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Piloting map service for navigating in punctuality analyses for trains

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Problem Description

Piloting map service for navigating in punctuality analysis for trains

Conceptualize and develop prototype of map based visualizations of real time signal data to improve punctuality.

Abstract

In a complex system such as the Norwegian railway network, there are much that can affect a trains punctuality. The undertakers strive to achieve higher and higher punctuality, while the infrastructure owner, Jernbaneverket, strive for minimal downtime on the railway network. There is collected much data for analysis about the trains run and the infrastructure, in order to achieve higher punctuality and less downtime. The users are able to track down the source of delays and find possible improvements on the infrastructure, by analyzing and comparing the different data sets collected.

There are many users across both different companies and internal divisions in a company that need to cooperate, due to the size and complexity of a railway network. The different users have different needs when studying the data sets. A area director have the need to see the big picture over time, while a segment director wants to see every detail within its segment.

In this thesis we demonstrate a system that is aware of the different stakeholders requirements when presenting data. The system also takes into consideration the stakeholders need for analyzing different types of data, and comparing these.

Finally, we conclude how users should be defined within a domain in order to be aggregated over.

Sammendrag (Norwegian Abstract)

I et komplekst system som det norske jernbane nettverket er det mye som kan påvirke punkligheten til et tog. Operatørene på jernbanen streber etter å oppnå høyere og høyere punklighet, mens infrastruktur eieren, Jernbaneverket, streber etter minst mulig nedetid på trafikk nettverket. For å kunne oppnå høyere punklighet og mindre nedetid, blir det samlet inn mye data om kjørte tog og infrastrukturen for å kunne analysere. Ved å analysere og sammenligne forskjellige de innsamlede data settene er det mulig å forstå grunnen til forsinkelsene.

Grunnet størrelsen og kompleksiteten på et jernbane nettverk er det mange brukere på tvers av selskaper og interne avdelinger som må samarbeide for å gi et best mulig togtilbud. De ulike brukerne har forskjellige behov når de studerer data settene. En områdedirektør har behovet for å kunne se de store trekkene over lengre tid innenfor området, mens en strekningsdirektør vil se alle hendelser på sin strekning.

I denne masteroppgaven demonstrerer vi et system som tar hensyn til de forskjellige brukerene sine behov for forskjellig presentasjon av data. Systemet tar også hensyn til behovene for å kunne se på forskjellige data og sammenligne disse.

Til slutt konkluderer vi med hvordan brukerne bør bli definert i forhold til domenet for å kunne aggregeres over.

Preface

The work of 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 during the spring semester of 2014.

During the work of this thesis, I have been supervised by Sobah Abbas Pettersen and co-supervised by researcher Andreas Landmark (SINTEF), research manager Andreas Seim (SINTEF), and researcher Rimmert van der Kooij (SINTEF), who have all been a great help throughout the process, providing valuable input and guidance.

I would also like to thank fellow students Magnus Bae and Bjørn Thomas Vee for feedback and help when needed.

I have also been part of the student organization Revolve NTNU this semester, which is a group of students building a prototype formula student race car for participating in the international Formula Student competitions. I would like thank my fellow team members for participating in some of the best times I have experienced.

I would like to give a final thank you to my supervisors for understanding that participating in Revolve NTNU has made time difficult to balance.

Trondheim, July 2, 2014

Magnus Krane

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Chapter 1

Introduction

In this chapter we introduce the problem which we discuss in this thesis. We first present an outline of the problem. In the second part we introduce the research question which we will answer with the help of the method presented in Chapter 2. In the three last parts, we briefly introduce the main parts of the research question.

1.1 Background and motivation

In a railway network, trains are run almost constantly to meet the demand for passenger and freight transport. The companies responsible for the transportation strive for more efficient capacity usage and increased punctuality. The Norwegian National Rail Administration (Jernbaneverket [1]) collects data about every train driven in the railway network and external events affecting the railway. Based on the analysis of the collected data, users throughout the companies can improve the performance of the infrastructure and the usage of the railway.

Most of the data collected is kept in different sets throughout the different companies with a non-coherent definition of data-fields. The structuring of the data sets makes comparison difficult for different users. Different users throughout the companies have different needs when, some have the need for a large geographical area and a low level of detail resulting in a overview, while others need a small geographical area and a high level of detail.

In order for the users to be able to analyze the data according to their needs, a system must not only be able to present different types of data to the users, but also process the data according to the stakeholders requirements. The system is able to allow the users to analyze the wanted data at the wanted level of detail, by processing the data according to the requirements.

1.2 Research Question and Goals

In this section we introduce the research question formulated based on the problem outlined in Section 1.1, and the goals found with the research method presented in Section 2.2.

A system which allows the user to select between different type of information to be presented, and at the same time to be aware of the stakeholders involved, is complex. By answering the research question below, we aimed to produce characteristics to help define a stakeholder aware system.

- **What are important characteristics for a stakeholder aware method to aggregate over a rich set of data?**

As part of answering the research question, we developed a prototype. Using the research method we produced the following goals for the prototype.

- Develop a map based prototype for train analysis.
- Sub goals:
  - Display dashboard with relevant information corresponding to current zoom level.
  - Aggregate through statistical data according to current level.
  - Limit the data visualization within selectable time scales.
  - Select different type of statistical data to display.
    - Display information for traffic density.
    - Display information for Speed restrictions.
    - Display information for train crossings.

As part of discussing a method for "awareness in presentation", a presentation of the key parts in the research question is needed.

By presenting a stakeholder aware method, there are some concerns which needs to be introduced first. In our problem, we define a stakeholder as a person within a organizational structure.

1.3 Stakeholders

As with any project, we had several stakeholders to take into consideration during the work of this project. A stakeholder is anyone who has a stake in the success of the system, which typically have different specific concerns that they wish the system to guarantee or optimize [2].

Stakeholders need to be defined further then just for instance the developers or project managers, in order to have awareness in how the data is processed and presented to the different stakeholders. By defining the system domain and environment, further defining of the relevant stakeholders within the domain is needed. When the stakeholders have been defined within the domain, their needs and requirements can be defined in a way that the data processing methods can take into consideration.

When defined within the domain, the stakeholders needs to be organized on a structure which enables awareness from the system. Along this thesis, we present a structure where the stakeholders have been placed in a hierarchy according to their areas of responsibility. By organizing a hierarchy of the stakeholder, we are able to process the data and limit the presentation according to the active stakeholder.

1.4 Data sets

Depending on the system and the stakeholders requirements, the amount of data to process can quickly grow quite large. As the data required by the stakeholders involves different types of data, the sets often originates from different sources. In order to allow the system to process the data according to the stakeholders, the sets need to be defined in a common structure. Different companies can for instance have different definitions of the same data field.

1.5 Aggregation

When the stakeholders have been organized in a data processing friendly structure as presented in Section 1.3 on the preceding page, we then aggregate the data accordingly. To aggregate data means to replace groups of observations with summary statistics based on these observations [3]. By aggregating the data according to the stakeholders, we summarize the data according to the areas of responsibility. The summarization method used on the data are specified by the requirements of the stakeholders. We also present aggregation through time. Each stakeholder are able to limit the data according the level of detail needed, by enabling time aggregation.

Chapter 2

Research Method

In order to structure the process of answering the research question presented in Section 1.2, we applied a research method to the process of this thesis. By implementing a methodology to the thesis, we are able to explain the theory behind the project and how it was performed.

In this chapter we will describe the research method used in this project. First we aim to introduce the method used in the project, and explain each step of the method. We will then present our implementation of the method and how it is executed.

Research methods can generally be divided in two directions, deductive or inductive. Deductive reasoning is the process of reasoning from one or more general statements to a more specific observations. Inductive reasoning is the process of reasoning from a more specific observations to broader generalizations and theories. [4] In addition, Thagard and Shelley [5] present a third approach, abductive [6] reasoning, which is the process of attempting to guess something that can be likely as a method for pulling the research frontier forward.

During the work of this thesis we have chosen a abductive method. Abductive enables us to draw the most likeliest possible explanation for a incomplete set of observations.

We found that deductive reasoning is poorly suited as it contains a premise that one has a testable hypothesis which can be rejected.

Inductive reasoning is poorly suited as it draws generalized conclusions based on a limited sets of observations. One has no way of knowing if all possible evidence has been gathered and no unobserved evidence which disproves the hypothesis exists, by using a limited set of observations[7].

2.1 Research Methods

During the research done in this thesis, we applied the Design Science Research Process (DSRP) as the research method. The DSRP is based on 6 steps which are presented in the list below. Depending on what the focus of the project is, the project can start at almost any of the steps below. [8]

1. **Problem identification and motivation** - Defines the problem to be researched.

2. **Objectives of a solution** - Infer the goals of the solution.

3. **Design and development** - Creates an artifact for the solution.

4. **Demonstration** - Demonstrate the created artifact.

5. **Evaluation** - Observe and measure how the artifact gives a solution to the problem.

6. **Communication -** Communicate the problem along with the artifact.

As Hevner, March, Park, and Ram [9] describe, evaluation of a product, created through a sequence of expert activities, provides feedback information and a better understanding of the problem in order to determine the quality of the product. A process loop which is typically iterated a number of times before the final design artifact is created by repeating the sequence of expert activities. An example of the process loop is demonstrated in Figure 2.1, where the loop is going from step 2 (Objectives of a solution) to step 5 (Evaluation) and back.

Objectives of a solution - A literature study was performed and workshops were held, as part of the method to define the objectives of the solution in step 2. Since the literature study reveals what kind of relevant systems that exists and how they fit to the requirements of the stakeholders, the study helps define the objectives. Focus groups can be a great way to learn about the work that occurs "between" and "around" the solutions [10], as focus groups can have a less formal ambiance which can lead to more information then for instance a prepared questionnaire.

Design and development - To help answer the research question, a prototype was developed as part of the method in the Third step. Developing the prototype helps us understand the user and criterias needed for having a system capable of providing stakeholder awareness.

Demonstration & Evaluation - Pilot was performed each week as part of the demonstration and evaluation in step 4 & 5. The studies were used as a measurement of the prototype developed as the method in step 3 against the requirements. Evaluation was then performed and lead to another execution in the process loop.

Communication - The final step of the process, communication of the results is done by presenting this thesis.

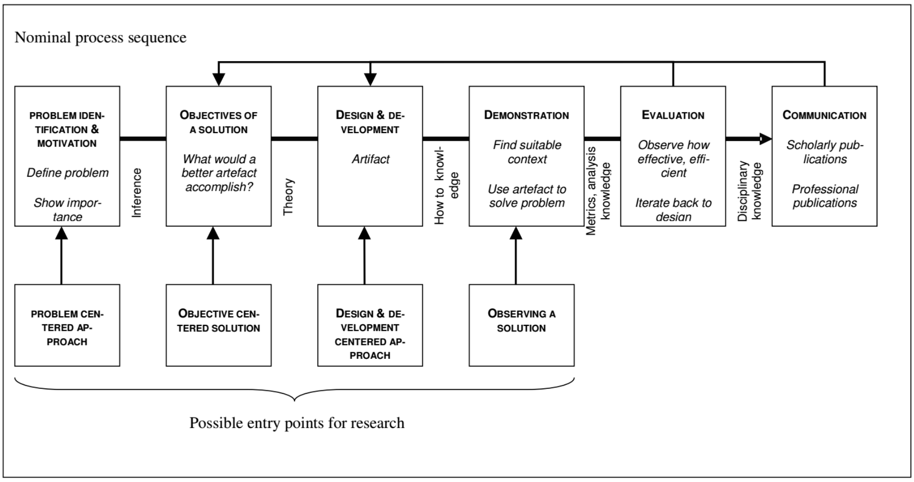

Nominal process sequence
PROBLEM IDENTIFICATION & MOTIVATION
Define problem
Show importance
Inference
OBJECTIVES OF A SOLUTION
What would a better artefact accomplish?
Theory
DESIGN & DEVELOPMENT
Artifact
How to knowledge
DEMONSTRATION
Find suitable context
Use artefact to solve problem
Metrics, analysis knowledge
EVALUATION
Observe how effective, efficient
Iterate back to design
Disciplinary knowledge
COMMUNICATION
Scholarly publications
Professional publications
PROBLEM CENTERED APPROACH
OBJECTIVE CENTERED SOLUTION
DESIGN & DEVELOPMENT CENTERED APPROACH
OBSERVING A SOLUTION
Possible entry points for research

Figure 2.1: Design research process (DSRP) model[8]

2.2 Project Research

In this thesis, the problem was identified and motivated prior to the thesis, thus the natural starting point of this research was to go into the second stage; objective centered. Figure 2.1 shows four entry points into a design research process; Problem centered-, objective centered-, design & development- centered-approach and observing a solution.

Objectives of a solution - This thesis was an interaction between objectives of a solution, and a study of prior art. Examining the state-of-the-art and existing systems is done by searching for scientific articles and commercial systems which contribute towards the goal of the thesis, and has been performed as a part of the background study. We are able to detect the holes in the available functionality, by describing and categorizing the systems found in the case study. As part of defining the objectives of the solution, we compared the provided functionality of the systems with the stakeholders and their requirements.

Two workshops were held as part of defining the goals of the solution and the prototype for step 2, define the needs of the stakeholders, and as part of the requirements elicitation. Several stakeholders were participating in these workshops helped to define the direction of the process. By using a focus group consisting of stakeholders, we were able to define specifications for the system and the domain.

By putting together a focus group, one can utilize stakeholders to define the objectives of a solution. As Nielsen [10] describes, focus groups can be a great way to learn about the work that occurs "between" and "around" the solutions. Focus groups have the advantage of allowing more natural interactions between people than interviews. By bringing together several users leads to spontaneous ad ideas [11]. To ensure that these focus groups stays focused during the entire workshops, the moderator has to make sure the groups discusses a pre planned set of issues and set goals for the kind of information to be gathered. The use of focus groups within requirements engineering have become more popular, because of their claim to greatly accelerate the development of requirements [12].

Design and development - A prototype were to be implemented, to help answer the research question. In order to implement the prototype, a set of goals for the prototype was defined with the help of the case study and the workshops held in step two, presented in Section 1.2. The final design of the prototype is presented in chapter 4 Implementation.

Demonstration & Evaluation - As part of the iterative process loop, pilots with the supervisors were performed each week. During these meetings the current status of both the case study and development of the prototype was demonstrated. The demonstrations were performed as the observational evaluation method case study, where the artifact is studied in depth in business environment [9]. The evaluation involves comparing the objectives of the solution to actual observed results from use of the artifact in the demonstration [8], and was performed as a comparison of the prototype's functionality with the solution objectives defined in step 2.

Chapter 3

Background

In this chapter we put the stakeholders and their needs mentioned in Section 1.3 Stakeholders in context of the railway system.

The chapter begins with a description of how the railway traffic in Norway are structured and how the infrastructure is organized. We will then describe the stakeholders in context of the infrastructure organization. The third part describes different data sets and their origin. The fourth part describes how to process the data according to the stakeholders. The fifth part presents the case study performed as part of the research method presented in Section 2.2 on page 10. The last part presents a framework definition of the case study.

3.1 Railway operations

Major train networks are complex systems with many dynamic effects. The Norwegian railroad consists of 4320 km of lines [13, p. 4], transporting 60 million passenger journeys and 27 million tons of cargo in 2012 [13, p. 9]. For a rail undertaking, there is a constant balance to be struck between capacity, demand, and safe and punctual operations. While safety is the highest priority, this thesis will focus on the capacity and punctuality concerns of railway operations.

On a railway network, the capacity of railway lines is defined as the maximum number of trains per unit of time that can be run, as described by Goverde[14]. One must take into consideration the properties of both the infrastructure and the trains, when determining the capacity. Properties of the infrastructure that needs to considered be can be such as sidings, double- or single-track, speed limits. Properties of the trains that needs to be consider can be such as top speed, acceleration, and brake length. Based on the capacity, the traffic will be organized in a timetable with some slack for dynamic adjustments.

Punctuality is usually divided into two central metrics, punctuality and regularity. In the Norwegian railroad, a train is considered punctual or on schedule if it operates at planned points in the infrastructure within a margin of 3 minutes and 59 seconds, for long distance and cargo trains the margin is 5 minutes and 59 seconds. Punctuality (in %) is the proportion of trains that arrives at their final destination within this margin.

Jernbaneverket (see Section 3.5.7 on page 28) defines regularity (in %) as the proportion of trains operated over the number planned in the schedule.

Other derived metrics include uptime, in regards to punctuality, is defined by Jernbaneverket from the hours of delay[1] caused by infrastructure relative to sum of planned train hours[2] per year.[15]

$$Uptime = \frac{\text{Train hours - Hours of delay}}{\text{Train hours}} \times 100 \tag{3.1}$$

[1] Hours of delay due to infrastructure excluded traffic management and external conditions

[2] Planned train hours (passenger and freight trains)

In order to continuously improve the quality of the services, reliability, and punctuality of the railway services, it is important to monitor train delays their causes [16]. Train delays can be divided in two types, primary delays where a schedule deviation is caused by some disruption at any location due to variations within a process; secondary delay is a process time extension caused by another train [14]. Analyzing the route conflicts which leads to a primary delays, is necessary in order to continuously improve the quality of the services, reliability, and punctuality of the railway services. An example of a application to analyze the conflicts is presented by Goverde and Meng [16].

The operations of the railway system are divided into infrastructure owner and rail undertakings that provide transport on the infrastructure. In Norway the infrastructure is constructed, operated and maintained by the state owned agency Jernbaneverket. The major undertakings operating in Norway include Norges Statsbaner (NSB), NSB Gjøvikbanen, CargoNet, CargoLink, and Flytoget [17]. The undertakings provide exclusively either passenger or freight traffic.

Due to the size and responsibility of these organizations, there is a need for a division of labor and responsibility. This differs between the infrastructure owner and the undertakings due to their different business areas. Example of their individual organization charts is shown in Figure 3.1 (undertaking) and Figure 3.2 (infrastructure owner).

To have a safe and punctual operation of the whole system there are many parts that need to cooperate and interoperate. There is not one unit that provides safety or punctuality by it self. The cooperation between the infrastructure owner and

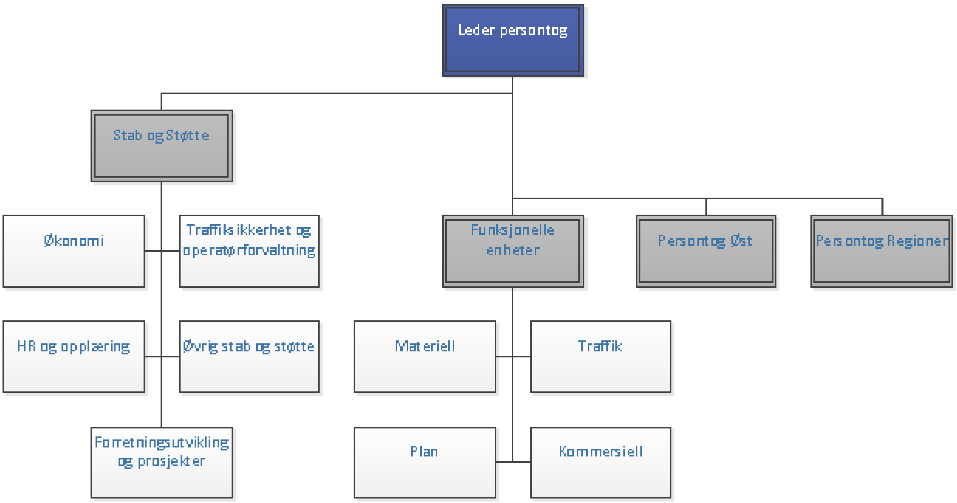


Figure 3.1: Rail operator / Railway undertaking [18]

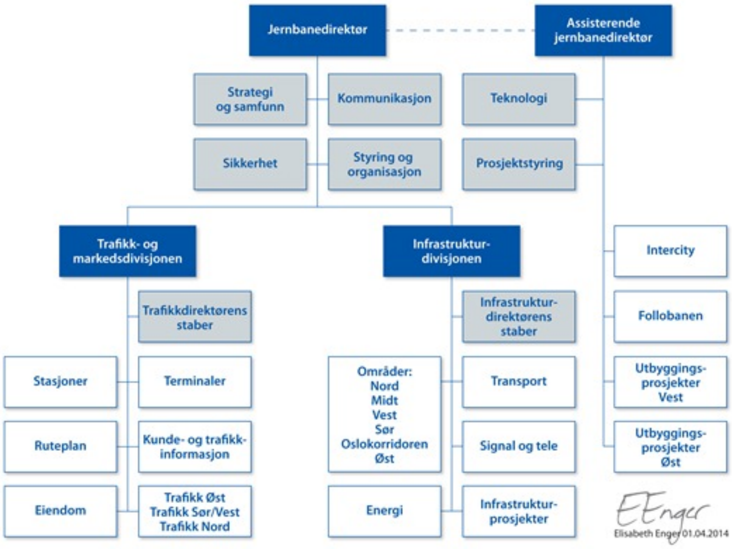

Jernbanedirektør
Assisterende jernbanedirektør
Strategi og samfunn
Kommunikasjon
Teknologi
Sikkerhet
Styring og organisasjon
Prosjektstyring
Trafikk- og markedsdivisjonen
Infrastruktur-divisjonen
Intercity
Trafikkdirektørens staber
Infrastruktur-direktørens staber
Follobanen
Stasjoner
Terminaler
Områder: Nord Midt Vest Sør Oslokorridoren Øst
Transport
Utbyggings-prosjekter Vest
Ruteplan
Kunde- og trafikk-informasjon
Signal og tele
Utbyggings-prosjekter Øst
Eiendom
Trafikk Øst Trafikk Sør/Vest Trafikk Nord
Energi
Infrastruktur-prosjekter
EEnger
Elisabeth Enger 01.04.2014

Figure 3.2: Infrastructure owner [19]

undertakings is also key for a good operation.

An example of a cooperation both within a company and between several, based on NSB (Figure 3.1) and Jernbaneverket (Figure 3.2), is as follows. The traffic division performs the execution of the schedule; the material division maintains and presents the necessary material to execute the schedule; the planning division work with planning the long term schedules - which the traffic division executes; the passenger trains east/region divisions makes personnel available, such as train operator, conductor, and line managers. These divisions and their cooperation can then be matched against the traffic- and marketing division, and infrastructure division in Jernbaneverket, presented in Figure 3.2.

When the planning division in the undertaker and the traffic- and marketing division in the infrastructure owner plans new schedules, they are both concerned with the railway capacity. Capacity is affected by many factors as described above, among them train crossings on sidings along the railway.

Since most of the railway structure in Norway is single line, most crossings have to be executed at places where sidings have been built, mostly this is at stations. This means that even though one train may be experiencing delay, this delay may be part of a sequence of problems that can be tracked back to a seemingly unrelated part of the the network and a perhaps a sub-optimal decision there [20].

As Landex[21] states, there exist few GIS-approaches concerning visualization of railroad capacity. Both the visualizations shown by Landex and in Section 3.5 Case study of similiar systems, only seem to take into consideration whether the trains are delayed, and the amount of delay.

3.2 Stakeholders

When looking at the Norwegian railway, there exists several types of users which may be taken into consideration. On the Norwegian railway operates several companies, who all have several positions in their organization hierarchy. Each of these positions have different responsibilities and therefor different interests in the system. A example of such a hierarchy is presented in Table 3.1.

User type	Responsibility
Railway director	Organization director
Infrastructure director	Responsibility to facilitate that the railway traffic in Norway is safe and reliable
Area director	Responsible for an area
Stretch director	Responsible for a stretch
Segment director	Responsible for a segment

Table 3.1: User roles in the Norwegian railway network

The hierarchy presented in the table is based on the organization structure of Jernbaneverket shown in Figure 3.2. As stated in Section 3.1, these stakeholders/divisions need to cooperate in order to provide safety and punctuality, both within the company and between the infrastructure owner and undertakings. Since the different stakeholders have different responsibilities but need to cooperate, they have concerns which overlap.

An example of stakeholders concerns overlapping can be taken from the example presented in Section 3.1. The material division is concerned with the maintainability of the material; the planning division is concerned with the capacity presented from the infrastructure owner, demands from the passengers; the passenger trains east/region divisions is concerned with the personnel; the traffic division is concerned that the traffic is executed according to schedule.

In the infrastructure divisions, the traffic- and marketing division is concerned with planning of the schedule; the infrastructure division is concerned with errors, and accounts for many of the speed restrictions, while they are partly under the responsibility of the security staff.

During the work of this thesis, we use parts of the hierarchy presented in Table 3.1 based on the organizational structure of Jernbaneverket.

Area director - Responsible for one of six areas in which the Norwegian railway is divided into.

Stretch director - Responsible for one of several stretches within one area.

Segment director - Responsible for a segment of stations within one stretch.

An example of such a hierarchy is presented in the list below.

Area - Midt (Middle-part of Norway).

Dovre- og Raumabanen - The northern part of the Dovreline and the Rauma line.

(Dombås) - Hjerkinn - The segment of the Dovreline which is between the exit of the station on Dombås and the entrance to Hjerkinn station.

3.3 Data sets

There are much data to process when performing a study of a relatively complex system as the Norwegian railway, as the different information types are stored independently.

As Hegglund[22, pp. 10-11] describes, Jernbaneverket measures punctuality data in two different ways and stores the data in a punctuality database called TIOS, Table 3.2 and Table 3.3 shows a extract from the TIOS database. They either have automatic measurements of when a trains passes a measure point on the eastern part of Norway, or manual registration in the rest of the country of each passing. In 2012, 884 passenger trains passed Oslo central station alone per day [13, p. 12]. Since the passing of a measurement point by a train is being stored, large sets of data gets accumulated over time.

caseid	utg_dt	tog_nr	stasjon_kd	sta_tid	ata_tid
2012110741	2012-11-07	41	OSL	2012-11-07 08:07:00	2012-11-07 07:31:49
2012110741	2012-11-07	41	HLR	NULL	2012-11-07 08:12:27
2012110741	2012-11-07	41	LLS	2012-11-07 08:17:00	2012-11-07 08:17:47
2012110741	2012-11-07	41	KLØ	NULL	2012-11-07 08:25:35
2012110741	2012-11-07	41	LAL	NULL	2012-11-07 08:27:44

Table 3.2: TIOS punctuality data part 1 [18]

Since the set of data stored in TIOS, stores every train that passes every measurement point, and the corresponding time point , is is possible to use the same set to calculate where every crossing between different trains happens. The usage of the same set is possible since one can compare the time stamps of the passing of

std_tid	atd_tid	tog_ktg	company_nv
2012-11-07 08:07:00	2012-11-07 08:08:59	Pt	NSB
2012-11-07 08:11:00	2012-11-07 08:12:55	Pt	NSB
2012-11-07 08:19:00	2012-11-07 08:20:30	Pt	NSB
2012-11-07 08:25:00	2012-11-07 08:26:16	Pt	NSB
2012-11-07 08:27:00	2012-11-07 08:28:06	Pt	NSB

Table 3.3: TIOS punctuality data part 2 [18]

each station to another train.

When the speed restrictions are registered, they are stored in their own set of data which is based on the users filling out different forms. The speed restriction sets are based on forms filled out by users, and cover both scheduled work and unscheduled work. Examples of scheduled work can be improvement on infrastructure, and example of unscheduled work can be destroyed tracks due to flooding.

Analyzing large different sets of data which might originate from different sources, will be required when a method shall be aware of the stakeholder. When developing such a method, one also needs to have a good way of limiting the visual representation of the data to avoid filling the display with to much information.

3.4 Aggregation

When using the hierarchy of relevant stakeholders presented in Section 3.2 and the large sets of data mentioned in Section 3.3, a good way to limit the amount of data presented is to aggregate over the sets of data based on hierarchy.

If one look at the example hierarchy presented in Section Section 3.2, an example of such an aggregation is as follows. The segment director wants information of every station along the segment. The Stretch director wants summarized information from each segment, which is aggregated from the stations. The area director wants information of every stretch, which is aggregated from each segment.

When one is aware of the different level of details each type of stakeholder wants, the aggregation quickly becomes a useful way of determining the necessary data.

3.5 Case study of similiar systems

This section will present some similar systems and we will explain what the systems try to present.

3.5.1 Tåg.info

Tåg.info[23] is a Swedish system that tracks SJ[24] trains. The service gathers and processes data from Trafikverket[25]. As with Cargonet (Section 3.5.6), Tåg.info provides a method (Figure 3.3) of tracking live trains and visually see whether the trains are on schedule or delayed.

Tåg.info also provides a method of analyzing national delays by presenting graphs, Figure 3.4. The service presents both a bar-chart which presents the minutes of delays and the accumulated delays per day, and a pie chart of the current status.

3.5.2 Zugmonitor

In the Zugmonitor application (see Figure 3.5) each long-distance train in the German railway network has been plotted as an arrow on a German map. To illustrate the punctuality of each train, a colored circle has been added to each

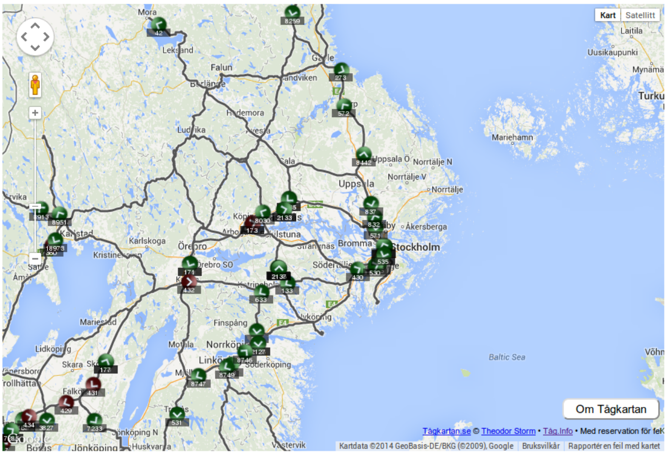
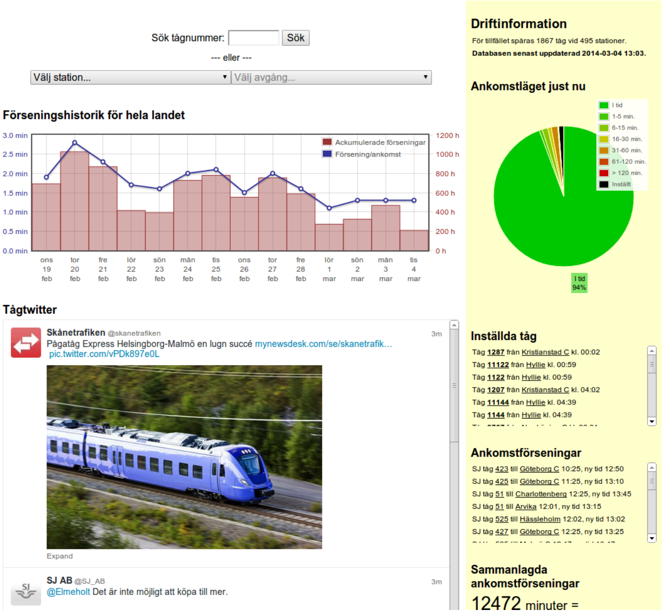


Figure 3.3: Tåg.info map [23]



Sök tågnummer: [ ] Sök

--- eller ---

Välj station... ▾ Välj avgång... ▾

Förseningshistorik för hela landet

Tågtwitter

Skånetrafiken @skanetrafiken 3m
Pågatåg Express Helsingborg-Malmö en lugn succé mynewsdesk.com/se/skanetrafik…
pic.twitter.com/vPDk897e0L

Expand

SJ AB @SJ_AB 3m
@Elmeholt Det är inte möjligt att köpa till mer.

Driftinformation

För tillfället spåras 1867 tåg vid 495 stationer.

Databasen senast uppdaterad 2014-03-04 13:03.

Ankomstläget just nu

Inställda tåg

Tåg **1287** från Kristianstad C kl. 00:02
Tåg **11122** från Hyllie kl. 00:59
Tåg **1122** från Hyllie kl. 00:59
Tåg **1207** från Kristianstad C kl. 04:02
Tåg **11144** från Hyllie kl. 04:39
Tåg **1144** från Hyllie kl. 04:39

Ankomstförseningar

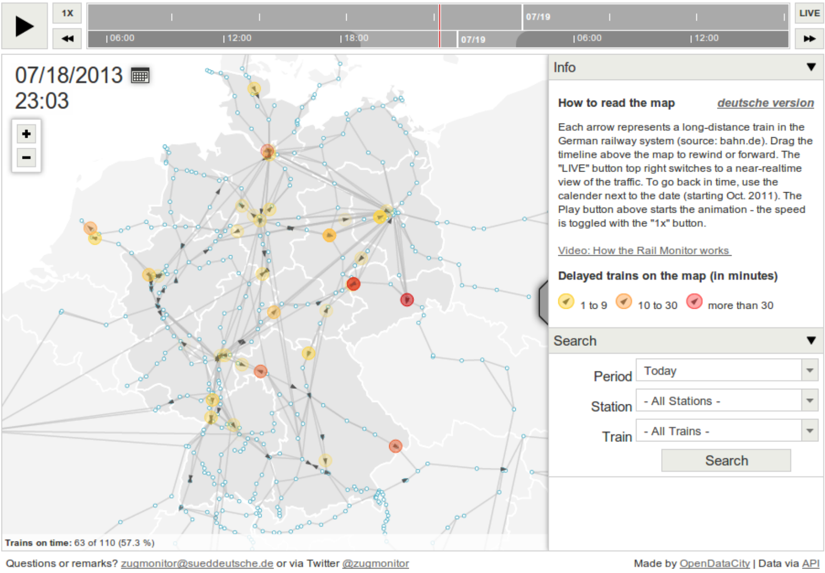
SJ tåg 423 till Göteborg C 10:25, ny tid 12:50
SJ tåg 425 till Göteborg C 11:25, ny tid 13:10
SJ tåg 51 till Charlottenberg 12:25, ny tid 13:45
SJ tåg 51 till Arvika 12:01, ny tid 13:15
SJ tåg 525 till Hässleholm 12:02, ny tid 13:02
SJ tåg 427 till Göteborg C 12:25, ny tid 13:25

Sammanlagda ankomstförseningar

12472 minuter =

Figure 3.4: Tåg.info history [23]

arrow if the train is delayed with varying color depending on how big the delay is. A time line is also displayed to see how the trains run on each step of the routes.



How to read the map *deutsche version*

Each arrow represents a long-distance train in the German railway system (source: bahn.de). Drag the timeline above the map to rewind or forward. The "LIVE" button top right switches to a near-realtime view of the traffic. To go back in time, use the calender next to the date (starting Oct. 2011). The Play button above starts the animation - the speed is toggled with the "1x" button.

Video: How the Rail Monitor works

Delayed trains on the map (in minutes)

● 1 to 9 ● 10 to 30 ● more than 30

Period: Today
Station: - All Stations -
Train: - All Trains -

Trains on time: 63 of 110 (57.3 %)

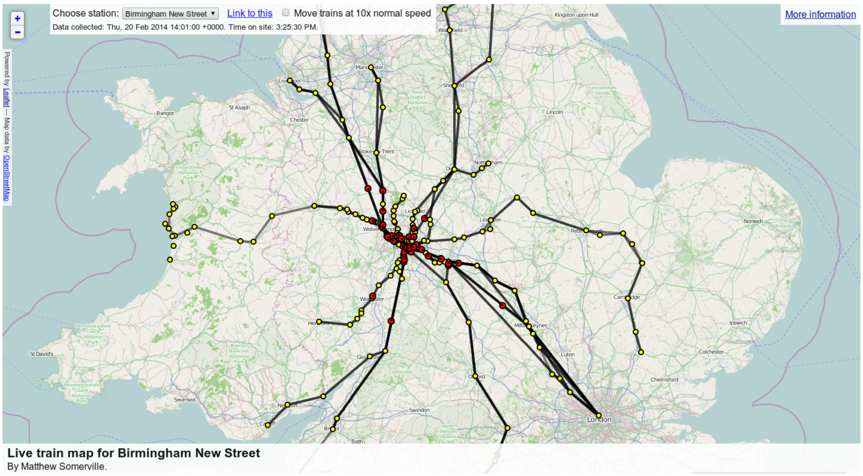
Questions or remarks? zugmonitor@sueddeutsche.de or via Twitter @zugmonitor

Made by OpenDataCity | Data via API

Figure 3.5: Zugmonitor [26]

3.5.3 Vaguely live map of trains in the United Kingdom

The "Vaguely live map" system is a map which plots the relative location of each train in the United Kingdom (see Figure 3.6). The plot fetches the departure time from the National Rail website and calculates the relative location. The plot does not indicate whether the trains are on schedule or delayed, if one wants to check for delays, one either has to do it manually on station, or for instance by checking a time table[27]. Both the map and time table is developed on hobby basis by the same person.



Choose station: Birmingham New Street ▾ Link to this □ Move trains at 10x normal speed

Data collected: Thu, 20 Feb 2014 14:01:00 +0000. Time on site: 3:25:30 PM.

More information

Live train map for Birmingham New Street

By Matthew Somerville.

Figure 3.6: UK live map [28]

3.5.4 MiseryMap

The MiseryMap (see Figure 3.7) shows how much different airports and the routes between them are delayed. The system also have a playback function to see the delays throughout the day. Since the plot sometimes also shows the weather conditions, the system gives the user the possibility to spot if the delays can be blamed on uncontrollable conditions.

3.5.5 MUNI Light Rail

The "Muni light rail" system is a train graph based on the N-Judah line on the Muni Metro light railway line in San Francisco (see Figure 3.8). The train graph plots the schedule of the each train and the actual time each train uses. The chart auto updates every 10 seconds, and combined with being able to spot the difference between the schedule and the actual time, makes it easy to spot the delay of each train. As with Section 3.5.3 the "Muni light rail" system has been developed on a

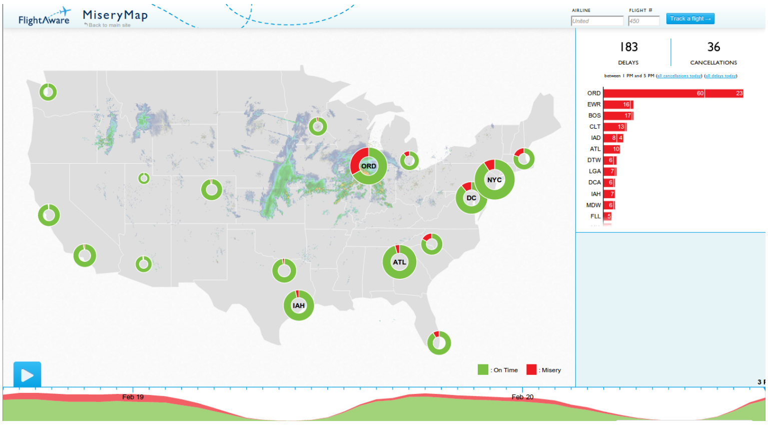


Figure 3.7: MiseryMap [29]

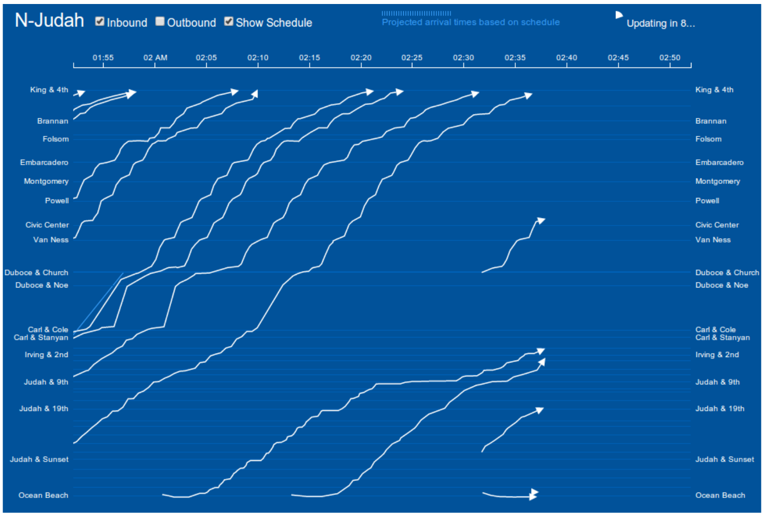


Figure 3.8: MUNI Light Rail [30]

hobby basis.

3.5.6 Cargonet

Cargonet is a Norwegian company which provides intermodal transport on rails. To provide an effective tracking service for the customers, Cargonet provides an internal service for the users which tracks all trains belonging to Cargonet. As can be seen in Figure 3.9, the system only shows a picture of the current status of each train. The system lacks the possibility to analyze every stretch individually and analyze trains and stretches over time.

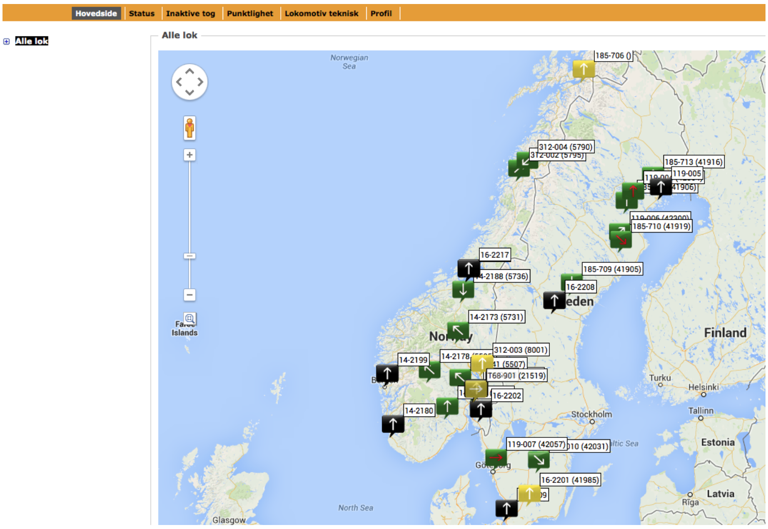


Figure 3.9: Cargonet [31]

Figure 3.9 legend

- Red arrow: Delayed.
- White arrow: On time.

- Red box: Locomotive driven 2km without carriages.

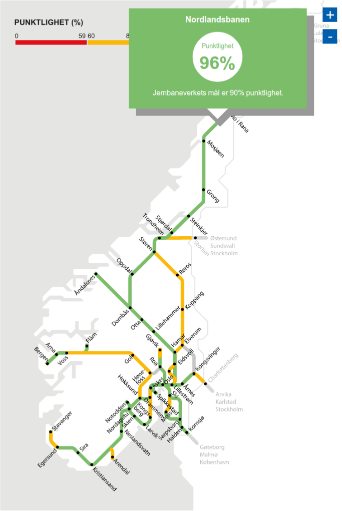
- Black box: Locomotive without carriages.

- Yellow box: Locomotive on time without schedule, or known position.

3.5.7 Norwegian National Rail Administration

Jernbaneverket is the Norwegian government agency for railway services. As described in Section 3.1, Jernbaneverket is responsible for the infrastructure of all the railway network in Norway. Since they have responsibility for the infrastructure, they also collect data from points that each train passes, as described in Section 3.3. Based on the collection of data, they have recently released a map (see Figure 3.10) over the punctuality on each track segment. The released map is an interactive map which shows a pop-up box containing the punctuality of the train segment clicked on, and the pop-up also shows which train routes that operates the train segment clicked on. The map, does not however, show more information if the user zooms in, which is possible within the map itself, and has a static view of Norway and the railway. The map only shows the punctuality for passenger trains, and not freight trains and/or both.

To analyze each stretch, on a detailed level between each station, Jernbaneverket has a internal system called TIOS. TIOS can create a train graph which plots all trains that passes between all stations, Figure 3.11 presents an example of the train graph between Oslo S and Drammen, where the red lines means planned time, black lines is actual time and the red circle indicates a a code for the cause of the delay.



Nordlandsbanen

Punktlighet 96%

Jernbaneverkets mål er 90% punktlighet.

Figure 3.10: JBV Punctuality map [32]

3.5.8 SINTEF PRESIS

The PRESIS[18] project is a collaboration between SINTEF[33], Transportøkonomisk Institutt [34], NTNU[35], Jernbaneverket(Section 3.5.7) and the train operators Cargonet (Section 3.5.6), NSB[36], and Flytoget [37]. The aim of the project is to systematically improve the precision level in the railway system by developing methods, tools, and processes.

A interaction plot, see Figure 3.12, plots the interaction between two selected trains at a selected station. The interaction plot makes it easy to see if a train is delayed, and how the delayed train might affect another train. Since the interaction plot only plots the interaction between two trains, the plot makes it difficult to follow a delay back through the railway network to find the source. Due to not being able to track the delay backwards, the plot is useful for individual trains, but are difficult to use if one wants to look at the entire railway network or a large portion of it.

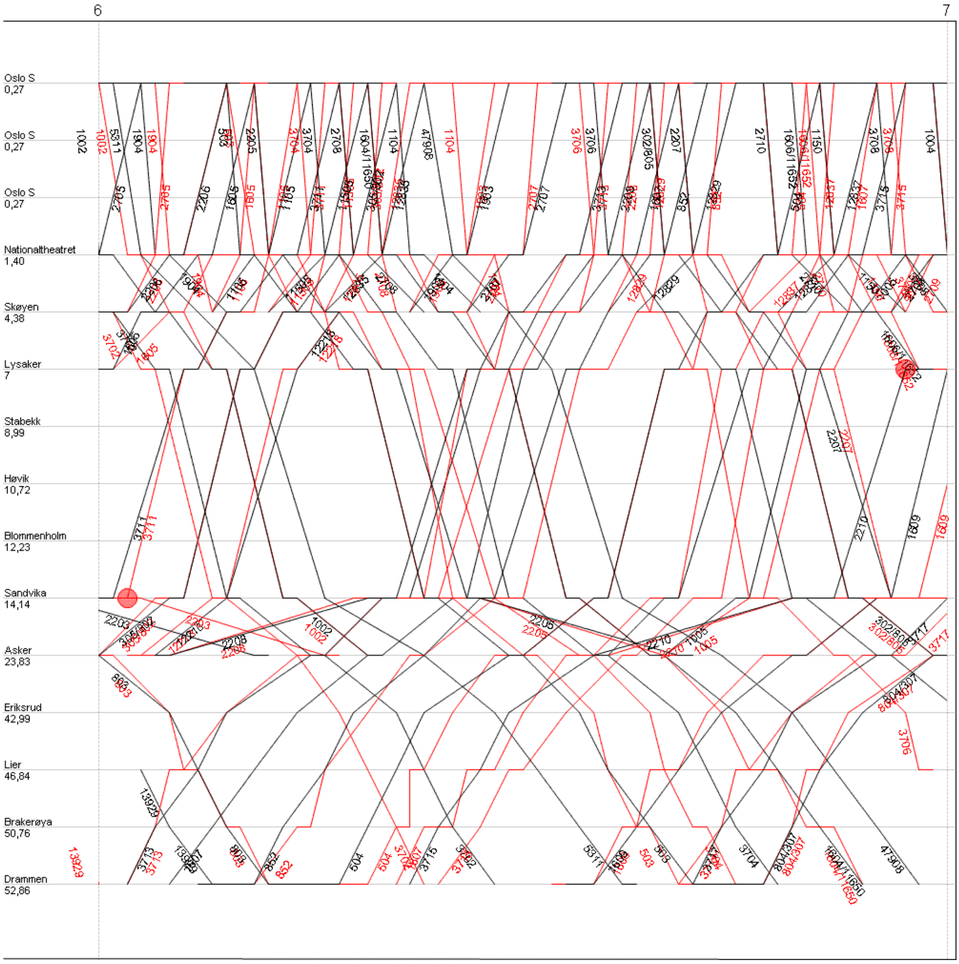
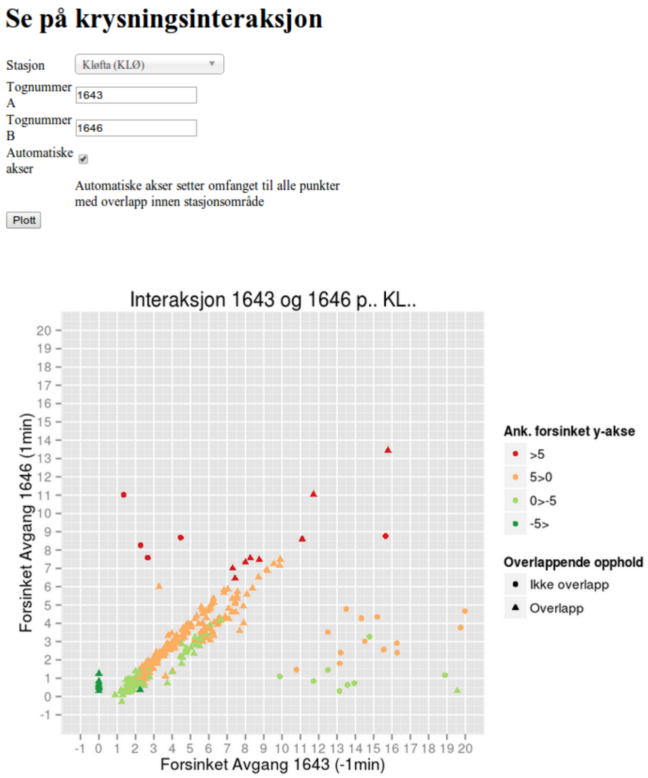


Figure 3.11: TIOS[1]

Publicly and internally the status of a train may differ whether a train are delayed or not. Public statistical data only shows delays on the final destination of the train, however all stations along the route show whether the train are on schedule or not on information screens on each station. Since Jernbaneverket collects data from all signal points along the route (see Table 3.2 and Table 3.3), Jernbaneverket are able to track and plot the delays the train may experience along the route and not only at the end station. The PRESIS project has developed a prototype for such a plot, see Figure 3.13. Here the circles represent a station and the lines between the station have different colors which represent the punctuality between the stations, and the data which the plot is based on are listed to the right. The PRESIS project have also made it possible to get a time used over distance plot (see Figure 3.14), based on the selected data in the Punctuality for routes plot.

A plot based on time over distance, Figure 3.14, plots the actual time used by all trains that have driven that stretch in the selected time period along with the running average. When plotting based on time over distance, the plot enables the possibility to spot where and when trains have experienced problems on the selected stretch. They also have a prototype plot which plots time used on station (see Figure 3.15) and other prototypes which is similar, just focusing on other parts of the process.



Se på krysningsinteraksjon

Stasjon: Kløfta (KLØ)

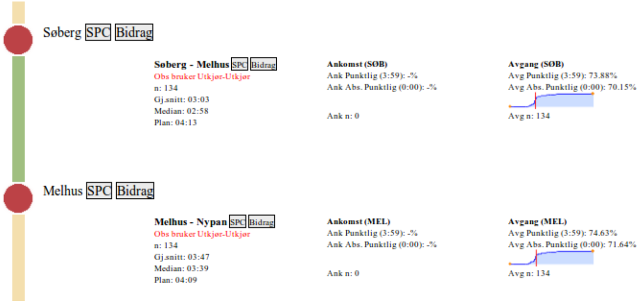
Tognummer A: 1643

Tognummer B: 1646

Automatiske akser: ☑

Automatiske akser setter omfanget til alle punkter med overlapp innen stasjonsområde

Figure 3.12: Train interaction plot [18]



Søberg SPC Bidrag

Søberg - Melhus SPC Bidrag
Obs bruker Utkjør-Utkjør
n: 134
Gj.snitt: 03:03
Median: 02:58
Plan: 04:13

Ankomst (SØB)
Ank Punktlig (3:59): -%
Ank Abs. Punktlig (0:00): -%
Ank n: 0

Avgang (SØB)
Avg Punktlig (3:59): 73.88%
Avg Abs. Punktlig (0:00): 70.15%
Avg n: 134

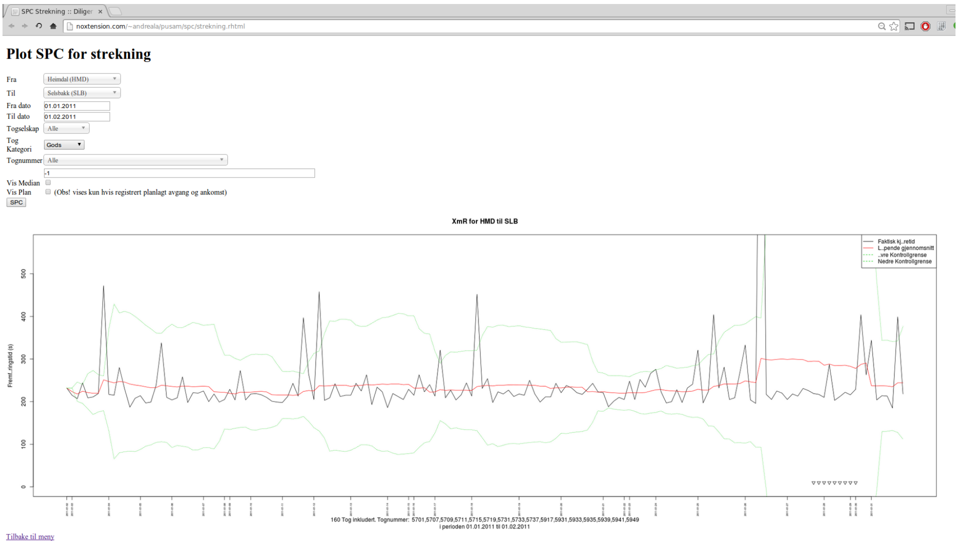
Melhus SPC Bidrag

Melhus - Nypan SPC Bidrag
Obs bruker Utkjør-Utkjør
n: 134
Gj.snitt: 03:47
Median: 03:39
Plan: 04:09

Ankomst (MEL)
Ank Punktlig (3:59): -%
Ank Abs. Punktlig (0:00): -%
Ank n: 0

Avgang (MEL)
Avg Punktlig (3:59): 74.63%
Avg Abs. Punktlig (0:00): 71.64%
Avg n: 134

Figure 3.13: Route punctuality[18]

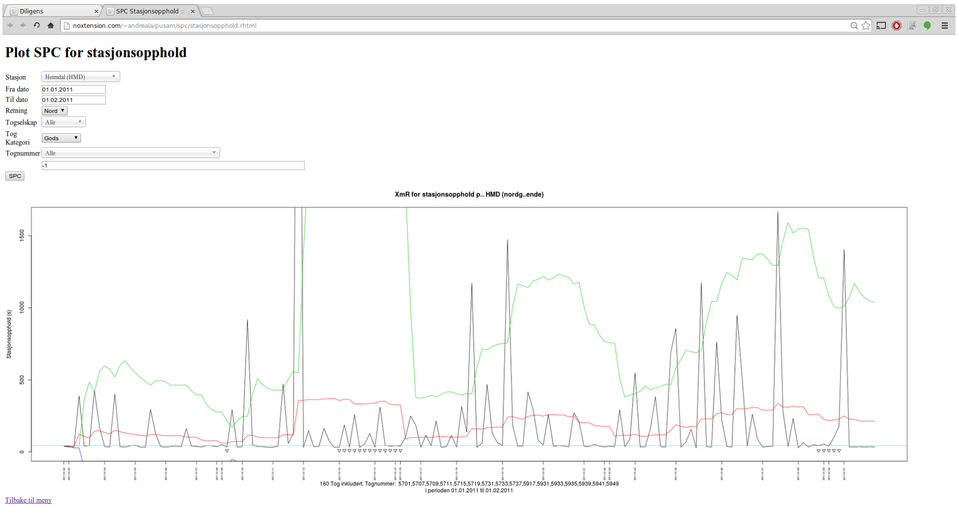


Plot SPC for strekning

Fra: Heimdal (HMD)
Til: Selsbakk (SLB)
Fra dato: 01.01.2011
Til dato: 01.02.2011
Togselskap: Alle
Tog Kategori: Gods
Tognummer: Alle
-1
Vis Median □
Vis Plan □ (Obs! vises kun hvis registrert planlagt avgang og ankomst)

160 Tog inkludert. Tognummer: 5701,5707,5709,5711,5715,5719,5731,5733,5737,5917,5931,5933,5935,5939,5941,5949
i perioden 01.01.2011 til 01.02.2011

Figure 3.14: SPC Stretch [18]


Diligens
SPC Stasjonsopphold ::
noxtension.com/~andreala/pusam/spc/stasjonsopphold.rhtml

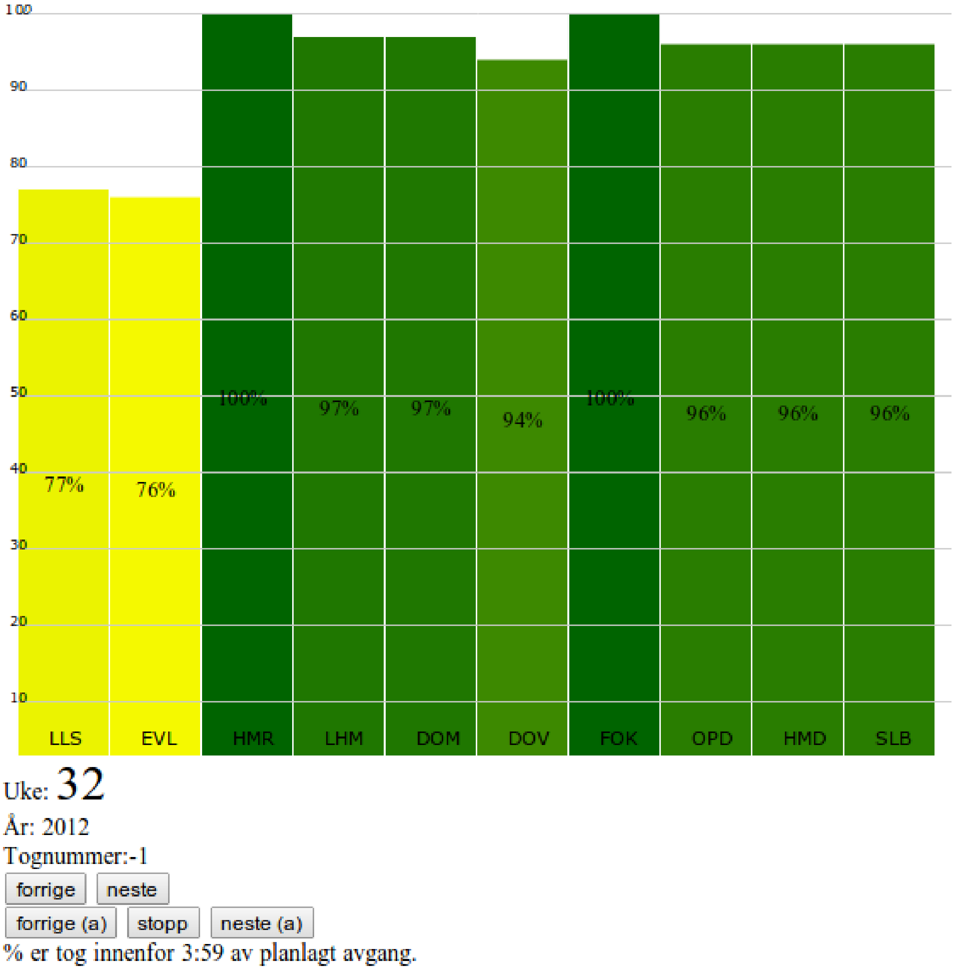
Plot SPC for stasjonsopphold

Stasjon: Heimdal (HMD)
Fra dato: 01.01.2011
Til dato: 01.02.2011
Retning: Nord
Togselskap: Alle
Tog Kategori: Gods
Tognummer: Alle
-1

SPC
XmR for stasjonsopphold p.. HMD (nordg..ende)
Stasjonsopphold (s)
0
500
1000
1500

160 Tog inkludert. Tognummer: 5701,5707,5709,5711,5715,5719,5731,5733,5737,5917,5931,5933,5935,5939,5941,5949
i perioden 01.01.2011 til 01.02.2011

Figure 3.15: SPC Station [18]



Uke: 32

År: 2012

Tognummer:-1

% er tog innenfor 3:59 av planlagt avgang.

Figure 3.16: Weekly punctuality[18]

3.6 Defining frameworks

In this section we will first define the users in the railway network, and then define framework(s) based on the need of the users and the information the systems in Section 3.5 presents.

3.6.1 Functionality description

In this section we define different types of information and determine the system which covers each type.

National Whether or not it gives a national overview.

Route Whether or not it is possible to study a whole route.

Stretch Whether or not it is possible to study individual stretches.

Live Whether or not it gives a live view of the current situation.

Historical Whether or not it is possible to study historical data.

System \ Functionality	National	Route	Stretch	Live	Historical
Figure 3.5 Zugmonitor	X	-	-	X	X
Figure 3.6 UK live map	X	-	-	-	X
Figure 3.8 MUNI Light Rail	-	X	X	X	-
Figure 3.7 MiseryMap	X	-	-	-	X
Figure 3.10 JBV Punctuality map	X	-	-	-	X
Figure 3.11 TIOS	-	X	X	-	X
Figure 3.3 Tåg.info map	X	-	-	X	-
Figure 3.4 Tåg.info history	X	X	X	X	X
Figure 3.12 Train interaction plot	-	-	X	-	X
Figure 3.13 Route punctuality	-	X	X	-	X
Figure 3.14 SPC Stretch	-	-	X	-	X
Figure 3.15 SPC Station	-	-	X	-	X
Figure 3.16 Weekly punctuality	-	X	X	-	X
Figure 3.9 Cargonet	X	-	X	X	-

Table 3.4: Functionality description

3.6.2 Type of information presented

In this section we summaries what kind of information the different systems presents.

System	Type of information
Figure 3.5 Zugmonitor	Delays
Figure 3.6 UK live map	Delays
Figure 3.8 MUNI Light Rail	Delays and schedule
Figure 3.7 MiseryMap	Delays
Figure 3.10 JBV Punctuality map	Punctuality
Figure 3.11 TIOS	Delays and schedule
Figure 3.3 Tåg.info map	Delays
Figure 3.4 Tåg.info history	Delays
Figure 3.12 Train interaction plot	Delays and crossings
Figure 3.13 Route punctuality	Delays
Figure 3.14 SPC Stretch	Time used vs others
Figure 3.15 SPC Station	Time used vs others
Figure 3.16 Weekly punctuality	Punctuality
Figure 3.9 Cargonet	Delays

Table 3.5: Information presented

As seen in Table 3.5, almost all of the system found presents either delays or punctuality in some way. The comparison shows that there are gaps in what kind of information that is being displayed.

3.6.3 User needs vs system information

Since each project presented in Section 3.5 on page 22 is based on different types of users accessing the systems, they present different amount of information. Since some of the projects presented contains different types of information presentations and they may cover different needs, the following definition will be based on the presented figures.

User	Need	Figure	
Nation director	Overview for the nation	Figure 3.5 Zugmonitor, Figure 3.7 MiseryMap, Figure 3.4 Tåg.info history, Figure 3.9 Cargonet	Figure 3.6 UK live map, Figure 3.3 Tåg.info map, Figure 3.13 Route punctuality,
Area director	Overview / detailed for the area	Figure 3.5 Zugmonitor, Figure 3.8 MUNI Light Rail, Figure 3.12 Train interaction plot, Figure 3.15 SPC Station,	Figure 3.6 UK live map, Figure 3.11 TIOS, Figure 3.14 SPC Stretch, Figure 3.16 Weekly punctuality
Segment director	Detailed for each segment	Figure 3.8 MUNI Light Rail, Figure 3.12 Train interaction plot, Figure 3.15 SPC Station,	Figure 3.11 TIOS, Figure 3.14 SPC Stretch, Figure 3.16 Weekly punctuality
Traffic responsible	Detailed for each line	Figure 3.5 Zugmonitor, Figure 3.7 MiseryMap, Figure 3.13 Route punctuality, Figure 3.9 Cargonet	Figure 3.6 UK live map, Figure 3.3 Tåg.info map, Figure 3.16 Weekly punctuality,
East responsible	Detailed for east	Figure 3.8 MUNI Light Rail, Figure 3.12 Train interaction plot, Figure 3.15 SPC Station,	Figure 3.11 TIOS, Figure 3.14 SPC Stretch, Figure 3.16 Weekly punctuality
None	Basic	Figure 3.5 Zugmonitor, Figure 3.7 MiseryMap,	Figure 3.6 UK live map, Figure 3.10 Route punctuality

Table 3.6: User needs vs system information

Chapter 4

Implementation

Based on the case study performed in Section 3.5 Case study of similiar systems, a prototype was developed to help answer the research question presented in Section 1.2 Research Question and Goals.

The first part describes the implementation of the back-end of the system, which processes the data. We then describe the front-end of the, which presents the data to the user. In the third part we present the architecture of the system. Lastly the different technology used throughout the system is presented.

4.1 Back-end

In this section we will describe how the back-end of the system was implemented. The back-end is the part of the system which functions as the interface between the user input from the front-end and data storages, and mediates data between these.

4.1.1 Data storage

Since the data was given in different sets and some sets serve a different purposes, different sets was stored differently. For the prototype developed, the data was stored in 3 databases although optimally the amount of databases would have been two. The increased amount of databases is due to one of the data sets which was given as a interface to an existing database, while the others were given as sets which had to be put into an database.

The first database (The "station database") that was set up, was the one that contained the stations. The structure was determined by the hierarchy of stakeholders presented in Section 3.2. We were presented with a list of all the relevant stakeholders, which were all the area directors, stretch directors, and segment director. The hierarchy in the "station database" database ended up as presented in the following list and the structure is similar for all 6 areas and all the different numbers of stretches and segments beneath each area.

- Area 1
    - Strech 1
        - Segment 1
    - Stretch 2
        - Segment 2
        - Segment 3

The second and third databases (the "information database(s)") were all built around the stations. By having the databases built around the stations, the relation between these events and the stakeholders were a connection between the events and either one or two stations. Since all events had a connection to a station, these "information database(s)" all had a similar structure with data points such as stations where event occurred, scheduled and actual time of arrival and departure and train number. An example of such a data set is presented in Table 3.2 and Table 3.3.

4.1.2 Aggregation

When the system shall aggregate for the stakeholders, the front-end sends the stakeholder, information type, and time parameters to the back end. The system then locates the correct stakeholder in the "station database", which returns the correct area to which the stakeholder belongs. Based on the area returned by the database, the information selected, and the time window selected, the system will fetch the relevant data from the "information databases".

Since most of the information is count based, the aggregation performed on these sets are a simple average function along with generating dummy markers for each sub-area. Say one was to select an area as the current stakeholder with crossings as current data type, the system will then loop through and average all crossings per station within every segments and generate a marker located on the average location of all the stations with the average crossing of all these stations. The system will then do the same for all segments within one stretch. By performing the aggregation method for an area, the system generates an average marker for each stretch, located on the average location of all segments generated from all the stations, with the average crossings of all stations in that area.

The database structure presented above is implemented similar on the other sets of data, except in the case of Speed restrictions. The difference in the data sets is due to that the workshops determined that the speed restrictions was to be displayed with a own marker limited by the time selector.

4.2 Front-end

In this section we will describe how the front-end was implemented. The front-end is the part of the system that interacts with the user.

4.2.1 Data set presentations

When presenting the information to the user, the ability to maintain a tidy presentation but at the same time present all the necessary information is important. Since the system shall present different kind of information, a selectable list of the implemented information types was implemented. The selectable list, presented in Figure 5.2b, sets a internal variable which determines what kind of information shall be fetched from the databases and in turn be presented to the user.

As was mentioned in Section 3.4, speed restrictions were meant to be displayed as a individual marker per event restricted within the selected time window. In the database, each speed restriction event is stored with an id which is equal to an image file with the plot. The data query will return with the id of each matched event, and the matching images will then be displayed within the popup of the marker for each event. An example of a speed restriction marker with plot is presented in Figure 5.4a.

Since the other information types were meant to be displayed in a dashboard, a simple way of displaying the aggregated data along side each marker was made. An example of an aggregated dashboard is presented in Figure 5.4b with the use of number of aggregated crossings in the Oslo area and East area as an example. When an user selects a new information type and the variable is updated, then sends a new request to the back end which in return presents the front-end with new data to present. The system will then dynamically update the dashboards and the markers.

When the time selection was to be implemented, the input method had been decided to be implemented as input boxes in one of the corners for from and to date and time, as presented in Figure 5.3b. When user changes the time interval, the input is validated to be in correct form and used in the request for data.

A top 5 list for some of the data types, was wanted during the workshops held. The wanted functionality from the top 5 list was to display a list of the worst or best of the current information type within each current stakeholders responsible area. In the case of crossings, the information would display the five stations with the most crossings. We made a proof of concept of a top 5 list, demonstrated in Figure 5.3a with the use of number of crossings.

The system adapts the view to the current stakeholder in order to further consider their requirements. The adaption of the view happens when the back-end has returner the processed data, by first displaying the data in markers on the map, and then automatically adjust the visible map to the data.

4.2.2 Aggregation

Since most of the aggregation was done in the back end, there was not much needed to be done in the front-end. One of the first things implemented, was the selection of stakeholders, see Figure 5.2a. The stakeholder is generated dynamically by sending a request for all the stakeholders to the back-end, and aggregate through the response which will generate the selectable list of stakeholders.

4.3 System architecture

In this section we will describe the architecture of the implemented prototype.

We designed our prototype around a client-server pattern [2, pp. 217-219] with a layered pattern [2, pp. 205-210] on the server, presented in Figure 4.1. The system are built around a request/reply protocol used to invoke services. The communication is between clients which initiates all contact with a server, which in turn responds to the initiated client requests. The client-server pattern simplifies systems by factoring out common services, which are reusable, by separating client application from the services they use. Other typical uses for the client-server pattern are Web-based application. In the prototype, the map presentation of the information are the clients which communicates to a server that aggregates the data.

The server has been build using the layered pattern, where the logic is divided into units called layers, where each layer offers a cohesive set of services. There are two layers implemented, *Logic* and *Storage* . The *Storage* contains all databases for all data sets used. The *Logic* layers performs all communication with the clients, and processes data fetched from the *Storage* layer. The two layers can be seen in Figure 4.1 as the *Logic* and *Storage* boxes within the *Server* box.

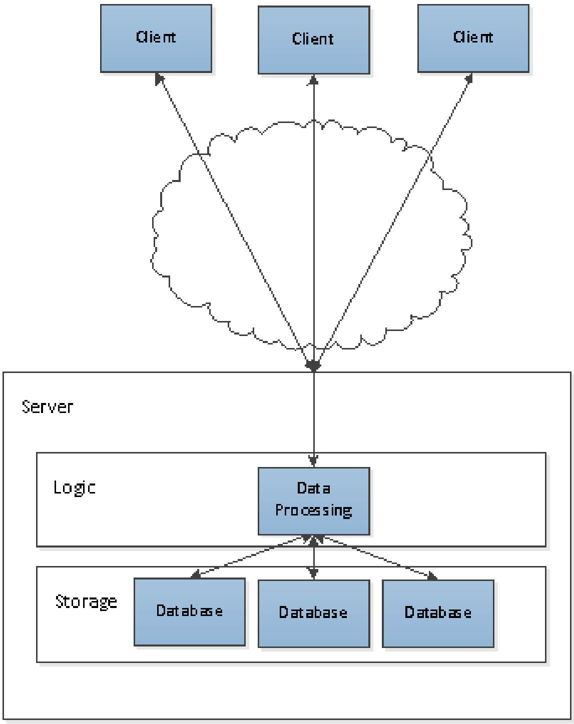


Figure 4.1: Prototype architecture

4.4 Technology

This section will describe the technology used to implement the prototype.

4.4.1 Server

When the back end was due for implementation, Node.js[38] was chosen as the framework for the server. Node.js is an event-driven, non-blocking I/O model framework which is based on Chrome's[39] JavaScript runtime. The Node.js framework enables small, fast, and scalable network applications.

When the user wanted to change information type or active stakeholder, the request for data was posted to the server through a REST[40] API. An example of a request for the number of crossings for the Oslo area is "/rail/numberOfCrossings/2012-01-01/2012-02-01/oslo". The server then uses the Express[41] framework to parse all get request to the server to send these request to methods within the Node server which parses these requests.

4.4.2 Data storage

When storing the data, several types of databases was used as mentioned in Section 4.1.1. The "station database" was implemented in a noSQL document database structure called MongoDB[42]. A MongoDB database holds a set off collections. A collection holds a set of documents. A documents is a set of key-value pairs. For this thesis, The MongoDB database structure meant that one can search on a single key, for instance the name of an area, and get all relevant data within that structure. The MongoDB driver called Monk[43] was used to access the implemented MongoDB database.

When setting up the last two databases, more traditional relational databases was used. The first database implemented was one in PostgreSQL [44]. The node-postgres[45] was used to access this database. The PostgreSQL database was chosen due the functionality of the database and since we were most familiar with PostgreSQL. The last database was given as an interface to connect to, and was set up in MySQL [46]. The node-mysql[47] driver was used to access the given MySQL interface.

4.4.3 Map

Since the map was a important part of the presentation of data, the selection of the map library was also an important decision. Both Google maps[48] and Leaflet[49] was looked at, however in the end Leaflet was chosen. Google Maps is a more known map framework, but one either has to limit the usage of the system or buy a license. Leaflet is a modern open-source JavaScript library which is designed with simplicity, performance and usability in mind[49]. As both Node.js and Leaflet is written in JavaScript[50], means that code are easily transferable and comparable.

All functions within the map is an extension of functions that exists in the map. Information selection, time selection, stakeholder selection and Top 5 is an extension of the L.Control object. The dashboards uses a standard marker, and a bit of CSS to display the marker icon and the information. The map prototype developed was presented in Figure 5.1.

Chapter 5

Results

This chapter will present results found by performing activities described in Chapter 2 Research Method.

In the two first parts we describe the results of the workshops held. The last part describes the functionality in the prototype developed. The implementation of the prototype was described in Chapter 4 Implementation.

5.1 Workshop 2014-04-04

The first workshops agenda was to help define the stakeholders of the system, their areas of responsibility, and their needs. The workshop was also meant to bring clarity to how the system will relate to these users and their needs. Attending this workshop were Andreas Amdal Seim (SINTEF), Andreas Dypvik Landmark (SINTEF), Rimmert van der Kooij (SINTEF), Nils Olsson (NTNU), Per Magnus Hegglund (Jernbaneverket), Magnus Bae (NTNU), and Magnus Krane (NTNU).

Perspectives that can be used when viewing the system were discussed first.

- Infrastructure: Segment director, etc.
- Traffic division / passenger / train companies.
- Delay causes: delay demographic.

Interests of users when using the system were then discussed based on the perspectives.

- Uptime, punctuality.
- Deviation.
  - What?
  - Where?
  - When?
- Delay time.
- Variation.
- Changes.

Causes that might affect the punctuality was also listed: weather, number of passengers, capacity utilization, animal accidents, cargo volume. The causes were concluded not to be included in this project, as the causes are difficult to prove and get data on.

The internal project in Jernbaneverket (section Section 3.5.7) uses a deviation registry for data to analyze each stretch on a detail level. To calculate the uptime, presented in Section 3.1, also uses the deviation registry for the needed data. A problem by using the deviation registry for calculating variation or changes, the registry have a five minute filter in which the trains are being calculated to be on time.

Two problems were agreed upon that needed to be addressed, the back end and the front end of the system. What kind of data is available and what is possible to do with this data? A data set can show both positive and negative results, based on what the set are compared too. For instance, Easter is not on the same week each year and the passenger volume increase during the holidays. Data sets ended up being addressed in the second workshop (Section 5.2).

As the different stakeholders might have need for different presentation of the data, different levels of stakeholders and what should be shown in each level was discussed. A suggestion was made to have the same perspective through the levels, but to have selectable views based on roles.

At the end of the workshop, three conclusions were made. The first conclusion was to have a dashboard next to each marker with relevant data to the current stakeholder. The second conclusion was to create an interactive list of the stakeholders which adapted the visual presentation to the selected stakeholder, presented in Section 3.2. The last conclusion was to have a second workshop where the content of the dashboard should be decided. This resulted in Section 5.2.

5.2 Workshop 2014-04-24

The second workshops agenda was to determine which statistical data was to be implemented in the dashboard, concluded upon in Section 5.1. Attending this workshop was Andreas Amdal Seim (SINTEF), Andreas Dypvik Landmark (SINTEF), Rimmert van der Kooij (SINTEF), and Magnus Krane (NTNU).

The workshop started with a brainstorming for different data to present in the map. The different data was ranked on implementation practicality from 1 - 3 where 1 is unpractical and 3 is very practical; and ranked on the desirability of the data from 1 - 3 where 1 is undesirable and 3 is very desirable. The brainstorming after ranking is presented in Table 5.1.

Functionality	Practicability	Desirable	Priority
Outstanding errors	1	1	1
Suspensions	3	1	3
Variation	1	3	3
Season effects	3	1	3
Follow delays	1	3	3
Speed limits	3	1	3
Cause	3	2	6
Worst stretch/station/train number	3	2	6
Delays	3	3	9
Traffic density	3	3	9
Speed restrictions	3	3	9
Crossings	3	3	9

Table 5.1: Dashboard functionality brainstorming ideas

Based on the ranking, the decision was made to only implement the data was ranked as a 3 both on practicability and desirability, presented in the list below.

- Speed restrictions
- Crossings

- Traffic density

The second part of the agenda, was to determine how the selected data was to be presented. The decision was made to split the presentation in two parts. The first was to display aggregated data in the dashboards next to the marker based on the current stakeholder. The second was to display top 5 lists for delays and speed restrictions.

5.2.1 Crossings

One of the problems discussed with crossing was to determine if the systems should take into account the difference between actual crossings and planed crossing or not. The difference is hard to calculate as one does not know whether one of the trains involved in the planned crossing, was canceled or just delayed. The decision was made to present the number of crossings occurred at each station, and aggregate the number as one navigates in the stakeholder hierarchy.

5.2.2 Traffic density

Several options to present traffic density were discussed, the problem was how to correctly show the number of trains based on the data available. Should the system present each train based on the train numbers and calculate for the entire line both ways? Should the system display train numbers divided by the segment directors?

In the workshop it was decided to show the number of trains that passes each block segment, based on the data available. When navigating in the hierarchy, the system shall aggregate the number of trains.

5.2.3 Speed restrictions

Speed restrictions was decided to be presented a marker per restriction, and be shown between the selected time interval. The data for the speed restrictions was to be presented in a plot which appeared in the marker for each restriction.

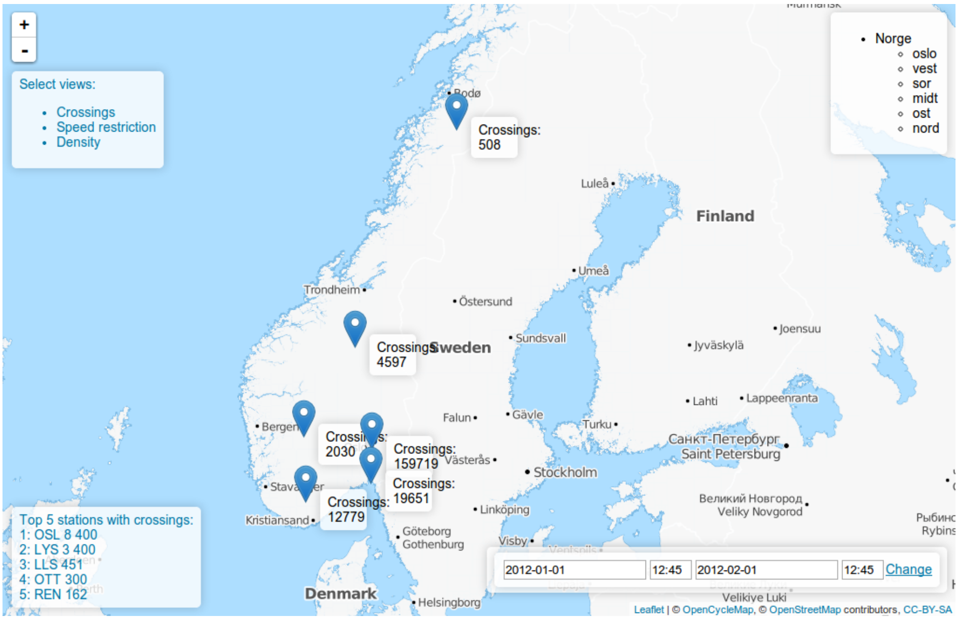
5.3 Prototype functionality

As part of answering the research question, a prototype was developed. In this section we will describe the functionality in the prototype.

The prototype is a map based system that presents the information according to the needs of the stakeholders, as presented in Figure 5.1. An interactive list was implemented, presented in Figure 5.2a, which gives the functionality to navigate through the stakeholders hierarchy. The system aggregates the data according to the current selected stakeholder, as presented in Section 4.1.2 on page 43. The visual presentation will be adapted to the areas of responsibility of the current stakeholder, which will focus the presentation of the data in the geographical area of the stakeholder.

To let the stakeholder be able to select different types of information according to their need, all types were presented in a list (Figure 5.2b). The system changes the information presented, when an information type have been clicked on. By letting the user select the information type to present, the system is able to present the stakeholders need for different information type according to their requirements. Figure 5.4 shows the presentation of two different types of information.

A method to navigate in time were implemented, as the stakeholders have different needs for the level of detail in the presentation of data. The time navigation was implemented as two input boxes, see Figure 5.3b. The system uses the time interval set by the user to limit the data to be processed.



Select views:

- Crossings
- Speed restriction
- Density

- Norge
  - oslo
  - vest
  - sor
  - midt
  - ost
  - nord

Crossings: 508

Crossings: 4597

Crossings: 2030

Crossings: 159719

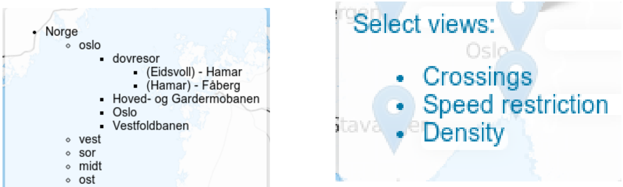
Crossings: 19651

Crossings: 12779

Top 5 stations with crossings:
1: OSL 8 400
2: LYS 3 400
3: LLS 451
4: OTT 300
5: REN 162

2012-01-01 | 12:45 | 2012-02-01 | 12:45 | Change

Figure 5.1: Map implementation



- Norge
  - oslo
    - dovresor
      - (Eidsvoll) - Hamar
      - (Hamar) - Fåberg
    - Hoved- og Gardermobanen
    - Oslo
    - Vestfoldbanen
  - vest
  - sor
  - midt
  - ost
  - nord

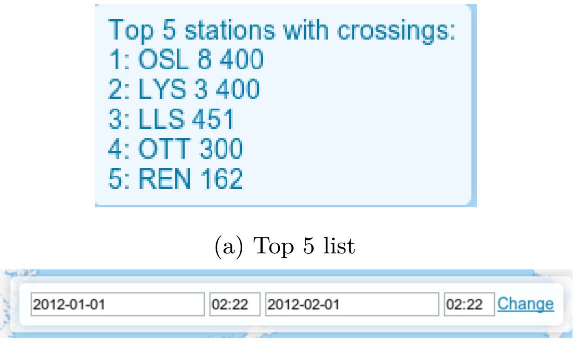
(a) Stakeholder selection list

Select views:

- Crossings
- Speed restriction
- Density

(b) Information type selection

Figure 5.2: Stakeholder selection and Information type



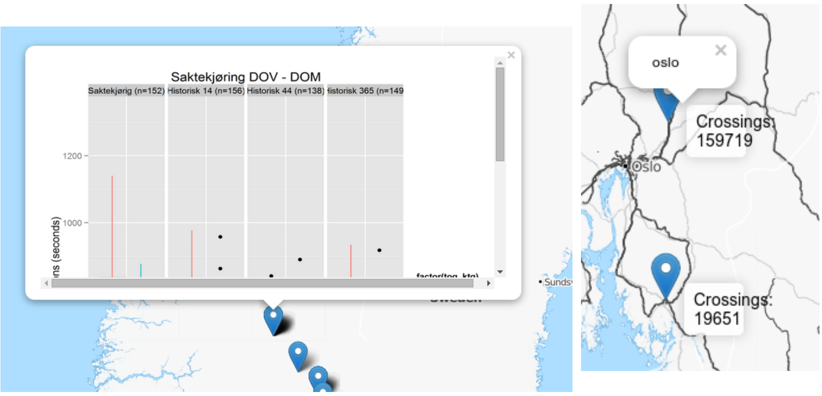
Top 5 stations with crossings:
1: OSL 8 400
2: LYS 3 400
3: LLS 451
4: OTT 300
5: REN 162

(a) Top 5 list

2012-01-01 02:22 2012-02-01 02:22

(b) Time selection implementation

Figure 5.3: Top 5 list and Time selection



(a) Speed restriction presentation

(b) Crossings presentation

Figure 5.4: Speed restriction and Crossings implementation

Chapter 6

Discussion

In this chapter we will discuss the results found during the work on this thesis.

First stakeholders, along with their requirements and needs, and processing the data according to the stakeholders, are discussed. In the second part, we discuss how the awareness of stakeholders affects the architecture of a system.

6.1 Stakeholders and aggregation

6.1.1 Defining stakeholders

It is important to define the needs and requirements of the stakeholders early in the project process, in order to design a system that gives the right scope. With the aid of workshops, we defined the requirements, as it is part of the research method (see Chapter 5). We can define the stakeholders in a hierarchy, based on their organizational structure, and areas of responsibility, this aids us in defining the requirements on the structure of the information presented.

When the system is designed with the stakeholders wishes for viewing different type of information in mind, there is good synergy between the requirements and the system. The synergy between the requirements and the system have both advantages and disadvantages. On one side, the system has a great possibility to satisfy the requirements and needs of the stakeholders, since the system is tightly connected to the requirements. On the other side, the system can be inflexible to large changes, if the requirements change late in the project. In the workshops, we defined that the stakeholders must have the ability to view different kinds of information and the system must take these needs into consideration.

A system capable of supporting and providing “awareness in presentation” of multiple stakeholders is by the very nature quite complex. Such a system would have to process a larger amount of data than a single-perspective system in order to provide the required functionality. Processing larger amounts of data leads to a more complex system (back-end) – and in turn a more complex interplay between user and front-end, with effects on the interplay between front-end and back-end. The system can be more dynamic by reusing parts of the data processing for different information types, when designed with the needs as well as the requirements in mind.

6.1.2 Aggregating to the stakeholder

Due to differing concerns, the different stakeholders require different levels of aggregation. There are several ways to aggregate the groups of data according to the given criteria. The method used for aggregation of data that enables the best view for the stakeholders is not straightforward. We have chosen to explore the following simple alternatives: average, minimum, maximum, median, and frequency (count). These are by no means an exhaustive list, but represent well established, robust and simple to implement alternatives. To decide the aggregation method, we have to consider how each information type is structured, but also how this structure fits in with the stakeholder and their hierarchy. During the workshops, we decided that the way to aggregate the data that was best suited to the requirements is to take the average of the data; the decision was based on how the data is connected to the stakeholders and their hierarchy. To pre-cache the results is almost impossible, as the system can aggregate both in time and space while both dimensions have a continuous growth.

When returning the processed data to the user, the system can use the context of the various stakeholders to aggregate the presentation of the data. Since the stakeholder hierarchy contains the area of responsibility of each stakeholder, the system can fit the visual display to the step of the current stakeholder. The system uses processed data for aggregating the hierarchy to find the stakeholder. Adapting the view to the stakeholder provides detail for a single stakeholder; this is useful for presenting a single stakeholder and their step. We decided to fit the visual presentation of data to the current stakeholder, and have the opportunity to jump, back and forth, within the hierarchy of the stakeholders. By adapting the view to the stakeholder, the display enabled the user to receive more relevant information on the current stakeholder. A conflict of interest occurs between stakeholders due to overlapping areas of responsibility. The conflict is extremely difficult to consider, and is not taken into consideration when aggregating the data or adapting the view.

As the area director wants to study data from the entire area for a large period of time, and the segment director wants to study almost every detail that occurs on the segment, manual navigating in time was decided to use as a way to increase and decrease the level of detail in the data presented.

6.2 Consequences for architecture

6.2.1 Data storage

As the data sets originate from different sources and contain different structures, they can be difficult to query efficiently. One option for the structure is to merge all the data sets into one large database, by merging the data sets in one large database, the data are structured in an client-server architecture. A client can either communicate to the databases directly or through a middle tier. Three-tier architecture is a very common solution on the Internet, where the communication between the client and the database goes through a service layer [51, pp. 294-297]. The client-server architecture has the benefits of giving the front-end applications a single point of connection, avoiding duplication of data, and giving the database manager both a single structure to maintain and a single point of access with easier access control.

The alternative of the client-server architecture is a distributed database [51, pp. 301-303]. The distributed database architecture is done by splitting the storage of data and the processing of data over several servers. Some benefits of the distributed architecture are easier expansion, modular sets with built-in flexibility, and if one node goes down the others still work. Exercising the built-in flexibility of each module is usually cheaper than to hand-code a specific change in hindsight[2, pp. 117-130]. The distributed architecture is a modifiable data storage, where the modular sets are loosely linked sets. We demonstrated a hybrid of the client-server and distributed architecture [51, pp. 297-299] with a three-tier architecture which contained a middle-tier for data processing and client communication, and a lower tier containing several databases, see Figure 4.1.

By using the three-tier architecture, we implemented a middle-tier which processed the data, and a lower tier containing several databases. For structuring the data sets with the stakeholders requirements in mind, we utilized one database which contained the stakeholders areas of responsibility in their hierarchy, and each of the other databases for different types of information. The semi-distributed databases mean that it is easy to remove or add data sets, since the different types of information are connected to the stakeholders hierarchy. There are also some negative aspects using the semi-distributed databases, for example: some data fields will be duplicated. The duplication of data will lead to redundancy and increased probability for errors. In our case the duplication can be found as stations in the databases, due to the stations acting as the connection between every data set.

In the three-tier, distributed database, and semi-distributed architecture, the data have to be processed from the original source to fit in with the data structure. Since the different types of information originates from different sources, usage of the sets has compatibility issues. The sets can have different sizes, different update interval on the content, and different set owners (NSB, Jernbaneverket, etc) have different definitions of the same data fields. We did not take this problem into consideration during the work of this project, due to the data sets given to us was already processed by SINTEF.

6.2.2 System performance

We can increase the responsiveness of the system by utilizing the back-end for processing the data, since it is usually on the same hardware as the databases or same sub-net, which provides quicker calls and responses to the databases from the data processing methods. As the aggregation averages the data based on the variables selected by the user, the data transferred from the back-end to the front-end will be reduced. Having a reduced amount of data to transfer results in quicker communication times. We have no control over what hardware the end user has, while the back-end is usually dedicated to one service and we can (more easily) control, and if necessary upgrade, the hardware.

The amount of data to be processed by the system is affected by three variables. The affecting variables are the stakeholders' need to navigate in time, the navigating in the stakeholder hierarchy, and the type of information. As the level of detail increases by navigating in time, the amount of data to process decreases. Similarly by decreasing the level of detail, the amount of data to process increases. The navigation in the hierarchy affects the amount of data, as the further up in the hierarchy one navigates, the larger the areas of responsibility grows. The information type affects the amount of data in a data-set, because each information type have different needs for the amount of data to be processed. The system performance is determined by the amount of data to process, as it uses more time to process more data.

Chapter 7

Conclusion and Future work

7.1 Conclusion

To have a system that is capable of awareness of stakeholder and their needs to aggregate over a rich set of data, it is important to both have a clearly defined stakeholders with their requirements and needs, data sets which are adapted to the stakeholders, and aggregation methods which fit the stakeholders needs and the data sets.

We have created a prototype to help define important characteristics for a system that are aware of the stakeholder and their needs when processing data, by the use of the Design Science Research Process. To properly define the stakeholders, their needs, and their areas of responsibility in a hierarchy is crucial, as everything is based on the stakeholders and their needs and requirements. The system is able to fetch data according to the needs of the current stakeholder and processes the data according to their step in the hierarchy, by being able to navigate through the hierarchy.

In order to have the ability to navigate the hierarchy and process the data accordingly, the areas of responsibility should be stored in the hierarchy for enabling the system to find the compatible data with the areas. The different data sets should be stored in a structure that enables a dynamic link to the hierarchy. We proposed a semi-distributed databases, where the hierarchy is stored in a database and the other data sets connected to the stakeholder through the hierarchy database. The database structure proposed does demand that the data sets are processed to a similar structure, and merged to a consistent definition of data fields.

Use of the hierarchy based areas of responsibility is important, to aggregate the data sets according to the stakeholders and their requirements. The aggregation method should be specified in the requirements for each information type, as each data set can be different and/or the stakeholders have a different need for that information.

The system should be able to use the visual presentation of the data to limit the visualization to the current stakeholder, by use of the area of responsibility of the current stakeholder.

In order for a system to provide stakeholder awareness, the domain it shall operate within needs to defined. The stakeholders the system shall provide awareness for, must be defined within the domain along with their requirements, needs, and areas of responsibility. When the stakeholders have been defined within the domain, they need to be organized in a aggregatable structure for the system to process and present the data according to the stakeholders requirements. We demonstrated this by defining the stakeholders within a railway domain in a hierarchy based on their areas of responsibility. The hierarchy enabled us to aggregate the data according to the active stakeholder, both when processing and presenting the data.

7.2 Future work

In this section we describe areas found during the work of this thesis in which there are a possibility for future work.

The most obvious work that can be done, is to test the system against users. One can observe how the users thinks the system takes the stakeholders requirements and needs into consideration, by testing the system with users. The observations can then be used in the process loop described in Chapter 2 Research Method to redefine the objectives of the solution.

As the system presented in this thesis uses historical data, a further expansion would be to test the system with live data. Measuring of the affect aggregated data have when users analyze the data in order to improve safety and punctuality, can be done when looking at current data.

A further way of improving awareness could be to expand the system by presenting more types of data, in order to take into consideration more of the different stakeholders needs. Presenting more data sets was discussed in the two held workshops (see Section 5.1 and Section 5.2).

References

[1] Jernbaneverket, "About." http://www.jernbaneverket.no/en/startpage1/Articles/Jernbaneverket/. [Online, accessed 26. February 2014].

[2] L. Bass, P. Clements, and R. Kazman, *Software Architecture in Practice.* Addison-Wesley Professional, 3rd ed., 2012.

[3] Wikipedia, "Aggregate data — wikipedia, the free encyclopedia." http://en.wikipedia.org/w/index.php?title=Aggregate_data&oldid=554141234, 2013. [Online; accessed 2-June-2014].

[4] W. M. Trochim, "Deduction & induction." http://www.socialresearchmethods.net/kb/dedind.php. [Online; accessed 28-June-2014].

[5] P. Thagard and C. Shelley, "Abductive reasoning: Logic, visual thinking, and coherence," in *Logic and scientific methods*, pp. 413–427, Springer, 1997.

[6] Wikipedia, "Abductive reasoning — wikipedia, the free encyclopedia." http://en.wikipedia.org/w/index.php?title=Abductive_reasoning&oldid=614085576, 2014. [Online; accessed 28-June-2014].

[7] Butte College, "Deductive, inductive and abductive reasoning." `https://butte.edu/departments/cas/tipsheets/thinking/reasoning.html`. [Online; accessed 28-June-2014].

[8] 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.

[9] 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.

[10] J. NIELSEN, "Focus groups to study work practice." `http://www.nngroup.com/articles/meghan-focus-group/`. [Online; accessed 14. June 2014].

[11] J. Nielsen, "The use and misuse of focus groups," *Software, IEEE*, vol. 14, no. 1, pp. 94–95, 1997.

[12] J. A. Goguen and C. Linde, "Techniques for requirements elicitation," *Requirements Engineering*, vol. 93, pp. 152–164, 1993.

[13] Jernbaneverket, "Jernbanestatestikk 2012." `http://www.jernbaneverket.no/PageFiles/25055/Jernbanestatistikk%202012.pdf`. [Online; accessed 02. June 2014].

[14] R. M. Goverde, *Punctuality of railway operations and timetable stability analysis.* Netherlands TRAIL Research School, 2005.

[15] Jernbaneverket, "Se punktlighetstall og tiltak." `http://www.jernbaneverket.no/no/Nyheter/Togenes-punktlighet-og-regularitet/`. [Online, accessed 26. February 2014].

[16] R. M. Goverde and L. Meng, "Advanced monitoring and management information of railway operations," *Journal of Rail Transport Planning & Management*, vol. 1, no. 2, pp. 69–79, 2011.

[17] Wikipedia, "Rail transport in norway — wikipedia, the free encyclopedia." `http://en.wikipedia.org/w/index.php?title=Rail_transport_in_Norway&oldid=603495807`, 2014. [Online; accessed 2-June-2014].

[18] SINTEF, "Presis project." `www.sintef.no/Projectweb/PRESIS/`. [Online, accessed 26. February 2014].

[19] Jernbaneverket, "Organisasjon." `http://www.jernbaneverket.no/no/Om-oss/Om_jernbaneverket/Organisasjonskart/`. [Online, accessed 27. May 2014].

[20] B. Cule, B. Goethals, S. Tassenoy, and S. Verboven, "Mining train delays," in *Advances in Intelligent Data Analysis X*, pp. 113–124, Springer, 2011.

[21] A. Landex, "Gis analyses of railroad capacity and delays," in *Proceedings of ESRI User Conference. San Diego, California, USA*, pp. 1–10, 2009.

[22] P. M. Hegglund, "Analyse av punklighetsdata i jernbanetraffik: Modell for prioritering av vedlikehold,"

[23] TStorm Technologies for SJ Trains, "Tåg.info." `http://tåg.info`. [Online, accessed 04. March 2014].

[24] SJ, "About sj." `http://www.sj.se/sj/jsp/polopoly.jsp?d=120&l=en`. [Online; accessed 08. March 2014].

[25] Trafikverket, "About the swedish transport administration (trafikverket)." http://www.trafikverket.se/Om-Trafikverket/Andra-sprak/English-Engelska/About-the-Swedish-Transport-Administration-Trafikverket/. [Online; accessed 08. March 2014].

[26] OpenDataCity, "Zugmonitor – leider außer betrieb." http://zugmonitor.sueddeutsche.de/. [Online; accessed 15. February 2014].

[27] M. Somerville, "Accesible uk train timetables." http://traintimes.org.uk/map/#bhm. [Online; accessed 2. February 2014].

[28] M. Somerville, "Vaguely live map of trains in the united kingdom." http://traintimes.org.uk/map/#bhm. [Online; accessed 15. February 2014].

[29] FlightAware, "Miserymap." http://uk.flightaware.com/miserymap/. [Online; accessed 15. February 2014].

[30] bdon, "Visualizing transit delays in real time: Muni light rail." http://bdon.org/2014/08/28/visualizing-transit-delays/. [Online; accessed 15. February 2014].

[31] Cargonet, "About cargonet." http://www.cargonet.no/en/About-us/. [Online; accessed 07. March 2014].

[32] Jernbaneverket, "Punklighet." http://www.jernbaneverket.no/no/Nyheter/Punktlighet/. [Online, accessed 26. February 2014].

[33] SINTEF, "SINTEF." www.sintef.no/. [Online, accessed 04. March 2014].

[34] Transportøkonomisk Institutt, "Transportøkonomisk Institutt." www.toi.no/. [Online, accessed 04. March 2014].

[35] NTNU, "NTNU." www.ntnu.no/. [Online, accessed 04. March 2014].

[36] NSB, "NSB." https://www.nsb.no/. [Online; accessed 09. June 2014].

[37] Flytoget, "Flytoget." http://www.flytoget.no/. [Online; accessed 22. June 2014].

[38] Node.js, "Node.js." http://nodejs.org/. [Online; accessed 09. June 2014].

[39] Google, "V8 javascript engine." https://code.google.com/p/v8/. [Online; accessed 09. June 2014].

[40] W3C, "Rest." http://www.w3.org/2001/sw/wiki/REST. [Online; accessed 09. June 2014].

[41] Express, "Express, web application for node." http://expressjs.com/. [Online; accessed 09. June 2014].

[42] MongoDB, "Mongodb: A document oriented database." http://www.mongodb.org/about/. [Online; accessed 09. June 2014].

[43] G. Rauch, "Monk: The wise mongodb api." https://github.com/LearnBoost/monk. [Online; accessed 09. June 2014].

[44] PostgreSQL, "Postgresql, about." http://www.postgresql.org/about/. [Online; accessed 09. June 2014].

[45] B. Carlson, "node-postgres: Non-blocking postgresql client for node.js. pure javascript and native libpq bindings.." https://github.com/brianc/node-postgres. [Online; accessed 09. June 2014].

[46] MySQL, "Mysql, about." http://www.mysql.com/about. [Online; accessed 09. June 2014].

[47] F. Geisendörfer, "node-mysql: A pure node.js javascript client implementing the mysql protocol.." `https://github.com/felixge/node-mysql`. [Online; accessed 09. June 2014].

[48] Google, "Hello map." `https://developers.google.com/maps`. [Online; accessed 22. June 2014].

[49] Leaflet, "Leaflet: An open-source javascript library for mobile-friendly interactive maps." `http://leafletjs.com/`. [Online; accessed 09. June 2014].

[50] Wikipedia, "Javascript — wikipedia, the free encyclopedia." `http://en.wikipedia.org/w/index.php?title=JavaScript&oldid=613934767`, 2014. [Online; accessed 22-June-2014].

[51] K. T. Hansen and T. Mallaug, *Databaser*. Gyldendal Akademisk and the TISIP foundation, 2nd ed., 2008.