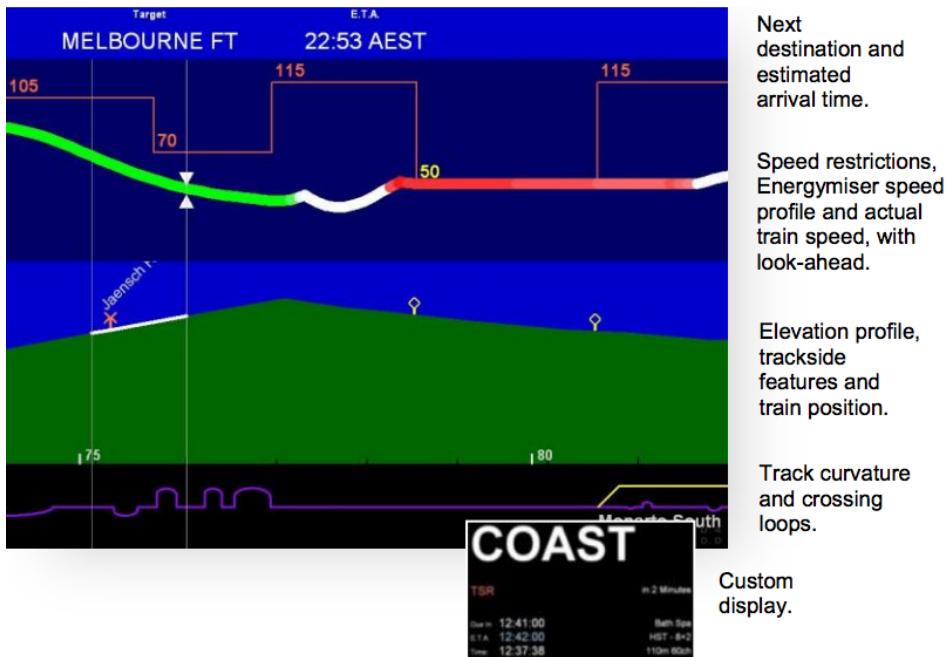
Figure 3.19.: A screen from the Energymiser user interface (from [46])
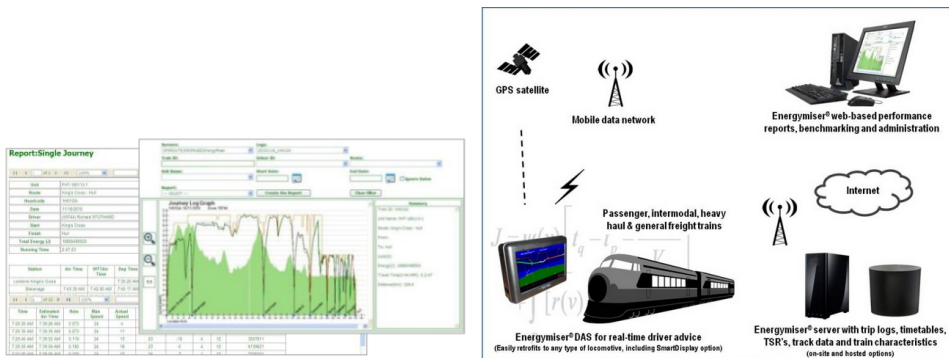
Figure 3.20.: A screen showing Energymiser data from a single run on the left, on the right
the Energymiser system's main components. Images from [46]
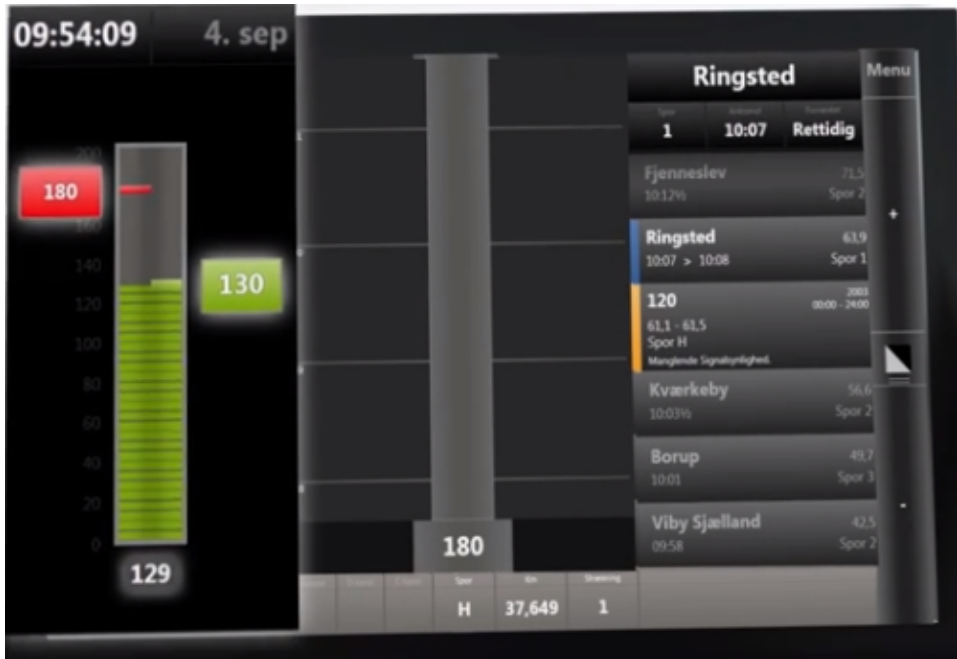
Figure 3.21.: A screen from the Greenspeed user interface (from [44]). The bar on the left shows the speed limit, the recommended speed (green number on the right side of the bar) and the actual speed (beneath the bar).

4. Results

The purpose of this chapter is to communicate the results of the research process. This chapter is divided into two main sections. The first section describes the results from the workshop. The second section presents the findings from the final demonstration and evaluation of the prototype. The prototype was evaluated as described in Chapter 2.8.

4.1. Workshop

Before work on the prototype started a workshop was arranged to elicit ideas and aid in defining the scope for both the prototype and the thesis. This section describes the results of the workshop, for a description of the workshop process see Chapter 2.6 on page 11, and Appendix B on page viii for a full summary of the workshop.

The original idea was to create a DAS that both included recommendations and SA support, but since NSB most likely were going to test DAS-functionality in May of 2014 anyway, it was recommended to focus on more novel applications of information systems in trains, with a focus on gamification.

The topic on gamification engaged the workshop participants and including listing the usual suspects in gamification (score cards, high score lists, badges), the discussion also gave more solid ideas:

- Analyzing whether or not the train driver meets goals (crossings).

- Comparing speed profiles against historical and average speed profiles.

- Support reflection through retrospective analysis of trips.

The idea of making the gathered data available for management to measure train driver performance and/or skill was also mentioned, but the consensus in the workshop was that collected data should not be used for external evaluation of train drivers, as this would most likely not be a positive contribution to the work environment.

There was also a discussion on data sources and the potential of getting live data and speed profiles from another SINTEF-project. In later discussions with SINTEF researchers it was learned that the speed profiles were mere calculations of average speeds, and the speed profiles where from different areas than the GPS- recorded datasets, making comparison between a recommended speed profile and recorded one difficult. In addition the live data sources available were found to have partial publishing delays, in certain cases arrival and departure times would be available too late for real-time use. These factors lead to the decision of using historical datasets instead of live data, and calculating the average speed between stations instead of relying on pre-generated sets.

In summary the workshop contributed valuable information and ideas to the project and helped shape the development process and end results.

4.2. Pilot testing

This section describes the results of the pilot test which was performed using the help of a volunteer SINTEF research scientist with extensive experience from the railway sector. The test subject was first given a quick introduction to the system before being allowed to use it. After the testing the participant was asked to fill out a System Usability Scale (SUS) form before moving on to a more in-depth interview. For a more detailed description of

the method and process see Chapter 2.8 on page 13, and Appendix A on page i for a transcription of the interview.

During the pilot test a larger dataset than during development was used, and some combinations of routes and dates had data that resulted in slight hick-ups with the system. The bugs experienced when using a larger dataset did not have a severe impact on the usability, except that one had to choose a different permutation of route and date.

The pilot testing indicates that the prototype was seen as both easy to use and consistent, but a bit too cumbersome, see Figure 4.1. See Chapter 5.5 for a discussion on the test results.

In the interview the test subject states that the information provided by the prototype system is both interesting and contributes positively to the understanding of the traffic situation. Both by providing an insight into the reasons why traffic is moving slowly in congested areas of the network, and also by showing opportunities for catching up with the route or driving more economically when there is less traffic.

The test subject also finds the prototype to be an interesting tool for reflection when used retrospectively. A train driver could play back interesting events during the day, or see how own driving style or delays has affected other trains later on - or how the driving style or delays of other trains had affected theirs.

Among the findings was the wish for information about the speed of other trains and information about whether or not they were still driving according to schedule. The ability to be able to scroll through time, or jump to a location and the time associated with being at that location was also a requested feature for a retrospective view.

With regard to the conventional type of Driver Advisory Systems that provides speed advice the subject is of the opinion that combining the two systems provide more value than one of them alone. Combining a traffic view with a regular DAS would provide an understanding of how the advice from the DAS is calculated and should make it more

System Usability Scale

© Digital Equipment Corporation, 1986.

	Strongly disagree				Strongly agree
1. I think that I would like to use this system frequently				X	
	1	2	3	4	5
2. I found the system unnecessarily complex	X				
	1	2	3	4	5
3. I thought the system was easy to use					X
	1	2	3	4	5
4. I think that I would need the support of a technical person to be able to use this system				X	
	1	2	3	4	5
5. I found the various functions in this system were well integrated					X
	1	2	3	4	5
6. I thought there was too much inconsistency in this system	X				
	1	2	3	4	5
7. I would imagine that most people would learn to use this system very quickly					X
	1	2	3	4	5
8. I found the system very cumbersome to use				X	
	1	2	3	4	5
9. I felt very confident using the system				X	
	1	2	3	4	5
10. I needed to learn a lot of things before I could get going with this system	X				
	1	2	3	4	5

Figure 4.1.: The SUS form that was filled out during the pilot testing. The prototype scored well except for points 8 and 4.

likely that the train driver follows the advice from the DAS, this is especially in situations where the advice from the DAS feels contradictory to what the driver would normally do. The opinions of the subject on how the traffic view contributes to the acceptance of speed advice are congruent with the suggestions of Tschirner et.al [4].

It was also noted by the subject that with the forthcoming introduction of ERTMS, a common traffic management and signaling system for Europe [48], DAS functionality might become part of standard in-cab instrumentation, and that combining traffic view and DAS-functionality in the same system might not be necessary.

When asked about potential usability of such a system for traffic controllers, the subject answered that as the system lacks capabilities for projecting future state based on the current state it would likely not provide much decision support or increase the level of SA with the traffic controllers. As a tool to support reflection for traffic controllers with a personal interest the system could fare better. Also suggested was using such a system for analyzing one or more situations, especially to learn from good or bad decisions with regards to re-planning.

This chapter has summarized the results from the workshop, and shown the findings from the pilot test of the software prototype developed as an effort to answer RQ 1. The workshop provided ideas and information that was used as the basis for further work and ultimately led to the development of the prototype that was evaluated in the pilot test and the definition of a framework that allows for gamification of an information system tailored for train drivers. The evaluation of the prototype system found the system to be quite usable, although a bit cumbersome. The prototype was found to contribute both to a train situational awareness by supporting the train drivers perception of surrounding traffic and as a tool for retrospective analysis of situations through the use of playback functionality and time compression. Further discussion of the findings presented in this

chapter takes place in the Discussion Chapter.

5. Discussion

The purpose of this chapter is to discuss the results of the work on this Thesis and the methodology used, as well as to define and discuss a framework for using gamification to increase the intrinsic motivation of train drivers to be punctual. The first section is dedicated to the framework for Gamification, while the next sections discusses the results presented in the Results chapter, before both the evaluation process and research method gets evaluated in the last sections of the chapter.

5.1. Applying Gamification

This section defines a framework that can be used to introduce gamification elements in information systems meant to support train drivers. The framework is based on previous work presented in Chapter 3.2 on page 31, combined with acquired domain knowledge, and results from the research process.

The framework focuses on strategies that apply gamification without replacing intrinsic motivation with external – instead they support intrinsic motivation through reflection and motivate the train driver to improve their own skills. The main points of the framework are:

1. Support reflection through retrospection.

2. Ease understanding

3. Emphasize interesting points

4. Compare, but do not rank.

5. Positive reinforcement

The key point in the framework is the reflection process, and points 2 and 3 also contribute towards the goal of creating a reflection process that works. Points 4 and 5 are important to make the most of traditional human behavior, like competitiveness and the need for positive reinforcement.

5.1.1. Learning Through Reflection

Train drivers work in an environment that requires them to monitor several systems as well as pay attention to their surroundings and acquire information from signals along the train line [49, 50] while driving at high speeds. There are also important safety aspects that require the train driver to keep a look ahead, this results in that the train driver does not have time to stare at screens in the train-cab.

Any information system in a train-cab should convey information in format that is as glance-able as possible. Unnecessary intrusiveness of any system should be avoided, that includes user interfaces asking for attention or audible bells.

By using gamification to support reflection one can encourage train drivers to learn about their own behavior and performance while not operating a train, and bring what is learned back to work. To maximize the outcome from time spent in a retrospective process it is important for the system to utilize techniques that simplify and shorten the interaction process.

A system that does not contribute to a retrospective process will not be able to give a meaningful contribution to learning for train drivers.

In the pilot testing of the prototype developed in the work on this thesis it was found that the prototype could contribute to reflection, this was not part of the design goals, but a result of designing the prototype to be tested with historical datasets. The test subject suggested that the system should have the possibility to navigate forwards or backwards in time, thus allowing rewinding or skipping ahead.

5.1.2. Ease Understanding

Since the recommendation is that a gamified system is to be used as a tool for reflection after work, the system should strive to make it possible to understand the information presented with a small mental workload. That means simplifying the information that is presented using aggregation or other techniques that can contribute to reducing the amount of data presented, or using visualizing techniques that allow seeing the interplay unfold. One example is the prototype system that was developed in the work on this thesis. The prototype has playback functionality and support for time compression, this allows seeing a trip that took several hours unfold at high speed in just minutes.

Making the information presented easy to understand will lower the learning curve for the system, and should contribute to increased adoption of the system.

5.1.3. Emphasize Interesting Points

Many train routes are long and will generate high amounts of data. Automatically identifying key points will be a success-factor for generating user interest in the system. If it is difficult to find situations that are interesting the user will most likely find that using the system requires too much effort after a long workday, the system might seem more

interesting if it automatically highlights interesting information. Interesting information might be stations where a crossing did not go by schedule, or a stretch where the train driver caught back a delay.

Between Oslo S (OSL) and Trondheim S (TND) there are 72 stations, it is difficult to imagine that all of these will have events that are interesting, and even if they do it would be too much information to try to take in a short amount of time. Human short term memory is also limited, therefore a the system should present a selection of less than 10 interesting situations, or key data points. Automating a process where the system selects interesting data points, for instance by finding patterns that deviate from the norm in positive or negative ways, should contribute to achieving a positive reflection process where the user is not left with a feeling of an overflow of information.

5.1.4. Comparison

A key part of understanding own skills is comparing against other individuals, but certain environments contribute to making it difficult to perform this self-assessment correctly. Studies of car drivers show that most car drivers rank themselves as better than average, and only 1% rank themselves as worse than average [51]. Since train drivers have less interaction with each other than car drivers, ranking own skill can appear to be quite difficult.

When comparing train drivers to each other it is important that the system does not rank them. Scoring very low can cause loss of motivation and self-esteem, or increased levels of stress [52]. Instead of ranking, a better way [39] is for the system to give an indication of whether or not the train driver is doing well, and if applicable indicate that others are doing better. Figure 5.1 on the next page shows an example of how a comparison could be visualized.

Although ranking train drivers amongst others based on datasets might seem trivial,
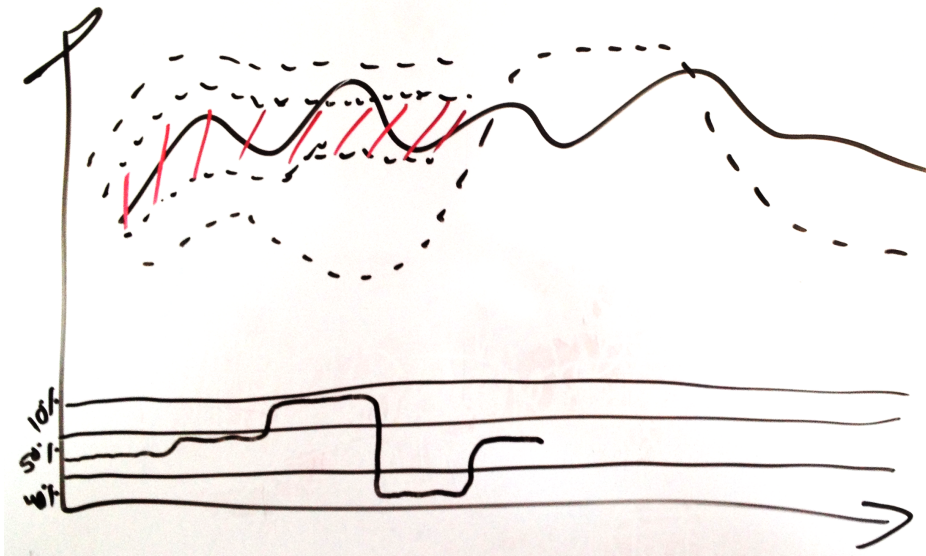
Figure 5.1.: Example of how a comparison of driving profiles of train drivers could look like

there are some pits that need to be avoided. The speed profile of any train is affected by the interplay between traffic, traffic controllers, and other external factors. To overcome these obstacles the system will need to make use of finesse to decide when a train driver actually is the one controlling the events. This will most likely require a tight integration to signal data, other data sources, and comparison with other routes on the same stretch, both before and after.

5.1.5. Positive Reinforcement

Research on process improvement has shown that a bad experience is three times as memorable as a good one [53]. Bad experiences also builds negativity, and most persons

met by a negative system will most likely avoid using it. The system should encourage improvement by pointing out situations where the train driver compares well or meet goals like crossing points in time, rather than pointing out the times where all crossing points were missed. Ideally the system should also keep a count of negative and positive feedback, and avoid sending more negative feedback if there is a lack of positive.

Focusing on positive feedback has the potential to contribute positively in an otherwise bad situation, but it is important that the system remains credible as well. Telling a train driver that something went well, when it clearly did not, will lower the credibility of the system and reduce acceptance among users.

5.1.6. Framework Summary

In this section a framework for applying gamification in information systems directed towards train drivers has been presented. The framework emphasizes the need to support the intrinsic motivation of train drivers to improve own skills or behavior. A key point with regards to the work environment of train drivers is to allow the train drivers to focus on what is their actual work, not on meeting some metric that will fool the system into thinking the train driver did a good job. A good implementation needs to support reflection through retrospective analysis of curated data presented in a way that is coherent and easy to take in. The system should present interesting information automatically, and filter out unnecessary information in favor of creating few but easy to remember points of information.

5.2. Workshop

The workshop was arranged to elicit ideas and aid in defining the scope for further work.

Evaluating the contributions from the workshop it is clear that the focus for the prototype

has changed away from gamification. There were several issues with developing a system prototype using gamification; first off the datasets are imperfect. The GPS-recordings contains less information than what is optimal, several stations are left out in the recorded data, making it difficult to work with speed profiles. Second, the schedule data can only give a certain amount of information, and because the signal points that register station departure and arrival is located outside the station it is very difficult to assess how much time a train should actually be spending at a station when the schedule data only contains arrival times for stations where the train is supposed to stop.

Because of the aforementioned reasons the focus was shifted to creating a prototype that supported situation awareness. The ideas from the workshop have been used in defining the framework for gamification described in Section 5.1 on page 58.

Part of the workshop also focused on acquiring data sources, and the feedback during the workshop seemed promising. Upon further research the live data-feed turned out to be incomplete with regards to actual arrival times, and the speed-profiles could easily be calculated from existing data. Since the quality of the live data sources were not suited for prototype testing it was decided to use historical data and adjust the prototype to work with data in that manner.

5.3. Prototype

As part of the research process a system prototype was developed to test solutions for RQ 1 (see Chapter 1.2 on page 4). The purpose of creating the prototype was to achieve knowledge and understanding of the problem.

The developed prototype contributed positively to the scientific research, and was a proficient way to gather understanding and knowledge of the domain. The evaluation of the prototype also showed that the prototype could have applications outside of the

intended scope of the prototype.

5.4. Evaluation process

The evaluation process consisted of a pilot test of the system with a volunteer SINTEF research scientist with extensive experience from the railway sector. The evaluation process worked smoothly and the information gathered seems relevant and to the point.

Testing with more people is an alternative, but due to time constraints it was difficult to find qualified people that had the time to participate.

In terms of the methodology used, SUS form and a focused interview, both worked well. The participant seemed to answer honestly on the form, and given the interaction observed during testing the answers seems like they reflect the participants experience.

The focused interview gave good responses, and the participant didn't seem to react negatively to being recorded and seemed to be open and positive throughout the interview, and taking the time to think the questions through as well.

For a future test with train drivers it would be very interesting to prepare some situations and compare how they would act in a general situation using the only the information they would normally have, and compare that to how they would act when presented with similar situations played out in the prototype system.

5.5. Evaluation results

The results from the evaluation were overall positive. The prototype performed almost as intended. It is assumed that some small technical difficulties along with the fact that the iPad application ran in an iPad simulator on laptop were contributing factors to the test participant experiencing the system as cumbersome (see Figure 4.1 on page 55).

The technical issues were due to using a larger dataset than what had been used during development and testing, the larger dataset had some small errors that caused the prototype system to be unable to load certain route and date combinations.

During the interview the test subject could see the system as both an aid during train driving, but also as a tool to trigger reflection by playing back earlier events. Important functions in the prototype that contributed to the ability to provide reflection was the systems implementation of time compression and the ability to pause playback, as well as the ability to detach the view from the train that was tracked.

The test subject, when asked, could also see the application of such a system to have some value for traffic controllers, again as a tool for reflection.

Considering the potential use cases for systems similar to the prototype there is a good case for equipping trains with accurate positioning systems that can be used to both increase train drivers situational awareness, and be used as a tool for triggering reflection in both traffic controllers and train drivers.

Reflection is also a way increase understanding through building better mental models (see Figure 3.10 on page 38 for an illustration). Using a system similar to the prototype to get a better understanding of how the traffic flows could result in better mental models that allow for better projection, thus increasing situational awareness.

There is obviously the slight problem that one cannot force users to use a system like this, but it is not unlikely that many would find the information provided by such a system interesting enough to use the system. At the end of the interview the test subject closed off with the following[1]:

> it is very interesting to see what is going on, especially just as far away that you can't really see it, like trains that drive in the same direction that you never meet. That's a situation where one today has very little comprehension

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[1] See A on page i for a full transcript of the interview

of whether or not they are doing what they should be. Ideally one shouldn't need to know about these, they shouldn't affect you, nor the other way. Having this knowledge though shows a bit of the limits for catching up on lost time and so forth. Especially it makes planning easier if one is driving a lot behind schedule and no longer know what the right schedule is.

The above quote shows that there is a lot of potential in a system that conveys traffic information to the train driver, but for the best usability updated and accurate information about other trains position is required.

The evaluation also found several easy ways of improving the system, including adding the speed of other trains, and information about whether or not they are behind schedule. Information about the scheduled stops of other trains and the ability to easily forward and rewind time could also be interesting to add.

It is important to avoid adding too much information. The information displayed should be easy to understand and the system should require minimal driver interaction. Adding too much information could easily clutter the display and severely hurt the user experience.

5.6. Method Validity and Reliability

According to Hevner et al [11] Design Science is a paradigm of information systems that through creating new and innovative artifacts achieves knowledge and understanding of a problem.

Part of the work on this Thesis has involved creating a software artifact, a prototype system, to get a better understanding of the problem domain as defined in RQ 1 (see Chapter 1.2 on page 4).

The prototype system was developed in an iterative fashion that allowed for rapidly testing out new ideas, elicit feedback, and use the feedback for evaluation when

progressing with further work.

In retrospective the process has mostly met the intents. The main concern is the lack of interaction with the actual intended group for the prototype system developed, but with a relatively short time-frame for development the priority has been on refining the prototype and not on testing. In hindsight a milestone review with a few train drivers in the middle of the process could have provided valuable input and provided verification of design and ideas with higher certitude than the process that was used.

The co-supervisors on this thesis have extensive experience from the railway sector and has proved a valuable replacement for the lack of access to actual train drivers during the development process. How much more insight than what they have provided could be contributed by train drivers is unknown.

Originally it was intended to test the prototype using a test panel with train drivers, but due to time constraints there was not enough time and a pilot test was performed instead. The pilot test was executed on a volunteer SINTEF research scientist with extensive experience from the railway sector. The results from the pilot test are shown in Chapter 4.2 on page 53 and an interview transcript is found in Appendix A on page i. The research scientist in question had spent extensive time in train cabs as part of earlier research projects, and had good knowledge of cab environments, train driver workload and their normal levels of situational awareness and as such was an ideal replacement candidate for a group of train drivers as one person could be.

Further experiments with train drivers should be performed to assert the reliability and validity of the results found.

Another part of the work on this Thesis has involved literature studies, learning about prior art, and acquiring knowledge on the paradigms that have defined the work and results.

The second research question, RQ 2 (see Chapter 1.2 on page 4), has been answered with the definition of a framework that allows for meaningful and constructive gamification

of an information system for train drivers. The framework is founded on theories on gamification and domain knowledge acquired through the research process.

To test and verify the proposed framework will require further research and development.

This chapter has defined a novel framework for constructive gamification for train drivers. The framework supports reflection, an introspective and retrospective process that should result in learning from the analysis of own actions. The framework also emphasizes using human behavior as a way to trigger intrinsic motivation to improve own performance, and hence to increase own punctuality. Evaluation of the results and methodology has also been performed, and it is considered that the research is reliable and valid, although further research in the area is encouraged.

6. Conclusions and further work

This chapter sums up the scientific contributions of this Master's Thesis and provides suggestions for further work.

This thesis has shown that there is a need to find a way to support the traffic awareness of train drivers, and has through the application of the Design Science Research Process created a prototype system that has been evaluated to have positive effects on train driver situational awareness (RQ 1, see 1.2 on page 4). Train driver situational awareness can be supported through an information system that displays information about the positions of other trains in a map-like view in real-time. The system should contain information about whether or not other trains are running as scheduled, how much delayed they are, their planned stopping points, and their current speed. Combining such a system with a driver advisory system should contribute to increasing acceptance of the advice given by the DAS. Ideally a traffic information system should also allow for retrospective use by allowing the user to play back earlier events and thus learning from the interplay that has occurred, allowing the user to develop better mental models for future use and thus increasing the situational awareness of the user.

Train Driver Advisory Systems and information about traffic is of little use if the train driver lacks motivation to use these systems to increase punctuality. The second research question (RQ 2, see 1.2 on page 4) was founded in the idea that using techniques from gamification in a driver advisory system could be used to improve train punctuality. The

findings of this Thesis is that train punctuality can be improved by applying gamification techniques to create a retrospective functionality to a driver advisory system, or other information system, that allows the driver to analyze own behavior in the interaction between other train drivers and with help of the system understanding what consequences own action has for other trains, or vice versa. The gamified system must aid the user in identifying interesting situations and allow the user to explore on their own initiative, all the while avoiding pit-falls like ranking lists and feedback that can create negative associations towards the system. The framework suggests techniques for providing train drivers with an understanding of own behavior while giving incentives to improve by showing a balanced comparison between own performance compared to that of other train drivers, this should cause an intrinsic motivation to increase own performance and thus also punctuality.

A prototype system that provides train drivers with information about their surrounding traffic situation was created, and the evaluation of the system uncovered possible uses for the system both as a way to trigger reflection for train drivers, but possibly also for traffic controllers who could use the system for group discussion or based on personal interest.

The scientific contributions in this thesis builds upon existing research. The results are both relevant and novel, and fills gaps in existing research. The research has been performed using the Design Science Research Process and the results are considered to be reliable and valid.

6.1. Further work

This section serves to present possibilities for future work uncovered during the course of the research process.

The most obvious would be to perform tests of the prototype system on train drivers, or

build a version that can work with real time data, although for it to be successful there is a need for location data with higher fidelity than the type provided by TIOS.

A more interesting possibility for future work would be to make further explorations around the gamification framework described herein. Finding other ways to support reflection, potentially overcoming the challenges inherent in comparing speed/time datasets were one can not use mathemathical techniques such as dynamic time warping to align the curves when the time spent differs.

A further way of improving a system that provides traffic information could be to find a good way to implement the system against FIDO or data generated by ERTMS.

Finally it could also be interesting to explore how to best support reflection for traffic controllers.

References

[1] SINTEF, "Presis." `http://www.sintef.no/Projectweb/PRESIS/`. [Online; accessed 03. June 2014].

[2] A.-G. Lium and A. Werner, *Hvordan gjennomføres togledelse i Norge?* SINTEF, 2013.

[3] S. Tschirner, B. Sandblad, A. W. Andersson, P. Hellström, and G. Isaksson-Lutteman, "Analysis of collaboration applied to train drivers and train traffic controllers in sweden," in *Rail Human Factors: Supporting reliability, safety and cost reduction*, pp. 389–398, CRC Press, 2013.

[4] S. Tschirner, A. W. Andersson, and B. Sandblad, "Designing train driver advisory systems for situation awareness," in *Rail Human Factors: Supporting reliability, safety and cost reduction*, pp. 150–159, CRC Press, 2013.

[5] M. Endsley, B. Boltâe, and D. Jones, *Designing for Situation Awareness: An Approach to User-centered Design*. Taylor & Francis, 2003.

[6] K. Kapp, *The Gamification of Learning and Instruction: Game-based Methods and Strategies for Training and Education*. Pfeiffer essential resources for training and HR professionals, Wiley, 2012.

[7] K. Peffers, T. Tuunanen, C. E. Gengler, M. Rossi, W. Hui, V. Virtanen, and J. Bragge, "The design science research process: a model for producing and presenting information systems research," in *Proceedings of the first international conference on design science research in information systems and technology (DESRIST 2006)*, pp. 83–106, 2006.

[8] J. Nunamaker, J.F. and M. Chen, "Systems development in information systems research," in *System Sciences, 1990., Proceedings of the Twenty-Third Annual Hawaii International Conference on*, vol. iii, pp. 631–640 vol.3, Jan 1990.

[9] J. G. Walls, G. R. Widmeyer, and O. A. El Sawy, "Building an information system design theory for vigilant eis," *Information Systems Research*, vol. 3, no. 1, pp. 36–59, 1992.

[10] S. T. March and G. F. Smith, "Design and natural science research on information technology," *Decision Support Systems*, vol. 15, no. 4, pp. 251 – 266, 1995.

[11] R. H. von Alan, S. T. March, J. Park, and S. Ram, "Design science in information systems research," *MIS quarterly*, vol. 28, no. 1, pp. 75–105, 2004.

[12] J. Brooke, "Sus-a quick and dirty usability scale," *Usability evaluation in industry*, vol. 189, p. 194, 1996.

[13] A. Bangor, P. T. Kortum, and J. T. Miller, "An empirical evaluation of the system usability scale," *Intl. Journal of Human–Computer Interaction*, vol. 24, no. 6, pp. 574–594, 2008.

[14] A. Tjora, *Kvalitative forskningsmetoder i prakis*. Gyldendal Norsk Forlag, 2010.

[15] Mari Gisvold Garathun, Teknisk Ukeblad, "Nytt verktøy skal få forsinkede tog tilbake i rute." `http://www.tu.no/samferdsel/2014/05/08/`

nytt-verktoy-skal-fa-forsinkede-tog-tilbake-i-rute, May 2014. [Online; accessed 01. June 2014].

[16] European Committee for Standardization, "Service interface for real time information cen/ts 15531 (prcen/ts-oo278181)." http://user47094.vs.easily.co.uk/siri/. [Online; accessed 23. March 2014].

[17] ECMA International, "The JSON data interchange format." http://www.ecma-international.org/publications/files/ECMA-ST/ECMA-404.pdf. [Online; accessed 13. June 2014].

[18] M. Jakl, "Representational state transfer,"

[19] Joyent, "About node.js." http://nodejs.org/about/. [Online; accessed 13. June 2014].

[20] Visionmedia, "Express - node.js web application framework." http://expressjs.com/. [Online; accessed 13. June 2014].

[21] N. Nurseitov, M. Paulson, R. Reynolds, and C. Izurieta, "Comparison of json and xml data interchange formats: A case study.," *Caine*, vol. 9, pp. 157–162, 2009.

[22] Qt Digia, "JSON support in Qt." http://qt-project.org/doc/qt-5/json.html. [Online; accessed 13. June 2014].

[23] Apple, "NSJSONSerialization class reference." https://developer.apple.com/library/ios/documentation/foundation/reference/nsjsonserialization_class/Reference/Reference.html. [Online; accessed 13. June 2014].

[24] Apple, "About Objective-C." https://developer.apple.com/library/mac/documentation/cocoa/conceptual/

`ProgrammingWithObjectiveC/Introduction/Introduction.`
`html`. [Online; accessed 13. June 2014].

[25] Apple, "Cocoa touch frameworks." `https://developer.apple.com/`
`technologies/ios/cocoa-touch.html`. [Online; accessed 13. June 2014].

[26] Core Plot, "Readme." `https://github.com/core-plot/core-plot.`
[Online; accessed 13. June 2014].

[27] Wikipedia, "Map projection — wikipedia, the free encyclopedia," 2014. [Online; accessed 14 June 2014].

[28] Wikipedia, "Fargeblindhet — wikipedia,," 2014. [Online; accessed 14 June 2014].

[29] N. Blindeforbund, "Fargeblindhet - myter og sannhet." [Online; accessed 14 June 2014].

[30] Jernbaneverket, "Fido | kurs." `https://fido-kurs.opm.jbv.no/`. [Online; accessed 01. June 2014].

[31] Jernbaneverket, "Filtrert distribusjon av operative kunngjøringer."
`https://fido.jbv.no/dokumenter/resources/pdf/`
`informasjonsfolder-om-fido.pdf`. [Online; accessed 24. February 2014].

[32] Jernbaneverket, "Brukermanual - distribusjonsportalen for jernbaneverket bane, jernbaneforetak og utførende enheter." `https://fido.jbv.no/dokumenter/`
`resources/pdf/brukermanual-fido-distribusjon-eksterne.`
`pdf`. [Online; accessed 24. February 2014].

[33] S. Nicholson, "A recipe for meaningful gamification," *Wood, L & Reiners, T., eds. Gamification in Education and Business*, Forthcoming.

[34] D. Boud, R. Keogh, D. Walker, *et al.*, *Reflection: Turning experience into learning*. Routledge, 1985.

[35] Waze, "Free community-based mapping, traffic & navigation app." `https://www.waze.com/`. [Online; accessed 12. March 2014].

[36] C. Dara Kerr, "Google reveals it spent $966 million in waze acquisition." `http://news.cnet.com/8301-1023_3-57595620-93/google/`. [Online; accessed 12. March 2014].

[37] M. Ludvigsen and C. Wallervand, "Gamifying an oil-gas-water separation process in a process control system to improve operators' motivation, skills, and process understanding," Master's thesis, Norwegian University of Science and Technology, 2012.

[38] S. Mora, A. Boron, and M. Divitini, "Cromar: Mobile augmented reality for supporting reflection on crowd management," *International Journal of Mobile Human Computer Interaction (IJMHCI)*, vol. 4, no. 2, pp. 88–101, 2012.

[39] Sigurd Øygarden Flæten, Teknisk Ukeblad, "Sammenligner husholdningens strømforbruk med naboenes." `http://www.tu.no/kraft/2014/04/13/sammenligner-husholdningens-stromforbruk-med-naboenes`, April 2014. [Online; accessed 07. June 2014].

[40] Alex Laskey, "How behavioral science can lower your energy bill." `http://www.ted.com/talks/alex_laskey_how_behavioral_science_can_lower_your_energy_bill`, February 2013. [Online; accessed 07. June 2014].

[41] B. Hollifield, "The high performance hmi." `http://www.isa.org/InTechTemplate.cfm?Section=Archives4&template=/ContentManagement/ContentDisplay.cfm&ContentID=93253`. [Online; accessed 12. March 2014].

[42] M. Scholte-Albers, "Foreign adoption of a dutch innovation: The case routelint," Master's thesis, University of Twente, 2009.

[43] R. G. I. Mario Lagos, "CATO offers energy savings," May 2011. [Online; accessed 14 June 2014].

[44] Cubris, "Benefits of greenspeed." `http://www.cubris.dk/benefits-of-greenspeed/`. [Online; accessed 02. June 2014].

[45] FAR SYSTEMS S.p.A, "Eco drive advisory system." [Online; accessed 15 June 2014].

[46] T. T. Technology, "Energymiser." [Online; accessed 14 June 2014].

[47] Cubris, "Cases and testimonials." `http://www.cubris.dk/benefits-of-greenspeed/cases-and-testimonials/`. [Online; accessed 02. June 2014].

[48] Unife, "Ertms - the european rail traffic management system." [Online; accessed 15 June 2014].

[49] T. Luke, N. Brook-Carter, A. M. Parkes, E. Grimes, and A. Mills, "An investigation of train driver visual strategies," *Cognition, Technology & Work*, vol. 8, no. 1, pp. 15–29, 2006.

[50] L. Kecklund, M. Ingre, G. Kecklund, M. Söderström, T. Åkerstedt, E. Lindberg, A. Jansson, E. Olsson, B. Sandblad, and P. Almqvist, "The train–project: Railway

safety and the train driver information environment and work situation-a summary of the main results," *Signalling safety*, pp. 26–27, 2001.

[51] A. F. Williams, "Views of us drivers about driving safety," *Journal of Safety Research*, vol. 34, no. 5, pp. 491–494, 2003.

[52] G. Hofstede, "Motivation, leadership, and organization: do american theories apply abroad?," *Organizational dynamics*, vol. 9, no. 1, pp. 42–63, 1980.

[53] T. Stålhane, "Software process improvement - a toolbox," in *Quality Assurance and Problem Improvement*, Tapir Akademiske Forlag, 2012.

A. Pilot test interview

Date: 2014-06-11

Subject: A SINTEF research scientist with extensive experience from the railway sector

Interviewer: Magnus Bae

The interview was conducted after running a pilot test on the driver advisory system prototype. Before the interview the interview subject was asked to fill out a System Usability Scale (SUS) form. See Chapter 2.8 on page 13 for a description of the original interview outline. Some questions were added as needed during the interview.

The interview was recorded and transcribed afterwards. The interview was performed in Norwegian and transcribed to English.

INTERVIEWER: How did the prototype contribute to your understanding of the traffic situation?

SUBJECT: When driving at night especially, seeing that you have a train in front of you gives on type of information, potentially making one want to throttle down a bit. At the beginning, around Eidsvoll, it was more that you see the local traffic. Showing quite literally how cramped it is around you. It doesn't make it any more fun to be waiting, but you will at least see why you are standing still - then one can choose to be happy or unhappy about that, but

you can at least see that no matter what were to be done one would be waiting somewhere.

The traffic situation communicated depends on the situation, whether one is driving in busy areas, or if one is driving "alone" at night, and the only "chaos" one can make is when meeting other cargo trains. It does visualize the need for precision to get smooth crossings on the mountain. It is not guaranteed that running the playback for a different day would show the same level of smoothness in the crossings, but if one were to use the tool regularly to review traffic flow one would maybe even improve the understanding of the traffic flow without this tool.

INTERVIEWER: If you imagine that this systems runs in real-time instead of showing a playback?

SUBJECT: I would like it to be able to do both, because when driving one would not be able to go and look at what other drivers are doing far ahead of you, but that is something one rather could do in retrospective.

INTERVIEWER: Do you think that a system that displays the traffic situation, like the one demonstrated today, or in any other manner you can think of, would contribute positively with regards to supporting you in making decisions while driving a train?

SUBJECT: That might depend on what attitude you have, but it will not contribute negatively unless one uses it to... (pauses) Well, driving slow gives you a more comfortable and economic drive at the expense of others, but that is something you can also see here: "what is the consequence if I dawdle here?", and opposite - one could see opportunities where one should drive a bit faster, within limits of reason.

INTERVIEWER: If you were given the choice of using such a system in your daily work, would you?

SUBJECT: Personally I would have, because I think it is very interesting. I do not think it is the alpha and omega of train driving, because at the end of the day you have to comply with the orders of the traffic controllers. You can't just drive through the stations even though it looks like there is clear tracks in front of you. There might be some variation there though.

INTERVIEWER: Would you prefer a system like the one demonstrated, a system whose sole purpose is to tell you which speed you should drive at, or a system which combines the two?

SUBJECT: A combination is what I would wish for. If you drive a route that you have driven a lot before, depending on what the speed recommendation is based on - if it's optimal for right now, or if it's a general advice based on the timetable. If one have both (speed advice and traffic information), it's easier to assess the quality of the suggestion and decide whether or not to follow it. In one way that makes it a system that shows more of what is going on, and gives more room for assessing the recommendation and a better foundation for decisions. If it was just a recommendation it might be easier to dismiss it because "so and so on", but if I get to see more around me, especially if I get to the see the speed of other trains, then that could also be part of affecting if one decides to follow the advice, in a positive way.

INTERVIEWER: What additional information would you like the system to display?

SUBJECT: What would be very interesting would be to see if the other trains are on schedule or not, a yes/no and maybe how much. In one way it's nice, but on the other hand it doesn't contribute much as I can't do anything about it. It is interesting with regards to whether or not I should try to reach a crossing in

time and I could see that another train is very delayed (or I'm delayed a lot), there is a high chance that the crossing is moved to different station than what is scheduled. That could easily contribute to my decision making, especially since you do not know the details of the schedules of other trains, and therefore not their stopping pattern either. I might know where I should meet them, but if they are off schedule then it's difficult to know upfront whether they are deviating from the schedule or not[1].

Other information that could be practical? Well, maybe the blocks that are configured (signals), but then you might be pushing the boundary on what is comprehensible, as well as pushing the need to actually keep a train driver in the cab.

I'd also like to see the ability to rewind, instead of performing the whole playback. Maybe the ability to jump to a specific time, place, or situation.

INTERVIEWER: Do you have any additional comments or feedback?

SUBJECT: The display of speed recommendations doesn't necessarily have to be in the same image (or system), since that is quite simple, and with the next generation of (signal systems) ERTMS, train control systems, than speed advice is very likely to be integrated into that - at least they show which speed you are allowed to drive at, and then you are very close to have them show which speed you should be driving at.

INTERVIEWER: So you think this system might have a purpose for retrospective analysis as well?

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[1]It is difficult to know if other trains are running according to schedule before the moment where it becomes apparent that they are late

SUBJECT: Maybe just as much actually. Because you don't have much time then and there to sit down and think through the situations as they happen. Let's say if you come in late for a crossing, for various reasons, it could be interesting to go back and look at what the consequence was for the train you met there, for instance does it meet it's next crossing, does it get more delayed, or does it all end well? That's also something when you are behind another train, it can be interesting to see if that train driver does what he/she can to stick to the schedule and make things more comfortable for you, that type of thing. It might be more likely to look at another trains behaviour than the one that I drove myself, jump in and see how things played out at a certain time or location. Maybe even detach the view from the trains and go in and look at how the traffic played out at, for instance, Hamar for a couple of hours. At that point you might be moving away from a DAS and you are looking much more at the learning side of things, more as a learning tool, than a system that pushes me in the right direction when I'm working. Right now it has a bit of functionality for both things, and therefor it's easy to wish for both.

INTERVIEWER: Some existing research suggest that traffic controllers lack of knowledge about the exact whereabouts of trains. Do you think that a system like this, maybe at another scale could help support traffic controllers?

SUBJECT: Yes and no. What might be most difficult there is to see the consequences further ahead in time. One thing is to understand what is going on, and you are not that far away from having that now since they know what is going on a block level, just with a bad time resolution. Seeing the consequences for a train which is at Hamar now and is going to Trondheim if you shuffle the plans about a bit is very difficult when it's more than three hours till it's there. It's not easy to see the consequences for the local trains it will be meeting in

three and a half hours, when they haven't even started yet. They don't exist. Maybe the train controller has even ended his workday and gone home, so that is a problem for the next shift.

Even if the traffic controller had made a change in plans because he thinks it will be good for local traffic, not only will he maybe have gone home when that happens, but it is also in another control region and he won't be able to see that, nor does he have the knowledge about the schedules that are local to that region. So either you would have to project future events to show effect, or one can do an optimization solution like the one Arnt-Gunnar has been working on (See Chapter 3.1.2 on page 24), where one just re-plans all routes.

Also for traffic controllers it (the prototype system) can be interesting as a learning experience. One can, after the shift is over, look at what happens to trains after they are out of one's area. It's not something you can do while at work, but afterwards if one is curious. It can also be used to show of good and bad solutions for various scenarios for days when everything was catastrophic.

SUBJECT: On an ending note it is very interesting to see what is going on, especially just as far away that you can't really see it, like trains that drive in the same direction that you never meet. That's a situation where one today has very little comprehension of whether or not they are doing what they should be. Ideally one shouldn't need to know about these, they shouldn't affect you, nor the other way. Having this knowledge though shows a bit of the limits

for catching up on lost time and so forth. Especially it makes planning easier if one is driving a lot behind schedule and no longer know what the right schedule is.

B. Workshop summary

Date: 2014-03-26

Participants: Magnus Krane, Andreas Seim, Andreas Landmark, Sobah Pettersen, Arnt-Gunnar Lium, Magnus Bae

Place: SINTEF, TS438

Date / time: 2014-03-26 0800-1000

The workshop was arranged to explore possibilities for further development of a software prototype in connection with the Master's Thesis carried out by Magnus Bae for SINTEF.

To begin with Arnt-Gunnar demonstrated a tool developed to support traffic controllers in re-planning train graphs, and a pilot project for testing of driver advisory systems (DAS) with start-up in May was discussed. The decision of whether or not this pilot project will be performed is slated to be taken on the 7th of April. It was also noted that NSB has bought in Android-tablets (CargoNet has iPads).

In conjunction with a testing process it is possible to come in with a prototype and test what has been developed, eg. gamification. In the case of the pilot project being executed there is little need to duplicate the functionality of traditional DAS-systems, as they will be giving the speed-advice. In this case it is deemed important to find a way to compare train drivers' speed profiles and goal achievement (arriving timely at crossings), than to

contribute to situation awareness (SA).

There is no indication that any of the candidate DAS-systems provides SA, which can be obtained by providing train drivers with an understanding of surrounding traffic.

How to best visualize traffic / situational picture was not followed up, but there were discussions around potential elements of gamification. Most of the suggestions were to use elements like score cards, badges, and high-score lists to motivate. Sobah also mentioned the possibility for management to use analysis of train drivers' driving profiles to measure skill or performance. There was some skepticism surrounding whether or not this type of information should be available to other persons than the one train driver.

Two other interesting elements of gamification that was mentioned was the use of retrospective analysis of a trip, and the ability to compare one-self against other train drivers.

There are some potential problems with regards to the availability of data from TIOS (data from traffic control). An alternative is to enter crossing points manually, or using the system developed by Arnt-Gunnar's team to estimate changes in crossing points assumed that the system's advice has been followed. In the DAS-pilot the train driver have to tell the system when the train should be arriving at a station.

Arnt-Gunnar needs feedback within Thursday April 3 on which data sources/types that would be desirable for further work, preferably including an overview of dependency between data sources and capabilities.

Speed profiles for calculation of speed / optimum speed seems to best obtained through SINTEF since these do not include the slack added to the timetables (in contrast to the Norwegian National Rail Administration and NSB).