CHALMERS

Low Speed Maneuvering Aids For Long Vehicle Combinations

Master of Science Thesis in the Master's Degree Programme Industrial Design Engineering

KRISTOFFER BORRE

RICHARD LARSSON

Department of Product and Production Development
Division of Design and Human Factors
CHALMERS UNIVERSITY OF TECHNOLOGY
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Department of Product and Production Development
Division of Design and Human Factors
Chalmers University of Technology
SE-412 96 Gothenburg
Sweden
Telephone + 46 (0)31-772 1000

Cover:
Rendering of a B-train. See Appendix A for a technical description.

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Abstract

The trend in Europe is for increasing the maximum length of vehicles to 25.25 meters. The aim of this thesis is to study the problems relating to low speed maneuvering of long vehicle combinations and to develop concepts that aid the driver in areas of safety, efficiency and ergonomics. Ten basic needs and problem areas are identified during maneuvering. Concepts are developed and subsequently evaluated in relation to these needs by interviews, need-weave matrix and by driving simulator. This results in five concepts that will undergo patent evaluation and several concepts that will be further developed by Volvo 3P.

Keywords: **Road train, maneuvering aid, simulator, user study, concept evaluation method**

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Definitions

For a more detailed description of technical terms, see Appendix A.

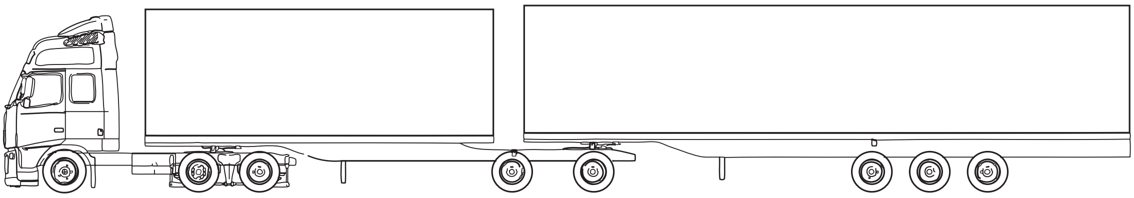
4x2: A truck with two axles with drive on the rearmost axle.

6x2: A truck with three axles with drive on one axle.

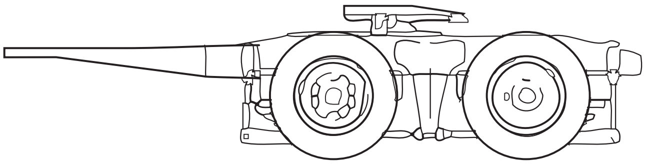
6x4: A truck with three axles with drive on two axles.

8x4: A truck with four axles with drive on two axles.

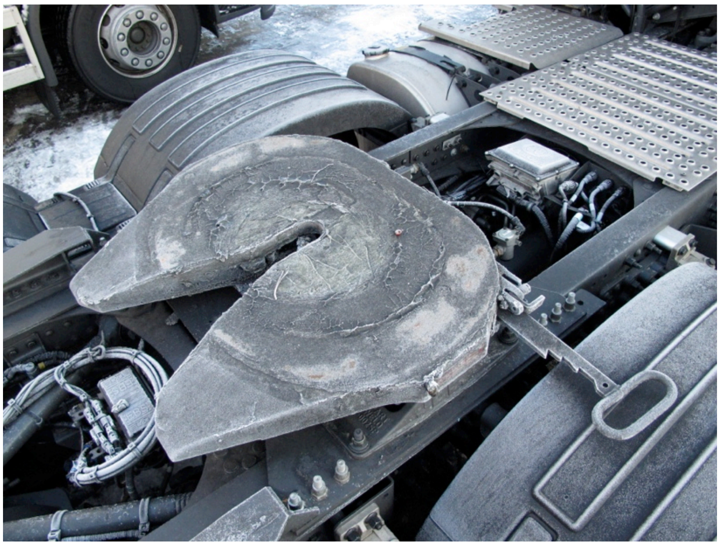
B-train: A Road train with a tractor that is pulling a lead trailer and a semitrailer.



Dolly: A small trailer with only a fifth wheel mounted on it, to allow a semitrailer to be towed by a rigid.

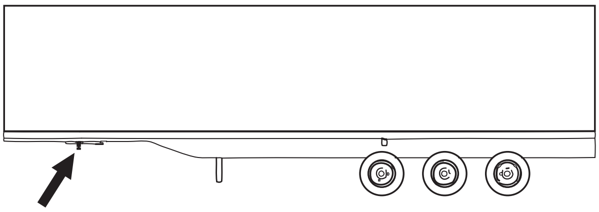


Fifth wheel: A connecting device used on tractors, dollies and lead trailers to connect semitrailers.

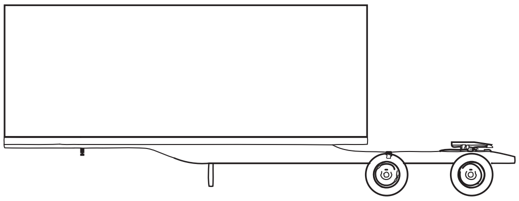


Freight terminal: A designated place where cargo is loaded and unloaded.

Kingpin: A pin on the front underside of the semitrailer and lead trailer that connect to the fifth wheel.



Lead trailer: A trailer with kingpin connection in the front and a fifth wheel mounted on the rear end to connect an extra trailer.



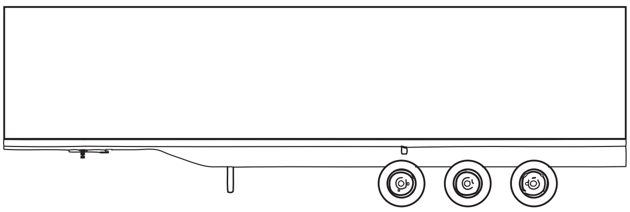
Loading dock: A gate where the cargo is loaded/unloaded from the trailer onto the warehouse or vice versa.

Nordic Combination: Also referred to as D-configuration. A road train comprised of a rigid, a dolly and a semitrailer.

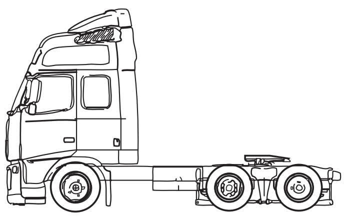
Rigid: A truck that carries load on its own chassis and could connect trailers by using a connection device other than a fifth wheel.

Road train: Vehicles with a maximum length of 25.25 meters, with two articulation points.

Semitrailer: A trailer with king pin connection and supporting legs, with all axles in the rear.



Tractor: A truck with a fifth wheel mounted on its chassis, allowing it to connect either a lead trailer or a semitrailer.



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1. Introduction

1.1 Background

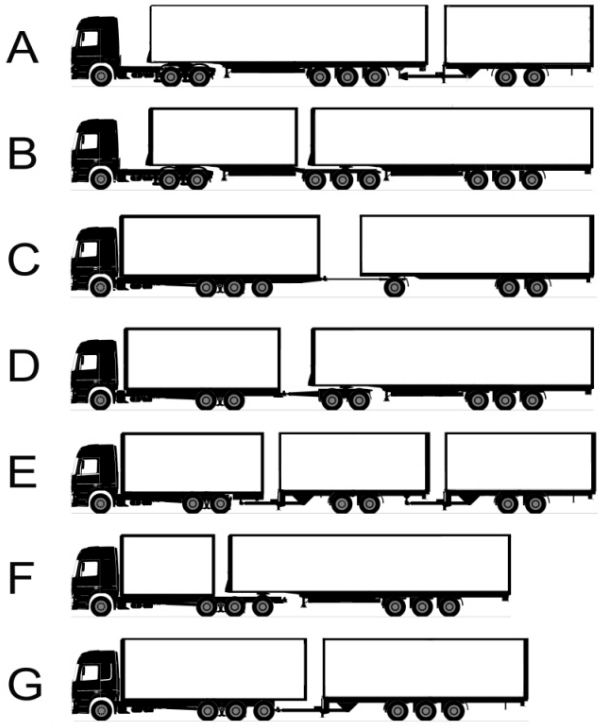

Fig. 1 Different type of road trains used in the EU

The last two decades has seen a steady increase in road vehicle transports, only slightly dampened during the financial crisis of 2008 and 2009[1]. To increase efficiency, both regarding economy and amount of load carried, the European length limit of 18,75 meters for commercial vehicles was proposed to be increased to 25.25 m. The most common vehicle combination, tractor and semitrailer (16.5 m), could then be lengthened accordingly by adding a lead trailer in-between, resulting in a so called road train (See type B in fig. 1).

Sweden and Finland have used 24 meter long vehicles since the 1970's and have been allowed to continue using these vehicles for domestic purposes under a special legislation even after they became members of the EU. Since 1997, both countries also allowed the use of 25,25 meter road trains for domestic transports. As the EU strived for legislative harmonization between member countries, the European Commission called in 2002 for investigations to be made for the introduction of road trains in all EU and Schengen countries. Since then, the Netherlands, Norway, Denmark, and some German states have introduced road trains on limited trials on their road networks, while the other European countries do not yet allow any use of road trains[2].

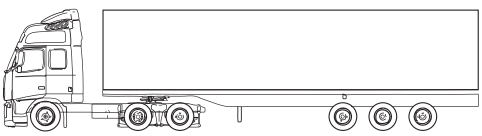

Fig. 2 Tractor-semitrailer vehicle

In total there were seven types of road train combinations proposed to be allowed on European roads, but the most common were type B and type D (see fig. 1). Using containers, a B-train could transport a 40ft. container on the semitrailer and a 20ft. container on the lead trailer. The traditional vehicle with a tractor and semitrailer could transport only one 40 ft. container or one 20 ft. container, which meant the B-train increased the volume load capacity by 50% or more. This would result in two vehicles that had the same volume capacity as three traditional vehicles. The road trains were also

[1] Eurostat, 2011
[2] Modulvogntog, 2007

allowed to increase the maximum weight from 40 to 60 tons in order to allow the longer road trains to get an equal increase in load volume as in weight.

With increasing number of countries starting to allow the use of road trains, Volvo 3P (Volvo Product Planning, Product Development, Purchasing and Product Range Management) saw an increased need to gain knowledge about the use of these vehicles and if there were any special needs connected to the handling of them. Depending on the needs that were discovered, there was also an interest from Volvo 3P that product concepts should be developed to address the needs and aid the handling and maneuvering of the road trains.

1.2 Purpose

The purpose was specified by Volvo 3P in the initial project description: Based on a study of real trucks, proposals were to be made for solutions that should have major impacts on ergonomics, safety and time efficiency regarding low speed maneuvering. In the end, one or more solutions should be chosen together with Volvo 3P. During the project, these solutions would be subject to a thorough study in order to establish the prerequisites for a later implementation that would mean mutual gains for the truck driver, Volvo 3P, the trailer supplier and the transport companies. The thesis work was to include an evaluation phase where a truck driving simulator would be used for evaluation of concepts in a simulated driving environment. The final concept should be a verified and holistic concept that is ready for further technical development in detail.

1.3 Aim

The aim of the master thesis was to get an increased knowledge of the real-life use of road trains, and define needs for development of maneuvering aids. The main focus was on low speed maneuvering, where problems were to be identified and technical solutions should be developed and subsequently tested in a driving simulator. As mentioned above, the initial aim that was described by Volvo 3P listed three main areas that should be considered:

- Ergonomics
- Safety
- Time spent/Efficiency

Ergonomics problems were defined as focusing on physical, cognitive and psychosocial problems regarding handling of and connecting and disconnecting the vehicle combinations. The original aspects listed by Volvo 3P included: control usage, climbing in and out of truck and physical work outside the truck.

Safety problems were related to the driver's field of vision and ability to monitor the environment surrounding the vehicle as well as safety for unprotected road users that were in close proximity of the moving vehicle. The original aspects listed by Volvo 3P included: direct and indirect vision from the driver seat, safety for unprotected road users around the vehicle and vision in bad light conditions.

Finally, **time studies** were to be performed in order to evaluate the efficiency of the suggested changes. The original aspect that had already been studied in part by Volvo 3P was an investigation of where time was spent in the whole process.

The aim could be summed in the following questions:

- What are the main problems and needs when using road trains in low speed maneuvering situations?
  - What are the user's/driver's needs?
  - How do the needs differ between the drivers and the transport companies?
- How are road trains used in the transport industry?
  - For what types of loads?
  - By what types of transport companies?
  - On what types of routes and freight terminals?
- What aids could be developed to improve the ergonomics, safety and efficiency aspects in low speed maneuvering?
  - To what extent could the physical and cognitive loads on the driver be lowered?
  - To what extent could the risks for injuries and damage be lowered?
  - How much money could transport companies save when implementing a concept?

1.4 Delimitations

During the project, it became necessary to narrow the scope and study only the process of driving the vehicle at low speeds. Thus, it did not include the load handling parts of the vehicle operations, i.e. the connection and disconnection of a semitrailer and lead trailer and the process of moving a cargo body back and forth on a lead trailer. The reason for choosing this scope was that interviews with drivers and transport companies yielded the following information:

- Low speed maneuvering was the most cognitively demanding part of driving road trains, especially the reversing maneuvers.
- The cost benefits of a technical solution would be greatest regarding maneuvering, due to the fact that this was the part of the transport where most wear and tear and damage from collisions were sustained.
- Technical solutions regarding the ranging process would be easier to develop and implement by the Volvo Truck Corporation because they mainly affected the tractor, while load-handling solutions mainly affected trailers.

The thesis only focused on investigating needs and developing concepts for the European market. A further delimitation regarded the type of road trains studied. There were seven types of road trains that were used on roads in Europe, where B-train and Nordic combination were the most common in both Scandinavia and the Netherlands[3]. Of these two types, the B-train was the most challenging to use during the ranging maneuvers. This was due to the longer distance between the articulation points, causing it to cut corners to a greater extent and to

[3] Longer and Heavier Vehicles in The Netherlands, 2010:14

require more space while reversing. The B-train was also the type of road train most suitable for container transports and it could be assumed that the B-train would gain an increasing market share in the future when containers from big ports could be transported throughout Europe on road trains, instead of the current situation where road trains were limited to domestic markets. The likely increase in B-trains combined with the challenges during low-speed maneuvering made it the main focus of the project.

1.5 Nomenclature

Unless this report states otherwise, masculine nouns and pronouns do not refer exclusively to men.

Following the project, a number of concepts were chosen by Volvo 3P for further development within the division of trucks (Volvo Truck Corporation). These were classified following a decision by Volvo 3P and a number of concepts were also chosen for patent application. When describing the work relating to the classified concepts, abbreviations were used instead of their working names (See chapter 4.7)

Concepts based on camera technology: C1, C2 and C3.

Concepts based on predicted path technology: P1, P2, P3, P4 and P5.

Concepts based on axle steering technology: A1, A2 and A3.

Concepts based on other technology: O1, O2, O3, O4, O5 and O6.

2. Methods

2.1 Project Process Overview

The project was divided into six main parts (See fig. 3). Each part was subsequently divided into sub-parts which are described in the chapters following the overview.

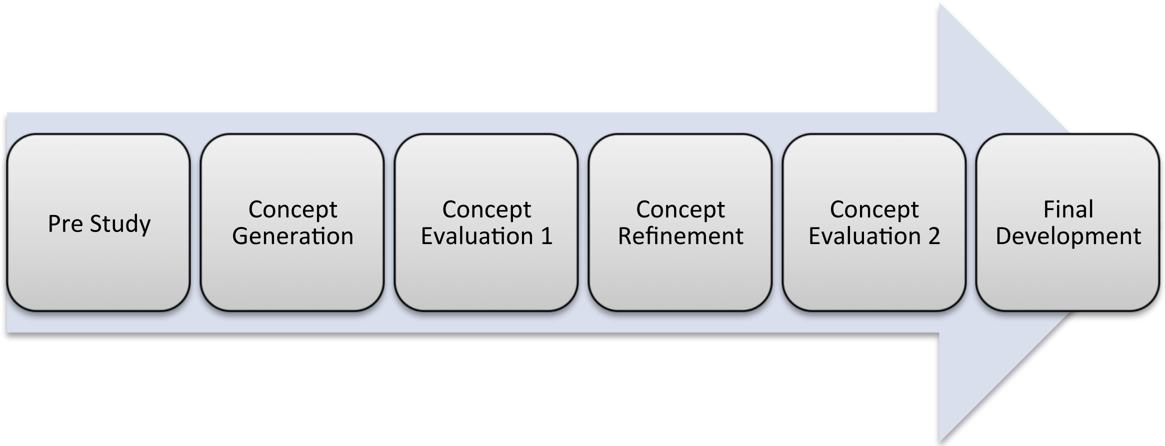

Fig. 3 The six phases of the project

1. Pre Study

The initial pre study was performed in order to gain an increased knowledge on the subject and gather information for the subsequent parts of the project. The following methods were used:

- Literature and internet study (2.2.1)
- Observations (2.2.2)
- Interviews (2.2.3)
- Personal field study (2.2.4)
- Need matrix (2.2.5)

2. Concept Generation

The result from the Pre Study formed the basis for the Concept Generation. The objective in this phase was to produce a vast range of concepts with different approaches to the problems observed. The following methods were used:

- Brainstorming (2.3.1)
- Negative brainstorming (2.3.2)

3. Concept Evaluation 1

When a number of concepts had been developed, a first concept evaluation was conducted. In order to get the most relevant feedback a number of different methods were used to get a triangulation of input. The following methods were used:

- Concept evaluation matrix (2.4.1)
- Need segments and scoring (2.4.2)
- Need-Weave matrix evaluation (2.4.3)
- Driving simulator test I (2.4.4)
- Interviews (2.4.5)

4. Concept Refinement

Following the first evaluation, the material was analyzed and the concepts were developed in accordance to the findings. The following methods were used:

- Initial results analysis (2.5.1)
- Structured interviews and questionnaire (2.5.2)
- Concept to matrix optimization (2.5.3)
- Theory for detectability (2.5.4)

5. Concept Evaluation 2

After further development of the most promising concepts, the second and final evaluation took place. The following methods were used:

- Driving simulator test II (2.6.1)
- Questionnaires (2.6.2)
- Semi-structured interviews (2.6.3)
- Business case evaluation (2.6.4)

6. Final Development

The results from the second concept evaluation were fine tuned in accordance with the findings and the top most concepts were developed further, in order to reach the level of completeness that was required by Volvo 3P.

- Method triangulation (2.7.1)
- Sustainability (2.7.2)
- Final results analysis (2.7.3)

2.2 Pre Study

The purpose of the Pre Study was to gain reliable information on the use of road trains. All information was analyzed with a critical mindset where the different motives of the sources were analyzed in relation to the information presented.

2.2.1 Literature and Internet Study

The study of written sources had a broad search perspective, where web sources as well as printed sources were analyzed.

Scientific articles relating to road trains were very few, and none had a subject that came sufficiently close to the objective of the project to be relevant to use. Instead, the focus shifted to analyze web sources of information. These could be divided into three groups: government reports, lobbyist reports and information from commercial sources.

Government reports came from countries that were in the process of introducing the road trains. The more debate surrounding the introduction of road trains, the more extensive the government reports prior to introduction. Reports from Denmark, Germany and Holland were the primary sources of information. Lobbyist websites were also studied in order to get a picture of what arguments are used in the debate. Information from commercial sources was mostly material made available by truck and trailer manufacturers on their web sites that related to road trains.

2.2.2 Observations

Observations were used in several parts of the project, but the methods used were similar to the ones used in the Pre Study.

All observations were made with the objective of being discreet as observers, but not hidden from the driver. It was assumed that the behavior of the driver would not change if the driver had knowledge that he was being observed, as long as there was no link between any emotional advantage/disadvantage and the driving behavior. Thus, during observations it was stressed that observations were not used to test the skill of driver in any way, and the reactions from the observers were consistently neutral whether the driver failed or succeeded in his efforts.

Observations also included timing of vehicles reversing at freight terminals. This was done for rigids, Nordic combinations, tractor-semitrailers and B-trains in order to get a reference and compare road trains to other vehicles regarding time spent in relation to the amount of cargo transported. The time spent on different part of the ranging process was also evaluated.

The following observations were made:

- Freight terminal study in Borås: two days were spent observing the behavior of vehicles on several different freight terminals, what different types of vehicles that frequented the freight terminals and how long time it took to maneuver, load and unload at the terminals. Observations were made from a parked car in connection to the freight terminals.

- Container handling at Skandia Harbor in Gothenburg: one day was used for observing the truck movements and to measure the time spent when reversing and maneuvering in the loading area. The observations were made from an observation platform adjacent to the loading dock.
- Co-riding with drivers during a working day: five days were used for observing the behavior from within the truck cab, from the passenger seat. Two rides were made with container transports and three rides were made with timber transports.

Fig. 4 Straddle carrier in the Skandia Harbor loading a 40 ft. container on a semitrailer

2.2.3 Interviews

During the Pre Study, the primary technique used for interviews was the semi-structured interview, which allowed room for the interviewee to expand on the different subjects. This kind of interview technique was also preferable since it offered both a way to gather specific information and a way to evaluate the attitudes of the interviewee. For detailed information on the semi-structured interviews, see Appendix B.

The construction of the semi-structured interview questions were based on the following questions:

- **Who** the interviewee was and how big experience the driver had
- **What** kind of truck brand and configuration he used and what driving aids the driver had personal experience using
- **Where** he drove and the layout of the logistical chain
- **When** different problems occurred
- **Why** the problems occurred
- **How** the loading and unloading procedure was performed and how problems could be solved

When selecting the drivers for interviews, as well as driving simulator test and co-riding, a selection that reflected the driver population was strived for. However, some limitations became evident during the project:

- The drivers selected in the Umeå area was somewhat restricted due to the low number of drivers with experience of driving road trains.
- The drivers with experience of timber transports were limited due to the small size of the trial project "Bigger Stacks".

The following interviews were made during the Pre Study, using the semi-structured questions:

PERSONAL INTERVIEWS

- Interview during co-riding with container transport from Gothenburg to Bankeryd and Jönköping and back to Gothenburg. The driver was 46 years old.
- Interview during co-riding with container transport from Gothenburg to Nässjö and back to Gothenburg. The driver was 41 years old.
- Interview during co-riding with timber transport between Glanskogen to Billerud paper mill in Gruvön. The driver was 20 years old.
- Interview with two representatives from a container transport company in Gothenburg.
- Interview with a representative of a warehouse manager for a general goods transport company in Helsingborg.

TELEPHONE INTERVIEWS

- Interview with 24-year old Swedish truck driver (Goods transports)
- Interview with 34-year old Swedish truck driver (Goods transports)
- Interview with 47-year old Norwegian truck driver (Container transports)
- Interview with 48-year old Danish truck driver (Goods transports)
- Interview with 56-year old Swedish truck driver (Goods transports)
- Interview with 58-year old Swedish truck driver (Goods transports)

The transported goods on road trains in Sweden could be divided into three groups: containers, general cargo and timber. To gain a better insight into the use of B-trains and the different needs that were present in the different uses, on site interviews were conducted with one transport company from each of the three transport types. The semi-structured questions used when interviewing drivers were slightly modified and there were also added questions relating to the strategic planning regarding road trains and the economic aspects of the transport business (See Appendix B).

2.2.4 Personal Field Study

In order to become more familiar with different truck brands as well as to get to know what kind of aftermarket products were available, the transport fair Transport 2011 in Lillestrøm Norway was attended for one day. Stationary trucks of different brands were studied and tried in order to gain personal experience of different design solutions, driving positions and field of vision from the driver seats.

In order to gain a better understanding of the vehicles and the handling characteristics of road trains, a visit was made to Volvo Demonstration Center in Gothenburg. It was possible to test drive a Nordic Combination that was fully loaded (60 tons) and had the strongest engine available at the time. There was also time to experience firsthand the difficulties of reversing a longer vehicle.

The use of mirrors was also studied during the test and the instructor demonstrated the different cues that are used to aid reversing and judgment of distance.

2.2.5 Need Matrix

In order to get a balanced picture of the different needs and their relation to each other, especially regarding the different user environments that were found on the market, a new evaluation method was needed. The foundation of this method was the need matrix (See fig. 5). It was constructed to weigh the needs of different user groups against each other, so that a need of one group was weighed according to the market share of the group. Later on it was supposed to be used to evaluate different solutions and concepts to see which best fulfilled the market needs (see chapter 2.4.1).

	Need matrix			
Need	**Group 1**	**Group 2**	**Group 3**	**SUM**
Need A	A1	A2	A3	(A1*f1)+(A2*f2)+(A3*f3)
Need B	B1	B2	B3	(B1*f1)+(B2*f2)+(B3*f3)
Need C	C1	C2	C3	(C1*f1)+(C2*f2)+(C3*f3)
Need D	D1	D2	D3	(D1*f1)+(D2*f2)+(D3*f3)
Need E	E1	E2	E3	(E1*f1)+(E2*f2)+(E3*f3)
Need F	F1	F2	F3	(F1*f1)+(F2*f2)+(F3*f3)
Need G	G1	G2	G3	(G1*f1)+(G2*f2)+(G3*f3)
Need H	H1	H2	H3	(H1*f1)+(H2*f2)+(H3*f3)
Need I	I1	I2	I3	(I1*f1)+(I2*f2)+(I3*f3)
Need J	J1	J2	J3	(J1*f1)+(J2*f2)+(J3*f3)
Frequency	f1	f2	f3	

Fig. 5 The need matrix

The need matrix was comprised of values that took into consideration the different user types on the market, their frequency, the different needs and the user's own ratings of their importance. For a reference of the different building blocks of the need matrix, see fig. 6.

	Need matrix			
Need	**Group 1**	**Group 2**	**Group 3**	**SUM**
Need A	A1	A2	A3	(A1*f1)+(A2*f2)+(A3*f3)
Need B	B1	B2	B3	(B1*f1)+(B2*f2)+(B3*f3)
Need C	C1	C2	C3	(C1*f1)+(C2*f2)+(C3*f3)
Need D	D1	D2	D3	(D1*f1)+(D2*f2)+(D3*f3)
Need E	E1	E2	E3	(E1*f1)+(E2*f2)+(E3*f3)
Need F	F1	F2	F3	(F1*f1)+(F2*f2)+(F3*f3)
Need G	G1	G2	G3	(G1*f1)+(G2*f2)+(G3*f3)
Need H	H1	H2	H3	(H1*f1)+(H2*f2)+(H3*f3)
Need I	I1	I2	I3	(I1*f1)+(I2*f2)+(I3*f3)
Need J	J1	J2	J3	(J1*f1)+(J2*f2)+(J3*f3)
Frequency	f1	f2	f3	

Fig. 6 The parts of the need matrix

THE PARTS OF THE NEED MATRIX

- A: The different user groups that comprise the market
- B: The frequency (or percentage) of the different user groups on the market
- C: The different needs
- D: The valuation of different needs by different groups on the market
- E: The sum of user needs weighed for their relative frequency on the market

The different user groups on the market were identified during the Pre Study as: timber, container and general cargo transports.

The frequency was the percentage share that the different user groups had on the Swedish market.

The different needs were identified during observations and interviews. A need was defined as the root cause of problems that occurred during the low speed maneuvering – for example the problem of hitting objects behind the vehicle and the problem of having to step out of the vehicle and see what was behind the semitrailer were grouped into the basic needs of “Vision in blind spots while reversing” and “Judgment of distance”.

Rating of different needs was made with a number between 0 and 4, defined as:

- 0 – Very unimportant
- 1 – Unimportant
- 2 – Neither important nor unimportant
- 3 – Important
- 4 – Very important

A scale from 0 to 4 was chosen instead of the more traditional 1-5 because it would allow a need to have the value of 0, meaning that the need did not exist at all for that market segment. If 1 had been chosen as the lowest value a concept that fulfilled a need that did not exist would still get points in the Need-weave matrix evaluation (See chapter 2.4.2).

The sum of the need matrix was the sum of needs multiplied by the frequency of the different user groups. In that way, a total sum could be established that reflected the need on the entire market, which could also be put into relation to the other needs that existed.

2.2.5.1 Need Matrix Estimations

The valuations of the different needs in the need matrix were initially made by estimations based on the initial interviews and observations. This was in order to get quick results in the matrix evaluation of the concepts, needed to decide which concepts to implement in the simulator for the first round of simulator tests.

Later in the project, the valuations would be made by drivers themselves (See chapter 2.5.3)

2.3 Concept Generation

After the initial pre study had resulted in a broad knowledge base of the users' needs, different concept solutions were established.

2.3.1 Brainstorming

The concepts were initially generated by brainstorming sessions. Brochures from different manufacturers of trucks were spread out and used for inspiration, as well as internet sources of pictures related to the trucking industry. The different concepts that were generated during the brainstorming sessions were collected on whiteboards for quick documentation. After the sessions the different concepts were collected and in the case of two similar concepts, one was discarded.

2.3.2 Negative Brainstorming

Negative brainstorming was also used for generating concepts. The difference between the two types of brainstorming techniques was that the negative sessions also gave room for questions and technical limitations. This method resulted in an increased frequency of concepts that were realizable, which was the main purpose of the master thesis specified by Volvo 3P.

A number of negative brainstorming sessions were need focused, where concepts were generated in direct connection to the need matrix. Based on the different needs, concepts were also generated by asking what product could solve a combination of needs that were rated as important.

2.4 Concept Evaluation 1

After the brainstorming sessions had generated a number of concepts, there was a need to evaluate them and separate the ones that were most relevant to be further developed.

2.4.1 Concept Evaluation Matrix

The structured interviews and the questionnaire resulted in a rated need matrix that could be directly connected to real world users. In order to use this matrix as a base for concept evaluation, a matrix of how well each concept fulfilled each need had to be constructed (See fig 7).

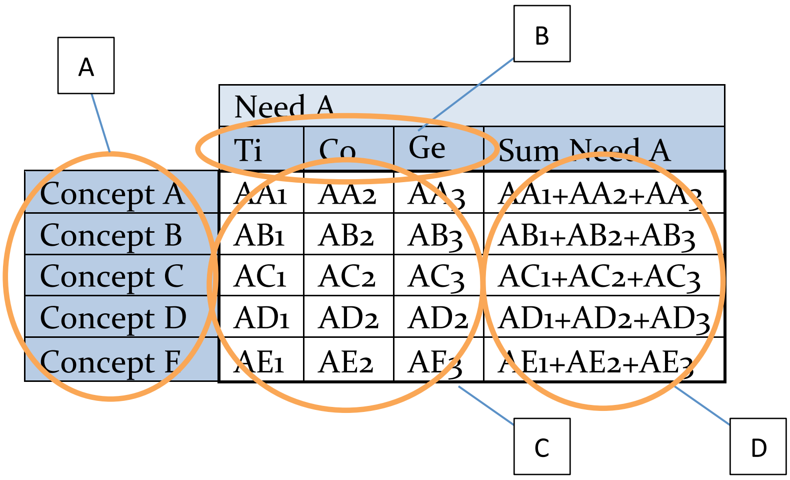

Fig 7 Concept evaluation matrix

THE PARTS OF THE CONCEPT EVALUATION MATRIX

A: List of concepts
B: The three market segments: Ti=Timber, Co=Container, Ge=General cargo
C: On a scale from -1 to 5 how well the concept fulfilled the need
D: The sum of how well each concept fulfilled the need in all market segments

In the concept evaluation matrix each concept scored points from -1 to 5 (in part C in fig 7). -1 meant that the concept increased the problem associated with the need, and a score of zero meant that the need was not affected by the concept. For the remaining steps, 1 to 5, each concept was divided into specific areas that were needed to fulfill the need as a whole. For example, camera concepts or concepts using other sensory technology would score points for each blind spot that it would cover. Different segments within a need were scored differently depending on the severity of problems associated with that area. This would mean that vision in the blind spot directly behind the semitrailer was rated as the most important since most accidents would occur there. For a full description of the different needs and the scores associated to the different need segments, see chapter 3.8.

2.4.2 Need Segments and Scoring

The division in segments that comprised a need and the score that was associated to each segment was made in accordance with interviews and observations performed during the Pre Study. Two steps needed to be established:

1. The division of a need into segments.
2. The scores given to each segment.

The division of a need into segments was made after all data had been gathered from interviews and observations. All mentions of accidents, problems and risks were analyzed as to what the root cause of each problem was. For example, accidents that occurred at freight terminals when semitrailers hit a loading dock with full force when they were reversing to load or unload, was determined to be caused by the difficulty of judging the distance between the rear end of the semitrailer and the loading dock.

After establishing a number of needs and their respective segments, scores were given to each segment that reflected their relative importance within a specific need. This was done by analyzing how often the different problems were mentioned during the interviews. While the frequency was not directly connected to the severity of a problem, it was argued that problems that were more severe were mentioned more often. Since the analyzed drivers came from three different countries and the transport companies were differentiated by location and type of goods transported, local problems and jargon associated to one specific company could be avoided.

An illustrative example could be made by "Vision in blind spots while reversing" – clockwise reversing (See chapter 3.8.2 for its implementation). In total, 23 interviews were conducted and 34 problems were mentioned (the most common area where problems were mentioned) that had their root cause in a lack of vision in blind spots while reversing.

- Problems on the right side of the tractor, mentioned 6 times. 6/34=0,176. 0,176*5=0,88 which was rounded to 1.
- Problems on the right side of the semitrailer, mentioned 7 times. 7/34=0,206. 0,206*5=1,03 which was rounded to 1.
- Problems on the right side of the lead trailer, mentioned 7 times. 7/34=0,206. 0,206*5=1,03, which was rounded to 1.
- Problems behind the semitrailer, mentioned 14 times. 14/34=0,412. 0,412*5=2,06, which was rounded to 2.

The total score for the entire need segment was 5, divided in the following parts:

- Problems on the right side of the tractor: 1
- Problems on the right side of the semitrailer: 1
- Problems on the right side of the lead trailer: 1
- Problems behind the semitrailer: 2

2.4.3 Need-Weave Matrix Evaluation

The Concept Evaluation Matrix resulted in a sum for each concept that described how well it fulfilled each need. To form the Need-weave matrix, this sum was multiplied with the rating of the need in the need matrix (see chapter 2.2.5). A score was then obtained that reflected how well the concept fulfilled the need weighed for the importance of that specific need in relation to other needs. For each concept, these scores were summed up to produce a total score that showed how well the concept fulfilled the users' needs on the whole market.

	Need fulfillment multiplied with need rating				
	Need A	Need B	Need C	Need D	**Sum**
Concept A	AA	BA	CA	DA	AA+BA+CA+DA
Concept B	AB	BB	CB	DB	AB+BB+CB+DB
Concept C	AC	BC	CC	DC	AC+BC+CC+DC
Concept D	AD	BD	CD	ED	AD+BD+CD+DD
Concept E	AE	BE	CE	DE	AE+BE+CE+DE

A B

Fig 8 Need-Weave matrix

THE PARTS OF THE NEED-WEAVE MATRIX

A: The rating of the importance of the need (from the Need matrix) multiplied with the sum of the need fulfillment (from the Concept evaluation matrix)
B: The total sum of how well each concept performed

The need-weave matrix gave each concept a score that represented its potential on the whole market, reflecting all the needs. This enabled the comparison between vastly different concepts that solved different problems for the users, for example the comparison between camera concepts and a safety concept.

2.4.4 Driving Simulator Test I

A simulator test was performed at Oryx Simulations in Umeå. This type of simulator consisted of two parts (see fig 9):

- **Cockpit part** – with a seat, pedals, gear lever and steering wheel that the driver had physical contact with.
- **Visual part** – with three large displays giving the driver a 180° view of the simulated environment. The instrument panel was also part of the simulated world, and next to the three main displays a smaller display (10”) was used to present the different concepts tested in the simulator. The simulator lacked however a way to look rearward out through the left side window, a behavior that was common among truck drivers while reversing.

Fig. 9 Test person in the driving simulator

Even though the simulator settings resembled a real life situation, there could be slight behavioral differences when using this type of interface. To evaluate this, the test persons were asked to answer a number of questions regarding the realism of the simulator and the differences compared to driving a real truck. The complete questionnaire used can be found in Appendix C.

The driving environment used during the simulations was based on a real freight terminal in Umeå (see fig 10). The terminal offered different types of loading docks (straight and angled) and with different length of maneuvering space in front of them. This allowed for variation in the tasks the test persons were asked to perform.

Fig. 10 The simulator environment in top view

When comparing the environment of the simulator to real freight terminals, the computer environment was too good in the sense that everything had high contrasts and was easy to see. The simulated weather was sunny without haze, resulting in perfect vision for both longer and shorter distances. Objects in the simulated environment cast shadows on the ground, but the vehicles did not, which possibly could affect the judgment of distance on two occasions:

1. When looking at the rear parts of the road train through the rearview mirrors. This could possibly be affecting the judgment of distance when using visual cues in the surrounding environment.
2. When looking at objects close to the vehicle through the windows. The cast shadows and reflectivity of the truck body would be used in reality to judge distances to objects and the lack of this possibility in the simulator could negatively affect the drivers' ability to judge distances.

Another limitation from using this type of simulator was that the driver lost his depth of view. That was not a problem for objects located far from the driver's position, i.e. things seen through the rear view mirrors that were not close to larger shadow areas, but it made it hard to judge distance to objects closer to the vehicle. A further drawback of the simulator was the general feeling that the driving was not for real, which possibly could affect the simulation. When a driver knew that a collision did not really matter and when there were no moving obstacles to keep track of, it could possibly affect the driving behavior. The way the simulator sequences were designed and how the test persons were instructed could however solve this problem to some degree.

Three test persons took part in Simulator study one:

	Truck driving experience	B-train driving experience	Cargo type transported	Sex
Test Person 1	33 years	4 years	General cargo	Male
Test Person 2	12 years	2 years	General cargo	Male
Test Person 3	6 years	2 weeks	General cargo	Male

Fig. 11 Test participants in Simulator test I

2.4.4.1 Design of Simulator Tasks

The simulator tasks were designed with two intentions in mind, testing both the realism level of the simulator and the performance of the concepts. A complete list of the 11 task sequences can be found in Appendix C.

All sequences consisted of a task that the test persons were asked to perform. The sequences had the same starting position, outside the freight terminal, which allowed the study of what track was chosen by the drivers. To add realism to the tasks, they were all designed to mimic real life situations that were common during normal driving on and around freight terminals. The sequences were designed with a varying degree of difficulty in order to study the overall skills of the driver and the effect of using the concepts. However, too hard tasks were avoided because the risk of having sequences that was too much related to the drivers' skills rather than the performance of the concepts.

To add realism to the simulator, moving obstacles were implemented in some sequences. They consisted of manikins walking along predetermined tracks. During reversing maneuvers, they could also be used to determine the vision in blind spots.

2.4.4.2 Testing Parameters in Simulator Environment

The parameters evaluated in the simulator study to analyze the realism level of the simulator were chosen to be comparable with parameters from the field studies, where timekeeping had been made and videos recorded. The parameters chosen to evaluate the performance of the concepts were chosen to give a view of how well they performed in relation to the needs that they addressed.

The evaluation methods used during the simulator test were timekeeping of maneuvers, video analysis, direct observations and semi-structured and structured interview questions. Due to the low number of test participants (three in total) it was not possible to use statistics to draw wide ranging conclusions. The test could however be used to give indications that would later be studied in greater detail, either during further interviews or during the Driving Simulator Test II. A complete list of all the test parameters monitored can be found in fig. 12 below.

The low number of test participants during the first driving simulator study made it necessary to make a closer comparison to the results from interviews and observations than during the second driving simulator test, where a greater number of test participants were used. By doing this, the results would still produce valid results, even though the number of test subjects was below what would have been the most suitable for a study group.

Parameter	Measurement method
Time for maneuvering	Timekeeping
Use of viewing aids	Video analysis
Driver behavior/movements	Video analysis
Chosen track to complete task	Video of top view of simulator environment
Impressions:	
Safety	Interview
Overview	Interview
Usability	Interview
Mistakes:	
Retakes during reversing	Video analysis
Collisions	Direct observation, video analysis

Fig. 12 List of testing parameters for Simulator test I

2.4.4.3 Observations During Simulation

During simulator testing, observations were carried out with a tripod mounted film camera that was placed outside the driver's normal field of vision. This allowed the driver to focus on the driving without distractions, making the behavior more natural. To increase focus on the driving task, efforts were also made to minimize all other sensory input during testing that were not related to the simulator rig.

The video camera was positioned to show both the driver and two of the three simulator screens surrounding him. In addition to this, a fourth screen was positioned behind the driver, but still in the field of view of the camera, showing a live rendering of a top view of the entire simulated environment. This allowed for an overview when monitoring the drivers' progress during the test, in addition to aiding the video analysis made afterwards.

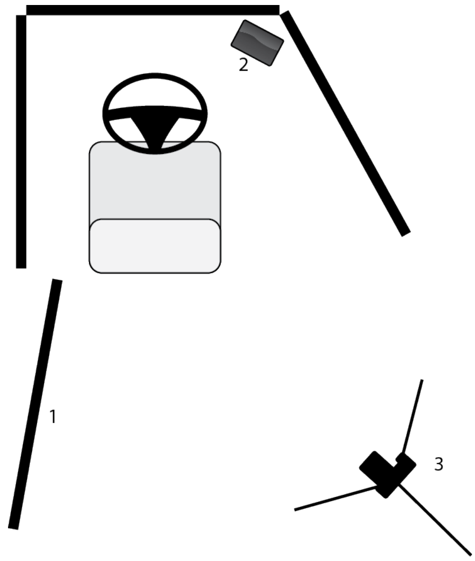

Fig. 13 Illustration of camera position and simulator setup. 1: Display showing a top view of the environment for the test leaders, 2: Display used to simualte the concepts, 3: Video camera

Fig. 14 The view from the video camera

2.4.5 Interviews

Prior to the Driving Simulator Test I and after each task sequence, both structured and semi-structured interview questions were asked. The structured questions were in the format that the test participants were asked to rate their experience of different aspects on a scale from 1 to 5. This was used to give some statistical material, but most information was gathered by using semi structured interview questions where the drivers could expand on their experiences and opinions.

The interviews consisted of three parts; one before the simulator driving, one during the driving and one after the driving were finished:

Part 1 – Structured questions about the drivers' background, e.g. their driving experience, sex etc.

Part 2 – Semi structured questions about the drivers' experience about each concept and driving sequence

Part 3 – Semi structured interview were the drivers' were asked to reflect on the complete experience and their conclusions regarding all the different concepts.

2.5 Concept Refinement

After finishing Driving Simulator Test I, the results from the test were analyzed and the concepts subsequently developed.

2.5.1 Initial Results Analysis

The results from Driving Simulator Test I were analyzed in different parts. All sequences were filmed and the film material was analyzed in the following ways, regarding:

- **The behavior of the drivers.**
    - What natural behavior was restricted in the simulator environment?
- **The viewing aids used by the drivers.**
    - Which mirrors were used by the drivers?
    - How much did the drivers use the mirrors?
    - How much did the drivers use the concepts to aid maneuvering?
    - In what situations did the drivers use the concepts?
- **Time spent during maneuvering.**
    - How much time did it take?
    - How many retakes were used?
- **Collisions.**
    - What kind of collisions occurred?
    - When did the collisions occur?
    - Why did the collisions occur?
    - Where at the freight terminal did the collisions occur?
    - How did the collisions occur?
- **Comments.**
    - What comments related to the simulated environment?
    - What comments related to the driving situation?

Special attention was given to situations where the different elements gave an indication in the same direction, for example if a driver in the same situation: a) commented on his insecurity; b) checked the mirrors more frequently; c) where a collision occurred.

The result from the film material was compared to the answers derived from the questionnaires.

2.5.2 Structured Interviews and Questionnaire

After the needs had been defined, it was necessary to evaluate their relative importance based on information gathered from actual users in the different market segments. This was done using a structured interview and questionnaires (with the same questions as the structured interview) where every question was directly related to one of the needs. The interviewee was asked to rate each need from 1 to 5 (later converted to the 0 to 4 scale). The complete questionnaire used in the evaluation can be found in Appendix E.

2.5.2.1 Need Matrix Finalization

Following the definition of needs by actual users, the need matrix was hereafter directly connected to the needs that were present on the market. This in turn improved the Need-Weave matrix, where concept rating were directly related to the actual needs they fulfilled.

2.5.3 Concept to Matrix Optimization

After the Need matrix finalization, the matrices could be used not only to evaluate concepts, but also as a base for developing new concepts and optimizing already existing ones.

For optimization of concepts, one concept at a time was studied in detail as to what aspects scored the most points in the Need-weave matrix. Technical details could then be changed if it was determined that it improved the overall functionality of the concept, while still maintaining the basic idea of the concept.

For developing new concepts, the list of need segments and the scoring of the individual needs were used to determine key areas that would produce concepts with a high score in the Need-weave matrix.

2.5.4 Theory for Detectability

A brief search was made for literature sources on the subject of interface design regarding detectability on a changing background. Since computer graphics overlaid on a camera image would be a central component of the final concepts, the factors that governed the detectability by the human eye were studied. While the most common background would be asphalt, the interface needed to be able to function with a background of snow, gravel road or at night.

2.5.4.1 Interface Development

Following the guidelines for detectability that were discovered, different interface concepts were designed and overlaid onto photos that would be representative of what a driver would see in a camera mounted on the vehicle. Different ideas could thus be presented as they would appear, without the need to make a fully functional prototype in the driving simulator at Oryx Simulations.

2.6 Concept Evaluation 2

After the concept refinement, a second round of concept evaluation was performed to gather information about the improvements from the first evaluation.

2.6.1 Driving Simulator Test II

The second Driving Simulator Test was performed using the same hardware as in the first Driving Simulator Test. However, the 10” screen on which the tested concepts were displayed was moved from the right of the steering wheel to the left of the steering wheel. This was done in order to test whether it was better suited for the users since most reversing was done in a clockwise fashion where the left side mirrors were mostly used.

A number of minor adjustments had been made to the software in order to increase the realism of the tests:

- The resistance when the driver turned the steering wheel had been slightly reduced in order to better simulate a real steering wheel.
- The weight of the vehicle was simulated to represent a fully laden vehicle instead of an empty laden vehicle, which improved the driving experience of the simulator.
- The overall stability of the software was improved so that the program never crashed during the simulator tests, which improved the results of the tests.

All other parameters of Driving Simulator Test 2 were similar to the Driving Simulator Test 1 (See Chapter 2.4.2).

During the first Driving Simulator Test, the height of the tractor cab was modeled on a Volvo FL cab, which was a distribution truck where the driver was positioned lower than in the FH cab used for road trains. This resulted in a lower eye-level for the driver than would be the case during real life maneuvering, which possibly could affect the simulator study. A change to an FH cab was asked for, but not enough time was available for reprogramming this parameter prior to the Driving Simulator Test II.

Ten test persons took part in Simulator study II:

	Truck driving experience	B-train driving experience	Cargo type transported	Sex
Test Person 1	7 years	None	General cargo	Male
Test Person 2	22 years	Very little	General cargo	Male
Test Person 3	3 years	None	General cargo	Male
Test Person 4	4 years	3 transports	General cargo	Male
Test Person 5	9 years	None	General cargo	Male
Test Person 6	3 years	None	General cargo	Male
Test Person 7	5 years	None	General cargo	Male
Test Person 8	45 years	None	General cargo	Male
Test Person 9	1 years	None	General cargo	Male
Test Person 10	2 years	None	General cargo	Male

Fig. 15 Test participants in Simulator test II

2.6.2 Questionnaires

Evaluation was also made using questionnaires where the drivers were given different suggestions for low speed maneuvering aids. Each suggested design was presented with a picture and an accompanying question as to how the driver would rate the concept on a scale from 1 to 5.

2.6.3 Semi-Structured Interviews

After each test sequence in Driving Simulator Test II, where a driver was given a concept to aid maneuvering, a number of semi-structured questions were asked. These questions were asked immediately following the test while the test sequence, concept and the given task was still in fresh memory:

- To what extent did the concept aid in the maneuvering of the vehicle?
- To what extent did the concept aid in the detection of objects in the blind spots of the vehicle?

The interviews were kept semi-structured in the sense that further questions could be asked depending on the various responses to the first questions. These follow-up questions were not specified beforehand.

2.6.4 Business Case Evaluation

The Business case evaluation detailed the basic information that was needed to assess whether a concept had any impact on the earnings or savings of a customer, how usefulness could be evaluated in economic terms and what the final price to customer would be.

The first step of the evaluation was a search to determine the costs that customers had which directly or indirectly could be related to low-speed maneuvering. Direct cost could mean damage or standstill, and indirect costs could mean for example the cost of having additional trailer chassis that were kept just in case an operational chassis would break down. From that point, a further assessment could be made to analyze to what extent the concepts would help the customer earn or save money, or both.

- In order to make the customer earn more money, a concept should make the process more efficient by reducing the bottlenecks that resulted from damage or other delays.
- In order to make the customer save money, a concept should reduce the running cost+-- for the customer.

When analyzing running cost, three values were needed to determine the scale of the problems for the users: the average cost, the lowest cost and the highest cost of the individual drivers in the population. The highest cost gave a reference to the span of the population and the lowest cost gave a minimum, which was regarded as being the best possible level that the average of the whole population could reach. It could be argued that improvements could reach beyond the lowest cost present today, but by using a conservative number, the uncertainty of a prediction was reduced. Future implementation of concepts in real trucks would reveal the correct number.

The difference between average and lowest cost could thus be regarded as the span in which the concepts could save money for the customers. When analyzing the concepts, an anticipated amount of savings could be calculated based on the degree to which the concepts solved the different problems or needs that were identified.

The final price to a customer would be calculated as the amount of money the concept saves or earns for a customer during a certain designated part of its lifetime. The lifetime of a truck was defined as the number of years that the first buyer of the truck owned it, since it would most probably be this customer who would decide if the truck would use the concept. The designated part of a lifetime would be adjusted so that both the manufacturer of the concept and the buyer has economic benefits.

2.7 Final Development

Following the Driving Simulator Test II, a final development of the concepts was made, with focus on the concepts that had scored the highest points in the matrices and were the most favored in the driver tests.

2.7.1 Method Triangulation

In order to develop final concepts that took all acquired knowledge into account, a method triangulation was used. It combined the results from the various evaluation methods that had been used during the thesis project. For a triangulation, the input from three sources would point in the same direction to give an increased probability of an accurate result.

2.7.2 Sustainability

The development of the concepts did not include any detailed manufacturing descriptions relating to processes or material selection. When regarding the concepts by themselves, there was no influence from any theoretical sustainability method, but when regarding the concepts as part of the operation of the whole vehicle, the idea of sustainability could be seen as a driving factor in the thesis project.

Sustainability in a general sense was used to view the concepts as part of the transport sector as a whole, and not just an isolated part with its own sustainability. In the term sustainability, several different aspects were included, including both indirect and direct ecological, social and legislative. Direct sustainability were related to the product life of the concepts itself, while indirect savings for example would include a reduction in accidents that resulted in reduced energy consumption for other agents as well as for the vehicle where the concept was included.

2.7.2.1 Sustainability Evaluation

A sustainability evaluation was performed at a stage when the concept had reached a degree where functionality was established in detail and construction could be estimated to some degree. The evaluation would take into consideration the concept and materials that are implied, and put this in relation to the overall benefits of the concept.

The method that was used for evaluating the sustainability of the project would be a holistic analysis where all aspects were taken into consideration, but without calculations of energy spent and saved. This was due to the fact that development of the concepts in the thesis project only would reach an early stage of development where exact construction and materials would not be specified.

2.7.3 Final Results Analysis

The analysis of the final results was made by gathering all available information and analyzing it in relation to the scope of the project. The final results analysis also took into consideration which concepts had the most potential of being developed and used by Volvo Truck Corporation as part of their product range. In that consideration, the possibility of patent protection for a number of concepts was also taken into account.

3. Pre study

3.1 Literature and Internet Study

An initial study of written sources was conducted. The purpose was to gain information regarding:

- Use of road trains in various countries
- Problems associated with road trains
- Legal requirements associated with road trains in various countries

3.1.1 Use of Road Trains in Sweden and Finland

Both Sweden and Finland have allowed the use of road trains since 1997 when they were first introduced. There were no restrictions as to what types of roads were allowed to be used by road trains and the same rules applied to road trains as for other vehicle combinations regarding the axle pressure allowed[4]. In general, due to the increased axle pressure on the drive axle, road trains were limited to using BK1-roads (Bearing capacity class 1, about 95% of the public road network), which allow the highest axle pressure. In reality, the axle pressure used by road trains could reach almost double the amount allowed by legislators. While the BK1-roads allow an axle pressure of 11,5 tons, a driver explained in one interview[5] that he could increase the pressure on the drive axle up to 19 tons in winter roads to get enough traction.

In Sweden, the most common road trains were the B-train and the Nordic Combination. The B-trains were most common in container transports, while the Nordic Combination vehicles mostly transported general goods.

Since 2008, there has been an ongoing research project in Sweden where Road trains have been introduced when transporting timber to aid efficiency and reduce fuel consumption[6]. They are divided in two parts:

- "Större travar" (Eng. "Bigger stacks"): A project that utilized a shorter road train with an increased transport capacity of 74 tons instead of the regular 60 tons. These tests were limited to one truck only, in the forests of Dalsland.
- "En Trave Till" (Eng. "Modular System for Timber Haulage"): A project that utilized longer road trains (>30m) that have the ability to carry one additional stack of timber (4 instead of 3). These tests were also limited to one truck only, on a specific stretch of roads in Norrbotten.

When compared to international use of road trains, the same types of goods were transported in Sweden and Finland with the exception of fluids (for example milk, gasoline and chemicals) and livestock.

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[4] Legal Loading, 2010
[5] Börjesson, 2011
[6] Löfroth & Svensson, 2010

3.1.2 Use of Road Trains in the Rest of Europe

Before the introduction of road trains, standard European trucks had a maximum length of 18,75 meters, while Sweden and Finland had a maximum length of 24 meters. The introduction of 25,25 meter long road trains only meant a 5% increase in vehicle length in Sweden and Finland, while the same change for other European countries meant an increase of 35%. Due to this difference, the introduction of road trains in other European countries has been much slower.

The added length of a road train corresponded to an increased load volume of 50%, as mentioned above. This subsequently increased the need for higher weight limitations than the standard European limit of 40 tons, up to the 60 ton limit that already existed in Sweden and Finland. However, such a 50% increase in the total gross weight of a vehicle met with resistance in a number of European countries (see chapter 3.3). The introduction of road trains in these countries were either halted or delayed following years of intensive studies and test periods with a limited amount of vehicles.

The Netherlands, Denmark and Norway have started allowing road trains, while Germany started a nationwide test in January 2012. However, the road trains were only allowed on certain designated roads, mainly motorways and other four lane roads. Road trains were also required to display warning signs at the rear end of the vehicle, to warn overtaking vehicles of the increased length.

3.1.3 International Use of Road Trains

The international use of road trains was dominated by USA, Canada and Australia. Each country has separate rules and regulations in different states depending on the level of urbanization and industrial needs[7]. This resulted in extremely long road trains in less populated areas, while the rules regarding more urbanized areas were similar to the rules in Sweden and Finland.

3.2 Government Reports

Sweden and Finland were the only European Union countries that allowed road trains on all roads, while all other countries stated that they only would accept road trains on a limited scale. Denmark and the Netherlands have started allowing road trains in this limited way and Germany started a nationwide study in January 2012. All other countries were awaiting a deeper study by the European Commission that would examine all aspects, including safety and economy. Following a question by the Danish government as early as 2002 when the Commission would start such a study, the Commission answered that there was insufficient demand for such a study and that it was postponed for an unspecified time[8]. It could however be assumed that such a study would follow the German tests in 2012, since Germany has a much greater influence in the European Union than Sweden and Finland.

[7] Nagl (2007:6-8)
[8] Modulvogntog (2007:11)

3.2.1 Denmark

Before the Danish government agreed on the limited use of road trains on Danish roads, the Danish Road Directorate (Vejdirektoratet) issued a report[9] where they outlined the different aspects regarding road trains. The results could be summarized as:

- The use of road trains led to an increased efficiency in transportation where the load of three ordinary trucks could be transported on two road trains. However, the practice of decoupling the road train (most notably the B-train) at a distance from a destination and first drive the lead trailer and then the semitrailer to the destination would reduce the difference in efficiency compared to a regular truck.
- Road trains had a smaller inner radius when turning compared to regular trucks, meaning the trailer cut corners to a greater extent. This in combination with slower acceleration resulted in an increased risk for accidents during turning in road junctions due to longer time spent turning.
- Road trains had no need for a larger outer radius when turning, if there was no extra need of increasing the inner radius.
- The pressure on the drive axle needed to be sufficiently high to ensure grip in bad weather conditions.
- The increased weight would lead to more kinetic energy in a crash.
- The road stability for road trains was less than for regular trucks. The most unstable was the B-train, while the most stable was the Nordic Combination.
- The reports that the Danish Road Directorate had access to regarding the wear and tear on the roads by road trains were inconclusive; one stated unchanged wear and tear, while the other stated an increase.

3.2.2 The Netherlands

The Dutch government started testing road trains in 2001 on a limited scale[10]. Tests were done over a ten-year-period with an increased number of participating transport companies and road trains. In 2011 the tests were ended with the result of allowing road trains on Dutch roads permanently. During the test period, there were intense research done regarding safety, wear and tear on infrastructure, economic and environmental benefits and impacts.

The report from the Dutch Ministry of Transport, Public Works and Water Management concluded[11]:

- Road trains caused less damage to asphalt roads due to reduced axle pressure (However, the calculations were made using an equal distribution of weight on the axles of the road train, which was an incorrect assumption, due to the need for increased pressure on the drive axle.)
- Road trains did not cause any increased damage to concrete bridges, but could cause damage to steel bridges.

[9] Modulvogntog, 2007
[10] Longer and heavier vehicles in the Netherlands, 2010
[11] Longer and Heavier Vehicles in the Netherlands, 2010.

- Road trains had 89% the CO_2-emissions compared to regular trucks per transported tons.
- Road trains had 86% the NO_x-emissions compared to regular trucks per transported tons.
- Road trains probably decreased the amount of PM10 particles.
- Road trains reduced the cost for "tons transported per kilometer" by 40% on average.

Regarding the practical aspects of using the road trains, it was concluded that road trains were not involved in more accidents. This could be due to the fact that only the best drivers were chosen to drive the road trains, and that this figure would change in the future. Safety aspects that needed to be met when using road trains were summarized in three parameters:

- Braking system
- Vehicle stability
- Driver's field of vision

Road trains put more demands on the braking system than shorter and lighter vehicles, and especially the synchronization between the brakes of the truck and the trailer or trailers. Stability depended to a large extent on what type of road train was used, where the B-train was considered the least stable combination.

Regarding the aspect of the driver's field of vision it was concluded that there was an increase in blind spots with road trains. Due to the limited amount of participating trucks, the statistical material could not be sufficiently determined, but it was assumed that accidents relating to driver's field of vision were similar to regular trucks. In the Netherlands, with about double the Swedish population, 750 people were killed in traffic accidents each year, and 18 of these deaths were caused when people got caught in the blind spot when a truck was making a sharp right turn. With increased blind spots, additional improvements like cameras could be used to increase safety.

The report also studied the time spent by road trains during loading, unloading and maneuvering at range yards. The conclusion was that the whole process on average took 32% more time than with regular trucks, but when comparing the amount of cargo being unloaded, the time per transported ton was roughly the same[12].

3.3 Lobbyist Websites

On the Internet there were several websites dedicated to the task of portraying road trains as dangerous, unnatural and bad for the labor market. The sites were financed by different lobbying groups in Europe, notably the railway lobby, the environmental lobby and the labor union lobby. Their main interests in preventing the introduction of 25,25m vehicles were:

- **Railway lobby**: Fear of increased competition to railway transports
- **Environmental lobby**: Fear of increased emissions from road transports
- **Labor union lobby**: Fear of increased unemployment due to increased efficiency

[12] Longer and Heavier Vehicles in the Netherlands, 2010:49

Their arguments were as follows:

- **Dangerous** – Longer and heavier vehicles resulted in more kinetic energy, leading to more severe accidents. The inner turning radius was smaller, making maneuvering more difficult. Overtaking was riskier with longer vehicles because it took longer time.
- **Environmentally damaging** – Two 25,25m trucks transported the same as three regular trucks, resulting in cheaper transports when compared to railroads. This would lead to an increased demand of truck transports, leading to increased pollution.
- **Expensive** – The road network in Europe was not designed for longer and heavier vehicles, resulting in the need to rebuild bridges and improve roads.
- **Will cost jobs** – The increased efficiency of the longer vehicles would lead to transports that used two trucks instead of three, thus making one truck driver unemployed. The increased competition to rail transports will also lead to more people facing unemployment in the railway sector.

There were obvious contradictions in these arguments, reflecting the different interests of the lobby organizations. The environmental argument was that the use of 25,25m trucks would lead to an increased number of larger trucks, while the labor union argument was the opposite: that the increased efficiency would result in job cuts.

3.4 Transport Fair in Lillestrøm

Transport 2011 was a national fair for the transport business in Norway held every third year. The exhibitor's included all the major truck brands on the European market as well as a great number of trailer and cargo body builders[13]. The results from the one day visit to the Transport 2011 fair in Lillestrøm could be summarized as:

- Experience of the Volvo Bird's eye view, where a rigid (see Appendix A) was equipped with four cameras that provided an all-round view of the vehicle. The combined image was displayed on a monitor that would be mounted on the dashboard of the cab or an equivalent position.
- Observations of the Scania camera system, that used a single wide angle camera directed at the front right corner of the truck.
- Observations of the Mercedes ranging mode for mirrors, where the mirrors were automatically angled 10 degrees outwards when the gear was put in reverse.
- Observations of range meters from Wabco, that utilized ultrasonic sensors mounted on different parts of the truck and/or trailer. These were combined with either an automatic braking system or with a system using warning lights.
- Hands on experience of the field of vision from the driver seat in all major truck brands on the European market (DAF, Scania, Volvo, MAN and Mercedes).
- Study of the different aftermarket products that existed, with a confirmation that no solutions existed for low speed maneuvering aids.

[13] http://messe.no/no/transport/

3.5 Logistical Chains Study

After finishing the general study of road trains, the focus shifted to a more detailed study of the way road trains were actually used in Sweden. Information about the different logistical chains was gathered during the study of government reports, observations on roads around Sweden, interviews with transport companies and during co-riding with drivers and discussions with employees at Volvo 3P. Three principal logistical chains were identified using road trains in Sweden: timber, container and general goods transports, where timber transports only were part of a limited trial (see chapter 3.1.1).

3.5.1 Container Transports

Container transports were the first to use B-train in Sweden[14]. The number of containers that could be transported was almost always the limiting factor as to how much goods that could be transported. Weight was only rarely the limiting factor and the advantage of using road trains compared to the older standards was therefore most notable on container transports. By using road trains, the load capacity was increased by 50% or more compared to using the standard semitrailer chassis that could either hold a 40ft. container or one 20ft. container (in some cases two 20ft. containers). In addition to the semitrailer chassis, a B-train had the capacity of another 20ft. container that could be transported on the lead trailer.

Fig 15 B-train utilized for container transports

Containers were mainly transported by truck to and fro major ports, after having been transported by boat from overseas. In Sweden, the major shipping port for containers was the Skandia Harbor in Gothenburg. Here, the containers were unloaded from the ships, placed in stacks awaiting further transports and subsequently loaded onto trucks. The trucks then transported the containers to different locations around Sweden and then returned to Gothenburg with the (most often) empty containers.

[14] Nilsson 2011

Fig. 16 Skandia Harbor freight terminal where the containers are loaded on the trucks.

Container transports had the following characteristics:

- The vehicle was often driven with no load (transporting empty containers approx. half of the time)
- The driver never unloaded the cargo himself
- Unloading times could be up to four hours due to loads not placed on pallets but in more irregular ways
- The freight terminal varies from the big ports to the smallest terminals.
- The transports often had varying destinations so the drivers visited a great number of different freight terminals.

3.5.2 General Goods Transports

General goods were characterized as transports that utilized road transports in the whole logistical chain (only occasionally transporting fully laden trailers on ships). The loads were almost exclusively transported using pallets. In contrast to container transports, road trains used to transport general goods were generally used in more homogeneous logistical chains that followed the same predefined routes. In the majority of cases, goods transports by road trains did not unloaded at the end customer, but at a freight terminal where the goods were unloaded and then transported to the end customer using smaller distribution trucks. In some cases, B-trains could serve in the role of distribution trucks when the semitrailer was detached and only the lead trailer was used.

The transport routes could be characterized as static and well planned, which resulted in trucks that only rarely drove without cargo. Cornflakes for example were manufactured in Bremen, Germany and transported by truck to a large reloading station in Padborg, Denmark. There the goods were loaded onto B-trains and transported to a warehouse outside

Helsingborg, Sweden. Once in Sweden, each B-train was picked up by a Swedish driver (due to labor union demands from ICA that only Swedish drivers were allowed to transport their goods in Sweden) and the B-train was then driven to an ICA-warehouse in Västerås, Sweden. The truck ran a short distance without load to Upplands Väsby, Sweden, where it was loaded with Marabou chocolate. The truck then drove down to Helsingborg where the chocolate was unloaded and the route was finalized.

General goods transport characteristics:

- The vehicle was seldom driven with no load
- The driver sometimes unloaded the cargo himself
- In general, the routes were similar on a day to day basis
- The vehicles often frequented large freight terminals
- Unloading of a B-train with pallets typically took about 30 minutes, while loading took slightly longer

3.5.3 Timber Transports

Timber transports were the latest type of transports that started using B-trains to transport goods in Sweden. This was done in a limited research project called "Större Travar" (Bigger Stacks), where vehicles were allowed an increased gross total weight of 74 tons, compared to the regular Swedish maximum weight of 60 tons[15]. The project was limited to only one vehicle using the B-train, but the project has been considered successful and awaited an increased number of vehicles participating in an expanded study.

Fig. 17 B-train utilized for timber transports

[15] Löfroth & Svensson, 2010

The logistical chain started with the freshly harvested timber that was placed in stacks along gravel roads in the forest. From these stacks, an 8x4 Nordic combination vehicle collected the timber with one stack on the rigid and two stacks on the semitrailer. The timber was then transported to a suitable open space in the forest or in close vicinity, where soft or waterlogged ground could be improved by bulldozer to withstand the weight of the vehicles. In this location, the timber was changed from the Nordic combination truck to a B-train. The loaded semitrailer was disconnected and the timber on the rigid was loaded onto a lead trailer. A 6x4 tractor then picked up the loaded B-train from the open space and transported the timber from the forest to a nearby sawmill or a paper mill.

Fig. 18 B-train being unloaded by a forklift truck at a paper mill

Since the source of raw materials was constantly changing, the open spaces used for loading and unloading were only used for two to four weeks. In addition to this, the sites were not always optimal regarding the room available for maneuvering or the stability of the ground. The terminals at sawmills and paper mills on the other hand were adapted to the extent that the B-train never needed to reverse. The vehicles followed a pre-designated track from the entrance to a specified spot where a crane or a truck unloaded the timber from the trailers. After unloading, the road train drove back empty to the forest to collect another load of timber.

Timber transports were characterized as follows:

- The driver never loaded or unloaded cargo himself
- The routes were always changing
- The vehicle often drove on gravel roads in the forest (often in bad conditions)
- The locations for loading and unloading were always changing
- The unloading process at the sawmills and paper mills was streamlined and no reversing was needed

3.5.4 Loading and Unloading Procedure

When regarding the loading and unloading at a freight terminal, the general procedure could be summarized in the following steps. This regarded all instances where general cargo was transported and where container transports were unloaded at a customer. For a description of the process used in the forest, see chapter 3.5.3 and for a description of the process used for loading container transports, see chapter 3.5.1.

1. The B-train arrived at the freight terminal and parked near the terminal building.
2. The driver left the cab and walked to an office building where he reported his arrival and was given a specific loading dock.
3. The driver walked back and drove the B-train towards the loading dock and generally made a clockwise turn in front of the loading dock to familiarize with the location.

After reversing the vehicle to a few meters from the loading dock, the B-train was stopped.

4. The driver left the cab and walked to the rear of the semitrailer and opened its doors.
5. The driver walked back to the cab, entered and reversed the remaining meters until the semitrailer was positioned at the loading dock.
6. The driver left the cab to decouple the semitrailer. First, the landing gear was lowered and all pneumatic hoses and electrical cables were disconnected. Then the kingpin was released and for extra security, additional straps could be used for attaching between the loading dock and the trailer, thus preventing it to move away while loading or unloading by forklift.
7. When everything was disconnected the driver entered the cab again and drove with only the lead trailer attached towards the next gate.
8. The truck reversed until the lead trailer was a few meters away from its designated loading dock.
9. The driver left the cab and pushed the button on the lead trailer and activated the hydraulic motor that moved the container to its rearmost end (thus allowing it to come close to the loading gate for loading or unloading).
    a. If the lead trailer was of the manual type, without hydraulic motor, the driver first walked to the lead trailer's controls and locked its wheel brakes and then unlocked its sliding mechanism. Then the driver entered the cab and reversed until the lead trailer slid together, thus moving the rear end of the cargo body to the rearmost end of the trailer. Then the driver left the cab once more to unlock the lead trailer's wheel brakes and to lock its sliding mechanism.
10. The driver walked to the rear end of the lead trailer and opened its (or the containers) doors.
11. The driver entered the cab and reversed until the rear end of the lead trailer was close enough to the loading gate.

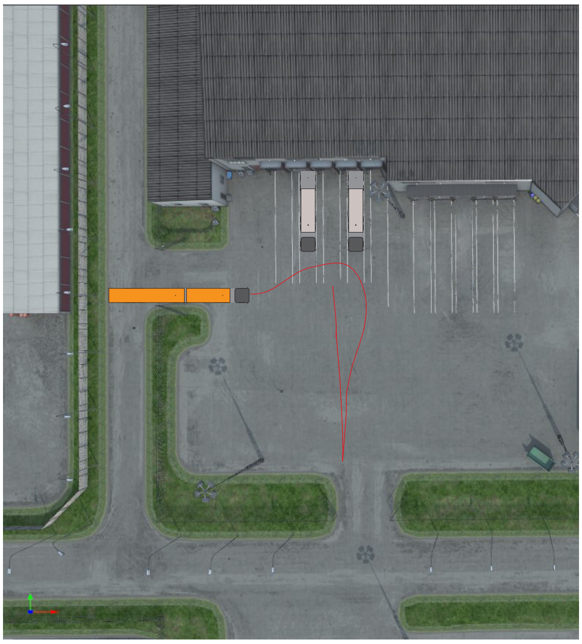

Figure 18 Illustration of a typical track used when reversing to a loading dock

When connecting the B-train after loading or unloading followed the same procedure was used in reverse. On some occasions, the goods in the lead trailer and semitrailer were destined for different freight terminals, sometimes separated by tens of miles. In those cases the procedure differed in the sense that only one of the trailers had to be maneuvered into position in front of a loading dock.

When driving on the grounds of a freight terminal, drivers' often followed typical patterns. Before reversing to a loading dock, the preferred way was to approach it in a clockwise, right hand turn, thus enabling the driver to scan the surroundings for obstacles through the left side window[16], which provided the best vision. Another pattern was that drivers preferred to reverse in a straight line, which was easier than reversing and turning at the same time. To give themselves the best possible starting position drivers maneuvered the vehicle as close to the loading dock as possible when approaching it, and when they were in front of the loading dock they made a sharp (right hand) turn place the vehicle in a straight line, perpendicular to the loading dock.

3.5.5 Time Study

A study made by Dutch authorities revealed that when comparing the goods by either volume or weight transported, the time for maneuvering, loading and unloading did not significantly differ between road trains and ordinary trucks[17]. The road trains spent on average 32% more time maneuvering, loading and unloading, which was roughly equivalent to the average increase in transported goods on a road train. Using this as a background, a time study was performed to compare the difference in the maneuvering time spent maneuvering at a freight terminal.

The time studies performed in this thesis project were based on a number of timekeeping sessions done at various freight terminals. All real locations were freight terminals that were representative of their respective transport type: three different freight terminals in Viared outside Borås which were frequented by both container transports and general goods, at Skandia Harbor in Gothenburg where all container trucks are loaded, and in the driving simulator at Oryx Simulations, Umeå.

In the time studies, the procedure of loading/unloading was divided in the following parts:

- Time spent maneuvering, i.e. the time it took from the moment the driver started to approach the loading dock until he had reversed with the semitrailer positioned in front of the dock
- Time spent on connecting and disconnecting
- Time spent waiting for loading and/or unloading
- Time spent on driving

Of these four parts only “Time spent maneuvering” was inside the scope of the master thesis, but the remaining three were used to get a more holistic perspective. For a transport company time saved usually equaled at least some money saved, and the effect of potential time savings in the maneuvering part had to be put in perspective to the other parts, in order to get a balanced picture.

The time studies concluded that the variation in time was very large. The variation could be seen as individual variations from time to time and individual variations between different kinds of terminals, as well as depending on the kind of goods transported and how it was loaded. In a statistical sense it was not feasible to conclude on mean times for the different parts of a transport, since a much greater statistical material would be needed. Results from

[16] Andreasson, 2011
[17] Longer and Heavier Vehicles in The Netherlands, 2010

interviews and observations of driving behavior therefore had to be included to get a more holistic view of the time spent on different tasks.

When regarding the four parts that a loading/unloading procedure could be divided into, only “Time spent maneuvering” displayed a sufficiently coherent picture so as to allow a statistically viable conclusion.

RESULTS FROM THE TIME-KEEPINGS, INTERVIEWS AND OBSERVATIONS REGARDING TIME SPENT ON DIFFERENT TASKS:

Transportation: The most time consuming part of a transport was usually the road transport itself. The effectiveness of road trains was most prominent for long distance transports where high volumes were transported. Three hours driving could be considered a minimum time, but it could vary to as much as several days of driving. This part of the transport was not part of the project scope, which focused exclusively on low speed maneuvering.

Loading/Unloading: Loading and unloading the trailers was usually the second most time consuming part of a transport. Containers with goods not stacked on pallets were by far the most time consuming to unload while timber was the fastest. For example, during a co-riding to a freight terminal in Nässjö, unloading of the two containers took almost four hours. However the driver stated that it usually took 2-3 hours, but longer times were not unusual. If the goods were stacked on pallets the time would be more in the range it took to load or unload general goods, which was about 15-40 minutes for a full trailer. Timber had the most efficient unloading procedure, with only five minutes being spent on unloading. Since the semitrailer and lead trailer were supposed to be fully laden when the driver of the tractor came to pick them up, the time spent loading them could not be counted in the same way as for the other transports.

Connecting/Disconnecting: The third most time consuming part was the connecting and disconnecting of the trailers (not including the maneuvering into position for coupling). As described in chapter 3.5.4 the driver had to exit the cab numerous times to attach connections and to perform other operations. It was observed during co-ridings that the connecting and disconnection time varied considerably between drivers. Some drivers were observing all safety precautions, while others worked as fast as possible and only adhered to the most rudimentary safety precautions. Typical time spent on these operations during a freight terminal visit (on those visits where disconnecting was needed) varied from 10 to 30 minutes. However, this part of the process was not part of the scope of the thesis project and no further analyses were made.

Low speed maneuvering: The fourth and least time consuming part of the transport was the maneuvering (including the reversing) on the freight terminal. The timekeeping studies showed that the average time to maneuver a B-train into position at a loading dock was 179 seconds (based on 25 different maneuvers by 17 different drivers at the five different places mentioned above). The design of the freight terminal had a major influence on the time spent where the streamlined and efficient design in the Skandia harbor in Gothenburg averaged 116 seconds while the same maneuver in more traditional freight terminals averaged 209 seconds. Even though the statistical material was mainly based on container transports, 3 minutes (rounded up from 179 seconds) could be considered an average for the whole market, since container transports had the largest market share for B-trains in Sweden. An average maneuvering time around 3 minutes was also confirmed during interviews, but the time was only valid for an experienced B-train driver while a less experienced driver could require considerable longer time. This was also observed with a driver that had only a few months experience of driving a B-train where the same maneuver took in excess of 15 minutes.

Reversing into position at a loading dock was only part of the maneuvers needed for a loading or unloading procedure (See chapter 3.5.4). No timekeeping was made for the entire process and no direct comparisons could thus be made to the Dutch study[18]. However, timekeeping showed that the average time to reverse a semitrailer was 74 seconds compared to the 179 seconds for a B-train. This was a greater difference than could be expected from the increased load volume or weight, but the difference was still minute compared to the entire loading or unloading procedure. It would be feasible to assume that the same difference in time spent maneuvering would exist in the Dutch material, but that the difference disappeared when studying all four steps in the loading and unloading procedure.

Apart from these four parts of a transport many other unforeseen events were found to cause time-consuming delays for B-trains and other trucks. Road works or traffic jams could easily cause long delays for a transport, but other waiting times in addition to loading or unloading itself were common. At the Skandia Harbor in Gothenburg where it took on average 2 minutes to maneuver to the loading position, the waiting time from reaching that position until two containers were loaded, could be up to 20 minutes and rarely was faster than 5 minutes. However, during peak hours during the day, it could take several hours just to get into the loading/unloading area at gate 4.

Even though all the results from the time study showed conclusively that reducing the time spent on low speed maneuvering would not be relevant in the big perspective, there was an important social aspect of maneuvering the road train. No drivers, regardless of transport company and transport type, claimed that the transport company put any stress on them to make any maneuvering faster. Instead, there was a social pressure from other drivers and straddle carrier drivers – the result of vocational pride among drivers, which was very much present in how well they managed to operate their vehicles. Especially low speed maneuvering, which was the most difficult part of driving, was something the drivers were proud to excel at. Doing many retakes or taking long time to reverse to a loading dock could result in teasing from other drivers or straddle carrier drivers, which was something that put a considerable amount of stress on the drivers to perform such maneuvers well.

[18] Longer and Heavier Vehicles in the Netherlands, 2010

3.6 Need Compilation

During the interviews, a number of problems with low speed maneuvering were encountered. These were initially grouped according to the source of the problem as follows:

- Collisions on freight terminals
- Retakes while reversing
- Load shifts
- Wear on couplings and connections
- Time spent reversing
- Maneuverability
- Traffic behavioral problems with unprotected road users
- Traffic behavioral problems with other road users
- Interference with other traffic
- General lack of perceived safety and feeling of control
- Problems regarding driver ergonomics
- The need to determine accessibility to a freight terminal
- Blind spots
- Vision in bad light conditions

These problems were converted into ten main needs that described the heterogeneous problem area in a more concentrated form. For example *Collisions on freight terminals* was considered a problem, but the underlying needs that would improve this was found to be better vision in the relevant blind spots and a better way of making judgment of distance.

3.6.1 Needs Expressed in Interviews

After the results from the interviews were collected, the main findings in the use of road trains in Scandinavia could be summarized. The result consisted of very openhearted input from the drivers. This was indicated by the fact that the drivers were honest in sharing even illegal practices that were used, for example a transport company that illegally drove road trains to a European country that did not allow road trains, or drivers who used magnets to knock out the tachograph to be able to drive for longer hours than legal. Neither the transport company nor any of the drivers that confessed to illegal practices were mentioned in this report, to protect their identities.

The findings from the interviews could be summarized as the following ten main needs:

- **Time reduction** related to maneuvering was not a major issue for the drivers or the transport companies interviewed. As expressed by one transport company: *"When the drive takes 10 hours, a few minutes difference in the ranging process doesn't really matter"*. A driver said: *"It has to take the time it needs. I can't be stressed. For example, if I'm stressed up and reverse quickly to a gate and then get into the warehouse and start looking at my watch to make them unload quickly, they simply refuse to work. That's how the forklift drivers work. You can't push them or they will punish you."* Instead of time meaning economic pressure, there appeared to be a social pressure that a good driver needed to reverse without many mistakes and not influence the routines of others. One driver described the ranging process at Skandia Harbor in Gothenburg: *"When you're reversing to a spot where a straddle carrier is waiting for you, he has a loudspeaker which he uses to make fun of you in front of all the other drivers if you're bad, and give you credit if you're good."*

- **Lack of vision in blind spots while reversing** was a big problem expressed by the interviewees. This was exemplified by one driver: *"When I come to a place and I don't know what's behind the vehicle, I take pride in leaving my truck and go out and look. I don't care what people think of me."* Another driver described the problem related to new drivers *"When a driver is fresh out of driving school, the first month he is insecure and really careful when he's reversing and leaves the truck to check if something's in the way. The second month he's starting to feel more confident, but is still careful. The third month, he thinks he's the best driver in the world, starts to be reckless and that's when accidents occur when he's reversing."*
- There was also a problem with **lack of vision in blind spots when driving forward**. This was especially the case when the vehicle made a right turn where it was not possible to widen the outer radius of the turn to eliminate corner cutting. The problem was especially apparent in driving through urban areas. One representative from an insurance company said: *"As late as last week there was an accident with deadly outcome where a road train killed a bicycle rider during a right turn. I don't know what to say, it's such a tragedy."* A Swedish driver transporting containers said: *"When I'm going into a town that I'm not completely familiar with, I always disconnect my B-train outside the town and first take the lead trailer and then the semitrailer. Of course, it could mean a delay of 20-30 minutes, but I don't want to run over someone."*
- **The maneuverability in tight spaces** was a general problem with B-trains. The problems could occur at a number of different locations, from small, gravel roads, to truck stops or parking lots. One driver said: *"When I divide my B-train, I sometimes park the semitrailer at a parking lot and when I come back with my lead trailer, someone have parked a trailer right in front of my semitrailer. It's not that they are stupid; they didn't think it was a road train that parked, so they just left enough room for a tractor to come in and take the semitrailer. That is one tricky reversing maneuver you have to perform then!"*. The problem of maneuverability in tight spaces also occurred in the forest, where road quality sometimes restricted the use of increasing the outer turning radius.
- Related to the problem of maneuverability of road trains, there was also the problem of how to **determine the accessibility** of the vehicle at different locations. One driver explained: *"When you get a job to drive cargo to a place where you haven't been before, you really have no way of knowing if you can get your vehicle in there. You can telephone the people there and ask if it's big enough for a road train and they always say 'No problem, we've had lots of trucks here'. But when you get there, it's such a small place that you have to turn back and divide the vehicle and take one part at a time."* The problem could also be the reverse, as described by one driver: *"Sometimes when you go to a new place, you divide the road train just in case it's a small freight terminal, but when you get there you realize that it wasn't necessary and that the freight terminal was big enough. That could easily eat 20 minutes for you."*
- **Vision in bad light conditions** was considered a big problem while reversing a road train. The rear lights were not strong enough to give good guidance, which could result

in reduced efficiency at night. One driver said: *"The lights are not good for reversing at night. One night I took a wrong turn and to get back to the main road I had to reverse a couple of hundred meters, which wouldn't have been any problem at daytime, but at night and with no good reverse lights, I just gave up. It wasn't possible at all, so even if I had a lot more hours to drive, I just went to sleep instead and waited for the sunrise. Then in the morning I continued driving."* There was also an increased risk of accidents related to bad lighting. One driver explained*: "It's the youngest and most inexperienced drivers who get to take the night shift because no one else wants to take it. Since the reversing light is inadequate on the vehicles, these drivers are much more prone to accidents – one because it's challenging to drive at night and two, because they don't have enough experience to do it without crashing into something."*

- The need to **communicate with unprotected road users** was also identified as a problem. When driving in an urban area there was a general opinion that people did not understand the behavior of the road trains. People riding bicycles drove too close to the vehicle, or as one Danish driver said*: "In Denmark, cyclists don't stop at the stop line at a crossing – they drive an additional couple of meters to save a few seconds. But the problem is when you're going to make a right turn and have people standing two meters out in the road. People are crazy!"* There could also be people walking around a freight terminal, as one driver said: *"Sometimes you come to a small freight terminal and there is this guy who is trying to help you by standing there and directing you by hand signals, or walking around and checking so that you don't hit his 'beautiful' loading dock. He doesn't know whether I see him or not and someday, he'll be overrun."*
- **Communication with other road users** was also an important issue that became apparent during the pre-study. Just as with the unprotected road users, there was a general lack of understanding of how the road trains behaved on the road. This could also be exaggerated on the careful side, as described by one driver: *"When you look at how different cars behave around the road train, there is a huge difference between Norway and Sweden. In Sweden, they behave like they always do, but in Norway, when they see the warning sign at the back [*of a 25,25m vehicle*] they are really afraid and can behave in all crazy ways. "* Another driver said*: "Some people seem to believe that a road train has the same stopping distance as a car and the same maneuverability. It could be a car on the road or a flower transport on a freight terminal – some people are just plain stupid."*
- There was also a need to **reduce general wear and tear** that resulted from low speed maneuvering of road trains. For example, when turning around a sharp corner with a fully laden vehicle, the tire wear could be much greater than normal. One driver said: *"When you take some turns, you can really hear the sound of the tires breaking apart."* During reversing and when doing retakes, there could also be an increase in wear on connections, fifth wheel and gearbox from reckless and stressful driving. When straightening the vehicle there was also the risk of accelerating the rearmost part of the vehicle to such a degree that the cargo was displaced in the cargo body, as described by one driver: *"When you're reversing with a road train and you fold the vehicle a lot, there is a real problem if you drive forward too fast when you straighten the vehicle. The B-train acts as a whiplash, which makes the cargo in the semitrailer accelerate really fast. There*

have been drivers who did this and where the cargo was displaced so much that it flew out of the back door."

- The final problem to be identified was the need to **judge distance** at the vehicle end by looking in the mirrors. The practice of using cues was widespread, for example using lines in the road and parked vehicles around the truck to put the own vehicle in relation to other objects with known positions. The problem was general for all transports, but especially notable when a vehicle that ordinarily transported a 40ft. container was transporting a 45ft. container, as explained by one transport company manager: *"When drivers transport 45ft. containers, they tend to hit the loading dock harder since they can't assess the longer distance. We had especially one freight terminal that caused us trouble, for the loading dock was so hard and angular that it damaged the containers when the trucks hit it. Then we put on large iron bars on the semitrailers to protect the containers, but when we did that we instead damaged the loading dock and weren't allowed to transport containers to that terminal any longer."*

3.7 Scope Creep

The initial aim, defined at the beginning of the project by Volvo 3P, identified three areas that were to be studied during the thesis project: physical ergonomics, safety and time spent. After the Pre Study where ten different needs were identified, it became apparent that the scope of the project had started to creep.

Ergonomics was the first part of the original aim. It was originally defined as: *control usage and driving position.* During the interviews with both drivers and transport companies it became apparent that physical ergonomics was not a big problem for individuals or companies using road trains. Cognitive ergonomics was not studied in itself during the remainder of the thesis project, but it was part of the continuing studies of the different needs and during concept development.

Safety was the second part of the original aim. It was originally defined as*: direct and indirect vision from the driver seat, unprotected road users around the vehicle and vision in bad light conditions.* During the interviews with drivers and transport companies, it became apparent that this was an area where major improvements could be made and where the most severe accidents occurred, causing both human and economic consequences. This part became the major focus for the rest of the thesis project.

Time spent and efficiency was the third part of the original aim. This had already been studied by Volvo 3P and it was described by Volvo 3P as an important area to be studied in the project. During interviews with both drivers and transport companies it became apparent that time spent during maneuvering a road train was not a major issue. Observations and timings concluded that there was a time difference between a road train and a tractor and semitrailer, but compared to the total amount of time spent driving, the time spent maneuvering at a freight terminal was negligible. A study made by Dutch authorities[19] also showed that the total amount of time spent maneuvering, loading and unloading was 32% higher when using road trains compared to regular vehicles, but this increase was equivalent to the average increase in

[19] Longer and Heavier Vehicles in The Netherlands, 2010

the amount of cargo volume/weight carried on a road train[20]. Connecting and disconnecting was however outside the scope of the thesis project. Time spent on maneuvering was studied during the remainder of the project and was part of the basic needs, but it was not given any special priority (See Chapter 3.8.1).

3.7.1 Adjusted Scope

The adjusted scope of the thesis project based on interviews and observations during the Pre Study was divided into ten areas that each comprised a basic need:

- **Economy and efficiency**
    - Time reduction (3.8.1)
    - Reduction of wear and tear (3.8.9)
- **Vision and safety**
    - Vision in blind spots while reversing (3.8.2)
    - Vision in blind spots while driving forward (3.8.3)
    - Vision in bad lighting conditions (3.8.6)
    - Communication with unprotected road users (3.8.7)
    - Communication with other road users (3.8.8)
    - Judgment of distance (3.8.10)
- **Maneuvering**
    - Maneuverability (3.8.4)
    - Determining of accessibility (3.8.5)

3.8 Components of the Need Matrix

Ten basic needs were identified during the interviews and observations in the Pre Study. Each need was then divided into segments that were scored according to their relative importance within each need, so as to provide a balanced picture of reality.

The need segments and their respective scoring were derived from interviews, observations and questionnaires. The different segments were defined in different ways according to the entity being evaluated, but all segments were divided on a five degree scale to be used in the future concept evaluation.

For further descriptions of the method used, see chapter 2.4.2.

3.8.1 Time Reduction

The need for time reduction was defined as a scenario: A B-train entered a freight terminal and reversed to a loading dock.

During real world observations, the average time for a reversing maneuver with a B-train for an experienced driver was 3 minutes (see chapter 3.5.6), and the fastest times observed were around 1 minute. This interval formed the two ends of the scenario, where 3 minutes was defined as the zero point level, or the level that could be expected without the use of any maneuvering aids. Performing the maneuver faster than 1 minute, where a reversing maneuver

[20] Longer and Heavier Vehicles in The Netherlands, 2010:49

is performed flawlessly, was defined as the 5 points level. The intermittent levels were divided in equal parts and graded from 1 to 4, since the benefits for time reduction would be proportional to the time reduced.

Need fulfillment	**-1**	**0**	**1**	**2**	**3**	**4**	**5**
Time spent	>3min	~3min	2,5-3 min	2-2,5 min	1,5-2 min	1-1,5 min	<1 min

Fig. 19 Time reduction need scoring matrix

3.8.2 Vision in Blind Spots While Reversing

The need for vision in blind spots while reversing was divided in three scenarios. They represented the three different configurations that a B-train could form while reversing: a clockwise, a counter clockwise and an S-shaped reversing where the vehicle no longer was reversing in a steady state.

The scores for different areas were derived from interviews, where the different numbers below corresponded to the frequency of which the problem area was mentioned. The results were compiled from 23 interviews in total.

- Clockwise reversing has four areas with increased risk:
  - Behind the semitrailer, graded 2.
  - To the right of the semitrailer, graded 1.
  - To the right of the lead trailer, graded 1.
  - To the right of the tractor, graded 1.
- Counter clockwise reversing has four areas with increased risk:
  - Behind the semitrailer, graded 2.
  - To the right of the rear end of the semitrailer, graded 0,5
  - To the left of the semitrailer, graded 1.
  - To the left of the lead trailer, graded 1.
  - To the left of the tractor, graded 0,5.
- S-shaped reversing has three areas with increased risk:
  - Behind the semitrailer, graded 2.
  - To the right of the semitrailer, graded 2.
  - In the area between the semitrailer and lead trailer, graded 1.

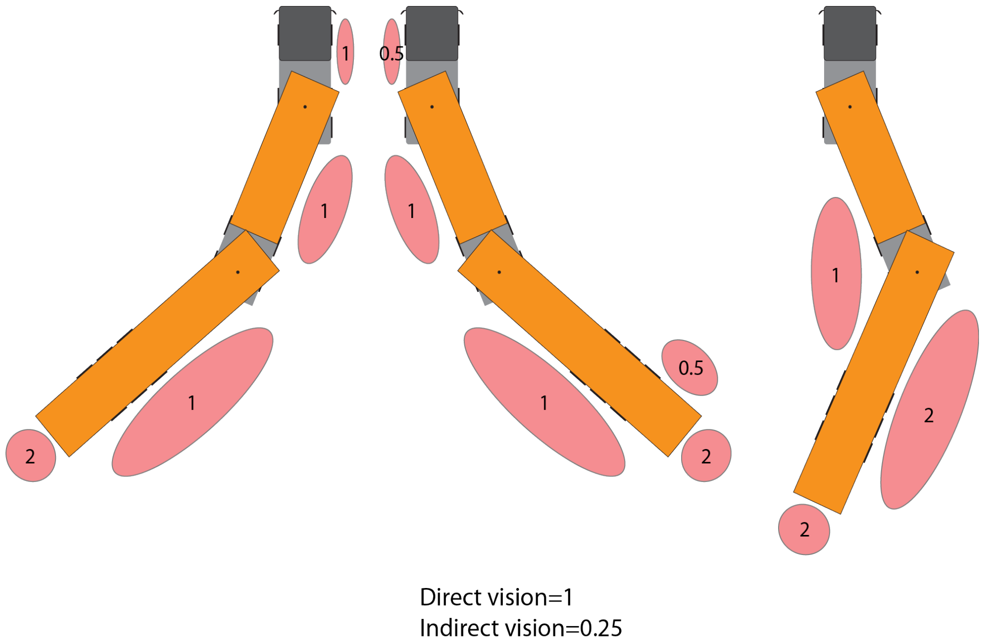

Fig. 20 Vision in blind spots while reversing

The increased score for the area behind the semitrailer was related to the increased risk of collisions in the principal direction of movement. Most frequently, this would be in the form of damages to light ramps and doors on semitrailers, and damage to the loading dock. The reduced score for the left side of the vehicle was a consequence of the practice of looking out through the left window of the tractor, which significantly improved vision.

When regarding the problem of vision in blind spots, there were two different technological ways to solve the problem, either by using direct vision or indirect vision. Direct vision was the use of cameras, while the indirect vision related to non-visual sensory equipment, for example ultrasonic sensors. In order to separate the two technologies as to what they provide in regard of vision, the score of the direct vision aids were multiplied with 1, while the indirect vision aids were multiplied by a factor of 0,25. This factor was determined by dividing vision aids into four parts:

- Recognition (What it was)
- Detection (When it was there and not)
- Differentiation (Differentiating between the dangerous and the harmless)
- Direction (Where it was)

A camera provided all four parts, while non-visual sensory equipment only provided detection of objects. Each part was considered equally important and the factor multiplied to non-visual sensory equipment was thus determined.

3.8.3 Vision in Blind Spots While Driving Forward

The need for vision in blind spots while driving forward was divided in two scenarios, see fig. 21. The first was a left turn (counter clockwise) and the second a right turn (clockwise), while no S-shaped driving scenario was relevant during forward maneuvering. The division of points was not equal between the left and right turn, depending on the increased risk associated with the right turn. In total, the left turn had a maximum of 4 points, while the right turn had a maximum of 6 points. This was caused by a distribution of mentioned problem areas that was roughly 40/60. If the focus had been more on driving in urban areas, the distribution would most probable have had an even higher weight on the right turn.

- Left turning had three areas of increased risk:
    - In front of the tractor, graded 1.
    - To the left of the tractor, graded 1.
    - To the left of the semitrailer, graded 2.
- Right turning had three areas of increased risk:
    - In front of the tractor, graded 1.
    - To the right of the tractor, graded 2.
    - To the right of the semitrailer, graded 3.

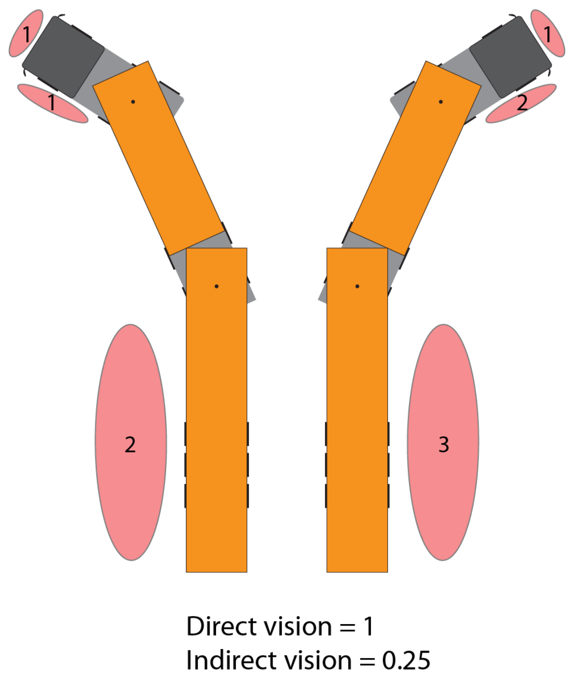

Fig. 21 Vision in blind spots while driving forward

A factor was implemented to accommodate vision aid devices that did not give the driver a direct vision in a blind spot (see chapter 2.4.2). The score of those indirect vision devices (ultra sound sensors for example) were multiplied with the factor 0.25 to better represent the level of aid they could provide in reality.

3.8.4 Maneuverability

The need for maneuverability was related to the reduced inner turning radius that was evident during all forms of turning maneuvers and to the increased sideways space required for reversing the road train. Following this division, the need was divided in two parts. The first part concerned concepts that would actually *enhance* the maneuverability of a B-train, such as turning axles or others. The second part was for concepts that would help the driver to *optimize* the maneuvering space so as not to use more space than needed when reversing.

The *enhancement* concepts were divided into concepts that would aid driving in both directions, i.e. forward and reverse, and concepts that would aid in only one direction. One-directional concepts would score half of the multidirectional.

Optimization concepts were divided into passive and active concepts. These were then divided into multi- and one-directional concepts in the same way as the *enhancement* concepts. The active concepts would be concepts that actively took over some (or all) control of the vehicle from the driver, while the passive concepts would aid the driver but still leave all control to him.

Maneuverability				
Enhances		Multi-direction	3	
		One-direction	1.5	
Optimizes	**Active**	Multi-direction	2	
		One-direction	1	
	Passive	Multi-direction	1	
		One-direction	0.5	

Fig. 22 Maneuverability need scoring matrix

3.8.5 Determining of Accessibility

Road trains required more space to maneuver than other trucks. Related to this, there was a need to determine the accessibility for such a big vehicle at different roads and freight terminals. This need was divided in three parts in which the need could be fulfilled. The first part was static determining of accessibility through detailed maps of different freight terminals, truck stops and the like. The second part was the dynamic determining of accessibility that took into consideration temporary obstacles in the form of vehicles and other mobile structures that obstructed the way for the road train. The third part related to the need for traction and the determining of accessibility relating to road conditions, e.g. the amount of friction that was present on different roads.

Determine accesibility		
Partly	**Completely**	**Type**
1	2	Static
1	2	Dynamic - obstacle
0,5	1	Dynamic - road conditions

Fig. 23 Determining of accessibility need scoring matrix

The determining of accessibility was divided between a partial and a complete determining, where the partial determining of accessibility scored half the points of the complete determining.

3.8.6 Vision in Bad Light Conditions

The need for vision in bad light conditions was divided in three parts. The scores were not divided between driving forward and reversing the road train since sufficient light in front of the vehicle was assumed to be provided by the headlights of the truck. Light conditions on the sides of the vehicle when driving forward would be adequately covered by the reversing condition.

Vision in bad light conditions was divided between:

- Vision behind the semitrailer, graded 2.
- Vision on the sides of the semitrailer, graded 1 for each side.
- Vision on the sides of the lead trailer, graded 0,5 for each side.

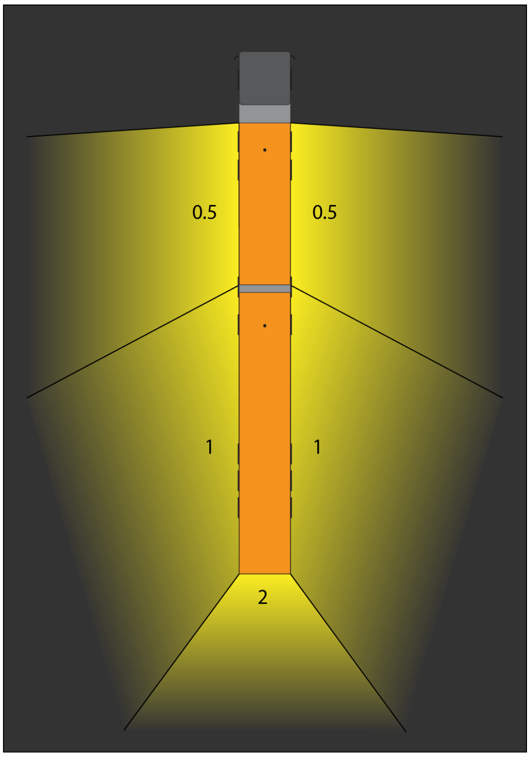

Fig 24 Vision in bad light conditions

3.8.7 Communicate with Unprotected Road Users

The need to communicate with unprotected road users, i.e. pedestrians and bicycle riders, was divided in two parts. The first part concerned the need to communicate with an individual that was in immediate danger in close proximity of the vehicle and the second part was the need to communicate with individuals that were further away from the vehicle, but ran the risk of moving into a dangerous area around the vehicle. The different areas could be seen in fig. 25.

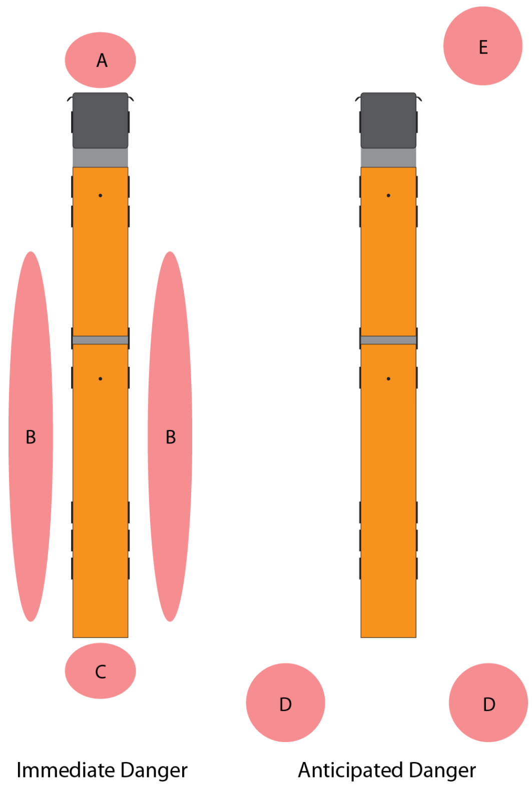

Fig. 25 Communicate with unprotected road users

The left scenario, immediate danger, describes the different areas in close proximity to the vehicle where people might be in immediate danger, and the right scenario, anticipated danger, describes the general areas where unprotected road users needed to be aware of the road train. Each concept was then scored by adding how many of these areas that it would cover and then multiplying that number with a factor representing different types of communication:

Communicate			
Maneuver right now		**Future maneuver**	
Depending on behaviour/active	1	Depending on behaviour/active	1
Passive/Human	0,5	Passive/Human	0,5

Fig. 26 Communicate with unprotected road users need scoring matrix

The highest score was awarded for communication that actively detected unprotected road users and warned them of upcoming dangers. The second level of score was given passive communication that either the driver himself was to activate or that was activated every time in certain situations where such communication was expected to be needed, for example during sharp cornering. A factor of 0,5 was determined to be a feasible reflection of the real world use, where use was dependent on the driver.

3.8.8 Communicate with Other Road Users

Communication with other road users was scored in the same way as communication with unprotected road users (see chapter 3.8.7). The only difference was that the communication was aimed at other drivers instead of pedestrians and cyclists, thus creating different demands on the communication itself.

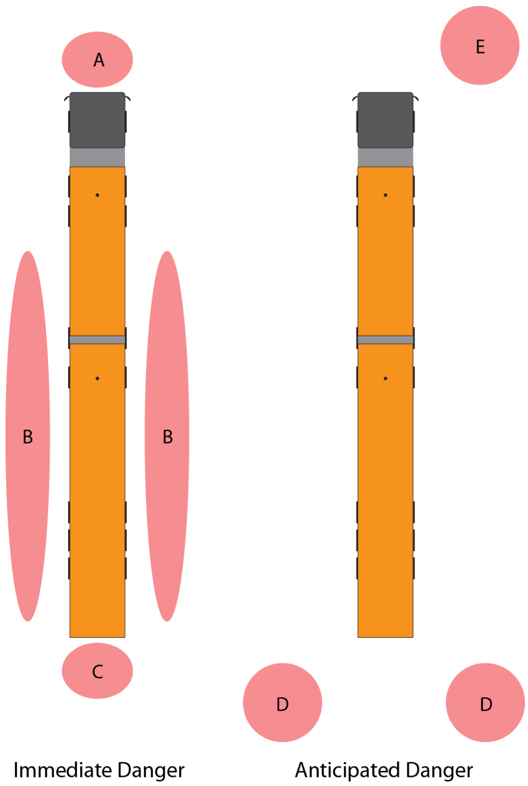

Fig. 27 Communicate with other road users

The different areas and the division into active and passive communication were the same as for communication with unprotected road users.

Communicate			
Maneuver right now		**Future maneuver**	
Depending on behaviour/active	1	Depending on behaviour/active	1
Passive/Human	0,5	Passive/Human	0,5

Fig. 28 Communicate with other road users need scoring matrix

3.8.9 Decrease Wear and Tear

The need to decrease wear and tear was divided into three parts (See fig. 29). The first part, *tires*, concerned the wear due to tight turning, which was a consequence of the difficulties related to the maneuvering of the road train. The second, *powertrain*, concerned the frequency of gear changes, accelerations and braking that was a consequence of the difficulties of reversing the road train. The third part, *connections/loads,* concerned wear and tear due to quick accelerations, either of parts of the vehicle or the entire vehicle. This was a consequence of the difficulties of reversing the road train, which sometimes resulted in sharp angles between the different parts of the vehicle. When the vehicle was to be straightened up in a forward motion, the resulting acceleration caused undue wear on the entire road train.

Wear and Tear		
Completely	**Partly**	**Wear type**
2	1	Tires
1	0,5	Powertrain
2	1	Connections/loads

Fig. 29 Decrease wear and tear need scoring matrix

The reduction wear and tear was divided between partial and complete, where the partial reduction scored half the points of the complete reduction to a minimal possible level.

3.8.10 Judgment of Distance

Aids for judgment of distance was discovered to be needed in three different areas, see fig 30. The different areas were rated according to their importance during low speed maneuvering, both forward and reverse. A concept that aided judgment of distance in one or more of the areas scored points by adding their respective ratings and then multiplying the sum with a factor related to which method the judgment of distance was performed by.

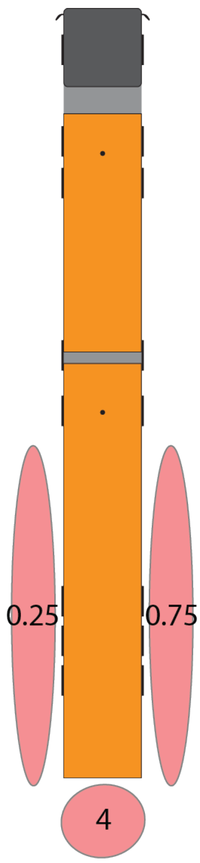

Fig. 30 Judgment of distance in problem areas

The method possible to use for judgment of distance was divided in four parts:

1. **Measurement tool** – A tool that would give an accurate measurement of the distance to an object, and at the same time presenting an image to the driver of the obstacle.
2. **Non-visual measurement tool** – A tool that would give an accurate measurement of the distance to an object, but not giving the driver any information of the nature of the obstacle.
3. **Top view** – A top view image of the surroundings of the truck for judgment of distance, leaving the judgment to the driver himself instead of utilizing range meters.
4. **Perspective view** - A perspective view of the surroundings of the truck for judgment of distance, leaving the judgment to the driver himself instead of utilizing range meters.

The four ways for judging distances were rated according to how well they would provide the necessary information needed by the driver, as can be seen in fig 31.

Judgment of distance	
Measurement tool	1
Non-visual measurement tool	0.75
Top view	0.5
Perspective view	0.25

Fig. 31 Judgment of distance need scoring matrix

4. Concept generation

4.1 Idea Generation

During the idea generation process a great number of concepts were developed using different techniques. A list of all the different concepts can be found in chapter 4.6 and 4.7. Common for all concepts was the development to solve various problems or meet specific needs that were identified in the Pre Study. Many concepts could be combined to produce even greater benefits in one way or another, but the concepts were compared in their most basic form to facilitate both the functional and the technical analysis.

4.1.1 Brain Storming

The first phase of the idea generation began with brain storming sessions. They were performed in “Silent rooms” at Volvo 3p, using a combination of whiteboard sketches that were quick and easy to erase, and paper sketches that were made in greater detail. In total, 14 brain storming sessions were held, with a difference in length between half an hour and 1,5 hours.

The following brain storming sessions were conducted, with a brief description of the subject that each session focused on:

1. Initial brain storming session, free thoughts
2. Need based brain storming session
3. Need based brain storming session
4. Brain storming with ship and sailing inspiration
5. Brain storming with car inspiration
6. Brain storming with inspiration from other truck manufacturers
7. Brain storming using concepts already developed and comparing them to the needs in order to reach a higher degree of development in concepts
8. Brain storming with military inspiration
9. Brain storming with inspiration from futuristic car concepts seen on car shows (mainly Geneva and Tokyo)
10. Brain storming with inspiration from technical solutions used in other transport types than the ones using road trains, mainly using truck magazines as sources
11. Brain storming with inspiration from historical technical solutions
12. Brain storming with inspiration from Science Fiction
13. Brain storming using all concepts developed as inspiration for new ones, and finding gaps between different existing concepts
14. Final brain storming session, free thoughts

4.1.2 Negative Brainstorming with Technical Limitations

The brain storming sessions were complemented by negative brain storming sessions based on the comments and discussions about the ideas that emerged during the weekly meetings at Volvo 3P. The purpose was to generate new ideas and improve the ones already developed.

The negative brain storming sessions often resulted in technical solutions that were proposed for a concept to be further developed into variations of the concept in order to fully explore all its possibilities. This was most obvious for the different camera concepts (See chapter 4.6), where all possible angles were investigated and the most promising were chosen for further development.

4.1.3 Sketches from Brain Storming

During the brain storming sessions sketching was used as a tool both for idea generation and to visualize and describe the concepts. As a quick tool for simple sketching, whiteboards were used to present ideas as they emerged and the most promising of the ideas were transferred to paper.

In addition to this, a number of sketches were made on paper from the beginning, to explore a problem or to sum up ideas about a problem or a concept. These sketches were also produced in a way that followed different idea paths, for example by exploring a technical possibility further than what is used today. Each path resulted in sketches that examined a situation or a technical detail for concepts that could be related to the basic needs or problem that was identified in the Pre Study.

During the brain storming sessions, the following major paths could be identified:

- Field of vision, based on existing truck design
- Safety, centered around hazardous traffic situations that had emerged during the pre-study
- Other technical fields, focused on known ideas that were in some way similar to low-speed maneuvering
- Outside the box, based only on the problem being solved

For examples of sketches made during brain storming sessions and descriptions of thought processes, see Appendix F.

4.2 Meeting with Representatives from Volvo Technology

A number of concepts utilized range meter technology and in order to increase the knowledge of this subject, as well as understanding the technical limits and possibilities, a meeting was held with representatives from Volvo Technology, working for Electrical Engineering. All were specialized in different measurement methods on the market today, with most having a PhD in their respective field.

Four different types of sensors where discussed during the meeting: laser, ultra sound, radar and optical (cameras).

Laser could be of two different types, scanning or fixed. A scanning laser would move the laser beam to measure the distance and position of an object in an area to form a picture of the surroundings. A fixed laser on the other hand would be aimed in just one direction and measure the distance to the closest object that would reflect the laser beam.

Laser was a relatively expensive technology, but it would give very precise measurements of distance. However the scanning laser would not give a sufficiently clear picture of the surroundings to become useful to the driver.

Ultrasonic sensors emit sound waves in a cone shape and could in that particular cone give a very exact measurement of the distance to the closest object. The sensors were common in automotive application, primarily for being very cheap while at the same time giving exact measurements. They were also robust in the sense that they would not be affected as much by any dirt stuck on the sensor as an optical (laser and camera) sensor would. The downside with the ultrasonic sensors was that they could not determine the position of an object within its cone, only the distance.

Radar systems were similar to scanning lasers in the sense that they gave a relatively good measurement of distance to an object as well as the positioning of an object. Radar systems were however better suited for applications where measurements at greater distances were needed, since they did not provide as exact measurements as the laser and ultrasonic sensors. Radar was also a relatively expensive technology, but more robust than lasers in the sense that they were relatively insensitive to dust and snow. Radar did not provide information accurate enough to form an image of the surroundings similar to the way they are used on ships, since accuracy levels down to a few centimeters were needed – which would make the costs too high for a civil application.

Cameras could, when used together with image processing software, be used for measurements of distance and position similar to the other sensors. However, the technology needed to achieve this was not yet developed to such a degree that it could be put into production.

Cameras were cheap to implement (but not as cheap as ultrasonic sensors that could cost as little as 1-2 euros each) and what was lacking in exactness of measurements could be compensated with more visual information about the area surrounding the vehicle. To aid the driver in determining the distance to objects in the surroundings, both static and dynamic graphics could be added to the displayed camera view. The downside of using cameras was their sensitivity to dirt and snow that could easily render them useless. A number of cameras on the market used protective covers and electric heating to resist frost and dirt, but interviews with drivers from the north of Sweden revealed that these protective measures were not adequate to prevent the cameras from malfunctioning.

In conclusion, cameras and ultrasonic sensors were chosen to be used in the concepts. They were both technologies that were cost efficient while at the same time providing sufficient information to the driver.

4.3 Ideas Discarded

Due to the large amount of generated concepts, there was a need to discard some concepts that were not suitable for further development within the thesis. This was done on the basis that the concepts needed to be realizable by Volvo in the foreseeable future and kept within a reasonable cost (cost aspects were evaluated at a later stage, see chapter 7.3).

Concepts of a more science fiction nature where thus discarded during the negative brain storming. Three examples of concepts discarded were:

- **Radar image** – Radar sensors mounted around the vehicle in order to provide a detailed real-time image of the area surrounding the vehicle similar to that of a ship's radar.
- **Apache style helmet cam** – A concept inspired by Apache helicopters, where the driver wore a helmet with a visir with a Head Up Display showing an image from cameras around the vehicle. When the driver moved his head, the image automatically changed to cameras viewing in that direction.
- **Remote controlled helicopter camera** – A concept where a remote controlled helicopter drone hovered above the vehicle while also carrying a camera that provided a combined view of the freight terminal and the vehicle, thus creating a bird's eye view of the surroundings.

4.4 Collective Brain Storming in Umeå

During the visit to Oryx simulations in Umeå (before the Driving Simulator Test I described in chapter 5.3), a collective brain storming session was held together with experts from different areas at Volvo 3P, Umeå Institute of Design and Oryx Simulations. All concepts that had been developed from the previous brain storming sessions were brought to the meeting to make up the baseline from which new concepts could be developed.

However, no new concepts resulted from the Collective brain storming session as such, but some variations emerged, which could be seen as a confirmation that the previous 14 brain storming sessions had been sufficiently thorough. However, a number of comments of a technical nature were taken into consideration.

The lack of new concepts could possibly be the result of participants having too niched knowledge in their respective field and that concepts mostly generated around one particular area of knowledge. To produce holistic concepts, the need for cross-disciplinary analysis was much greater as well as a thorough understanding of the complete picture as to what user needs needed to be considered.

4.5 Technical Descriptions of Concepts

Below is a list of the concepts that were the result of the concept generation. Some are concepts that are similar to products on the market, while others combine different existing products and make unique configurations, or represent completely new ideas.

The list of concepts does not show the concepts that were to be further developed by the Volvo Group, including the five concepts that later on were considered for patent application.

4.5.1 Camera Systems

One-camera-system on semitrailer

Technical Description: "One-camera-system on semitrailer" consists of a camera with a horizontal viewing angle of 80 degrees, mounted on the rear end of the semitrailer. On a container chassis, the camera needs to be mounted about the height of the rear lights, but with other vehicles the camera could be mounted at a more favorable position higher up. The camera lens is equivalent to a 20mm lens, which gives an image that is relatively undistorted and presents an image that is easily understood. Inside the cab, a display shows the camera image to the driver as an aid for maneuvering. On the display, guidelines in the image could show distances rearwards from the vehicle and an extension of where the sides of the vehicle are.

Functional Description: The one-camera system on the semitrailer is an existing concept that is used for reference. It provides additional vision and has a viewing angle that is familiar to drivers, due to the fact that it has been out on the market for several years.

Visualization Sketch:

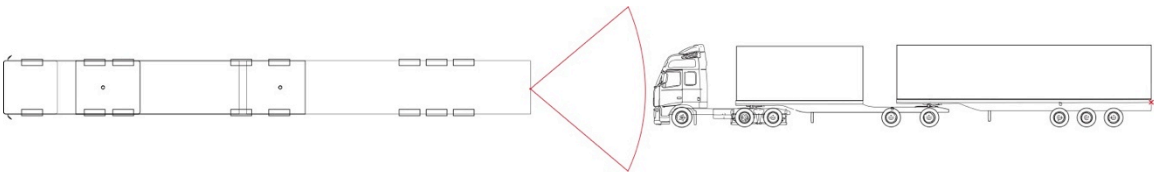

Fig. 32 One-camera-system on semitrailer

One-camera-system underneath lead trailer

Technical Description: "One-camera-system underneath lead trailer" consists of a camera with a horizontal viewing angle of 80 degrees that is mounted centrally underneath the lead trailer, at its rear end. The camera is housed in a protective shell that covers the camera from stone chips and dirt. The camera gives an indication of the angle between lead trailer and semitrailer, as well as providing vision in blind spots when the vehicle is angled in a bend.

Functional Description: The camera mounted underneath the lead trailer is most functional when the vehicle is turning and the camera shows the ground beside instead of underneath the semitrailer. It could be used to provide vision in blind spots while reversing as well as when driving forward, and to some extent also as an implicit maneuvering aid showing the articulation between the lead trailer and the semitrailer.

Visualization Sketch:

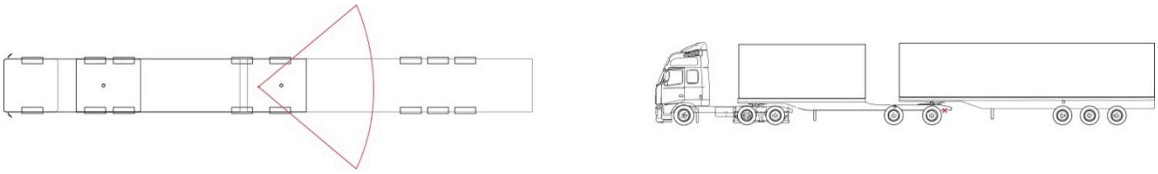

Fig. 33 One-camera-system underneath lead trailer

One-camera-system on tractor

Technical Description: "One-camera-system on tractor" consists of a camera with 80 degrees horizontal viewing angle that is mounted at the rear end of the tractor. The mounting is centered on the tractor, and the image is displayed on a screen inside the cab.

Functional Description: The one-camera system on the tractor is an existing concept that is used for reference. It provides vision in blind spots while reversing with the tractor and facilitates the coupling maneuver, but has limited use when used in other maneuvers as well as when a semitrailer or a lead trailer is connected.

Visualization Sketch:

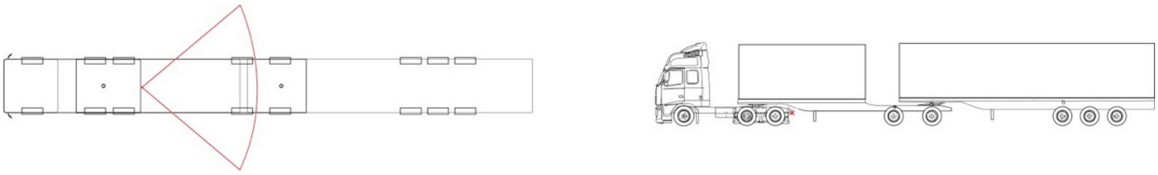

Fig. 34 One-camera-system on tractor

Two-camera-system on lead trailer

Technical Description: "Two-camera-system on lead trailer" consists of two cameras with a horizontal viewing angle of 80 degrees that are mounted at each side of the lead trailer, close to the front of the sides. The cameras are angled slightly outwards, giving a camera view that shows a part of the lead trailer at the edge of each image, so as to aid orientation. Inside the cab, a display shows the two camera views simultaneously on a wide screen that shows the left side camera view on the left side and the right side camera view on the right side. The image is naturally divided by the static side of the images that shows the lead trailer, which stands in contrast to the moving surroundings that are displayed on the edges of the image.

Functional Description: Two-camera-system on lead trailer provides vision in blind spots while reversing and driving forward. It would be particularly useful for vision in the area exposed to corner cutting by the road train, when the rear end of the semitrailer disappears from the scope of the rear view mirrors. The further out from the sides of the lead trailer that the cameras get, while still staying within legislative limits, the better vision they can provide. However, the risk for damage increases at the same time.

Visualization Sketch:

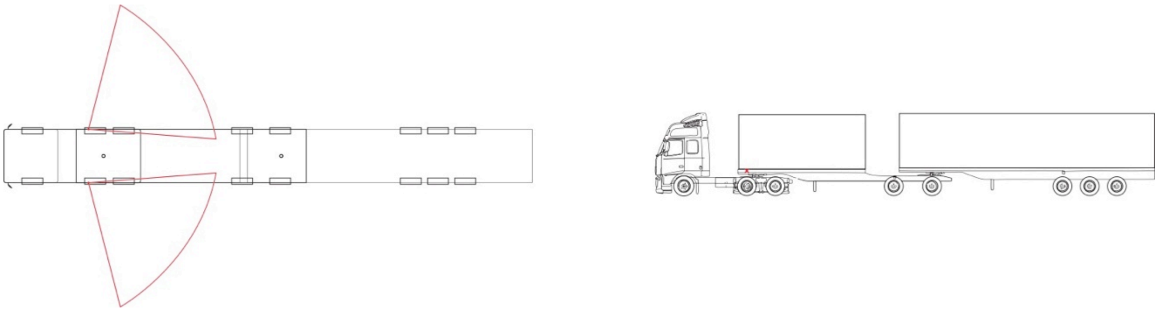

Fig. 35 Two-camera-system on lead trailer

Moving right side camera on tractor

Technical Description: "Moving right side camera on tractor" is a concept that consists of a camera that is mounted on the right side of the truck. The camera has a horizontal viewing angle of 80 degrees and is mounted on a motor that takes input from sensors that track the point that is furthest back on the vehicle combination. This needs to be differentiated between the event when the vehicle has one trailer (for example only the lead trailer or only the semitrailer) and when it has two (for example dolly and semitrailer or lead trailer and semitrailer). The motor on the camera adjusts the camera angle so that it always includes the point of the vehicle that is furthest back.

Functional Description: The moving right side camera on the tractor works as a regular rearward facing camera, with the added benefit that it continuously provides a relevant camera image as the vehicle is turning. This is most useful when making a right turn with the road train, which is the direction that is associated with the largest blind spots and that the driver has least control over, being on the far side of a left hand steered vehicle.

Visualization Sketch:

Fig. 36 Moving right side camera on tractor

Three-camera-system (Semitrailer)

Technical Description: "Three-camera-system (Semitrailer)" is a concept that consists of three cameras mounted on the semitrailer. One camera is mounted on the rear end facing straight backwards and the other two cameras are mounted on the front end of either side, facing rearward but angled slightly outward (while still including a part of the side of the semitrailer in the camera view). All cameras have a horizontal viewing angle of 80 degrees. Inside the cab, a monitor with a split screen shows all three camera views simultaneously, with the option of manually choosing one camera at a time to cover the full screen.

Functional Description: The three-camera-system mounted on a semitrailer provides vision in blind spots during reversing and while driving forward. While the cameras provide vision on all exposed sides of the semitrailer, the information needs to be presented in an understandable way to the driver. Provided this, the three-camera-system can be used for avoiding collisions during low-speed maneuvering. Mounting the cameras as far out from the semitrailer sides as legislation permits can improve the field of vision even further.

Visualization Sketch:

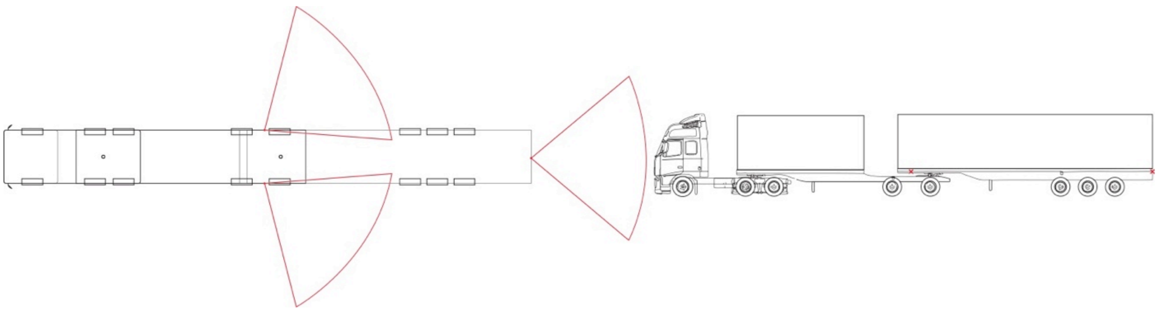

Fig. 37 Three-Camera-system (Semitrailer)

Three-camera-system with rear and front view (Semitrailer)

Technical Description: "Three-camera-system with rear and front view (Semitrailer)" is a concept that consists of three cameras mounted on the semitrailer. One camera is mounted on the rear end facing straight backwards and the other two cameras are mounted on the rear part end of either side of the chassis or cargo body, facing forwards but angled slightly outward (while still including a part of the semitrailer in the camera view). All cameras have a horizontal viewing angle of 80 degrees. Inside the cab, a monitor with a split screen shows all three camera views simultaneously, with the option of manually choosing one camera at a time to cover the full screen.

Functional Description: Three-camera-system with rear and front view mounted on a semitrailer provides vision in blind spots during reversing and while driving forward. While the cameras provide vision on all exposed sides of the semitrailer, the information needs to be presented in an understandable way to the driver. Provided this, the three-camera-system can be used for avoiding collisions during low-speed maneuvering, both while reversing and driving forward.

Visualization Sketch:

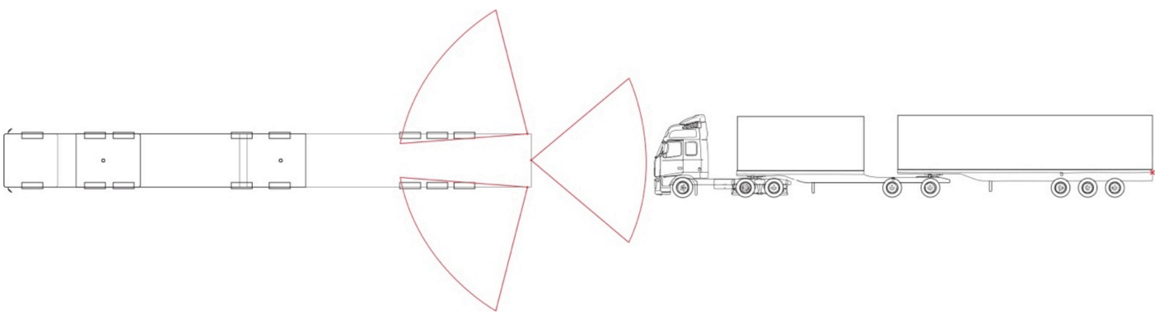

Fig. 38 Three-camera-system with rear and front view (semitrailer)

Three-camera-system (Lead trailer + Semitrailer)

Technical Description: "Three-camera-system (Lead trailer + Semitrailer)" is a concept that consists of three cameras. One camera is mounted on the rear end of the semitrailer, facing straight backwards, and the other two cameras are mounted on the front end of either side of the lead trailer. The cameras on the sides of the lead trailer are angled slightly outward (while still including a part of the lead trailer and the semitrailer in the camera view). All cameras have a horizontal viewing angle of 80 degrees. Inside the cab, a monitor with a split screen shows all camera views simultaneously, with the option of choosing one camera at a time to cover the full screen.

Functional Description: The three-camera-system that is mounted on the sides of the lead trailer and the rear end of the semitrailer provides vision in blind spots during reversing and while driving forward. The benefit of having cameras mounted on the lead trailer is that it provides a larger field of vision, on both the sides of the lead trailer, semitrailer and behind the vehicle. The drawback is that an articulated vehicle quickly would produce its own blind spots.

Visualization Sketch:

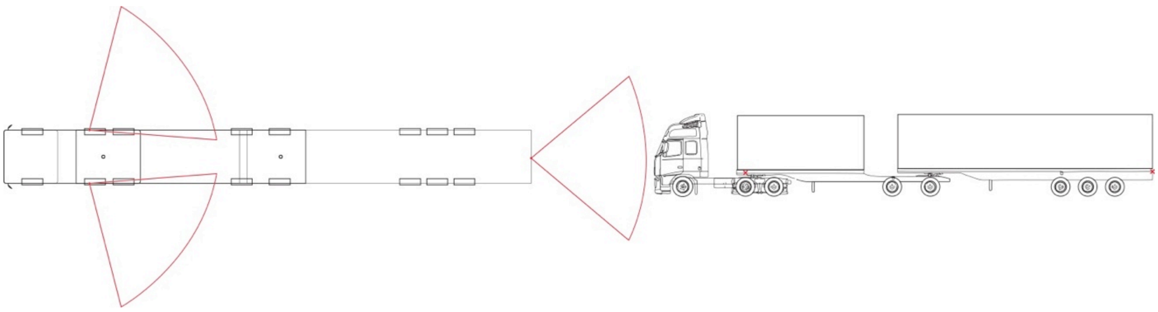

Fig. 39 Three-camera-system (Lead trailer + Semitrailer)

Five-camera-system

Technical Description: "Five-camera-system" consists of five cameras that are mounted on the vehicle. One camera is mounted on the rear end of the semitrailer, two cameras are mounted on the front end of either side of the semitrailer and two cameras are mounted on the front end of either side of the lead trailer. The camera on the rear of the semitrailer is facing straight backwards, while the other cameras are facing backwards, but are angled slightly outward (while still including part of the semitrailer in the camera view). All cameras have a horizontal viewing angle of 80 degrees. Inside the cab, a monitor with a split screen shows all camera views simultaneously, with the option of showing a reduced number of three camera views or one camera at a time to cover the full screen.

Functional Description: The Five-camera-system provides all-round vision on the parts of the road train that is behind the tractor. The information needs to be presented in an understandable, albeit functional way despite being constructed by as many as five camera views. Provided this, the five-camera-system could be used to avoid collisions during low-speed maneuvering, without having the problem of the vehicle generating blind spots of its own. Automatic selection of views according to driving circumstances could also be used.

Visualization Sketch:

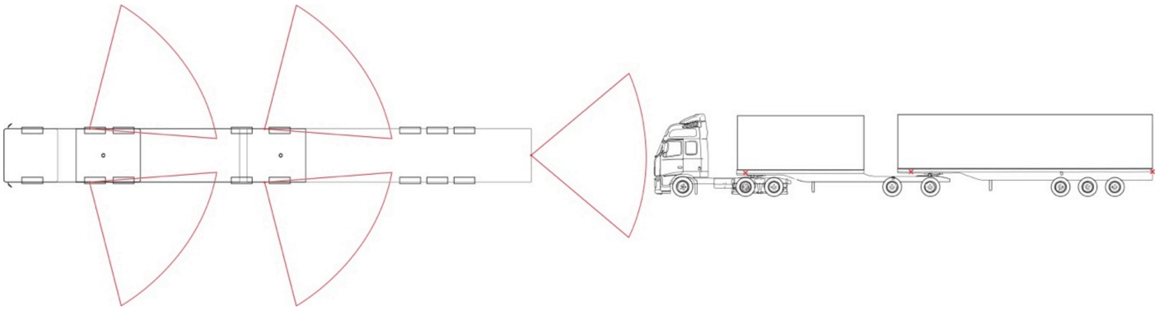

Fig. 40 Five-camera-system

4.5.2 Sensor Array Systems

Rear blind spot detector with automatic braking

Technical Description: "Rear blind spot detector with automatic braking" consists of several ultra sound sensors that are mounted on the rear end of the semitrailer. They are mounted in a line with equal distance apart, at similar height as the rear lights. Inside the cab, a display shows which of the ultrasonic sensors that detect an object and at what distance, giving a possibility of discriminating between smaller objects and larger objects depending on how many of the ultrasonic sensors that are activated. An automatic braking system is activated at a pre-defined distance between the rear of the semitrailer and the object in question.

Functional Description: The rear blind spot detector with automatic braking is a concept that is available on the market that is used for reference. It provides detection of objects and accurate distance measurements to them by using ultra sound sensors that give information to the driver via a simple interface in the cab. Warning lights give information in three stages depending on how close the object is to each sensor. At a distance defined by the driver, the vehicle then automatically brakes to avoid a collision, while still being close enough to allow loading and unloading at a loading dock. The automatic braking could also depend on the relative speed between vehicle and object.

Visualization Sketch:

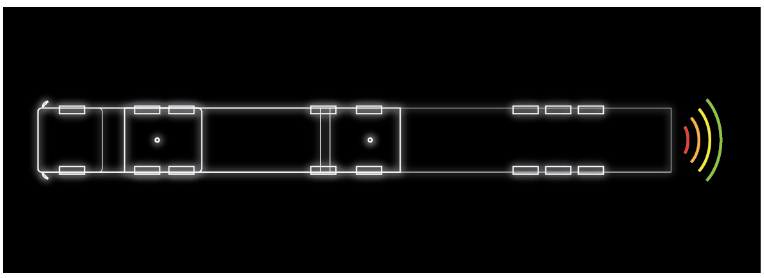

Fig. 41 Rear blind spot detector with automatic braking

Rear blind spot detector with warning indicator

Technical Description: "Rear blind spot detector with warning indicator" consists of the same sensor equipment as "Rear blind spot detector with automatic braking". Inside the cab, a similar display shows which of the sensors that detect an object and at what distance, which gives the same ability to discriminate between objects of different sizes and distances. Warning indicators with either light, sound or both are used instead of an automatic braking system, to indicate different pre-defined distances. There could be different signals depending on distance, for example increased intensity and/or frequency when the semitrailer is coming closer to an object, and different signals if one or more of the sensors are indicating an object.

Functional Description: The rear blind spot detector with warning indicator is an on the market available concept that is used for reference. It provides detection of objects using ultrasonic sensors that give information to the driver via a simple interface in the cab. Warning lights give information about how close the object is to the sensor(s).

Visualization Sketch:

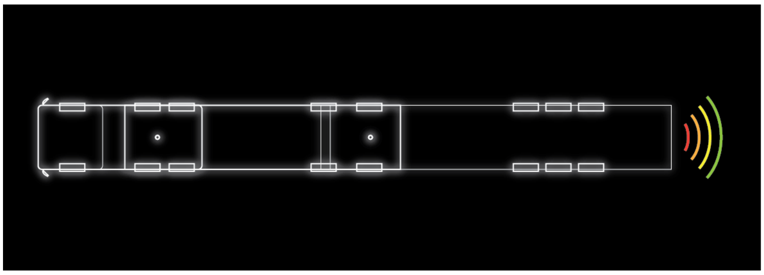

Fig. 42 Rear blind spot detector with warning indicator

Range meters mounted on loading dock

Technical Description: "Range meter mounted on loading dock" consists of range meters mounted on a loading dock, using laser, infrared light, ultrasonic sensors or an optical system with a software that analyzes camera images. When a truck or a trailer is reversing towards a loading dock, a visual display on the wall shows the distance so the driver is given the choice of adjusting his speed and brake before hitting the loading dock. This could be displayed in several ways, for example by using color displays like traffic lights, a numerical digital display showing the distance or a number of lights that are turned on as the vehicle approaches.

Functional Description: Range meters mounted on the loading dock is a concept that is available on the market that is used for reference. The main function is avoiding collision damage that occurs when the rear end of a trailer hit a loading dock.

Range meters around the vehicle

Technical Description: "Range meters around the vehicle" consists of ultrasonic range meters that are mounted around the vehicle. The sensors are placed at about the height of one meter with equal spacing in between, giving an all-round coverage of the vehicle boundaries. Translating the information to the driver, an interface is mounted in the cab which graphically displays the signals from the sensors.

Functional Description: Range meters mounted around the vehicle are used for determining distances between the vehicle and objects in the vicinity of the vehicle. The main function is avoiding collision damage that could occur at any part of the vehicle, with the same distribution of sensors around the vehicle. The concept is used for providing a form of indirect observation in the blind spots around the vehicle both while reversing and driving forward.

Visualization Sketch:

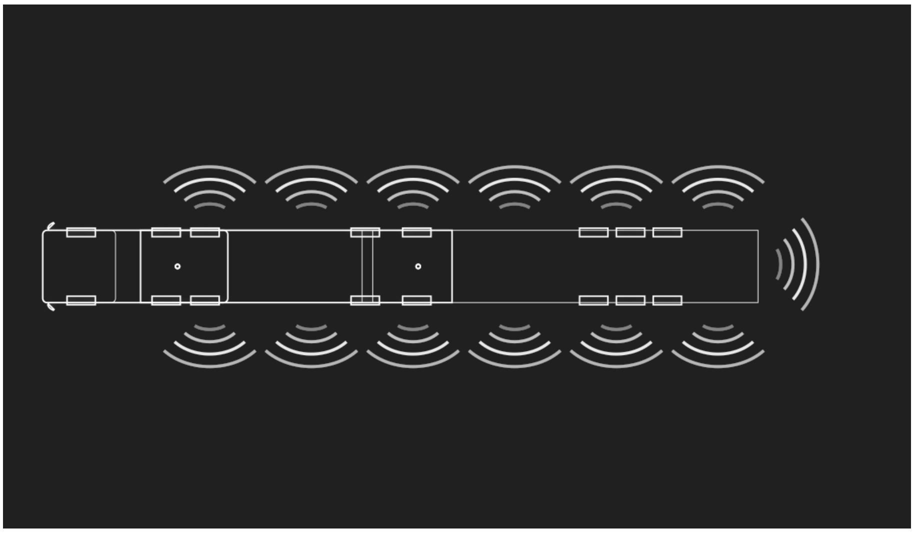

Fig. 43 Range meters around the vehicle

4.5.3 Lighting Systems

Reversing lamps on semitrailer

Technical Description: "Reversing lamps on semitrailer" consists of several lamps on the rear end of the semitrailer that is facing rearward and slightly outward. When the driver activates reverse, the lamps are turned on.

Functional Description: The reversing lamps mounted on the semitrailer are activated when the vehicle is reversing in bad light conditions. It provides light support to the rear of the road train, but does not in itself give any additional fields of vision than is provided by the rearview mirrors.

Side reversing lamps on semitrailer

Technical Description: "Side reversing lamps on semitrailer" consist of one lamp on either side of the semitrailer that is facing rearward and slightly outward in an oblique angle from the side of the semitrailer. When the driver puts gear in reverse, the lamps are turned on.

Functional Description: The side reversing lamps mounted on the semitrailer are activated when the vehicle is reversing in bad light conditions. It provides light support mostly on the sides of the semitrailer but also to the rear of it, but the concept does not give any additional fields of vision than is provided by the rearview mirrors.

Side reversing lamps on lead trailer

Technical Description: "Side reversing lamps on lead trailer" consist of one lamp on either side of the lead trailer, facing backwards and angled slightly outward, from the side of the lead trailer. When the driver puts gear in reverse, the lamps are turned on.

Functional Description: The side reversing lamps mounted on the lead trailer are activated when the vehicle is reversing in bad light conditions. It provides light support mostly on the sides of the lead trailer but also to the sides of the semitrailer and to the rear of it, but the concept does not give any additional fields of vision than is provided by the mirrors.

4.5.4 Drive Systems

Command steer axles on semitrailer and/or lead trailer

Technical Description: "Command steer axles on semitrailer and/or lead trailer" consists of command steer axles, i.e. axles that respond to the steering wheel movements, which give a reduced inner radius of the entire vehicle combination when turning. They can be mounted on either the semitrailer or the lead trailer, or both. Command steer axles work both when the vehicle is driving forwards and when it is reversing.

Functional Description: The command steer axles work to improve the turning radius of the road train and are used in all low speed maneuvering (both forward and reverse). While not providing any maneuvering aid, the track of the whole road train to a greater degree follows the track of the tractor, making the path more predictable and minimizing the problems of corner cutting. The steering axles could also be used at higher speeds for improving stability, using a different control algorithm.

Self-steer axles on semitrailer and/or lead trailer

Technical Description: "Self-steer axles on semitrailer and/or lead trailer" consists of self-steer axles that are not fixed like regular axles, but are allowed to turn when the vehicle is turning. They can be mounted on either the semitrailer or the lead trailer, or both. Self-steer axles only work to increase the inner radius when the vehicle is turning and driving forwards.

Functional Description: The self-steer axles work to improve the turning radius of the road train when the vehicle is driving forward. While not providing any maneuvering aid, the track of the whole road train to a greater degree follows the track of the tractor, making the path more predictable and minimizing the problems of corner cutting.

4.5.5 Other Concepts

Ranging mode for side mirrors

Technical Description: "Ranging mode for side mirrors" consists of side mirrors that are controlled by electrical motors. When the driver changes to reverse, the side mirrors are turned outward to a pre-defined angle that is set by the driver. When the vehicle is driving forwards more than 15 km/h the mirrors are changed back to their original positions.

Functional Description: The concept provides a way of changing the angle of the mirrors automatically, thereby providing a wider field of vision. At the same time, a similar amount of vision is lost closer to the vehicle sides and as a whole the concept does not provide any increased total amount of vision for any given moment. It is a concept that already exists on the market, and is included for reference.

Rearward facing light corridor

Technical Description: "Rearward facing light corridor" consists of two lamps that are mounted on the rear corners of the semitrailer. Each lamp projects a thin corridor of light on the ground rearwards from the semitrailer, showing the direction of the semitrailer as well as the continuation of the sides.

Functional Description: The concept is an implicit maneuvering aid that is somewhat restricted, in the sense that it works in light conditions where the driver can still be able to view the light corridor using the rearview mirrors. It could also be additionally restricted by heavy downpour or fog, but during the time the light corridor is lit up, the concept also provides a passive warning to people behind the vehicle that it is reversing. It works in the way that it provides the driver with straight lines on the ground to use as reference in relation to other objects. It is especially useful at freight terminals where no lines are painted on the ground.

Side facing light projection

Technical Description: "Side facing light projection" consists of two lamps that are mounted on the rear corners of the semitrailer, perpendicular to the sides. Each lamp projects a thin corridor of light on the ground showing a perpendicular line in relation to the semitrailer, thus indicating the rear edge of the semitrailer.

Functional Description: The concept is an implicit maneuvering aid that is somewhat restricted, in the sense that it works in light conditions where the driver can still be able to view the light corridor using the rearview mirrors. It could also be restricted by heavy downpour or fog, but during the time the light corridor is lit up, the concept also provides a passive warning to people behind the vehicle that it is reversing. Since the light projection is facing sideways, the concept could possibly be better suited for communicating intent with unprotected road users that are standing to the sides of the semitrailer. It works in the way that it provides the driver with straight lines on the ground to use as reference in relation to other objects. It is especially useful at freight terminals where no lines are painted on the ground.

Less aggressive, additional horn

Technical Description: A second horn with a less intimidating sound that can be used to alert road users around the truck without causing so much alarm as with the regular horn. The additional horn could be used when moving away from standstill, or when there are a lot of unprotected road users around the truck that might not take notice of the truck. The sound of the additional horn should be of a lower noise level than the ordinary horn and with a higher frequency, which is perceived as less aggressive. The sound should if feasible be provided by loudspeakers all around the vehicle combination.

Functional Description: The less aggressive horn could be a second horn that could be used in situations where the driver wants attention, but not alarm. It is a passive safety device that is dependent on the driver for both awareness of a problem and the decision to use the additional horn. If provided by loudspeakers all around the vehicle combination, the volume could be even further reduced as the sound will have an optimum direction and be closer to the road users being warned.

Terminal mounted optical docking system

Technical Description: The terminal mounted docking system works like a lighthouse in the sense that light is emitted from one point at the terminal and depending on where the user is positioned with his truck, the light level changes to indicate certain information about the positioning. It could work with different colors or with different light pulses. For example, there could be a corridor of steady light in the center to indicate that the truck is reversing in a correct path towards the gate, but if the truck veers too much off course, the truck could enter a corridor of pulsing light, which could also be different for either side.

Functional Description: The concept is restricted in the sense that it does not provide any additional vision. It works only as an implicit maneuvering aid at a certain place, which would be best suited for a transport company that frequently visits the same terminals, for example during transports of general cargo. It is implicit in the way that it only shows the driver which way he should move, but not how that correlates to steering wheel revolutions.

Range probes

Technical Description: “Range probes” consists of flexible rubber probes that are mounted on the rear end of the semitrailer. The probes lie in a protective housing when the vehicle is driving forward. When the vehicle is reversing, the driver can activate the range probes which will make them extend to a distance of some decimeters behind the vehicle. If the vehicle touches an object, the probes give a signal inside the cab, which will give the driver time to stop the vehicle before hitting the object behind the vehicle.

Functional Description: The range probes are used to measure the distance to objects primarily behind the vehicle. The rubber probes ensure that the signals are not triggered by soft objects like plants or small bushes, and only by hard objects that are vital to avoid. To avoid that the probes' functionality is too dependent on individual loading dock design, it could also be necessary to extend them vertically so as to warn for protruding edges or bars.

4.6 Classified Concepts

Following a decision by Volvo 3P, a number of concepts were classified in order to be further developed within Volvo. When describing the methods and results in the report, these concepts were mentioned in terms of abbreviations so as not to reveal the technical nature of the concepts.

The descriptions of these concepts are intended to give a general idea of the concept technology in order to facilitate understanding of the development process. They are not intended to be fully understandable, in order to keep them under patent secrecy, and the descriptions are intentionally vague.

4.6.1 Camera Concepts

C1

C1 is a camera concept based on the existing Volvo "Bird's eye view". It consists of cameras mounted on all sides of the vehicle to provide an all-round view. The images are then combined by software to produce a single image to the driver that is easily understandable and with minimized distortions and disturbances. The combined camera image is presented to the driver in the cab, on a display that is mounted in a position favorable to the driver.

C2

C2 is a camera concept that utilizes a camera mounted in an optimal location on the vehicle with an adaptive functionality that relates to the maneuvering of the vehicle. The camera lens has a horizontal viewing angle of 80 degrees which provides distortion free images, while also giving the driver an overall picture in the camera direction. The image is presented to the driver in the cab, on a display mounted in a position favorable to the driver, where the driver also has the possibility of controlling the functionality of the camera.

C3

C3 is a camera concept that utilizes a camera mounted in an optimal location. The camera lens has a horizontal viewing angle of 80 degrees which provides distortion free images, while also giving the driver an overall picture in the camera direction. The image is presented to the driver in the cab, on a display mounted in a position favorable to the driver.

4.6.2 Prediction Concepts

P1

P1 is a prediction concept that provides a graphical display of the vehicle's future path. The concept utilizes a camera mounted on the vehicle with a display in the cab. The graphical representation of the path of the vehicle is overlaid onto the camera image, providing the driver with both real-time information about the area surrounding the vehicle and a visual guide for the future movements of the vehicle.

P2

P2 is a prediction concept that provides a graphical display of the future path of the vehicle. The concept utilizes a camera mounted on the vehicle with a display in the cab. The graphical representation of the path of the vehicle is overlaid onto the camera image, providing the driver with both real-time information about the area surrounding the vehicle and a visual guide for the future movements of the vehicle. The P2 differs from P1 in that it provides additional information to the driver that is intended to improve efficiency, safety and reduce the time needed to reverse the road train at a freight terminal.

P3

P3 is a prediction concept that provides a graphical display of the future path of the vehicle. The concept utilizes a camera mounted on the vehicle with a display in the cab. The graphical representation of the path of the vehicle is overlaid onto the camera image, providing the driver with both real-time information about the area surrounding the vehicle and a visual guide for the future movements of the vehicle. The P3 differs from P1 in that it provides additional computer assistance to the driver that is intended to improve efficiency, safety and reduce the time needed to reverse the road train at a freight terminal.

P4

P4 is a prediction concept that provides a graphical display of the future path of the vehicle. The concept utilizes a camera mounted on the vehicle with a display in the cab. The graphical representation of the path of the vehicle is overlaid onto the camera image, providing the driver with both real-time information about the area surrounding the vehicle and a visual guide of the vehicle's future movements. The P4 differs from P1 in that it provides additional computer assistance as well as visual information to the driver that is intended to improve efficiency, safety and reduce the time needed to reverse the road train at a freight terminal.

P5

P5 is a prediction concept that provides a graphical display of the future path of the vehicle. The concept utilizes a camera mounted on the vehicle with a display in the cab. The graphical representation of the vehicle's path is overlaid onto the camera image, providing the driver with both real-time information about the area surrounding the vehicle and a visual guide of the vehicle's future movements. The P5 concept differs from the P1 concept in that the camera image has been digitally improved by computer software prior to it being displayed to the driver.

4.6.3 Automation Concepts

A1

A1 is a concept that utilizes a second interface that the driver uses for controlling the vehicle during low speed maneuvering. It provides a different viewing angle, but does not aid in the maneuvering itself. The design of the interface could be made to better suit maneuvering at a freight terminal.

A2

A2 is a concept that utilizes a mechanical solution on the semitrailer as well as a second interface that the driver uses for controlling the vehicle. It provides the driver with additional viewing angles, but does not aid in the maneuvering of the vehicle.

A3

A3 is a concept that utilizes a mechanical solution on the semitrailer in combination with a camera mounted on the vehicle. The driver uses the camera to spot obstacles in close proximity to the vehicle, with the additional aid of graphical displays of distances in the camera display.

4.6.4 Other Concepts

O1

O1 is a concept that is used for maneuvering the tractor or lead trailer to a semitrailer and docking the fifth wheel to the kingpin of the semitrailer. The concept does not provide any maneuvering aid in other situations.

O2

O2 is a safety concept used to warn unprotected road users of an approaching road train. The O2 concept warns the unprotected road users in the most hazardous situations when most corner cutting and blind spots occur, for example in a sharp right turn. It does not provide any maneuvering aid for the driver.

O3

O3 is a safety concept used to warn unprotected road users of an approaching road train. The O2 concept warns the unprotected road users when the road train is making a sharp turn, allowing them to move out of harm. It does not provide any maneuvering aid for the driver.

O4

O4 is a safety concept used to avoid collisions with hard objects on a freight terminal or other areas where low speed maneuvering takes place. It does not include any maneuvering aid for reversing the vehicle.

O5

O5 is a navigation concept using GPS technology to track the vehicle on a map. It does not provide any aid for maneuvering the vehicle.

O6

O6 is a navigation concept using GPS technology to track the vehicle on a map. In addition, it provides an implicit maneuvering aid for the driver, which the driver can utilize to maneuver the vehicle to a known spot on the map.

5. Concept evaluation 1

5.1 Design of New Evaluation Method

The complex reality encountered during the pre-study called for a new evaluation method that could present a balanced picture of a heterogeneous market. The matrix evaluations sought firstly to evaluate the different needs expressed by different groups on the market and weigh them according to their market share. Secondly, this would be used to evaluate the concepts in another matrix where the concepts were rated according to the degree by which they fulfilled the different needs of the market participants. Thirdly, the concepts could be rated according to their market potential and a list would be derived that showed the different concepts according to their overall utility.

These three steps in the evaluation method were described in detail in chapter 2.2.5, 2.4.1 and 2.4.2 respectively.

5.1.1 The Need Matrix

The need matrix was based on the problems identified in the pre study (see chapter 3.8).

The frequency of the different transport types was presented as the market share in percent of the Swedish B-train market divided in sections of ten percent each. The timber transports, which had a market share of less than ten percent, still received ten percent as this was the smallest quote used. In addition to this, it was considered reasonable since their market share was expected to increase in the near future with an expanded study in the ST-project (see chapter 3.1.1). The percent of container transports and general cargo transports that used B-trains were estimated from observations and interviews. The following market share percentages were used for the need matrix:

- Timber transports 10%
- Container transports 50%
- General goods transports 40%

5.1.2 Estimates of Need Matrix Value

Before the first driving simulator test, the number of drivers interviewed was not sufficient to draw any conclusions regarding the evaluation of the different needs. In order to determine which concepts should be evaluated at Oryx Simulations, estimates were made for the need matrix to give a preliminary choice of concepts. The values (see fig. 44) were based on experiences and observations, as well as information that had been gathered through interviews.

	Timber	Container	General goods
Time reduction	0	0.25	0.25
Vision/reversing	1	3.25	2.75
Vision/driving forward	1.5	3.25	3
Maneuverability	2	1.5	1
Determine accessibility	3	2	1
Vision in bad light	2	4	4
Communicate/unprotected	1	3	3
Communicate/other vehicles	2	2	2
Reduction of wear and tear	1	2	2
Judgment of distance	1	2	2,5

Fig. 44 The estimated values used in the need matrix

COMMENTS ON THE ESTIMATED NEED MATRIX VALUES:

- Time reduction was given a zero for timber transports. This was due to the fact that there was a big time margin for loading and unloading which would not have been affected by faster reversing maneuvers. For container and general goods transports, the values were 0,25, due to the fact that container transports had other, more severe time delays and general cargo used longer transport routes, where the reversing was only a small part of the total time spent.
- Differences between timber transports and the other user groups regarding vision and judgment of distance resulted from the fact that timber transports had more space for maneuvering and only rarely came in contact with unprotected road users.
- Vision in bad light conditions scored lower for the timber transports than the other user groups due to the fact that the vehicles used in the forest already were equipped with extra lights.

5.1.3 The Complete Need Matrix

The complete need matrix was based on interviews and questionnaires as described in chapter 2.5.2. In total 23 persons responded in either a questionnaire or took part in a structured interview, and the results can be found in fig. 45 below. For a more detailed description of the design of the need matrix, see chapter 2.2.5.

Need	Timber	Container	General goods	Sum
Time reduction	0	1	1	0.9
Vision/reversing	2.5	3	3.6	3.2
Vision/driving forward	3	3.5	3	3.4
Maneuverability	2	2	1.9	2
Determine accessibility	3	0	1.3	0.8
Vision in bad light	2	4	1.8	2.9
Communicate/unprotected	1	4	2.9	3.3
Communicate/other vehicles	2	3.5	1.9	2.7
Reduction of wear and tear	2.5	2.5	2	2.3
Judgment of distance	1	1.5	1.2	1.3
Frequency	0.1	0.5	0.4	

Fig. 45 The complete need matrix with all the needs graded on a scale from 0 to 4.

COMMENTS ON THE COMPLETE NEED MATRIX VALUES:

- The sum in the rightmost column in the need matrix takes into account the rating of each need for each market segment and their respective frequency on the market. This gives a total sum for each need representing its total rating on the market.
- The two highest scoring needs were better vision while driving forward and reversing.
- Communication with other road users also scored high in the need matrix, together with vision in bad light conditions.
- The lowest graded need was time reduction.
- Overall the complete need matrix' values corresponded well with the values from the estimated need matrix, even though some individual differences could be noted. For example vision in bad light conditions for general goods transports were not graded as high as expected. This was due to the fact that those transports usually had better reversing lights than container transports and more frequently visited larger terminals with better lights.

5.1.4 The Concept Evaluation Matrix

The concept evaluation matrix can be found in its entirety in Appendix G.

5.1.4.1 Scoring the Concepts

The concepts were scored according to how a need was fulfilled, as described in chapter 3.8.1-3.8.10, but each of the different transport categories had a number of unique features that required special screening before a score could be given. Concepts that utilized the cargo body could not be implemented in its original form on a container transport, where there were no fixed cargo bodies, only containers that were changed for each transport. The same was the case for timber transports that had no cargo body at all.

The following differences between the transport categories resulted in changed scores for the concepts:

- Timber transports never frequented freight terminals. Any concept that was restricted to this location was scored zero for timber transports.
- Container transports only frequented freight terminals when delivering the cargo to the customer and not during loading and unloading of containers. Any concept that was restricted to freight terminals had its score multiplied by 0.5.
- Timber transports and container transports had no fixed cargo bodies on the trailers – i.e. the logs and containers were removed completely when unloading. Concepts that were dependent on a fixture above the height of the chassis were divided into two sections regarding these transport categories. If it would be impossible to change the fixtures to adapt the concept, it would result in a zero. If it was possible to adapt the concept with loss of function to some degree, the score of the concept was multiplied by 0.5.
- For concepts that utilized non-optical sensors, concept scores were multiplied by 0.5 for timber transports. This was due to the fact that timber transports often used forest roads where a multitude of objects were present in close vicinity of the moving road

train. Some objects were hard and associated with a risk of damage when colliding with them, while others were soft and did not present any risk to the vehicle and non-optical sensors would not know the difference, thus resulting in a number of false signals. There would also be an increased risk of damaged sensors, or sensors that were moved out of place.

5.1.4.2 Results of Concept Evaluation Matrix

The result from the concept evaluation matrix was a rating for all concepts regarding how well they fulfilled the needs. The result in itself did not take into account how important each need was, which meant that a comparison between the concepts based solely on their scores from the concept evaluation matrix did not make up a useful result. Instead the need-weave matrix had to be used to weigh in the value of each need.

5.1.5 The Need-Weave Matrix

The need-weave matrix was the final evaluation matrix combining the results from the need matrix and the concept evaluation matrix. The need weave-matrix can be found in its entirety in appendix H.

5.1.5.1 Results of Need-Weave Matrix

The result from the need-weave matrix was a list of all concepts with a rating mirroring how well they would fulfill the users' needs on the market. It took into account needs in different market segments, different ratings for each respective need and all the different ways to fulfill a need. By doing this it made it possible to compare different concepts of very different nature in the same matrix.

The following ten concepts were found to be the best, i.e. the ones that fulfilled the users' needs to the greatest extent. Their score in the second column reflected how well they met the complete needs of the users. For reference an "Ultimate Concept" was included that was given the maximum score in all the matrices. In that way it was possible to get an indication as to what extent any concept fulfilled the complete needs.

Concept	**Score**
1. Ultimate Concept	**340.05**
2. Three-camera-system with rear and front view	**83.58**
3. C1	**74.98**
4. P2	**71.86**
5. Three-camera-system (Semitrailer)	**65.71**
6. A3	**59.00**
7. P1	**56.75**
8. Five-camera-system (lead trailer + semitrailer)	**50.21**
9. Range meters around the vehicle	**43.59**
10. Three-camera-system (lead trailer + semitrailer)	**41.67**

Fig. 46 The ten concepts with highest score, including the Ultimate concept

A cut was made after these first 11 (12 including the Ultimate Concept) because there it was a significant drop in rating to the next concept.

In general it could be said that two types of concepts scored high in the need weave matrix: vision aids and explicit maneuvering aids. It could also be seen that none of the concepts by themselves were close to the ultimate concept, e.g. close to fulfilling all the users' needs. A combination of different concepts could however quite easily approach that score, but that specific combination of concepts would then be needed to be scored in the concept evaluation matrix.

5.2 Concepts Chosen for Driving Simulator Evaluation

The following three concepts were chosen to be tested in Driving simulator test I:

- One-camera system on semitrailer (See chapter 4.6.1)
- C1 (See chapter 4.7.1)
- P1 (See chapter 4.7.2)

These concepts were chosen on the basis that they scored among the highest in the need-weave matrix, while still being possible to implement by Oryx Simulations within the timeframe. The number of concepts tested was kept low because the first simulator test was a combined study of the capabilities of the simulator itself as much as it was an evaluation tool for the concepts.

5.3 Driving Simulator Test I

Driving simulator test I had a split focus. It was partly done to evaluate the performance of different concepts and partly to evaluate the level of realism level in the simulator itself and to what extent it could be used in the following concept evaluation process. The results were expected to give an indication of how the concepts performed and in what direction they should be further developed, and how well the simulator worked to replicate a real world scenario. Different test parameters were utilized to test both aspects.

5.3.1 Design of Simulator Tasks

The tasks that were to be performed in the driving simulator were designed to simulate real world situations (see chapter 2.4.4.1). The tasks were designed to be challenging, but still realistic in the sense that they were situations that were encountered on a regular basis as a truck driver. All tasks were designed to be performed at or in close proximity to a freight terminal.

- The first task was reversing to a loading dock with space on either side of the loading dock. This represented an easy reversing maneuver in the sense that there was sufficient space to maneuver, but there were no objects to use as reference in order to judge the distance to the loading dock.
- The second task was reversing to a loading dock with trucks parked on either side of the dock. This was a more difficult reversing maneuver in the sense that space was restricted and the vehicle was forced to approach the loading dock along a straight line. However, if this was achieved, the added vehicles provided an aid for the judgment of distances.

- The third task was driving forward and as close as possible around a pole to study corner cutting. This was an easy task to perform, but a difficult task to perform well. No visual reference on the ground indicated the distance from the vehicle to the pole, which made it possible to study the driver's use of mirrors and other visual cues.

In order to evaluate the concepts, a baseline for all the tested parameters was established for each reversing task, where the driver's ability to complete the task without any maneuvering aid was studied. This could then be compared to the way the task was accomplished when the driver had the support of the maneuvering aid.

The first test sequence was also run using tractor-semitrailer and Nordic combination vehicles. This was done to compare the drivers' impressions of them with driving in real life and also to compare the time it took for them to reverse to the loading dock with the time keepings done at real freight terminals.

5.4 Results from Driving Simulator Test I

In general, all drivers were positive to maneuvering aids:

- One camera system on semitrailer – Was useful in all reversing maneuvers but was not chosen for further development since it was a product already existing on the market.
- Concept C1 – Was chosen for further development since it proved useful in all the simulator sequences. It lived up to its high score from the need-weave matrix but the implementation in the simulator was too good compared to how it would be implemented on a real B-train. Further evaluation on a more limited version was determined necessary in order to make a feasible conclusion of the usefulness of concept C1.
- Concept P1 – The drivers were all positive to the idea behind the concept but did not find the version in the simulator useful. The concept was chosen for further development to further evaluate its potential.

5.4.1 Results from Tested Parameters

The following parameters were evaluated in Driving Simulator Test I (see also chapter 2.5.1):

- Time for maneuvering
- Use of viewing aids
- Driver behavior/movements
- Chosen track when driving
- Impressions of safety, sense of overview and usability
- Retakes
- Collisions

5.4.1.1 Time for Maneuvering

Timekeeping studies were performed for all the test sequences in the simulator, but because of the low number of test participants, only three, it was impossible to draw any far-reaching conclusions. The results from the second task (see chapter 5.3.1) was chosen to be best suited for statistical significance since it was a hard task that tested all the difficulties of reversing a B-train, and was tested by all participants using all the concepts. The results can be seen in fig. 47 below.

Average time taken to reverse to loading dock 7 in the driving simulator	
No aids (baseline)	248 seconds
One-camera system on semitrailer	151 seconds
P1	152 seconds
C1	138 seconds

Fig. 47 Average time for reversing to loading dock in the driving simulator

As can be seen in fig. 47 all the tested concepts gave similar results in time saved, about 40 % compared to using no aids. The baseline test without any maneuvering aids was placed as the sixth task, while the tests with maneuvering aids were placed as tenth to twelfth task. This could have affected the results to some extent in that the drivers gained additional experience from performing tasks 7 to 9. However, the learning curve was assumed to be steepest during the first tasks and the effect on this stage of the test was assumed to be limited.

The P1 concept performed similar to the One-camera system on semitrailer. However, due to a complex technical design and limited time available for programming, the functionality of the P1 concept was not implemented in the simulator, causing a test to be made using a display with the appearance of a P1, without the functionality. This caused confusion among the drivers that all neglected the P1 concept and instead used the One-camera system on semitrailer. This explains their similar results.

The conclusion for the time studies in the simulator was that the concepts, with the exception of the P1 concept, proved that significant improvements could be made by using maneuvering aids.

5.4.1.2 Use of Viewing Aids

Use of viewing aids was evaluated by analysis of the video material from the simulator test. It could be summarized as:

- All drivers were missing the possibility to look rearwards out through the left side window, which was a serious drawback of the simulator. It was a method used to get a better view of things that disappeared from the side mirrors and to aid judgment of distance between the semitrailer and the loading dock.
- The front mirror and the kerb view mirror on the right side were not used at all during the low speed maneuvering at a freight terminal. This however was a reflection of the driver's normal driving behavior, where these mirrors were never used, and did not reflect any lacking functionality of the simulator.
- The mirrors on the left side were used more frequently than the right mirrors since the drivers preferred to reverse to the loading dock in a clockwise turn. This was also consequence of compensatory behavior, since the possibility of looking rearwards through the left window was not available.
- When reversing a B-train, the drivers used a number of visual cues to aid in determining the angle between the semitrailer and the loading dock and the distance

between the semitrailer and the loading dock. For example, the drivers used the positioning lights on the truck and trailers, lines drawn on the ground in front of the loading docks and other vehicles that were parked at the same freight terminal.

5.4.1.3 Behavior Studies

The behavior study of the drivers was done to get a general impression of how they operated the truck in a simulator environment and compare it to driving that was observed during co-riding in real life situations. A comparison was also made between experienced and non-experienced drivers.

Experienced drivers were observed to reverse faster to a loading dock and with fewer retakes than the less experienced. An experienced driver also used smoother maneuvers and smaller and fewer corrections with the steering wheel, while an inexperienced driver seemed to want a reaction from the B-train when turning which could then be used as a visual reference in the rearview mirrors of what direction the vehicle was heading. However, when the steering wheel has been turned sufficiently to cause sideways movements in the semitrailer, the vehicle had already started to make a big turn. This caused an erratic, zigzag movement of the vehicle in the hands of inexperienced drivers.

In general the behavior of the drivers reflected the behavior observed during co-riding, and when asked to rate the level of realism in the simulator all test participants rated it as a 4 or a 5. However, the drivers pointed out some areas in the simulator design that might have caused them to change their driving behavior to some extent.

- A freight terminal in reality was a more chaotic environment than what existed in the simulator, which was a completely static scene, or a "Saturday morning" as described by the drivers.
- In the simulator the drivers could be certain that no other trucks or people would get in their way, which resulted in a behavior where they paid less attention to the surrounding environment and focused more on the driving. To achieve a more chaotic situation a trial was made to implement walking computer manikins in the simulator to simulate humans walking in their path. This however did not come out well: when the drivers realized that the manikins behavior was not natural and that they did not react on things in the environment the drivers neglected them completely or laughed when they hit them.
- The fact that collisions did not cause any simulated damage to the truck (and did not cost money) might have made them a little bit more incautious in their driving style, but in general they took the test seriously and seemed to drive with the similar care as they would have done in reality. In order to make simulations more realistic in a future setting, damage to the vehicle as well as the possibility of multi-player modes and more chaotic situations could be implemented.

One thing that was expected to affect the drivers' behavior was that the brake pedal and the gear lever were positioned in the wrong position. No such tendencies could however be observed and when asked, all the drivers answered that it was no problem and that they learned to use the unusual setup very fast. In addition to this, there was an initial fear that shorter drivers would have trouble reaching the pedals since the chair could not be adjusted, but this proved not to be the case.

5.4.1.4 Chosen Track

The chosen track observed during the simulator sequences corresponded well to the observations of chosen track in reality (see chapter 3.5.4). All drivers tried to position themselves straight in front of the target loading dock so they could reverse the road train in a straight line towards it. If that was not possible the drivers preferred to reverse using a clockwise turn, which in a real world situation was done with the aid of looking rearwards through the left window but, to the drivers' frustration, this could not be performed in the simulator. The habit of driving in a clockwise turn in front of the loading dock to scan the surroundings as observed in the pre study was not observed in the simulator study, most probably a result of the fact that the drivers learned the terminal very quickly and knew that no other vehicles or pedestrians would move into their way.

An additional problem occurred during tasks 8 and 9 (see Appendix C) where the drivers were asked to drive as tight as possible around a pole, but where there was enough room to choose a track to make the turn as easily as possible. The test setup thus proved too far from reality and normally the drivers expressed that they wanted to choose as wide track as possible to minimize tire wear as well as reduce the risk of accidentally colliding with objects in the blind spots.

None of the concepts tested could be observed to alter the chosen track of the drivers during the test. Some changes might have been possible to identify if the drivers had been given sufficient time to familiarize with the concepts, but this was not the primary focus of the Driving Simulator Test I.

5.4.1.5 Impressions of Safety, Overview and Usability

The impression of safety, overview and usability was mainly covered in the semi-structured interviews held during the simulator test. The answers clearly showed an improvement in the impression of safety and overview of the vehicle and the freight terminal using the concepts compared to not using any aids.

All the concepts aided vision in different blind spots and concept C1 also helped the driver to determine the articulation of the different parts of the vehicle. This feature provided the drivers with an increased sense of control, in the sense that the articulation of especially the semitrailer could be determined when it was obscured in the rearview mirrors. Two of the drivers stated that this positive effect would be even greater for inexperienced drivers that were not as familiar with the movements of a B-train.

Regarding the usability of the concepts, all comments were generally positive. The only concept that received negative comments was P1, but these orelated to the lacking functionality of the P1, which was an expected result.

5.4.1.6 Retakes

Retakes were common during the test, only once did a driver manage to reverse completely without retakes. The drivers mentioned several different reasons for doing a retake and the number of retakes needed for a maneuver: it depends on your driving style, lack of vision in blind spots around the vehicle, limited maneuverability, the design and size of freight terminals and disturbances by other traffic. Only some of these were affected by the concepts, e.g. vision in blind spots and maneuverability, and the concepts were not expected to have a great effect on the number of retakes used.

As can be seen in fig. 48 below the average number of retakes for a reversing maneuver did not differ significantly between the concepts. It was assumed that performing the same maneuver several times in a row had a greater impact on the number of retakes needed than the use of different concepts. Using number of retakes as a test parameter was not considered feasible for concept performance, and more focus had to be put on the drivers' comments and answers during the interview connected to the simulator test.

Concept	Average number of retakes
No aids (baseline)	7
Rear view camera on the semitrailer	4
P1	4
C1	5

Fig. 48 Average number of retakes for the second test sequence (see chapter 5.3.1) for all the concepts

5.4.1.7 Collisions

No collisions occurred during the test which made this a parameter that did not yield any results. The fact that no collisions occurred was however a good indicator that the driving in the simulator was close to reality and that the drivers took the test seriously and drove in a realistic way.

5.4.2 Comparison between Vehicle Combinations

The first test sequence was run once for the vehicle combinations tractor-semitrailer and once for Nordic combination using no aids. Regarding the realism, all the drivers graded the vehicle combinations equally high as driving the B-train. The same went for the timekeepings and number of retakes, which corresponded well with values measured at real freight terminals. The conclusion would then again be that the simulator was suitable for the tests conducted in this thesis.

6. Concept Refinement

6.1 Concept Refinement Overview

During the concept refinement stage, the following areas were developed into greater depth:

- Technical Descriptions (Chapter 6.2)
- Interface design (Chapter 6.3)
- Final design of need matrix (Chapter 6.7)

6.2 Concept Descriptions

The technical descriptions of the different concepts in chapter 4.6 were refined and more details were added. In relation to each concept, a functional description was also established, which described a possible real life situation where the concept could be used (See chapter 4.6).

6.3 Applying Recognition Factors

Research made by the United States Army has identified a number of recognition factors[21] that is used by the human eye to detect objects in relation to its surroundings. While the report "Camouflage, Concealment and Decoys" described various techniques to avoid detection, the same principles could be used in reverse when the opposite was sought. In the case of this thesis, the recognition factors were used to aid detectability when designing graphical interfaces overlaid on a camera image display. The structured design of visual elements was crucial for obtaining functional consistency using one design that could be used with the same degree of functionality over vastly different backgrounds.

6.3.1 Reflectance

Reflectance was defined as the wavelength of electromagnetic radiation reflected by the object in relation to the wavelengths reflected by the surroundings. Three types of reflectance could be identified:

- Visual reflectance
- Temperature reflectance
- Radar signal reflectance

Radar and temperature reflectance was not applicable on graphical user interfaces since the electromagnetic waves were outside the visual range of the human eye.

Visual reflectance was defined as the color of an object. The use of contrasting colors was an important tool that aided detectability, but the effects were greatest at close range and with homogenous backgrounds. However, color had two drawbacks: when viewed from long distances colors tended to merge into a single tone and when viewed in poor light, colors were

[21] FM 20-3 Camouflage, Concealment, and Decoys, 1999

harder to discriminate. This on the other hand could be used as an advantage since it only affected the camera image, not the graphics on the display.

6.3.2 Shape

Since natural backgrounds had relatively random shapes, straight lines and smooth curves were easily detectable in such terrain. For urban areas, straight lines occurred in all human constructions, but they were generally short and disjointed, especially at greater distances. At closer ranges, straight lines could be more dominant and take up a greater portion of the field of view.

Related to shape was the size of objects that also could be used to distinguish graphics from the surroundings. In urban areas where straight lines in the cityscape could make the detectability of straight lines more difficult in a display interface, size could be used to some extent to avoid this.

6.3.3 Texture

Differences in texture could be detected as a rough surface appeared darker than a smooth, even if both had the same color. It depended on the presence of small shadows that formed on the rough surface and that the light would be more dispersed after hitting a rough surface than a smooth. In general, all terrain except recently fallen snow and ice displayed large amounts of heterogeneous texture. To stand out from the background a very smooth surface could thus be effective, but it could be a problem if the background displayed a similar homogeneity, as could happen in for example snowy condition. However, snow on road surfaces would quickly become less homogenous as tracks and discolorations start to affect the surface, thereby reducing the problem.

6.3.4 Pattern

Pattern was a good recognition factor since regular patterns seldom appeared in nature. A row of objects or parallel lines usually stood out from the background even in urban areas like freight terminals. When designing patterns to be used in a graphical interface, it was important to emphasize the predictability and regularity of the pattern. However, it was not necessary to always have equal spacing between visual parts as long as the difference was highly predictable, for example by designing patterns that used an incremental increase or decrease in spacing or size of the visual parts.

6.3.5 Movements

Fast and erratic movements were easier to recognize than smooth and slow, but all movements did attract attention against a stationary background. When designing a graphical interface to be combined with a camera, it was important to recognize the principal direction of movements that occurred as the vehicle moved. Moving parts in the graphical design should thus have movements that stood in contrast to the movements of the background, for example when designing graphics for a rearward facing camera, sideways movements should be emphasized for detectability.

6.3.6 Conclusion of Recognition Factors

There were a number of recognition factors that could be used to create optimal display graphics that would be easily detectable. Movement was the strongest to attract attention, but since the whole image of a vehicle mounted camera moved when the vehicle was set in motion, the movement had to have a different direction than the surrounding image to attract any significant attention. It could also be argued that movement was the strongest recognition factor against a stationary background and that against a moving background, the different recognition factors would be more equal in the way they attract attention.

Other factors that could be implemented in a graphical interface overlaid on a camera image were colors, patterns and shapes that were not usually found in the environment were the maneuvering aid is supposed to be used. Light intensity could also be used since strong light sources were unusual in the environment, and those that did exist were different kinds of lamps, which were easy to distinguish from graphics.

The general conclusion of recognition factors was that no single factor could be used by itself to produce display graphics that would be optimal for overall use. Instead, all different factors should be used in a combination that utilized the different factors in ways that were optimal for the particular camera position or positions connected to a concept.

6.4 Understandability

The aspect of understandability was an important factor when designing the different interfaces. Not all future users of the concept would be able to see the relation between their own actions and the economic benefits of the company and their own occupation as a truck driver in the end. There would also be drivers who would have difficulties understanding a complex interface with text information and therefore would hesitate to use it, or would be intimidated by it and avoid it altogether. When designing the graphical interfaces, this would be considered the critical user group.

6.5 Interface Design

Based on the considerations described above, interface design was commenced with rough sketches on paper to get quick results (See Appendix I). The design work had a broad perspective and all types of graphics that could be used on the concepts were sketched, with most focus on the design of computer generated graphics that would be overlaid onto a camera image, which included the majority of concepts. The following sketches were made:

- Range measuring graphics
- Predicted path graphics
- Information graphics from non-visual sensors

6.5.1 Range Measuring Graphics

Range measuring graphics could be used in a wide range of concepts that utilized camera images of some sorts. In real life, distances would be measured by the brain using the combined image of both eyes, but a camera image only presented a perspective image that was flat. To aid this deficit, range measuring graphics could be used that allowed the driver to measure the distance between his vehicle and a specific object on the camera image.

Range measuring graphics were designed in three principal ways, using:

- Horizontal measuring aids
- Vertical/horizontal measuring aids
- Perspective aids

6.5.2 Predicted Path Graphics

Graphics representing the predicted path of the vehicle could be found in a number of premium cars. This would be represented in a similar way for use in a road train, i.e. a moving image that was overlaid onto a camera image. The graphics would thus need to be able to provide adequate information for the driver regardless of background. It also needed to display the path in a way that would be easily understood, so as to allow the driver to observe the surrounding areas displayed at the sides of the predicted path.

The graphics made for the predicted path were designed in four principal ways, using:

- Ground following track
- Perspective track
- Spatial track
- Overhead track

6.5.3 Information Graphics from Non-Visual Sensors

Sensor array systems, for example ultrasonic sensors or radar sensors, could be used to create an image of the surrounding world that was non-visual. In order to visualize the information to the user and make it understandable, a representation was needed that translated the sensor information. The design of the representation was dependent on the information that was gathered from the sensors, which could be divided in two types:

Distance – The distance to the object from the edge of the vehicle (or the sensor itself)

Location – Where (or in what horizontal direction) in relation to the vehicle the object was located.

Different sensors had different accuracy in determining the two types and thus required different kinds of interfaces. The more accurate a system, the better resolution could be implemented in the interface allowing more precise distances and locations to be displayed. The need for accuracy could also vary depending on different functionality. A less accurate system could be used for detectability and warnings, while a more accurate system could be used as an actual maneuvering aid, for example allowing the driver to make precise judgment of distance to the loading dock.

Another possible use was to overlay a camera image with information from sensor array systems to aid judgment of distance or detectability of obstacles.

The visualization of the sensor information needed to be adapted to the precision of the sensors, so as not to give a false sense of security regarding their precision. An example of visualization design could be the use of pixels that were sufficiently large to indicate the presence of an object in the general area, while not giving an impression of millimeter precision in the sensor.

The graphics made for the non-visual sensors were designed in four principal ways, using:

- Bar graphics
- Scale graphics
- Clock graphics
- Representational graphics

6.6 Final Design of Need Matrix

The final design of the need matrix was made according to the answers received from the structured interview questions that were sent to drivers from the three different transport categories (See Appendix E). The drivers were asked ten questions – one question corresponding to each of the needs where the drivers were asked to rate it on a scale from one to five. This was then subtracted by one, in order for the needs rated as "Very unimportant" to receive a zero (See Chapter 2.2.5)

In total, 23 drivers participated in the structured interviews. The scores were then averaged and entered into the need matrix to be used in the evaluations of the concepts. When comparing the estimations made earlier (See chapter 5.1.1), the following differences were notable:

- **Determine accessibility** was scored zero for container transports, compared to a 2 in the estimations. When asked about this, the drivers explained that container drivers used a network of other drivers to call on the phone and ask about accessibility in different locations.
- **Vision in bad light conditions** scored 2 for general goods, compared to a 4 in the estimations. This was due to the fact that general goods transports generally frequented larger and better equipped freight terminals than container transports and thus had a reduced need to provide additional light.

	Timber	**Container**	**General goods**
Time reduction	0	1	1
Vision/reversing	2,5	3	3,5
Vision/driving forward	3	3,5	3
Maneuverability	2	2	2
Determine accessibility	3	0	1,5
Vision in bad light	2	4	2
Communicate/unprotected	1	4	3
Communicate/other vehicles	2	3,5	2
Reduction of wear and tear	2,5	2,5	2
Judgment of distance	1	1,5	1

Fig. 49 Final need matrix based on structured interview questions

6.7 Concept to Matrix Optimization

When evaluating the individual need segments regarding their importance, the following list could be established with the major need segments and their individual points scored in the Need-weave matrix:

1. Vision in blind spots (right side of semitrailer) when driving forward and making a right turn (9.78)
2. Vision in blind spots (left side of semitrailer) when driving forward and making a left turn (6.52)
3. Rear vision (behind semitrailer) during reversing maneuvering (6.4)
4. Vision behind semitrailer while reversing at night (5.86)
5. Enhancing maneuverability, multi-directional (5.85)
6. Judgment of distance behind semitrailer while reversing (5.32)
7. Reducing tire wear and tear (4.62)
8. Reducing wear and tear on connections (4.62)
9. Optimization of maneuvering space, multi-directional (3.9)
10. Communication with unprotected road users (one area) (3.26)

This resulted in both optimization of current concepts and the design of new concepts. The optimization resulted in slight changes in the technical descriptions, mostly relating to the use of cameras. New concepts were also developed, most notably the *Three-camera-system with back and front view (Semitrailer)* that was optimized to score high points with limited use of technology.

7. Concept evaluation II

7.1 Driving Simulator Test II

Driving Simulator Test II was a pure concept evaluation. Following the remarks made during Driving Simulator Test I, a number of improvements were made in the simulator software that positively affected the driving experience. The following major changes were implemented in the simulator:

- The resistance in the steering wheel was improved to better simulate a real steering wheel of a truck.
- The weight of the vehicle was increased to simulate a fully laden vehicle.
- The overall stability of the simulator was improved which meant that no crashes occurred during Driving Simulator Test II.

7.1.1 Time Studies

During the second driving simulator test, no time studies were made. The time studies made during Driving Simulator Test I (See chapter 5.4.1.1) revealed that a simple concept like "One-Camera-System on semitrailer" (See chapter 4.6.1) significantly improved the time to complete a task compared to not using any maneuvering aid. The difference in time reduction between individual concepts were much smaller and a larger study was deemed necessary to make a satisfactory conclusion as to which concepts had any advantages compared to the others. The number of concepts tested during Driving Simulator Test II also made such a study impossible due to the limited time available at Oryx Simulations. Furthermore, time reduction scored relatively low in the need-matrix, which focused the attention on other needs and a more detailed study of them were done instead.

7.1.2 Additional Needs Not Studied

No exclusions of any needs were made as a result of simulator limitations, but due to limitations in the time available to program the simulator a number of needs could not be studied at the Driving Simulator Test II.

The following needs were not studied:

- Vision in bad light conditions
- Communication with unprotected road users
- Communication with other road users
- Determining of accessibility
- Maneuverability
- Reduction of wear and tear

7.1.3 Needs Studied in Driving Simulator Test II

The tasks for the Driving Simulator Test II were designed to evaluate different needs. As described in chapter 7.1.4, there were some restrictions as to what concepts could be tested in the simulator environment. The following needs were possible to study in the simulator:

- Judgment of distance
- Vision in blind spots while reversing
- Vision in blind spots while driving forward

7.1.4 Design of Simulator Tasks

The simulator tasks were designed using the needs that were possible to test in the simulator (See Chapter 7.1.3). For a graphical representation of the tasks and the layout of the freight terminal, see Appendix D. The following tasks were included in the Driving Simulator Test II:

1. Driving forward and turning right in a restricted situation. This task was designed to test the vision in blind spots while driving forward, especially in the corner cutting zone on the right side. This was used, as it was one of the most dangerous situations when driving forward, which resulted in a high number of fatal accidents with unprotected road users[22].
2. Reversing to a gate with sideways restriction. This task was designed to make a combined analysis of vision in blind spots while reversing and judgment of distance. The vehicles parked next to the target loading dock were shorter than a semitrailer and could not be used as a visual cue.
3. Driving forward on a street with obstacles to either side of the vehicle. This task was designed to analyze vision in blind spots while driving forward and judgment of distance. Obstacles on either side of the road enabled the analysis of the difference between the left and right side of the vehicle.
4. Reversing to a gate with obstacles restricting the straightening of the vehicle before reversing. This task was designed to present a challenging situation where the benefits of the concepts possibly could stand out. Since the obstacles forced the drivers to reverse using a turn, the task would be particularly useful for studying judgment of distance when making a clockwise reversing.

7.1.5 Concept Evaluation in Simulator

Most concepts were tested twice during the simulator test, in two separate tasks, with the exception of Moving right side camera on tractor that was tested only once and the concept C1 that was tested three times. For comparison, each task was also performed without any maneuvering aids, with a random distribution among drivers: one driver performed the task first without aids, while another performed it second or third. This was used to avoid the effect of learning that otherwise could affect the results.

[22] *Longer and heavier vehicles in the Netherlands*, 2010

The following concepts were tested in the tasks:

Task 1: The concepts C1 and Moving right side camera on tractor were tested. The task focused on the judgment of distance when the vehicle was driving into the freight terminal and especially when the semitrailer cut the corner and came close to the fence that surrounded the freight terminal. Although Moving right side camera on tractor was a concept primarily intended for reversing, it was tested in this task to see whether it would have any impact on the judgment of distance while driving forward. For real life situations, this would mostly be used in traffic situations where the driver could detect unprotected road users in the corner cutting area on the right side of the vehicle.

Task 2: The concepts C1, C2 and C3 were tested. The task focused on the judgment of distance behind the semitrailer, with two lead trailers parked by the adjacent gates to provide additional objects that needed to be taken into consideration for the driver. This was a common task for drivers who frequented freight terminals, and the two concepts were especially designed for reversing situations like task 2.

Task 3: The concepts C1 and Two-camera-system on lead trailer were tested. The task was an obstacle course where objects on both sides of the road needed to be taken into account. The two-camera-system on lead trailer was designed for improving the vision in blind spots and this task was used to analyze how objects that were very close to the cameras were perceived by the driver. With cameras mounted low on the vehicle, there would also be a question how the movements of the ground would be perceived by the driver and if the images would present any difficulties in their interpretation.

Task 4: The concepts C1 and C2 were tested. The task was a reversing maneuver to a gate where the possibility to straighten the vehicle was restricted. The concepts could possibly be used as implicit maneuvering aids as well as aids for judgment of distance, which could be thoroughly tested during this task. It could also be used as a comparison between the effects of vehicles parked at adjacent gates to using only the lines on the ground and using the different concepts as maneuvering aids.

7.2 Results from Driving Simulator Test II

The software improvements that were made on the simulator significantly improved the driving experience and thus improved the ability to test the concepts. Several drivers expressed how close the simulator came to reality in low speed maneuvering situation and were reluctant to quit driving after the test was finished.

7.2.1 Judgment of Distance

Judgment of distance was a difficult need to test in the simulator. In the real world, the driver used the combined image of both eyes to measure distance to objects, but the simulator environment was presented on a two-dimensional screen making such measurements impossible. This resulted in difficulties during maneuvering close to objects that were observed through the cab windows, which would not occur in real life. When analyzing the drivers' ability to judge distances, this fact had to be taken into consideration.

When regarding the view in the mirrors, both the simulator and the real world mirrors presented the view on a two-dimensional surface. Even though the distortion was slightly different, the judgment of distance in the mirrors could still be considered comparable to reality.

During the tasks, drivers could judge the distance up to a certain degree when turning the vehicle and when the semitrailer came close to objects. Three drivers came within a meter of an object when commenting that they were about to hit the object with the semitrailer. However, two drivers also made the same comment after the semitrailer had hit the object in question, which indicated that the ability to judge distances in the mirrors was somewhat restricted.

Judgment of distances when reversing to a loading dock was mostly made by using different cues, for example by using parked semitrailers that stood by adjacent loading docks. In general, the less visual cues that were available, the more difficult the judgment of distances became. When the drivers perceived that the vehicle was approaching the loading dock, they reduced the speed of the vehicle and reversed with a low speed until they hit the loading dock and came to a standstill. However, as with turning the road train, the judgment of distance when reversing was only accurate to roughly a meter which sometimes caused the driver to reduce the speed to late, causing the vehicle to impact the loading dock with higher speed than intended.

7.2.2 Vision in Blind Spots while Reversing and Driving Forward

The concepts tested in the simulator all utilized cameras in some way to provide vision in blind spots. For the drivers that had little or no experience of driving B-trains all the vision aids helped them in their maneuvering of the vehicle. Both to be able to monitor the articulation of the vehicle itself but even more so to get a better view of the surroundings to aid their spatial orientation was a big improvement for them.

When providing vision for drivers in areas that would otherwise be blind spots, they were observed to reverse with higher confidence in the test sequences. This was especially obvious close to the loading dock. The concepts were both increasing the safety by showing the drivers an image of what was present in their blind spot, but also increasing the drivers' perceived safety. When they could be certain that nothing was hidden in the blind spots they did no longer feel that they had to take risks when maneuvering. By the fact that the cameras not only alerted them that something was present beside the vehicle but also exactly what was present, false alarms that would come from other types of non-visual range meters could be eliminated.

Another positive effect by using the vision aids was that already present visual cues such as lines on the ground or parked objects that were used for reference could be utilized in more situations. The B-train easily created big blind spots by itself during reversing and as a result from that, any vision aids would have a positive impact on this.

6 out of the 10 drivers participating in the test mentioned that they could see a problem with vision aids that provided too much vision. If it aided maneuvering to a great extent, a driver might focus too much on it and lose track of the rest of the surroundings. It was not a problem in the simulated environment where no other vehicles or pedestrians were present, but in a

real situation that was much more chaotic it could be dangerous to focus too much on only one camera angle.

Another aspect of using cameras to expand the field of view for the drivers was that camera angles that resembled the image from the rear view mirrors could be confusing to use. This was due to the fact that the image in a mirror was inverted while the view on a display from the camera was not. When reversing using the camera concepts in the simulator the drivers were switching between looking in the mirrors and looking at the display, which meant that they had to think one extra step to interpret the image into what actions they should take with the steering wheel. For images that did not resemble an image in a rearview mirror, like the camera on the rear of the semitrailer, this was not a problem.

7.2.3 Accomplishment of Tasks

Accomplishment of the tasks was defined for the forward driving tasks as: performing the maneuver without any collisions, and for the reversing tasks: managing to position the semitrailer in the right position in front of the loading dock. However, accomplishment of a task was not measurable in all the reversing sequences during the tests since the tasks for some drivers tended to take an unreasonable long time. Therefore the tests sometimes had to be cut short to remain within the time slot for each driver, but also not to tire the drivers too much so they could stay focused throughout the whole test.

Accomplishment of the different tasks when driving with and without the use of any maneuvering aids varied considerably. This was primarily observed to be an effect of differences between tasks as to how difficult they were, and not a result of the simulator or whether a task was performed in the beginning or in the end of the study. Because some of the reversing tasks were cut short it was not possible to have conclusive statistics for all drivers and as a result of this, accomplishment had to be redefined to have varying levels of accomplishment, where a driver could be closer or further away from accomplishing a task within the timeframe.

It did not influence the results to any significant degree in which order the concepts were tested in each sequence and it could therefore be concluded that the effects of learning within the sequence were negligible. This could possibly be the result of the randomness connected to performing a task, where smaller decisions in different stages of the task resulted in slightly different information in mirrors and windows later on. During critical phases of the tasks, this could have overshadowed the effect of learning.

The varying experience of the drivers' and their general lack of experience in driving a B-train did affect the tests, primarily task 4 which was the most difficult (see chapter 7.1.5). It made it harder to compare the drivers' results with each other since it varied how well they adopted their driving style to the new vehicle combination.

7.2.4 Accomplishment of Tasks With and Without Maneuvering Aids

The tasks were designed to be hard, but not too hard, in order to avoid testing the drivers' skill level rather than the concepts' performance. Task 1 however proved to be slightly too difficult since most drivers failed to accomplish it, and for some drivers task 2 and 4 were difficult to accomplish within the timeframe. This led to that the test parameter accomplishment of task did not give a good indication of concept performance as can be seen in the following list.

The tasks were accomplished in the following way:

Task 1. Two drivers managed to accomplish the task one time each with concept C1 and Moving right side camera, all other runs were failures. It however did not affect the evaluation of the concepts since a failure could provide equal amounts of information, something that could be compared to the drivers' comments and answers in the interview.

Task 2. Approximately half of the drivers accomplished this task, and those who accomplished it did so in all their test runs. The others who did not accomplish it were however on their way to accomplish it but had to be interrupted since it took to long. No tendencies could thus be observed as to determine a connection between a particular concept and accomplishment of the task.

Task 3. All the drivers accomplished this task at least once. In most cases of failure it was without any concepts.

Task 4. Approximately half of the drivers accomplished this task, and those who accomplished it did so in all their test runs. However, the others who did not accomplish it were on their way to accomplish it but had to be interrupted because it took too long. No tendencies could thus be observed to determine a connection between a particular concept and accomplishment of the task.

7.2.5 Result from Semi Structured Interviews during Driving Simulator Test II

During the simulator sequences the drivers were continuously asked about their experiences of using the concepts. Because of the semi structured type of interview the questions varied to some degree, and follow up questions were common, but the main questions that were asked were as described in chapter 2.6.3:

- To what extent did the concept aid in the maneuvering of the vehicle?
- To what extent did the concept aid in the detection of objects in the blind spots of the vehicle?

In chapter 7.2.5.1 to 7.2.5.5 the results from the interviews could be viewed.

7.2.5.1 Concept C1

The concept was used during the test sequences for the following purposes:

- Judgment of distance close to the vehicle
- Monitoring vehicle articulation to aid maneuvering
- Monitoring the angle of the semitrailer in relation to the lines in the ground
- Vision in all blind spots

10/10 test participants answered that the concepts aided them in all the test sequences (it was tested in total in three of the sequences)

Selected quotes by the drivers during test of concept C1:

- *"This is the one that I love most of all"*
- *"It was OK when I learned to used it, but it felt a bit weird in the beginning"*
- *"I would never have managed it without it, in that case I would have had to exit the cab all the time"*

7.2.5.2 Concept C2

The concept was used during the test sequences for the following purposes:

- Judgment of distance close to the loading dock
- Monitoring the articulation of the semitrailer relation to the surroundings
- Vision in the blind spot behind the vehicle, while reversing to the loading dock

9/10 test participants answered that the concept aided them in reversing to a loading dock.

Selected quotes by the drivers during test of concept C2:

- *"This one would save a lot of rear doors"*
- *"I believe in this one"*

7.2.5.3 Concept C3

The concept was used during the test sequences for the following purposes:

- Judgment of distance to, mostly tall, objects around the vehicle
- Monitoring the articulation between the lead trailer and the semitrailer
- Vision in some blind spots

7/10 test participants were positive to the concept as an maneuvering aid

Selected quotes by the drivers during test of concept C3:

- *"Not bad at all, I thought it was going to be worse"*
- *"I don't know if I would have so much use for this one"*
- *"This one was good when you are reversing to a loading dock"*

7.2.5.4 Concept Moving Right Side Camera on Tractor

The concept was used during the test sequences for the following purpose:

- Detect objects in blind spots on the right side

6/10 test participants were positive to the concept as aid for extended field of view

Selected quotes by the drivers during test of Moving right side camera on tractor:

- *"You see exactly how close you are"*
- *"The view feels inverted"*

7.2.5.5 Two-Camera System on Lead Trailer

During the test only the camera mounted on the right side was tested, because it was impossible to display the views from two cameras simultaneously on one screen in the simulator. It would have been possible to let the drivers switch between the two cameras by themselves instead, but that would probably have been confusing and difficult to use since it meant that you had to move your hands from the steering wheel. It was then decided to only use the right side camera because that was the side with the worst view through the mirror and the most blind spots.

The concept was used during the test sequences for the following purpose:

- Detect objects in blind spots on the right side

6/10 test participants were slightly positive to the concept

Selected quotes by the drivers during test of Two-camera system on lead trailer:

- *"It's enough with one on the right side, because there is where you have the worst view"*
- *"I don't see any real use for it"*

7.2.6 Interview Evaluation of Concepts

Five concepts that were not implemented were instead evaluated by showing the test participants illustrations of them and asking semi structured interview questions. The concepts evaluated using this method were:

- P1
- Range meters around the vehicle
- Rear blind spot detector with warning indicator
- O2
- O3

In chapter 7.2.6.1 to 7.2.6.3 the results from the interview evaluation of the concepts is described in detail about for what purposes the respective concepts were expected to be used and to what extent they would aid during low speed maneuvering. A collection of selected quotes is also presented to describe the impression the drivers got about the concepts.

7.2.6.1 Concept P1

The concept was expected by the drivers to have the following use during low speed maneuvering:

- Vision in the blind spot behind the semitrailer
- Maneuvering aid
- Judgment of distance behind the vehicle

9/10 test participants were positive to the concept as a maneuvering aid

Selected quotes by the drivers during test of concept P1:

- *"Could probably be useful, especially when you don't have any lines on the ground to relate to"*
- *"Good, but only if you don't use it to much and loose track of what's happening around you"*
- *"It would make it easier to do it right from the beginning"*

7.2.6.2 Range Meters Around the Vehicle and Rear Blind Spot Detector with Warning Indicator

The concepts Range meters mounted around the vehicle and Rear blind spot detector with warning indicator were evaluated at the same time since they were two versions of the same system using range meters.

The concept was expected by the drivers to have the following use during low speed maneuvering:

- Judgment of distance to objects close to the vehicle

0/10 test participants were positive to the concept Range meters around the vehicle, but 9/10 were positive to Rear blind spot detector with warning indicator.

Selected quotes by the drivers during test of concepts Range meters around the vehicle and Rear blind spot detector with warning indicator:

- *"I don't see any use for the range meters on the sides, only those at the back"*

7.2.6.3 Concept O2 and O3

The concepts O2 and O3 were evaluated at the same time since they were two versions of the same system.

The concepts were expected by the drivers to have the following use during low speed maneuvering:

- Warn other road users in dangerous positions

8/10 test participants were positive to use the concept as a mean to warn other road users.

7.2.7 Conclusions Driving Simulator Test II

The conclusions from Driving Simulator Test II could be summarized in the following points:

- In general, drivers were positive to add different aids for vision and implicit maneuvering to their trucks. This corresponded to the findings in the pre study that there is several needs where such aids could be a great improvement.
- There was a general demand for explicit maneuvering aids that directly helped the driver during low speed maneuvering.
- Before the test it was expected that older and more experienced drivers would be more negative to technical aids than younger and less experienced, but no such correlation between drivers' age and acceptability of new concepts could be found.
- The drivers perceived during the simulator tests that there was a risk with complex vision aids that the driver could spend too much time focusing on a display and neglecting the vision through windows and mirrors, thus losing their view of the surroundings.
- The need for range meters was limited since they did not provide any indication of what type of obstacle they detected. Therefore, it did not work fully as an aid for blind spots and the only real use found in the test was directly behind the semitrailer to aid judgment of distance while reversing to the loading dock.
- Judgment of distance was improved with all camera concepts, but some kind of visual reference of where the vehicle was in relation to the camera was needed. It could be that a part of the truck was showing in the image, but some kind of graphics overlaid on the screen would be more useful.
- All the cameras in the test used a horizontal viewing angle of 80°. That was sufficient for all the concepts and did not give any noticeable distortions. Minor adjustments to camera positions and directional angles for camera fixtures were however needed to maximize their capabilities.

- All concepts with cameras aided the drivers' spatial orientation when maneuvering at a freight terminal. Especially the more inexperienced drivers were observed to use the camera images to keep track of where they were.
- Camera images that resembled the view in the mirrors or that had overlapping fields of view were by some drivers perceived as confusing. Switching between a mirror with an inverted view and a camera with a regular view was not intuitive, and made the drivers confused to what direction they were reversing in. For views that did not directly resemble a view from a rear view mirror, for example the rear view camera mounted on the semitrailer, no such problems were observed.
- During the test the display was mounted to the left of the steering wheel near the base of the A pillar. That positioning were never a problem for views that did not resemble the view in right rear view mirror image, but for those that did a few drivers had problems interpreting the image and using it intuitively.
- There was a correlation between use of concepts and improved performance (i.e. task accomplishment, time spent or number of retakes). However, due to the limited amount of tests on the individual concepts, no conclusions could be made as to which concepts resulted in the greatest improvement. A more thorough study could also be made on the question of improvements over time, when the driver could become increasingly familiar with a concept and thus utilize it in a more optimal way.

7.3 Business Case Evaluation

In order to make a business case evaluation, information about the cost was gathered from a Swedish transport company. Several larger transport companies were contacted that operated in the Nordic region, but apart from one, all other companies regarded this information as too sensitive to be released outside the company. No exact information could be gathered about the additional cost related to delays or unscheduled stops, but interviews with representatives from the company indicated that they were not insignificant.

The running cost relating to the maneuvering of road trains at freight terminals could be gathered for the combined lead trailer and the semitrailer, but not for the tractor. For the combined vehicle using a lead trailer and semitrailer, the costs were collected by the company on an individual basis linking one driver to a specific lead trailer and semitrailer. The average cost for a lead trailer and semitrailer was 175 SEK/day. The lowest cost per driver, described by the company representatives as their best and most careful driver, was 50 SEK/day. The highest cost on the other hand was 400 SEK/day.

From these costs, it was assumed that the average cost of 175 SEK/day at the maximum could reach 50 SEK/day. That meant 125 SEK/day that could be improved. In a two-year timeframe using 250 working days, this would mean a cost of 62500 SEK that would be considered improvable. When considering that the costs of standstills and the running costs of the tractor was not included in this amount, it could be assumed that the total cost in reality was higher.

8. Final Development

8.1 Method Triangulation

During the thesis project, there were a number of different methods that had been used to evaluate the concepts in different ways. In order to combine these methods, a method triangulation was used to collect the results in one, final analysis.

8.1.1 The Top Concepts

After making several analyses that focused on different aspects of low speed maneuvering with road trains, a summary could be made as to what concept or concepts could be considered the best in the thesis project. Since the problem area was to a large extent a heterogeneous area, the evaluation of what concepts could be considered the top ones also had to take this fact into account.

The most balanced analysis was made with the Need-weave matrix, where the concept Three-camera-system with rear and front view (semitrailer) received the highest score. However, in a real situation, it could not be assumed that the most balanced maneuvering aid on every occasion was the most usable. The need-weave matrix also evaluated the total market with all its participants. For one of the transport types, a completely different concept could be seen as the most usable. Rather than naming one top concept, it would be more feasible to name a number of concepts a top cluster, from where the different users could choose the concept that best suited their specific needs. This would especially be the case for concepts that could be used for shorter truck combinations or if the use of road trains became more widespread.

In summary, the concepts that could be considered top concepts mostly included the ones that were classified by Volvo 3P. These were both of a general type that focused on several needs, while others were of a more niched type that focused on one single need. In addition to these, the above mentioned Three-camera-system with rear and front view (semitrailer) stood out as a concept that focused on several needs.

8.2 Sustainability Analysis

The sustainability aspects of the concepts in this thesis project were analyzed according to their direct and indirect impacts on the environment. The sustainability aspects were not needs in the same sense as the user's needs, but as one of Volvo's core values it was an important part that had to be addressed when developing new products. This was expressed on the corporate website as:

"Our environmental commitment doesn't just stay on the desk. We always look at the full life cycle of a product, starting with materials extraction and moving to better, more sustainable methods of manufacturing, running, servicing, and recycling.[23]*"*

The inclusion of a sustainability aspect was also emphasized by Chalmers University of Technology.

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[23] http://www.volvotrucks.com/trucks/UAE-market/en-ae/aboutus/our_core_values/pages/our_core_values.aspx

8.2.1 Direct Environmental Impact

Estimations of direct environmental impact from the concepts were derived from analysis of the imagined manufacturing, use and disposal of them. In all aspects, the concepts could be said to have a negative impact on the environment, since not manufacturing them at all would consume less resources. The objective could instead be focused towards reducing the negative environmental impact as far as possible by choice of production methods, materials and existing technology.

The level of technological sophistication was very different among the concepts. Their environmental impact could thus differ in the same way, for example between a concept that only utilized one camera and a display to a concept that utilized several cameras, a display with computer graphics and computer hardware. At a later stage in the production process, this could be used as one of the criterions for selecting concepts for further development, but this was outside the scope of this thesis.

Further analysis could also be made of aspects such as choice of materials, manufacturing process and design for recyclability to minimize the negative environmental impact the products would have. In the thesis project, all concepts were kept on a conceptual level where these aspects were not taken into consideration and any such analysis would be part of the further development at Volvo 3P.

For many of the concepts the best way to minimize their environmental impact would be to integrate them into the existing systems on the truck and in the cab. For example, for the concepts that needed a display it would be better if an already existing display could be used instead of adding another one.

8.2.2 Indirect Environmental Impact

Indirect environmental impact was defined as the effects a concept would have during its use on the environmental impact of the logistical chain as a whole. In that sense, it represented a more holistic perspective of sustainability that had more relevance for concepts with the primary intent of aiding the maneuvering of a vehicle.

The indirect environmental impact could be summed in the following points:

- Reduced number of collisions with economic consequences
- Reduced number of accidents with human consequences
- Increased transport effectiveness
- Reduced wear and tear

The reduced number of collisions with objects and structures on a freight terminal also reduced the need for repairs, replacements and delays due to unscheduled stops. All these aspects had their own sustainability consequences – for example the replacement of a part on the freight terminal was associated with:

- Manufacture of the part, often in another country, using energy and different material resources that could come from yet another country

- Transport of the part from the factory to the service station
- Transport for service personnel to the freight terminal and back

A reduced number of accidents with human injuries had an obvious positive impact on the individuals and their relatives that would otherwise have been affected. In addition to this, there could also be economic and sustainability consequences, but these often differed significantly between individuals and were difficult to calculate.

A consequence of reducing accidents of all sorts and to some extent also by reducing the time spent reversing, transport effectiveness was also increased. By avoiding time spent on repairs, the need for transport companies to have extra trailers as backup was reduced, which would lead to significant economic and environmental benefits. A reduction of wear and tear on the vehicle had the same consequences.

8.2.3 Total Environmental Impact

When analyzing the total environmental impact of the concepts, both the direct and indirect environmental impact had to be taken into consideration. The direct impact was negative for all concepts even though there could be differences between the concepts depending on their technical sophistication. On the other hand, the indirect environmental impact was positive for all concepts. The level of positive impact was related to how well the concepts fulfilled the needs where the problems occurred – the same concepts that scored high in the Need-weave matrix.

When comparing the levels of impact for the best concepts, it is apparent that the positive, indirect environmental impact is significantly higher than the direct one. A concept that prevented a few replaced light ramps on a semitrailer would have compensated for its own direct environmental impact. When considering the savings for the entire product lifetime, the advantages and the positive environmental impact would be significant.

8.3 Final Results Analysis

The outcome of this thesis work was a large number of concepts that solved different user needs and that were aimed at different parts of the market. The results from the need-weave matrix evaluation concluded that concept *Three-camera-system with rear and front view (semitrailer)* would be the single best concept, while the evaluation using the driving simulator and interviews with drivers pointed towards the C1 concept.

The top solution could though be viewed as a combination concept that utilized one or several concepts and thereby formed a combination concept that fulfilled more of the user needs. Such solutions were not evaluated in this thesis work, but could easily be done by Volvo 3P or any other party at a later stage using the need-weave matrix.

In the bottom line, for Volvo 3P or any other company to develop such solutions as this thesis proposes they had to make financial sense. As the business case solution in chapter 7.3 proved there were large savings for a transport company to do by implementing the concepts, which meant that most of them were realizable.

8.3.1 Camera Concepts

Many of the camera concepts scored high in the need-weave matrix and proved to fulfill their intended purpose in the simulator tests. A number of the most promising ones were among the concepts that were kept confidential by Volvo 3P for further development.

Concepts were intuitive except possibly those concepts with camera angles that resembled the image from a rear view mirror. The concepts that included several (more than two) camera angles that needed to be visualized at the same time were dependent on the future interface design for their intuitiveness.

The only question that needed to be addressed that arose during several of the interviews was the robustness of the cameras. There were different solutions on the market with for example lens covers and heated lenses, but the fact remained that cameras were sensitive to dirt and snow and might need more maintenance than what was wanted. Those problems were however at a detailed level that was not part of this thesis, which merely presented the technological principle for the concepts.

8.3.2 Sensor Array Concepts

The different concepts using sensors for range metering were overrated earlier in the project. When asked about what use they could have, none of the respondent drivers could see any use for them with one exception: on the rear end of the semitrailer. In that placement they could be implemented with positive results since they would have a very clear and simple use in an area where many collisions happen today.

It was also a cheap technology that was fairly developed and used on the market already. The advantage for Volvo Group AB would be that they could implement the visualization panel and the controls for the system in the existing driver interface, instead of having other manufacturers add an extra display/interface that would add to the visual clutter in the driver environment.

8.3.3 Lighting Concepts

The need for extra lighting in bad light conditions was a need that differed significantly between different markets. In the forest where the need for lighting actually was the greatest, the need for more lighting was the smallest since they already had sufficient lights for most situations. On the other markets the situation with reversing lights was poor. The problem for Volvo to produce extra lights for reversing was that they would need to be mounted on the trailers, which was a part of the vehicles that Volvo did not produce.

8.3.4 Drive Concepts

The different drive concepts were not evaluated to any great extent during the thesis work, mainly because they scored low points in the matrix evaluations but also because it would be difficult to fully evaluate their potential without physical testing or a much more realistic simulator. The conclusions in the thesis were that the use for such systems was questionable. No big improvements could be identified by implementation on a B-train, and they would be expensive products to produce.

8.3.5 Other Concepts

The "Other concepts" group included several different concepts that were innovative and showed great potential as niche products. Most of the concepts in this group addressed individual needs in the need-weave matrix in contrast to the highest scoring concepts which meant that they did not end up at the top of the list.

In this group concept O2 and O3 fulfilled the need for communication with other road users in the best way. These concepts were also chosen by Volvo 3P for further development, partly due to the fact that they were safety related, which was one of Volvo Truck's core values.

8.3.6 Prediction and Automation Concepts

In chapter 4.7 two groups of concepts could be found that were all kept confidential by Volvo: the prediction and automation concepts. These groups of concepts were probably the most technologically advanced concepts and the ones who needed the most development before they could be put into production. However they showed great potential in areas were other concepts struggled, namely as explicit maneuvering aids. To fully evaluate their potential extensive testing would need to be performed, preferably in a driving simulator to evaluate a number of different solutions before moving to live tests.

8.4 Development for Patent Application

Five of the concepts generated in the thesis work were chosen during the final development phase by Volvo 3P for a possible patent application. Following meetings with a patent specialist at Volvo 3P, the concepts were chosen and screened against the patent criteria used by Volvo 3P (see chapter 4.7 for reference to the confidential concepts).

In order to develop the concepts towards patent application, there was a need to alter them slightly to suit the application procedure. The technical descriptions were made less specific, thus covering a larger area of possible technologies that otherwise could be used by competitors to solve the same problem. At the same time the descriptions needed to focus more on what was unique with the different ideas.

9. Conclusion

The master thesis project concluded that the user's need that related to low speed maneuvering for long vehicle combinations could be summed in ten points:

1. Time reduction
2. Vision in blind spots while reversing
3. Vision in blind spots while driving forward
4. Maneuverability
5. Determining accessibility
6. Vision in bad light conditions
7. Communication with unprotected road users
8. Communication with other road users
9. Reduction of wear and tear
10. Judgment of distance

The difference was small between drivers and transport companies in relation to priorities of the different needs.

Road trains were mainly used for three main purposes: transporting timber, containers or general cargo.

All types of transport companies used road trains that were transporting goods in large volumes over longer distances.

Road trains utilized routes on BK1-roads and frequented all types of freight terminals regardless of size.

The physical load on the driver was negligible for low speed maneuvering.

The cognitive load on the driver during low speed maneuvering could be improved by a number of different concepts for increasing safety or as maneuvering aids. Implementation of these concepts could lead to significant reductions in the risks associated with low speed maneuvering. This would translate into money that could be saved by transport companies.

Five of the concepts were chosen by Volvo 3P for further evaluation whether they could be protected by patent. In addition to these, a number of concepts were chosen for further development by Volvo 3P without patent application. This indicated a high degree of innovation in the concepts, while still adhering to the user's needs and the demand that could be found on the market.

10. Discussion

10.1 Method Discussion

In hindsight, the methods that were used during the project were all found to be suitable and productive. If the need arose, new methods were created. This was mostly apparent with the matrix evaluation that was used for comparing three heterogeneous transport types with different needs and market share to each other. As a tool for evaluation of complex environments, this method proved to be useful.

In the beginning of the thesis project, a detailed time plan was made that related to the scope in detail. When looking at that time plan at the end of the project, it was interesting to note how little of the scheduling that was adhered to. It was an important part of project management that these kinds of scope creep were allowed where the reality directed in what way the project should be heading. This was a clear contributing factor to the results in the thesis project.

During the thesis work, the opportunity to test a number of the ideas in a driving simulator was a great benefit for the validity of the results, but the simulator focus was not without drawbacks. Since there were limitations on what could be implemented in the simulator in time for the tests, the focus of the thesis moved somewhat toward the concepts that could be therein tested. In the end it meant that some concepts were evaluated thoroughly, while some that could be equally good, or better, were not. The use of the need weave-matrix, the interviews and the other evaluations methods in a method triangulation were however a solid ground to base the conclusions about the other concepts on.

If the simulator had not been available, or had it not been as good as it was, alternative evaluation methods would have had to be sought. Using focus groups was one method that could have been used, where truck drivers would be allowed to discuss the different concepts. Another way would have been to try to build and test mockups of the concepts. It would have had to been done in a limited way, to test the different camera concepts one of the wireless camera systems available on the market could have been bought and used to test different camera angles.

10.2 Result Discussion

The results from this thesis were quite unusual compared to other product development projects in the sense that the end result was not one concept or product that best fit user needs or a list of requirements, but a number of concepts with great variation between them. This was mainly because of the wide scope of the project and it was realized early on that it would not result in just one concept solving all the problems. The choice to aim for many concepts solving different problems meant that all needs could be addressed by at least one concept, and that Volvo 3P at a later stage could choose what needs and what market to aim for when developing concepts further.

The results from the matrix evaluations could be looked at in different perspectives. Either it could be used exactly as the rating in the need-weave matrix where a graded list of the concepts was obtained, or focus could be shifted to parts of it. The concepts that scored highest were not necessarily the concepts that scored highest in the specific markets, or needs, that were sought after. That was one of the advantages of the method that from the existing matrix a number of different evaluations could be made. For example the scores from some of the needs, or one or two of the market segments, could be blanked out and a completely new list would emerge.

Since no combinations of concepts were evaluated there was great potential for even better solutions than those evaluated in the thesis. To not do so in the thesis was chosen partly because each idea was evaluated in its most basic form to facilitate the analysis on a deeper level. When later on combining them into combination concepts those results could be used to make assumptions about their performance, but to reach the same level of validity for the result each combination would have to be evaluated in the same way as the basic concepts were.

10.3 Project Discussion

The thesis project was part of another, larger project at Volvo 3P that was operating with funding partly from the Swedish government, through Vinnova. It was a multi-year-project including many parts and also other master theses, and apart from the project group it involved Volvo 3P, Volvo Technology, Oryx Simulations and Umeå Institute of Design. When working as part of such a large project, it became apparent how important it was for every participant to know what function it had in the project as a whole. Confusion could easily arise otherwise, which could risk hampering the development of the project.

Every week, usually on Fridays, a weekly follow-up meeting was held with the supervisor at Volvo 3P. The participants varied but usually one or two persons from chassis development at Volvo 3P attended, one person from Volvo technology, one person from Umeå Institute of Design and one or two persons from Oryx simulations participated, either in person or via phone. Quite often other people interested in the project participated as well, for example from Volvo Truck Corporation or a project leader from another project. At the meetings the progress in the thesis work were presented together with a plan for the upcoming week. It was a good way to discuss ideas with different experts, but also to get their continuous feedback on the methods and the results.

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Appendix A

Explanation of technical terms

4x2

A 4x2 is truck with two axles and drive on the rear axle.

6x2

A 6x2 is a truck with three axles and drive on one axle. The driving axle can be mounted either in the middle or rearmost of the axles. The axle that is not steered could be lifted, either to reduce tire wear or to increase the axle pressure on the drive axle.

6x4

A 6x4 is a truck with three axles and drive on the two rearmost axles.

8x4

An 8x4 is a truck with four axles and drive on the two rearmost axles.

B-train

A B-train is a road train that comprises of a tractor, a lead trailer and a semitrailer. The total length of a B-train never exceeds 25.25 meter, but the different components of a B-train can vary. The standard B-train utilizes a 13.6 meter semitrailer and a 7.82 meter lead trailer, but a second variant utilizes a 15.4 meter long lead trailer and a 6.1 meter trailer. The standard B-train is used to transport 20 ft. container or the equivalent on the lead trailer and a 40 ft. container or the equivalent on the semitrailer. The second variant transports the 40 ft. container on the lead trailer and a 20 ft. container on the small semitrailer.

Container

A container is a metal box with doors at one end, mainly used for a goods that is transported by ship during some part of the transport. In Europe, the main type of goods transported in containers is manufactured goods from the Far East. Most goods in containers is loaded without the use of pallets, reflecting that they are packed in countries where manual labor is cheap and forklifts are expensive. This is the opposite to Sweden, but the unloading of containers without pallets have to be made manually here as well, which can take up to four hours.

Containers come in varying sizes, but there are three main types used in Sweden:

20 ft. container (6.1 m) is the shortest type of container that is used. One or two can be transported on a semitrailer and one on the lead trailer for use with a B-train combination.

40 ft. container (12.2 m) is the most common type of container used in Sweden. One can be transported on a semitrailer and there are special lead trailers that either are the length of the semitrailer or can extend to carry this type of container.

45 ft. container (13.7 m) is a container with a special length that sometimes is used for goods that need extra space. It is placed on an ordinary semitrailer, resulting in a slight overhang at the rear that can make reversing more difficult, meaning an increased risk for collisions at freight terminals.

Dolly

A dolly is a small trailer with two axles and only a fifth wheel mounted on it, to allow a semitrailer to be towed by a rigid.

Fifth wheel

A fifth wheel is a connecting device used on tractors, dollies and lead trailers to connect semitrailers. The kingpin on the semitrailer is locked in place on the fifth wheel, and the surrounding metal surface of the fifth wheel is used to distribute the pressure from the semitrailer. A handlebar is used to release the kingpin when the semitrailer is to be detached.

Freight Terminal

A freight terminal is a warehouse used to store goods while awaiting reloading and further transportation. On the side of the terminal are a number of gates that trucks use to back up against and when the truck is at a certain designated distance from the gate, there is often a platform that extends to the truck and allows a forklift to drive over and onto the trailer.

There are three principal variations of gates:

- Straight gates with level ground
- Straight gates with slope (where the warehouse floor is level to the ground outside)
- Angled gates

Kingpin

A kingpin is a metal pin on the front underside of the semitrailer and lead trailer that connect to the fifth wheel.

Loading dock

A loading dock is a gate where the cargo is loaded/unloaded from the trailer onto the warehouse or vice versa. The loading dock in its most basic form consists of a platform about 1.3 meters above the ground where the trailer is backed up against with its doors open, to allow easy access to the cargo by warehouse staff. Most loading docks are however also equipped with rubber cushions that connect to the top and sides of the trailer end to close out the weather.

Nordic combination

The Nordic combination, also referred to as D-configuration, is a road train comprised of a rigid, a dolly and a semitrailer.

Rigid

A rigid is a truck that carries load on its own chassis and could connect trailers by using a connection device other than a fifth wheel. The cargo body could consist of any type of construction, for example carrying containers, gravel or general goods.

Road Train

There are seven types of road trains that are allowed in European regions that permit this type of vehicle (See fig. 50).

A: Tractor – Semitrailer – Trailer

B: Tractor – Lead trailer – Semitrailer

C: Rigid – Trailer

D: Rigid – Dolly – Semitrailer

E: Rigid – Trailer – Trailer

F: Tractor with cargo body – Semitrailer

G: Rigid – Trailer

The maximum length of a road train is 25.25 meter and the gross maximum weight of the vehicle combination is 60 tons. The three most common on Swedish roads are type B, D and F.

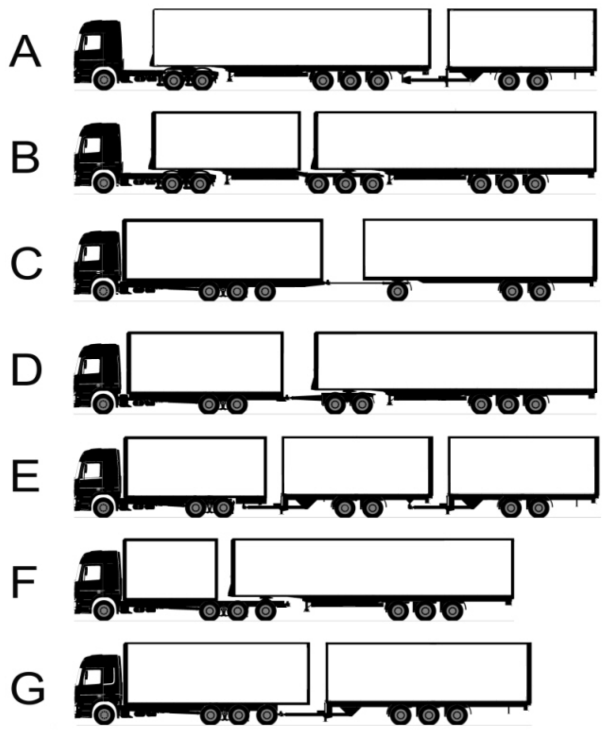


Fig. 50 The seven types of road trains allowed on European roads that allow road trains

Semitrailer

The semitrailer is the most common trailer used for transporting cargo by trucks. It is built on a separate chassis and is pulled by a tractor. The front of the semitrailer is attached to the fifth wheel of the tractor by a kingpin connection that is mounted underneath the front part of the semitrailer chassis.

Since the semitrailer only has wheels at the rear, it cannot support itself on the wheels only. Instead, it uses metal legs to prevent it from tipping forward when parked. These legs are operated by the driver when he is connecting/disconnecting the semitrailer, either using a traditional crank or a hydraulic motor.

Semitrailers with three axles are the most common type on Swedish roads, but semitrailers with one and two axles also exist.

The length of the semitrailer is 13.6 meters. A smaller semitrailer is also used in several European countries, called a *city trailer* with a length of either 8 or 10.6 meters[24].

Tractor

A tractor is a truck that has a fifth wheel mounted on the chassis, allowing it to connect either a lead trailer or a semitrailer. A tractor can have any axle combination. There are also tractors that have a small cargo body mounted behind the cab used for the road trains of type F (See fig. 50).

[24] Longer and Heavier Vehicles in the Netherlands, 2010

Appendix B

Semi-structured questionnaire

The following interview questions were used in the pre-study.

1. For how long have you been working as a truck driver?
2. For how long have you been driving a road train?
3. What kind of truck do you drive?
4. Do you have any additional safety systems, for example reversing camera, radar etc.?
5. Do you drive a pusher or boogie? 6x2/6x4/4x2?
6. What type of lead trailer do you use?
7. What do your routes look like when you are driving a road train?
8. What kind of terminals do you visit?
9. Do you sometimes divide the vehicle when you are going to small terminals?
10. How do you know when the place is too small for a road train?
11. What do you see as the main difference between driving a road train compared to driving with only a semitrailer?
12. What do you think about reversing with a road train?
13. What do you think about corner cutting with a road train? For example in relation to unprotected road users?
14. Are there any special problems using a lead trailer during the ranging process?
15. What do other truck drivers say about these problems?
16. On a scale from one to five, where one means it doesn't matter, and five means it's really important, how important is it that reversing to a gate takes one minute instead of three minutes?
17. What do you think about the fact that there are more and more aids and safety systems in modern trucks?
18. On a scale from one to five (with the same scale as before), how much help would you have by using:
    a. Reversing camera (furthest back on the semitrailer)
    b. Extra reversing lights
    c. Distance measurements to loading dock
19. How are slippery road conditions affecting the ranging process?
20. How are bad light conditions affecting the ranging process?
21. How is uneven or sloping road surface affecting the ranging process?
22. How do you use the mirrors when you are reversing? Do you look out through the window also, or only use mirrors?
23. Is there any part that needs to be improved on the road train as a whole?
    a. Rearward vision
    b. Distance to loading bay
    c. Safety
    d. Comfort
24. Are there any problem areas that other truck drivers complain about?

25. Are there any improvements that you would like to see at terminals, especially regarding road trains?
26. We are going to make a simulator study – are there any sequences that you recommend that we include in the test? Critical situations that are specific to road trains?

Appendix C

Simulator test sequence during Concept Evaluation 1

The test sequence was run according to the schedule below. During the Driving Simulator Test I, the sequences were in a fixed order and were not changed in order to evaluate the learning process among the drivers.

Introduction

- I1: Study of low speed maneuvering
- I2: Master thesis at Chalmers, in cooperation with Volvo and Oryx
- I3: Testing a prototype of the simulator, in part for testing the simulator in itself, but also to discuss how driving with a road train compares to other vehicle combinations
- I4: Will film every sequence. The result will be part of the final report, but you are completely anonymous.
- I5: Will test three types of vehicles in different driving sequences. They are modeled with a total weight of around 20 tons.
- I6: We will ask questions after each task

Familiarizing phase

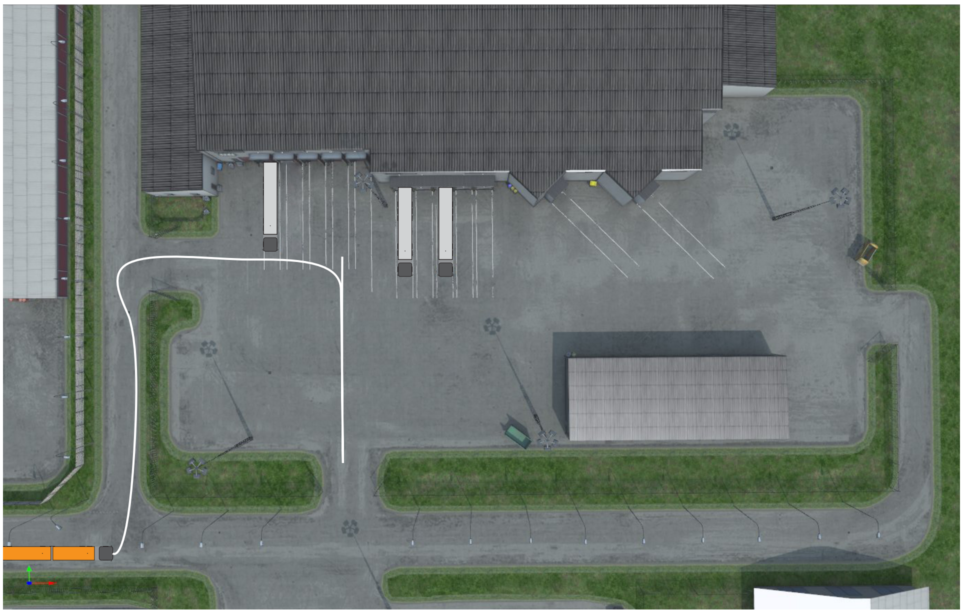
- F1: Display the different parts of the simulator (rear camera turned off)
    - Show gear shift
    - Show how mirrors are working
    - After familiarizing phase:
        - Did anything go wrong?
        - Sense of safety?
        - How close to reality was the simulator?
- F2: Make sure to test driving in the freight terminal, braking and reversing.
- F3: Scale from 1-5, 1=No contact with reality, 5=Just like reality

Test sequences

Sequence 1

- Vehicle: Tractor and semitrailer
- Display: Off
- Task T1: Drive into the freight terminal and reverse to gate 4.
- Question Q1: How realistic did the behavior of the vehicle feel during the sequence, on a scale from 1 to 5, where 1 is no contact with reality and 5 is where the behavior is precisely as reality?

- Question Q2: How secure did you feel about what was happening in the blind spots of the vehicle while reversing? (1=not secure at all, 5=completely secure)
- Question Q3: If you compare with reality, how did it feel to judge the distance between the loading dock and the rear end of the trailer (1 to 5, where 1=no contact with reality and 5=just like reality)



Sequence 2

- Vehicle: Tractor and semitrailer
- Display: Off
- Task T2: Drive into the freight terminal and reverse to gate 7

Sequence 3

- Vehicle: Nordic combination
- Display: Off
- Task T1: Drive into the freight terminal and reverse to gate 4

Sequence 4

- Vehicle: Nordic combination
- Display: Off
- Task T2: Drive into the freight terminal and reverse to gate 7

Sequence 5

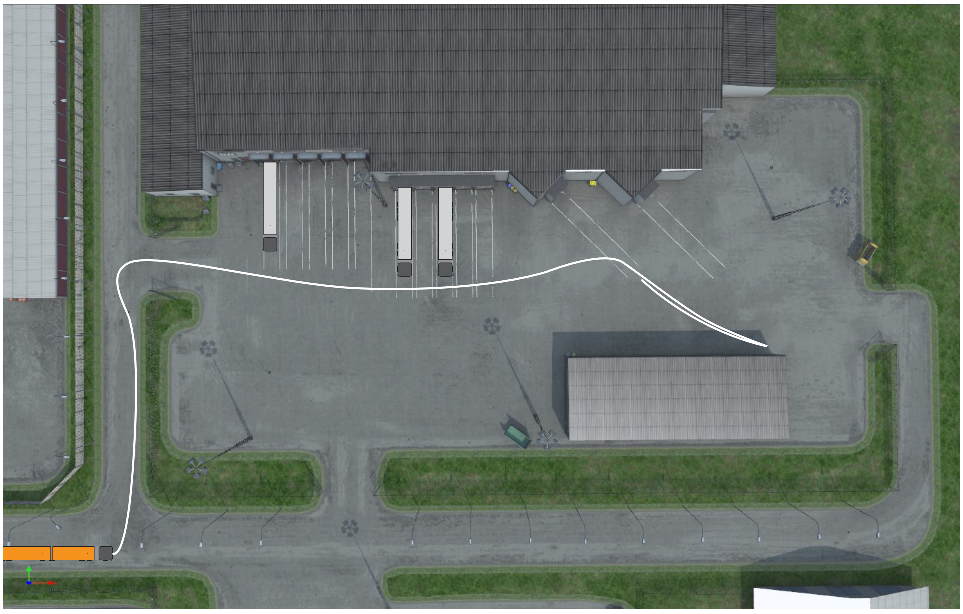
- Vehicle: B-train
- Display: Off
- Task T1: Drive into the freight terminal and reverse to gate 4

Sequence 6

- Vehicle: B-train
- Display: Off
- Task T2: Drive into the freight terminal and reverse to gate 7

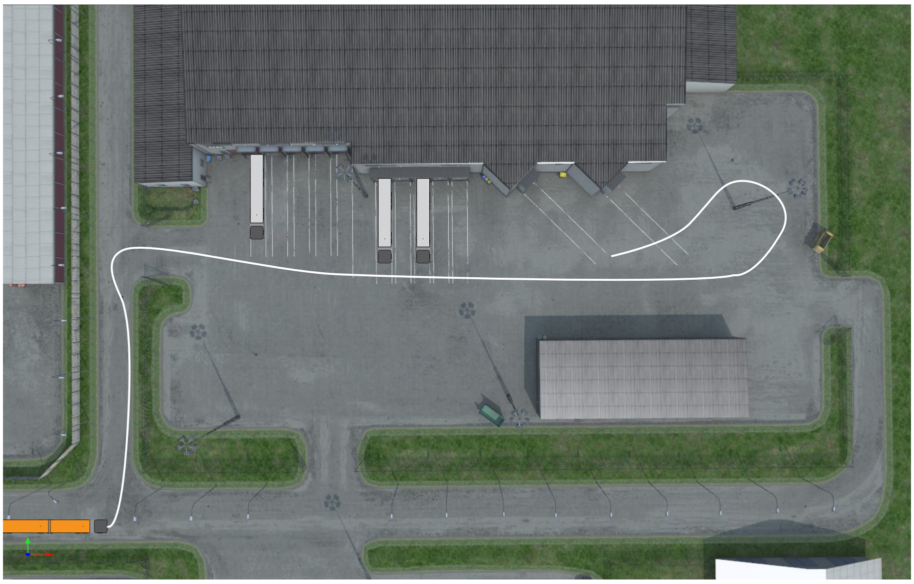
Sequence 7

- Vehicle: B-train
- Display: Off
- Task T3: Drive into the freight terminal and reverse to the nearest angled gate.



Sequence 8

- Vehicle: B-train
- Display: Off
- Task T4: Drive into the freight terminal and make a left turn around the pole being farthest away. Take the vehicle as close as you can.



Sequence 9

- Vehicle: B-train
- Display: Off
- Task T5: Drive into the freight terminal and make a right turn around the pole being farthest away. Take the vehicle as close as you can.

Sequence 10

- Vehicle: B-train
- Display: Rear camera on semitrailer
- Task T2: Drive into the freight terminal and reverse to gate 7
- Question Q4: How did the rear camera on the semitrailer affect your driving?

Sequence 11

- Vehicle: B-train
- Display: P1
- Task T2: Drive into the freight terminal and reverse to gate 7
- Question Q5: How did the P1 concept affect your driving?
- Question Q6: To what extent did the predicted way aid you in the reversing process?

Sequence 12

- Vehicle: B-train
- Display: C1
- Task T2: Drive into the freight terminal and reverse to gate 7
- Question Q5: How did the C1 concept affect your driving?

Appendix D

Simulator tasks and sequences used in Driving Simulator Test II

Sequence 1

- Concepts: C1, Moving right side camera
- Task T1: Make a right hand turn through the gates into the freight terminal.

Fig. 51 The vehicle track for simulator test sequence 1

Sequence 2

- Concepts: C1, C2, C3
- Task T2: Reverse to loading dock number 3, between the two parked trucks.

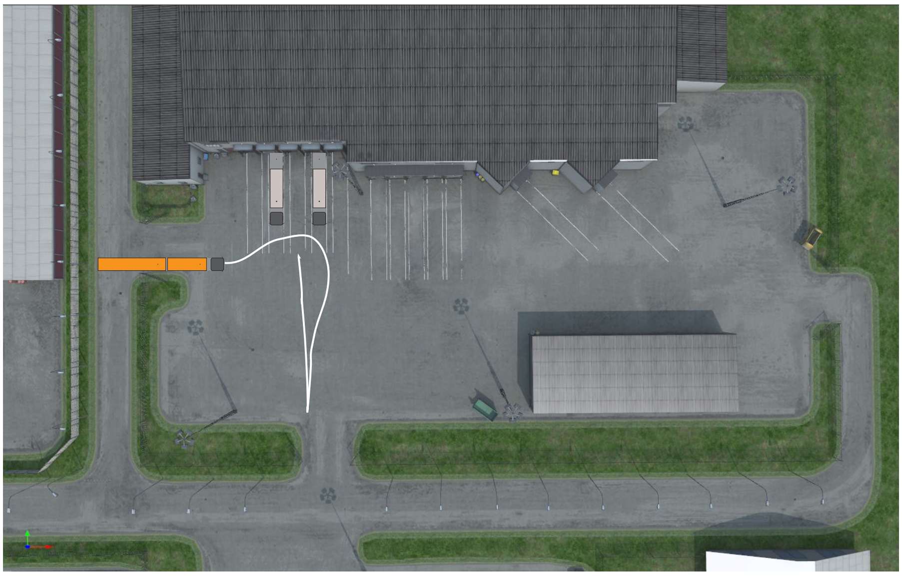


Fig. 52 The vehicle track for simulator test sequence 2

Sequence 3

- Concepts: C1, Two-camera-system on lead trailer (only the right side camera)
- Task T3: Drive through the obstacle course consisting of three containers and two parked tractors.

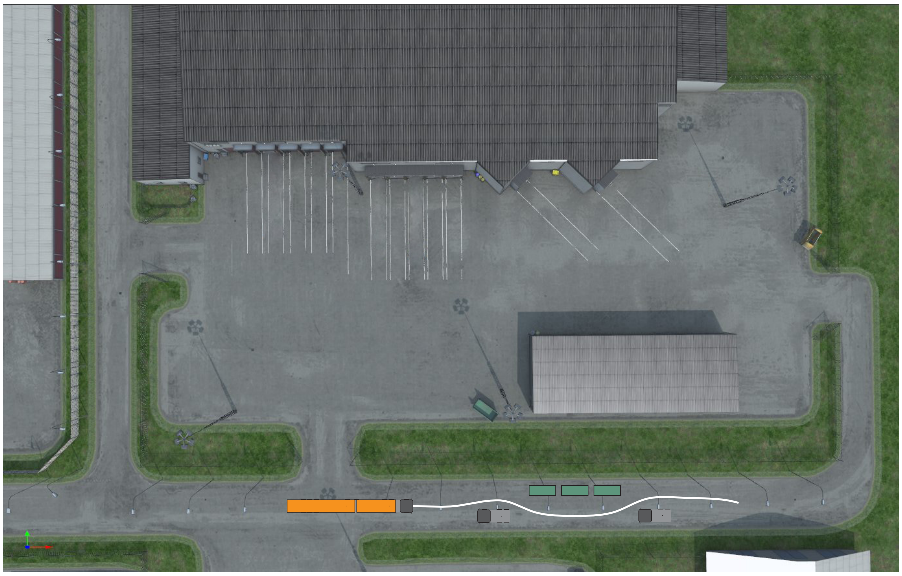


Fig. 53 The vehicle track for simulator test sequence 3

Sequence 3

- Concepts: C1, C2
- Task T3: Drive into the freight terminal and reverse to gate 2, partly blocked by the parked B-trains.

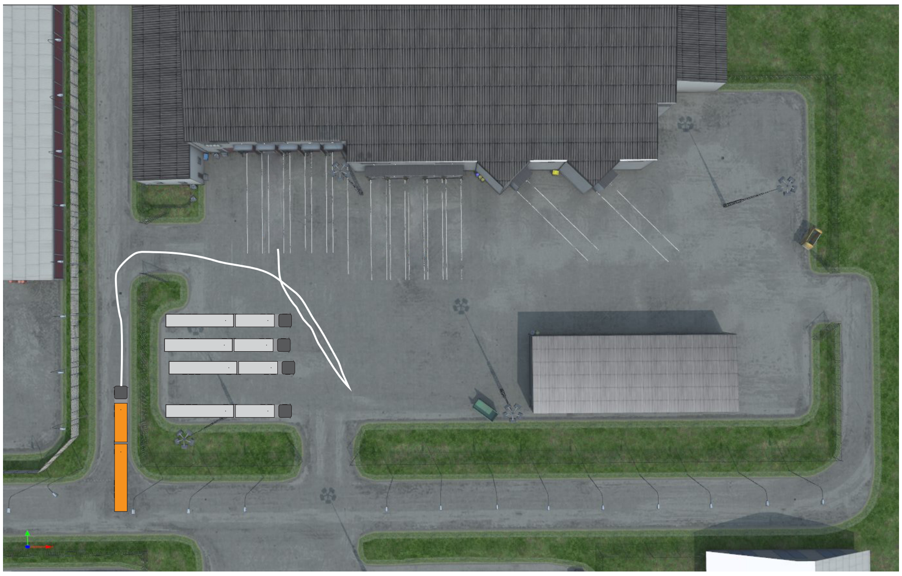


Fig. 54 The vehicle track for simulator test sequence 4

Appendix E

Questionnaire with structured questions

Text presented to the interviewee:

Questionnaire used for research of problems and needs related to low speed maneuvering with road trains.

Answers will be fully anonymous. They are a part of the thesis work “Low Speed Maneuvering Aids For Long Vehicle Combinations” at Chalmers University of Technology, in cooperation with Volvo 3P

Background of driver

B1: How many years have you been driving?

B2: How many years’ experience do you have with a B-train?

B3: How many kilometers do you drive with a truck per year?

B4: What type of cargo do you transport?

The following questions are answered on a scale of 1 to 5, where 1 means completely unimportant and 5 means that it is very important or a very big problem.

Q1: On a scale of 1-5, how important is it to make a fast reversing to a loading dock, for example that it takes 1 minute instead of 3 minutes?
Q2: On a scale of 1-5, how important is it to have control of what is going on in the blind spots while you are reversing?
Q3: On a scale of 1-5, how important is it to have control of what is going on around the vehicle while you are driving forward?
Q4: On a scale of 1-5, to what extent is it a problem that the road train need more space when maneuvering? For example when it is cutting corners while turning or that you need to make large sideways maneuvers when reversing.
Q5: On a scale of 1-5, to what extent is it a problem that when you arrive at a freight terminal, you do not know if there is enough room to maneuver or if you have to disconnect the road train before arriving?
Q6: On a scale of 1-5, to what extent is bad light conditions a problem when you are reversing in dusk or darkness?

Q7: On a scale of 1-5, when you drive in an environment with people walking or riding bicycles, to what extent is it a problem that people do not understand the movements of the vehicle and what you intend to do with it?

Q8: On a scale of 1-5, when you are driving in traffic or at freight terminals, to what extent is it a problem that other drivers (professional as well as non-professional drivers) does not understand the movements of the vehicle and what you intend to do with it?

Q9: On a scale of 1-5, to what extent is it a problem with wear and tear caused by maneuvering on the freight terminal? For example tire wear, connections and by load shifts.

Q10: On a scale of 1-5, to what extent is it a problem that you collide with objects on freight terminals?

Appendix F

Examples of sketches from the brain storming sessions

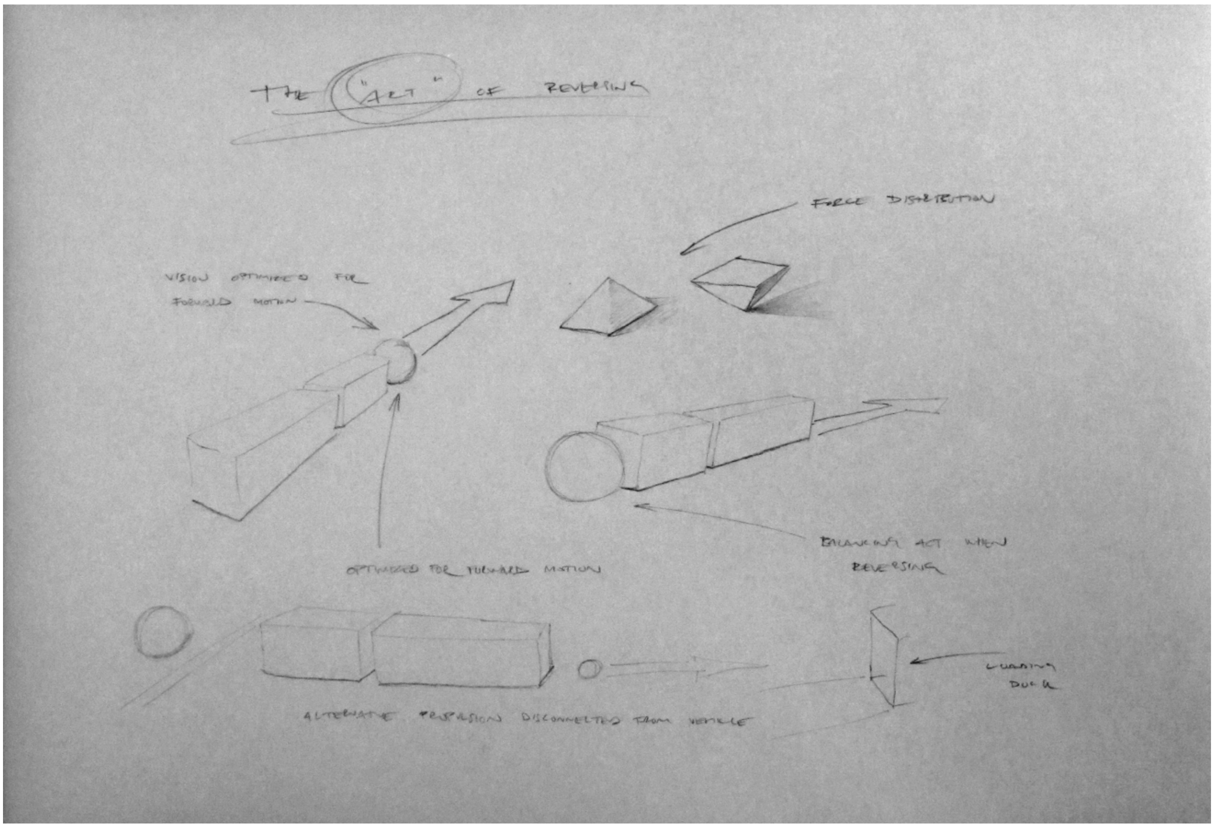


Fig. 55 was a sketch that explored the differences of driving forward and reversing. The balancing act was a revealing comparison that formed a base for ideas that explored other means of propulsion.

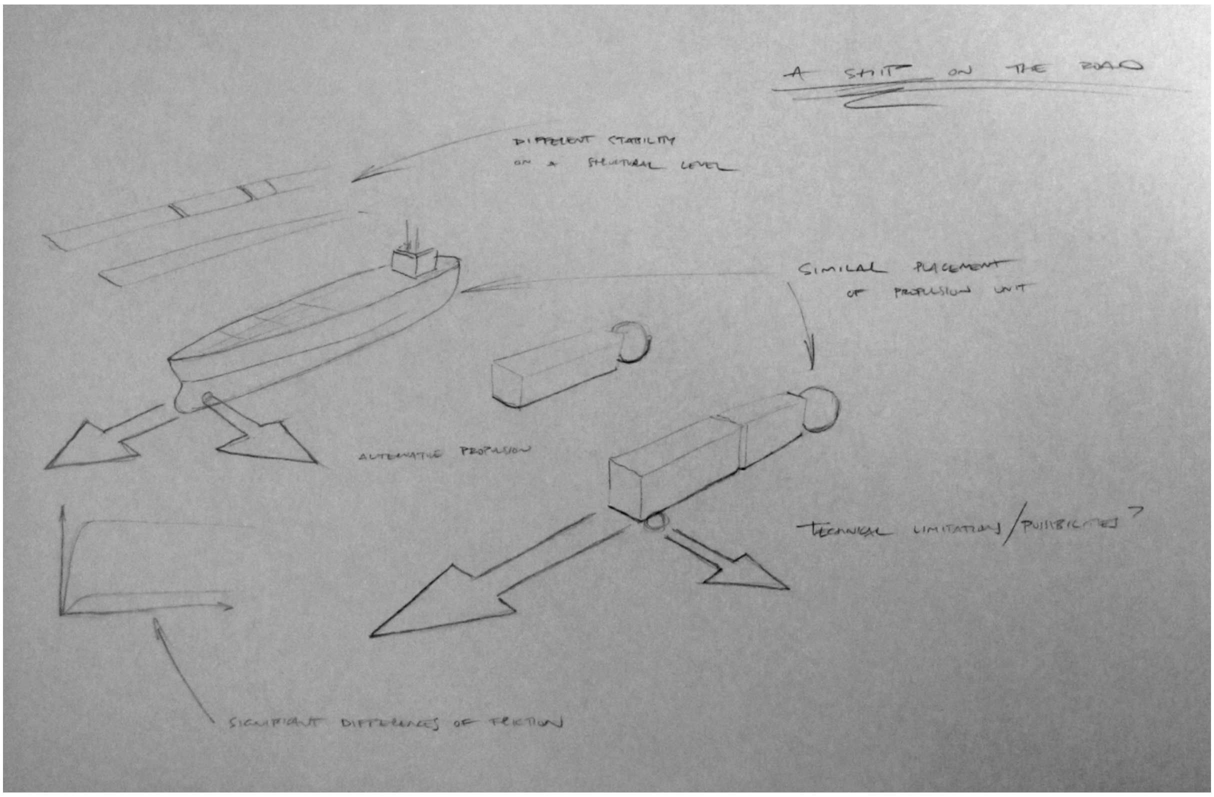


Fig. 56 was a sketch that explored the technical solutions that was used for maneuvering large ships in port. Could similar propulsion be used for road trains? The problem of friction must be addressed for a concept to work on asphalt.

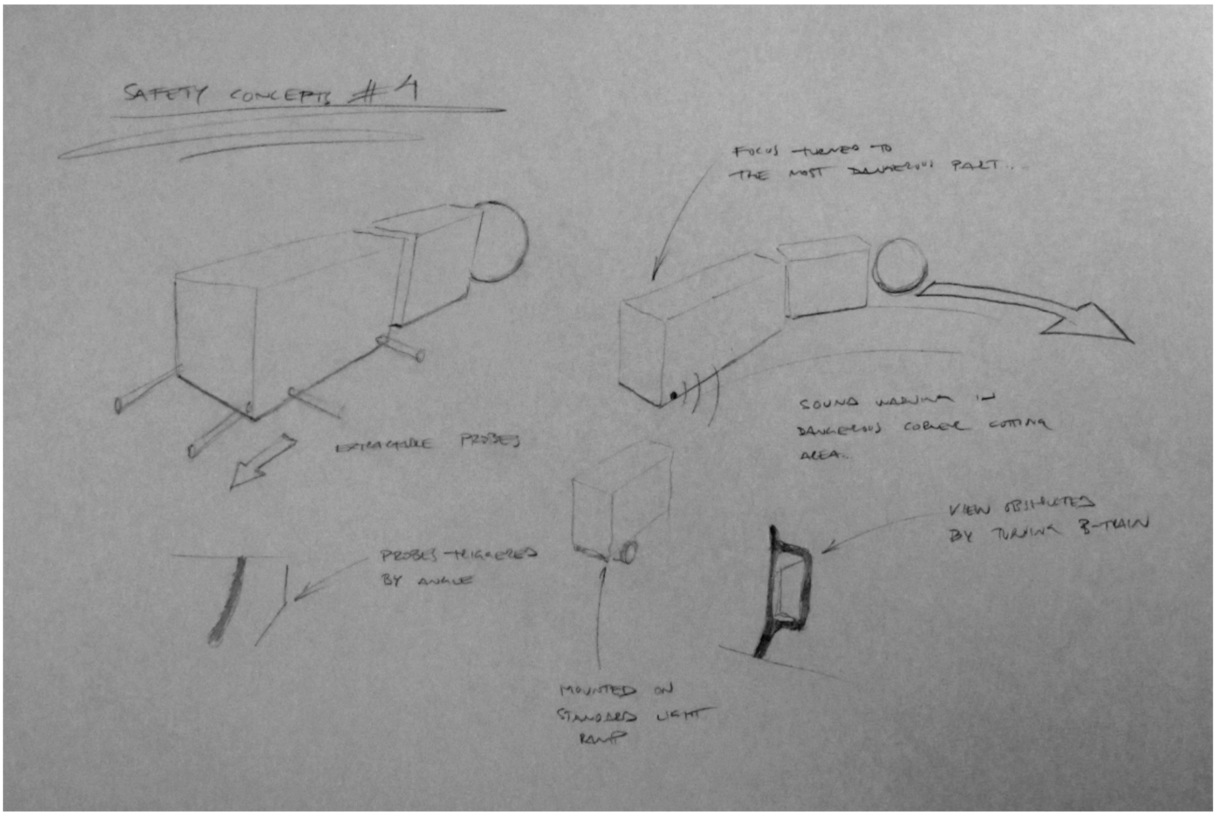


Fig. 57 was a sketch that explored the safety aspects of maneuvering a road train and where the perceived danger zones are and where the actual ones are. Different solutions for changing the focus of the pedestrians, from the tractor towards the semitrailer were explored.

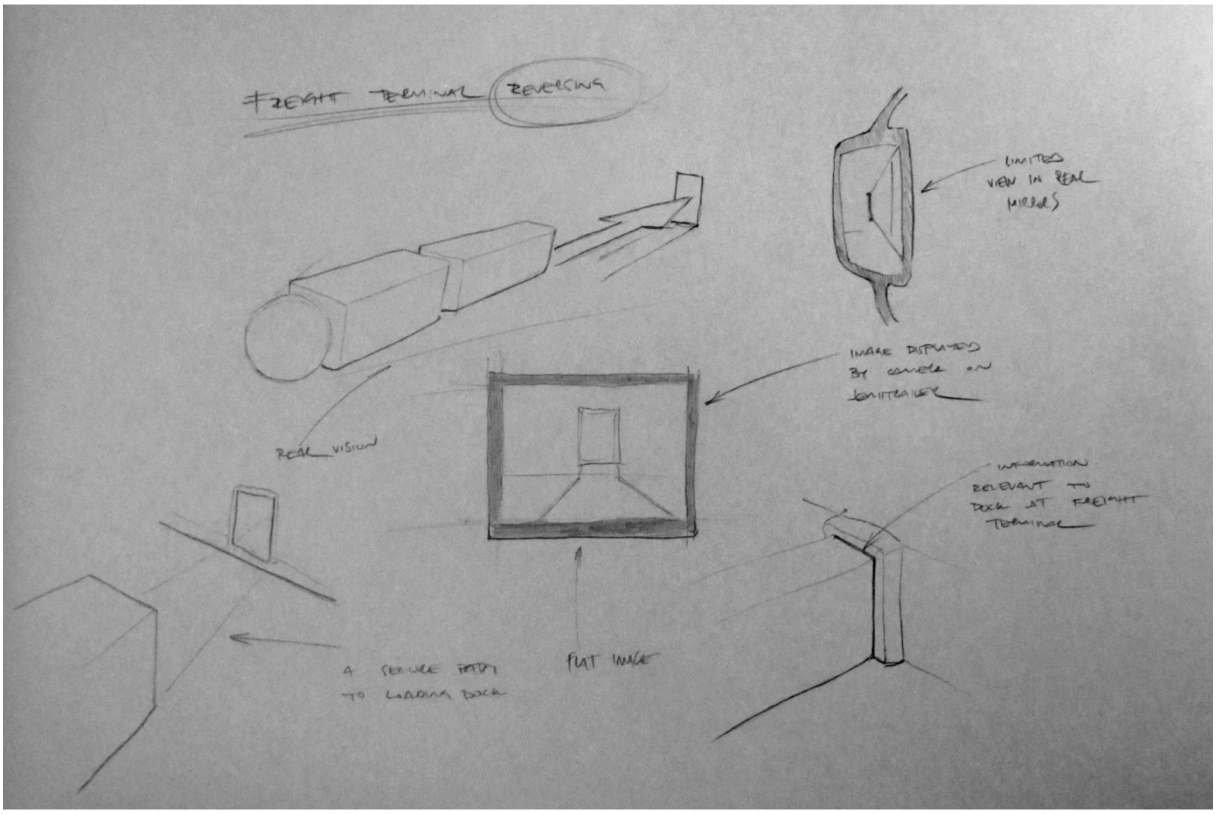


Fig. 58 was a sketch that explored the reversing maneuver at a freight terminal. The view that could be seen in mirrors was compared to a camera view from a camera mounted on the rear end of the semitrailer.

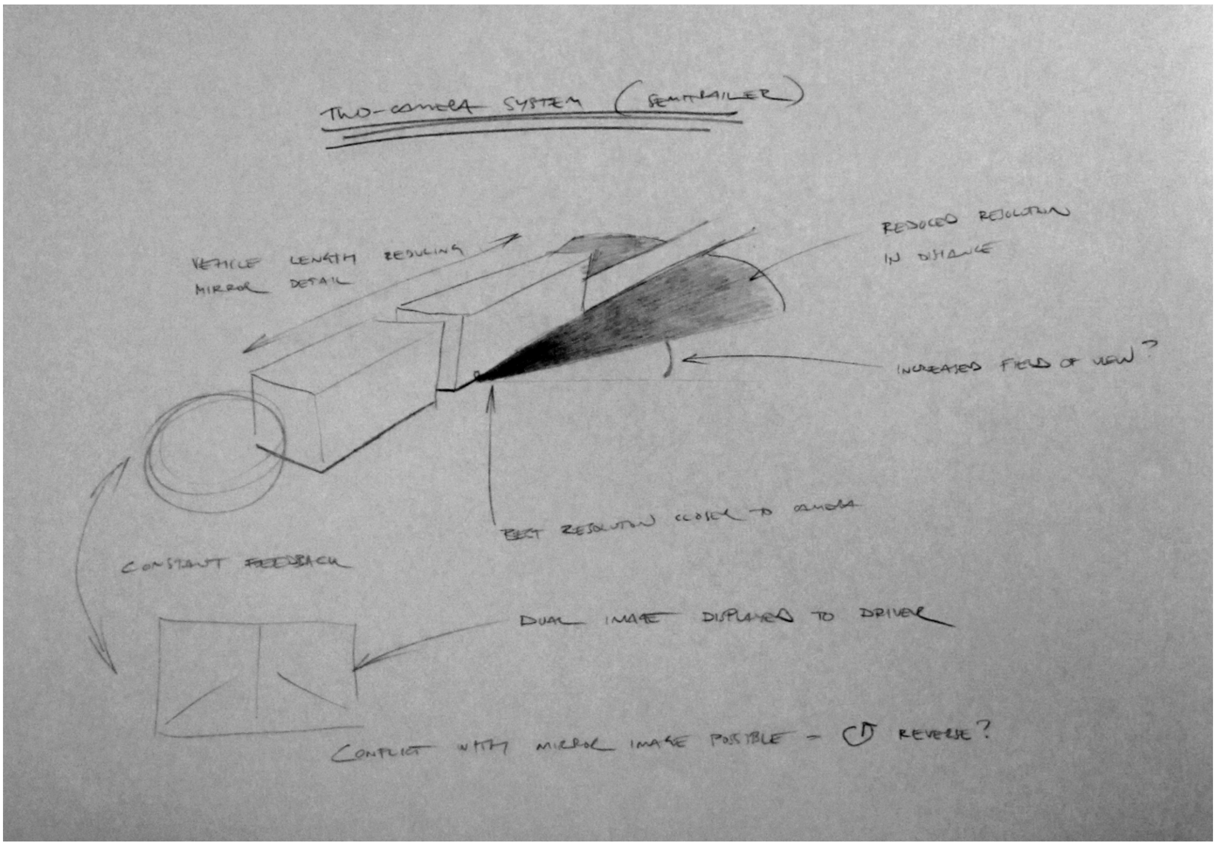


Fig. 59 was a sketch that showed the concept Two-camera system (Semitrailer) and the way information from two cameras could be presented to the driver.

Appendix G

Concept evaluation matrix

Nr	Concept	A				B				C				D				E				F				G				H				I				J			
		Ti	Co	Ge	Sum	Ti	Co	Ge	Sum	Ti	Co	Ge	Sum	Ti	Co	Ge	Sum	Ti	Co	Ge	Sum	Ti	Co	Ge	Sum	Ti	Co	Ge	Sum	Ti	Co	Ge	Sum	Ti	Co	Ge	Sum	Ti	Co	Ge	Sum
1	Rear blind spot detector with automatic braking	-1	1	1	1	0.3	0.5	0.5	1.3	0	0	0	0	0	0	0	0	0	0	0	0	0.3	0.5	0.5	1.3	0	0	0	0	0	0	0	0	0	0	0	0	1.5	3	3	7.5
2	Rear blind spot detector with warning indicator	0	1	1	2	0.3	0.5	0.5	1.3	0	0	0	0	0	0	0	0	0	0	0	0	0.3	0.5	0.5	1.3	0	0	0	0	0	0	0	0	0	0	0	0	1.5	3	3	7.5
3	Reversing lamps on semitrailer	0	2	2	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	2	6	0.5	0.5	0.5	1.5	0.5	0.5	0.5	1.5	0	0	0	0	0	0	0	0
4	Side reversing lamps on semitrailer	0	1	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	2	6	0.5	0.5	0.5	1.5	0.5	0.5	0.5	1.5	0	0	0	0	0	0	0	0
5	Side reversing lamps on lead trailer	1	1	1	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	3	0.5	0.5	0.5	1.5	0.5	0.5	0.5	1.5	0	0	0	0	0	0	0	0
6	Range meter mounted on loading dock	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.5	3	4.5
7	Ranging mode for side mirrors	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	One-camera-system on semi trailer	1	1	1	3	2	2	2	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	3
9	One-camera-system underneath lead trailer	0	0	0	0	1.3	1.3	1.3	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	Two-camera-system on lead trailer	0.5	0.5	1	2	0.5	0.5	1	2	1.3	1.3	2.5	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.1	0.1	0.3	0.5
11	One-camera-system on tractor	0	0	0	0	1	1	1	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	Rearward facing light corridor	1	1	1	3	0	0	0	0	0	0	0	0	0.5	0.5	0.5	1.5	0	0	0	0	0	0	0	0	0.5	0.5	0.5	1.5	0.5	0.5	0.5	1.5	0	0	0	0	0	0	0	0
13	Side facing light projection	1	1	1	3	0	0	0	0	0	0	0	0	0.5	0.5	0.5	1.5	0	0	0	0	0	0	0	0	0.5	0.5	0.5	1.5	0.5	0.5	0.5	1.5	0	0	0	0	1	1	1	3
14	Less aggressive additional horn	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	3	0	0	0	0	0	0	0	0	0	0	0	0
15	Command steer axles on semitrailer and/or lead trailer	1	1	1	3	0	0	0	0	0	0	0	0	3	3	3	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	2	6	0	0	0	0
16	Self steer axles on semitrailer and/or lead trailer	0	0	0	0	0	0	0	0	0	0	0	0	1.5	1.5	1.5	4.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	3	0	0	0	0
17	P1	2	2	2	6	2	2	2	6	0	0	0	0	1	1	1	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.5	1.5	1.5	4.5	4	4	4	12
18	P2	2	4	4	10	2	2	2	6	0	0	0	0	1	1	1	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.5	4	4	9.5	4	4	4	12
19	Terminal mounted optical docking system	0	0.5	1	1.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	3	6
20	O1	1	1	1	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21	C1	0.5	0.5	1	2	2.5	2.5	5	10	2.5	2.5	5	10	0.3	0.3	0.5	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.3	1.3	2.5	5
22	C2	0	0.5	1	1.5	0	1	2	3	0	0	0	0	0	0.3	0.5	0.8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	3
23	A1	-1	-1	-1	-3	-1	-1	-1	-3	-1	-1	-1	-3	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	3	-1	-1	-1	-3	0	0	0	0	0	0	0	0
24	C3	1	1	1	3	1	1	1	3	1.8	1.8	1.8	5.3	0.5	0.5	0.5	1.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	3
25	O2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	3	1	1	1	3	0	0	0	0	0	0	0	0
26	O5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	2	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
27	O6	0	1	1	2	0	0	0	0	0	0	0	0	0.5	0.5	0.5	1.5	2	2	2	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
28	A2	1	1	1	3	-1	-1	-1	-3	-1	-1	-1	-3	1.5	1.5	1.5	4.5	0	0	0	0	0	0	0	0	1	1	1	3	-1	-1	-1	-3	3	3	3	9	0	0	0	0
29	Automatic straight line reversing	0	0	0	0	0	0	0	0	0	0	0	0	0.5	0.5	0.5	1.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30	P3	0	2	4	6	0	0	0	0	0	0	0	0	2	1	2	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	4	6	0	0	0	0
31	A3	2	2	2	6	2	2	2	6	0	0	0	0	1.5	1.5	1.5	4.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	3	3	9	1	1	1	3
32	Range meters around the vehicle	0	1	1	2	0.6	1.3	1.3	3.1	0.6	1.3	1.3	3.1	0	0	0	0	0	0	0	0	0.6	1.3	1.3	3.1	0	0	0	0	0	0	0	0	0	0	0	0	1.9	3.8	3.8	9.4
33	Range probes	0	0	0	0	0.3	0.5	0.5	1.3	0	0	0	0	0	0	0	0	0	0	0	0	0.3	0.5	0.5	1.3	0	0	0	0	0	0	0	0	0	0	0	0	0.5	1	1	2.5
34	O4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.5	1	1	2.5	0	0	0	0	0	0	0	0	0	0	0	0
35	Ultimate Concept	5	5	5	15	5	5	5	15	5	5	5	15	5	5	5	15	5	5	5	15	5	5	5	15	5	5	5	15	5	5	5	15	5	5	5	15	5	5	5	15
36	Three-camera-system (lead trailer + semitrailer)	0.5	0.5	1	2	1.6	1.6	3.2	6.3	1.3	1.3	2.5	5	0	0	0	0	**0**	**0**	**0**	0	0	0	0	0	**0**	**0**	**0**	0	0	0	0	0	0	0	0	0	0.6	0.6	1.3	2.5
37	Three-camera-system (Semitrailer)	1	1	1	3	3.5	3.5	3.5	11	2.5	2.5	2.5	7.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.3	1.3	1.3	3.8
38	Five-camera-system (lead trailer + semitrailer)	0.5	0.5	1	2	2.3	2.3	4.5	9	1.3	1.3	2.5	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.6	0.6	1.3	2.5
39	P5	0	0	2	2	0	0	2	2	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.5	1.5	0	0	2	2
40	O3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.3	0.3	0.3	0.8	0.3	0.3	0.3	0.8	0	0	0	0	0	0	0	0
41	Moving right side camera on tractor	1	1	1	3	0.2	0.2	0.2	0.5	1.5	1.5	1.5	4.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.2	0.2	0.2	0.6
42	P4	0	2.5	5	7.5	0	0	0	0	0	0	0	0	2	1	2	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	4	6	0	1.9	3.8	5.6
43	Three-camera-system with rear and front view	1	1	1	3	3.8	3.8	3.8	12	4	4	4	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.3	1.3	1.3	3.8

	Need
A	Time Reduction
B	Vision in blind spots while reversing
C	Vision in blind spots while driving forward
D	Maneuverability
E	Determine accessibility
F	Vision in bad light conditions
G	Communicate with unprotected road users
H	Communicate with other road users
I	Decrease wear and tear
J	Judgment of distance

Appendix H

Need-weave matrix

	Concept	A	B	C	E	F	G	H	I	L	M	Sum
1	Ultimate Concept	13.35	48	48.9	29.25	12.3	43.95	48.9	40.8	34.65	19.95	**340.05**
2	Three-camera-system with rear and front view	2.67	36.8	39.12	0	0	0	0	0	0	4.99	**83.58**
3	C1	1.78	32	32.6	1.95	0	0	0	0	0	6.65	**74.98**
4	P2	8.9	19.2	0	5.85	0	0	0	0	21.95	15.96	**71.86**
5	Three-camera-system (Semitrailer)	2.67	33.6	24.45	0	0	0	0	0	0	4.99	**65.71**
6	A3	5.34	19.2	0	8.78	0	0	0	0	20.79	3.99	**59.00**
7	P1	5.34	19.2	0	5.85	0	0	0	0	10.40	15.96	**56.75**
8	Five-camera-system (lead trailer + semitrailer)	1.78	28.8	16.3	0	0	0	0	0	0	3.33	**50.21**
9	Range meters around the vehicle	1.78	10	10.19	0	0	9.16	0	0	0	12.47	**43.59**
10	Three-camera-system (lead trailer + semitrailer)	1.78	20.27	16.3	0	0	0	0	0	0	3.33	**41.67**
11	P4	6.68	0	0	9.75	0	0	0	0	13.86	7.48	**37.77**
12	C3	2.67	9.6	17.12	2.93	0	0	0	0	0	3.99	**36.30**
13	Command steer axles on semitrailer and/or lead trailer	2.67	0	0	17.55	0	0	0	0	13.86	0	**34.08**
14	Reversing lamps on semitrailer	3.56	0	0	0	0	17.58	4.89	4.08	0	0	**30.11**
15	P3	5.34	0	0	9.75	0	0	0	0	13.86	0	**28.95**

16	Side reversing lamps on semitrailer	1.78	0	0	0	0	17.58	4.89	4.08	0	0	**28.33**
17	One-camera-system on semi trailer	2.67	19.2	0	0	0	0	0	0	0	3.99	**25.86**
18	Two-camera-system on lead trailer	1.78	6.4	16.3	0	0	0	0	0	0	0.67	**25.15**
19	Side reversing lamps on lead trailer	2.67	0	0	0	0	8.79	4.89	4.08	0	0	**20.43**
20	Moving right side camera on tractor	2.67	1.6	14.67	0	0	0	0	0	0	0.75	**19.69**
21	Rear blind spot detector with warning indicator	1.78	4	0	0	0	3.66	0	0	0	9.98	**19.42**
22	Side facing light projection	2.67	0	0	2.93	0	0	4.89	4.08	0	3.99	**18.56**
23	Rear blind spot detector with automatic braking	0.89	4	0	0	0	3.66	0	0	0	9.98	**18.53**
24	O2	0	0	0	0	0	0	9.78	8.16	0	0	**17.94**
25	C2	1.34	9.6	0	1.46	0	0	0	0	0	3.99	**16.39**
26	P5	1.78	6.4	0	1.95	0	0	0	0	3.47	2.66	**16.26**
27	Self steer axles on semitrailer and/or lead trailer	0	0	0	8.78	0	0	0	0	6.93	0	**15.71**
28	Rearward facing light corridor	2.67	0	0	2.93	0	0	4.89	4.08	0	0	**14.57**
29	A2	2.67	-9.6	-9.78	8.78	0	0	9.78	-8.16	20.79	0	**14.48**
30	One-camera-system underneath lead trailer	0	12.8	0	0	0	0	0	0	0	0	**12.80**
31	Range probes	0	4	0	0	0	3.66	0	0	0	3.33	**10.99**
32	Less aggressive additional horn	0	0	0	0	0	0	9.78	0	0	0	**9.78**
33	O6	1.78	0	0	2.93	4.92	0	0	0	0	0	**9.63**
34	One-camera-system on tractor	0	9.6	0	0	0	0	0	0	0	0	**9.6**

35	Terminal mounted optical docking system	1.34	0	0	0	0	0	0	0	0	7.98	**9.32**
36	O4	0	0	0	0	0	0	8.15	0	0	0	**8.15**
37	Range meter mounted on loading dock	0	0	0	0	0	0	0	0	0	5.99	**5.99**
38	O5	0	0	0	0	4.92	0	0	0	0	0	**4.92**
39	O3	0	0	0	0	0	0	2.45	2.04	0	0	**4.49**
40	Automatic straight line reversing	0	0	0	2.93	0	0	0	0	0	0	**2.93**
41	O1	2.67	0	0	0	0	0	0	0	0	0	**2.67**
42	Ranging mode for side mirrors	0	0	0	0	0	0	0	0	0	0	**0.00**
43	A1	-2.7	-9.6	-9.8	0	0	0	9.8	-8.2	0	0	**-20.43**

Appendix I

Sketches for Interface Design

A number of sketches were made that examined different ways of presenting information to the driver. Focus was on three main areas: range measuring graphics, predicted path graphics and non-visual sensors graphics.

Range measuring graphics

Horizontal measuring aids used horizontal lines that were spaced at intervals that represented an increasing distance from the vehicle. The lines could for example indicate meter by meter, or be individually set by the driver to suit his driving style.

Vertical/Horizontal measuring aids used the combination of vertical and horizontal lines to aid measurements of distance. There could be lines that were used for aiming the vehicle and lines that represented the sides of the vehicle. This design could also be utilized as a predicted path graphics.

Perspective aids used lines to make a graphical perspective in the display. It could either be in the form of a closed corridor with an end that was set at a specified distance or the combination of an open corridor with graphics representing the height of the wheels and cargo body. There could also be graphics that represented a certain height at a certain distance, for example vertical lines that could be used to determine the distance to a loading dock, which height was known.

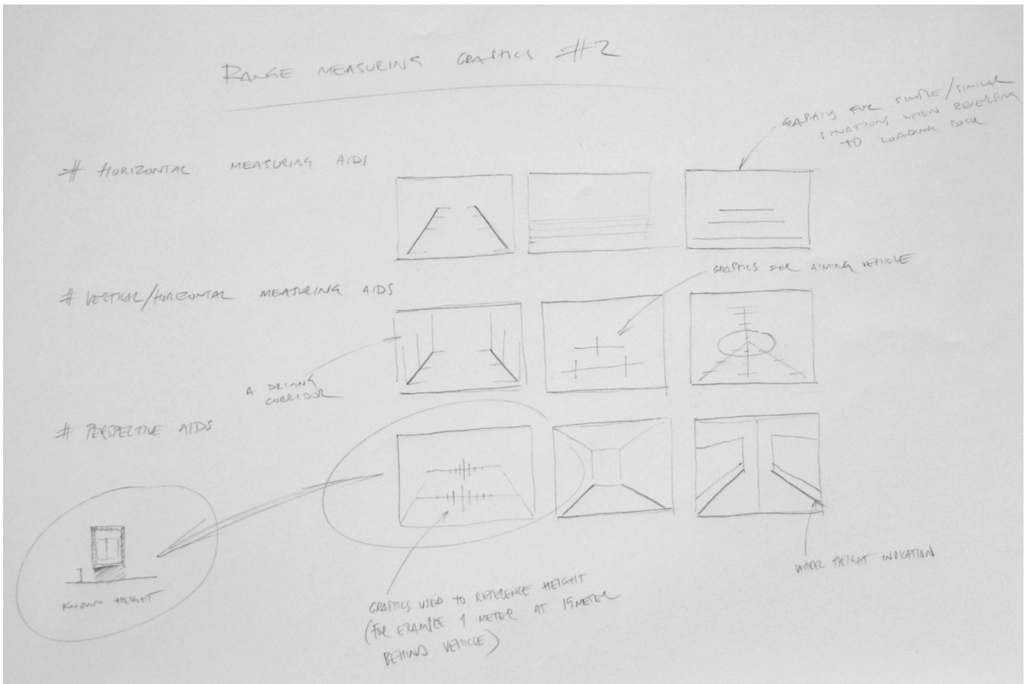


Fig. 60 Visualization sketch of range measuring graphics

Predicted path graphics

Ground following graphics used simple lines to display the predicted path. They could also be used with serifs to possibly increase the readability of the lines on the background, in a similar way as for fonts.

Spatial graphics used corridors to display the predicted path. The corridors could either be used only as a directional aid, but they could also be used as a guide to indicate the entire volume of the vehicle to the sides and to the top.

Perspective graphics used graphics that had a perspective view that resembled the perspective on the ground. This could be combined with horizontal lines, or by using circles to adapt the graphical display to a less precise predicted path.

Overhead graphics used different designs to present a predicted path for an overhead image. The different designs could be used for concepts with different technical refinement, where a less precise design could use graphics without hard edges.

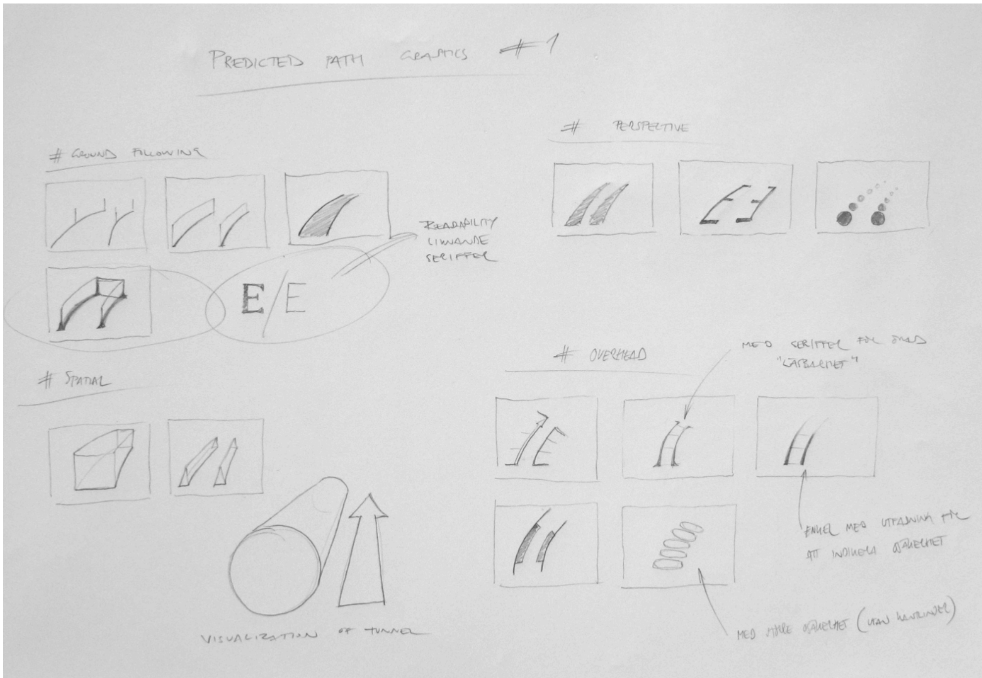


Fig. 61 Visualization sketch of predicted path graphics

Non-visual sensors graphics

Bar graphics used bars of different design to represent distance to an object. Both horizontal and vertical bars could be utilized, depending on the functionality of the sensors.

Clock graphics used the symbol of the clock, or a pie chart to indicate by color fill the distance to an object.

Scale graphics used a traditional symbol used by mechanical indicators to indicate distance to an object. If several sensors were used, the information could either be presented in a combined way on one scale, or by lining scales in a row.

Representational graphics used computer graphics to represent distance in an easily understandable way. It could either be by graphics that look like the end of a trailer, but it could also be made by using squares that represent objects.

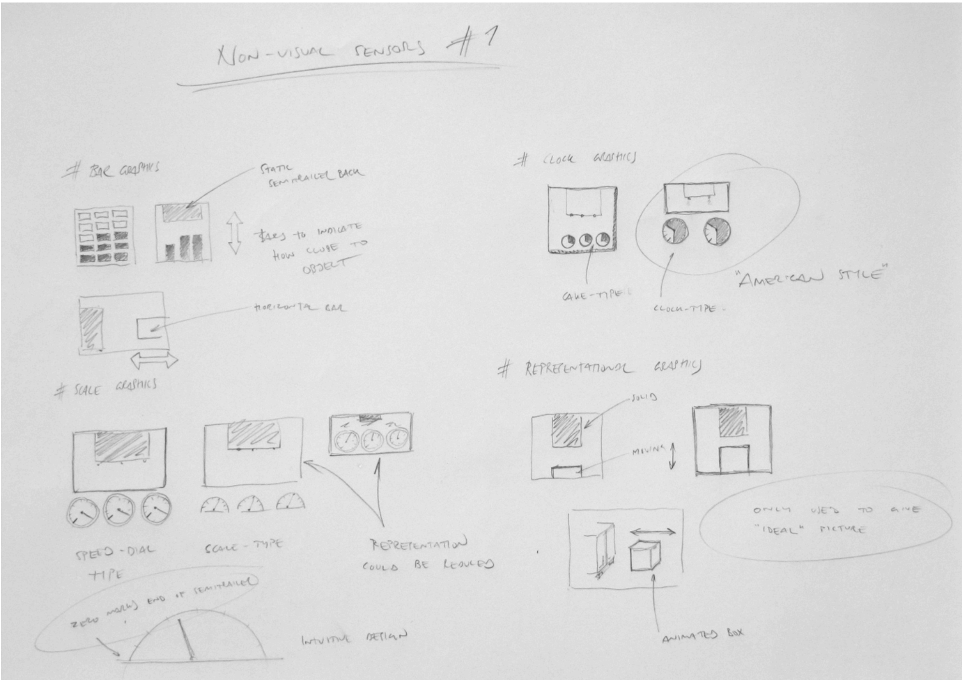


Fig. 62 Visualization sketch of non-visual sensor graphics