# Development Concept for Timber Truck

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# Preface

This Master Thesis is the final part of the Master of Science education in Mechanical Engineering with Industrial Design at Department of Design Sciences LTH, Lund University. It has been conducted at Volvo Technology, Gothenburg from September 2009 until Mars 2010.

We would like to thank our mentors, Lennart Cider at Volvo Technology, Lena Larsson at Volvo 3P and Alfred Johansson at Epsilon. You have been very supportive throughout the project and we are grateful for your enthusiasm and encouragement.

We would also like to send special thanks to a number of people who have helped us in many ways. These are Per Olsson at Parator, Jens Larsen and Anders Tenstam at Volvo Technology, Niklas Peinert at Volvo 3P, Jacques de Giacomoni at Michelin, Kent Bjälmsjö at Bjälmsjö Skog och Transport and Magnus Jönsson at Bergsfegen. You have all been helpful and provided us with the information we have asked for.

Thanks to all of you who have participated in our interviews. Without your comments and thoughts on the project we would not have been able to present this development concept. And thank you to everyone at the office at Chalmers Teknikpark, and all of you who have provided us with information.

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# Abstract

The project “ETT-Modular system for timber transport” investigates the possibilities of making logging shipments more effective, decrease their fuel consumption and road wear without compromising traffic safety. As part of this project a timber vehicle, the ETT-vehicle, that pulls four piles of timber, is 30 metres long, and has a gross combination weight of 90 tons, is tested on a distance between Överkalix and Piteå in the north of Sweden. By adding one more pile to each vehicle and also increasing the load in each pile, two logging shipments will be able to replace three. Fuel consumption measurements on the ETT-vehicle indicate a 20% fuel reduction per ton-km compared to a conventional timber truck with a maximum weight of 60 tons.

The purpose of this thesis is to investigate the strengths and weaknesses with this particular vehicle and present a development concept of a vehicle more optimised for the application. Focus is the fuel consumption, the safety and the identity of the vehicle. The development process used is adapted from the *Generic Development Process* presented by Ulrich and Eppinger and the main source of information is interviews with project members and experts. The interviewees are asked questions about the existing vehicle and wishes and ideas for a future ETT-vehicle. From the interviews statements are translated into customer needs with some of the most important needs being reduced aerodynamic drag and rolling resistance, increased loading capacity, improved visibility of vehicle and a wish that the vehicle is seen as a transport solution, rather than a truck with a number of trailers. From these needs a concept generation is performed where solutions to all the needs are generated. These solutions are then evaluated and tested in simulations, illustrations and discussions, from which a number are chosen for the development concept. The chosen solutions are combined into one complete vehicle development concept. Vehicle simulations in GSP – Global Simulation Platform, are used for testing and evaluation of product concepts and the determination of product specifications for the development concept.

The development concept indicates a possible fuel reduction of about 10% compared to the existing ETT-vehicle. Focus in the development concept regarding the fuel consumption is improved aerodynamics, increased loading capacity, an optimised driveline and reduced rolling resistance. Further the safety is improved and the identity of the vehicle made stronger.

Further research can be conducted in order to firmly establish the results of this development concept and the estimated effects of some solutions. However, the results show high potentials in improving the fuel consumption for timber trucks.

Keywords: Truck, Concept, Development, Timber, Transport

# Sammanfattning

Projektet ”ETT – Modulsystem för skogstransporter” är ett stort samarbetsprojekt mellan bland annat, Skogforsk, AB Volvo, Vägverket, skogsindustrin och diverse fordonstillverkare. Målet med projektet är att studera förutsättningar för och konsekvenser av högre bruttovikter och längre virkesfordon. En del av projektet är ETT - En Trave Till, där ett timmerekipage på 30 meter och 90 ton testas på en sträcka mellan Överkalix och Piteå, se Figur 1. Genom att dra en extra trave timmer och mer timmer i varje trave, kan två ETT-ekipage ersätta tre konventionella timmerekipage. Mätningar utförda på ETT-ekipaget pekar på 20 % bränslebesparing per ton-km. Tesen är också att trafiksäkerheten ökar på grund av det blir färre fordon på vägarna.

**Figur 1.** ETT-ekipaget

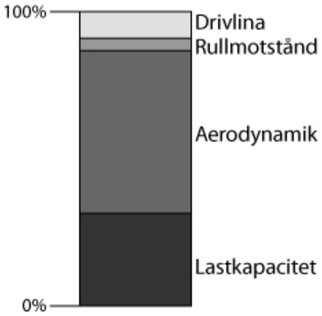
Målet med det här examensarbetet är att utvärdera det existerande ETT-ekipaget och ta fram ett utvecklingskoncept mer optimerat för de aktuella förutsättningarna, med fokus på bränsleförbrukning, säkerhet och identitet hos fordonet.

Processen bygger på Ulrich och Eppingers metod *The Generic Development Process* och den främsta informationskällan är intervjuer med projektmedlemmar och experter. Bland dessa återfinns chaufförer, åkeriägare, skogsindustrirepresentanter, forskare, fordons-, släp- och timmerutrustningstillverkare. Frågor ställs till dessa om fördelar och nackdelar hos ETT-ekipaget och om önskningar och idéer om en framtida version av ETT-ekipaget. Från intervjuerna tolkas utlåtanden och påståenden om till kundbehov som rankas efter viktighetsgrad. De högst rankade behoven berör minskat luftmotstånd och rullmotstånd, ökad lastkapacitet och förbättrad bränsleeffektivitet, förbättrad synlighet av fordonet och att fordonet ska utstråla att det är en komplett transportlösning. Utifrån kundbehoven utförs en konceptgenerering där förslag på lösningar till varje behov tas fram. Alla förslag utvärderas mot kriterier som rör bland annat potentiell bränslebesparing, säkerhetspåverkan, pålitlighet och genomförbarhet.

De som får högst poäng i utvärderingen testas i simuleringar, illustrationer och diskussioner, varifrån ett antal väljs ut till det slutliga konceptet. De utvalda förslagen presenteras till sist kombinerade i utvecklingskonceptet. Kompletta fordonssimuleringar används av flera anledningar i det här arbetet. En modell byggs upp av det befintliga ETT-ekipaget och används som referens för olika förändringar. Tester utförs för att se vilka parametrar som påverkar bränsleförbrukningen mest och var fokus därför bör läggas. Testning och utvärdering av produktkoncepten utförs för att se vilka effekter olika förändringar har, och produktspecifikationerna för utvecklingskonceptet tas fram. Figur 2 visar en bild av konceptfordonet.

**Figur 2.** Fordonskoncept

Resultaten av simuleringar av det slutliga utvecklingskonceptet visar på en möjlig bränslebesparing på cirka 10 % jämfört med det existerande ETT-ekipaget. De främsta förändringarna bidragande till den här minskningen är minskat luftmotstånd, ökad lastkapacitet, en mer optimerad drivlina och minskat rullmotstånd. Även säkerheten förbättras och identiteten förstärks. Figur 3 visar hur mycket av den totala bränslebesparingen de olika faktorerna bidrar till.



**Figur 3.** Olika faktorers del av totala bränslebesparingen

Resultaten visar på att det finns stora möjligheter att förbättra bränsleförbrukningen hos timmerekipage. Vissa uppskattningar på effekten av förändringar som gjorts i arbetet innehåller stor osäkerhet, då nödvändiga beräkningar och undersökningar inte kunnat utföras inom ramarna för examensarbetet. Vissa områden har också helt lämnats utanför arbetet, som till exempel fordonsstabilitet och logistik. Det här behöver undersökas noggrannare i ett led för att förverkliga konceptet.

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# 1 Introduction

*This chapter aims to give an introduction and background information to the thesis work and present the purpose and problem statement. The goal of the thesis, as well as limitations due to time regulations, is presented. The chapter also includes a short presentation of the initiator of the thesis.*

## 1.1 The 'ETT- Modular System for Timber Transport' – Project

The project "ETT – Modular system for timber transport" aims to investigate the possibilities to make logging shipments more effective, decrease their fuel consumption and road wear without compromising traffic safety. This benefits the environment, the road safety and the economy of the forest industry.

The project is a wide cooperation and research project that runs during five years (2007-2011) to study prerequisites and consequences of higher gross combination weights and longer timber trucks. Skogforsk, The Forestry Research Institute of Sweden, leads the project, which is a co-operation with The National Road Administration, the forest industry, Volvo Trucks and other vehicle manufacturers and The Swedish Association of Road Haulage Companies, among others (Skogforsk 2009:1).

As a start, theoretical calculations and analysis work has been carried out on different vehicle combinations with trucks and different trailers (Skogforsk 2009:1). The 'ETT – Modular System for Timber Transport' - project further consists of two practical tests of timber logistics and vehicles;

- ETT – One More Pile (in Swedish ***E****n* ***T****rave* ***T****ill*)
- ST – Bigger piles (in Swedish ***S****törre* ***T****ravar*)

The two sub-projects have together three vehicle combinations that use trailers from the European Modular System, and combine them in different ways, see Figure 1.1 (Larsson 2009). The 'ST- Bigger Piles' -project includes two reinforced timber trucks that will carry heavier loads of timber out of the forest and on country roads in the western part of Sweden (Skogforsk 2009:2).

The 'ETT- One More Pile' – project which this thesis will target, includes one vehicle combination that combines three modular trailers (dolly, link, semi-trailer) and pulls four piles of timber (Larsson 2009).

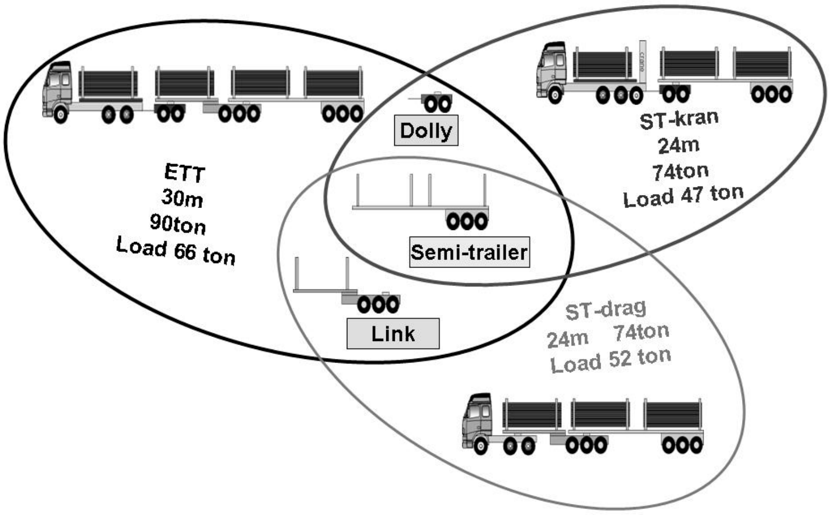

**Figure 1.1.** Vehicle combinations in the 'ETT- Modular system for timber transport' – project

## 1.2 ETT – One More Pile

In the 1980's and the 1990's the restrictions regarding maximum gross combination weight for trucks were increased from 50 tons to 60 tons. This led to a 20% fuel saving and $CO_2$-emission reduction due to the fact that the number of trucks in use was decreased in combination with more efficient use of the remaining. Skogforsk, and other project members, are now looking, through the 'ETT-One More Pile'-project, to increase this percentage even more, by using longer timber vehicles with heavier cargo. By adding one more pile of timber to each vehicle, and also increasing the load in each pile, two logging shipments will be able to replace three, see Figure 1.2 (Skogforsk 2009:3).

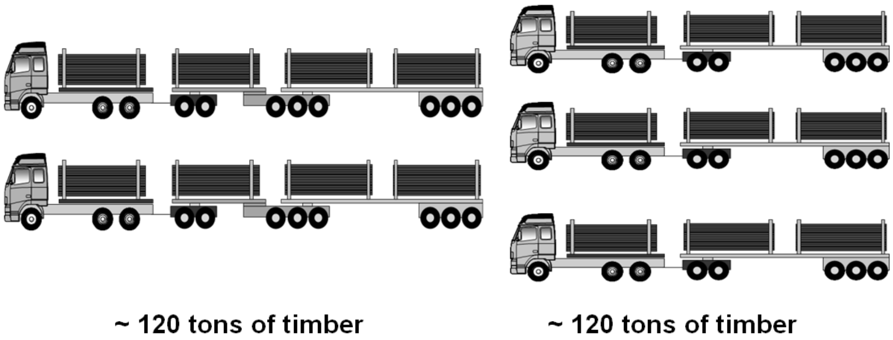

**Figure 1.2.** Two ETT-timber trucks can replace three conventional.

As part of the project, Volvo has in cooperation with other vehicle manufacturers developed and manufactured a vehicle combination that pulls four piles of timber, the ETT-vehicle. This vehicle combination is 30 metres long and has a gross combination weight of 90 tons, as opposed to a conventional timber vehicle that pulls three piles, is 24 metres and has a gross combination weight of 60 tons. The vehicle combination has 11 wheel axles and weighs 24 tons unloaded, giving it a loading capacity of about

66 tons. The hypothesis is that traffic safety will increase thanks to fewer vehicles on the roads, and road wear will decrease due to the weight being distributed on an increased number of wheel axles. The vehicle is now being tested on a distance between Piteå and Överkalix in the north of Sweden (Skogforsk 2009:3).

## 1.3 Purpose

Fuel consumption measurements on the existing ETT-vehicle combination indicate a 20% reduction per ton-km. The numbers are in comparison to test runs with the same towing truck with a four axle trailer and a gross combination weight of 60 tons, a vehicle combination presently often used in timber transport, Figure 1.3 (Löfroth 2009).

**Figure 1.3.** ETT-towing truck with full-trailer

The purpose of this master thesis is to, with the experience gained from the ongoing tests and existing vehicles, present a vehicle combination more optimised for the purpose. Design will, through the whole process, be used as a tool to improve features. The project is unique and could benefit from making some properties more visible, such as the environmental benefits, the modular system and safety issues.

## 1.4 Problem Statement

Questions this thesis is based on are;

- What can be done to save even more fuel?
- How much is the fuel consumption reduced by various modifications?
- What can be done to improve safety?
- How can the identity of the vehicle be strengthened and the benefits of the concept communicated in a more effective way?

Identity includes features that affect how the vehicle is perceived, what impression it gives and its general appearance. When developing the ETT-vehicle, the aim was to keep it similar to conventional timber trucks and not stand out. However, as the project, and the ETT-vehicle, is more accepted over time, certain positive properties as for example transport efficiency, can be emphasised and made more visible.

## 1.5 Objective

The goal of this master thesis is to, together with Volvo and other involved parties, evaluate the existing ETT-vehicle combination and its properties and present solutions for further improvements in the form of a development concept. The concept will optimise the function, value and appearance of the product for the mutual benefit of users, the public and the manufacturers and consider factors such as fuel economy and emissions, safety and the identity of the vehicle. The concept will target development for the near future, suggesting improvements on the existing vehicle combination or a similar vehicle that can be built within the next two to three years. Ideas will be presented to create the "vehicle of our wishes", combining the ideas and wishes of the involved parties.

The result will include a number of technical solutions and industrial design solutions to optimise the vehicle. These will be evaluated with consideration to the impact on fuel savings and safety, where the suggestions and needs of the project members will be considered. A design concept regarding strengthened identity of the vehicle will also be included.

### 1.6 Limitations

Ulrich and Eppinger describes a product concept as "… *an approximate description of the technology, working principles, and form of the product. It is a concise description of how the product will satisfy the customer needs."* (2004 pp 98). Since the goal of this thesis is a product concept, and there is a limited time of 20 weeks, the result will not include detailed technical solutions for all propositions. However there will, in some cases, be general suggestions to overall working principles for the proposed improvements of the ETT-vehicle. It is assumed that the vehicle is combined with parts from the European Modular System. Vehicle dynamics, such as stability or turning radius are not investigated in this thesis.

### 1.7 Initiator of Thesis

This thesis is commissioned by Volvo Technology (VTEC) and Volvo 3P. VTEC is the centre of innovation, research and development within the Volvo Group. Main customers include all Volvo Group companies, Volvo Cars and some selected suppliers. Volvo Technology also participates in national and international research programmes involving universities, research institutes and other companies. Areas they participate in are for example logistics, ergonomics, combustion and mechanics. Important tools in these areas are simulation, modelling and systems engineering (Volvo Group 2009:1).

Volvo 3P is an advanced engineering company which delivers high technology, innovative concepts and ensures the competitiveness of the truck companies in the Volvo Group. The three P's, which are now four, are; Product Planning, Product Range Management, Product Development including Global Engineering and Global Vehicle Development and Purchasing. Volvo 3P collaborate within and outside the Volvo Group, as well as with universities, research centres and industry partners (Volvo Group 2009:2).

# 2 Methodology

*In this chapter the methodology used in this thesis is described. The steps are presented with modifications specific to this project. The method for the Development Concept is based on the Generic Development Process described by Ulrich and Eppinger (2004).*

The method of the thesis is divided into two main parts; see Figure 2.1; The Background Study where background information is gathered, and the Concept Development Process adapted from Ulrich and Eppinger (2004). Interviews are used as a source of information during the whole process. During the development process, the collected material is investigated and analysed before the final result is presented.

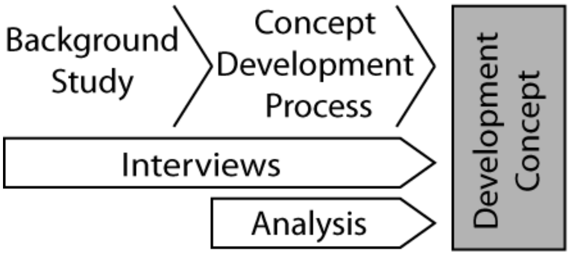

**Figure 2.1.** The process used throughout the project

## 2.1 Interviews

As an important part of the thesis, interviews are held with people involved in the project and experts in different areas. These interviews are a main source of information to the project.

### *2.1.1 Interview Approach*

The aim is to keep the interviews structural as far as possible, asking everyone the same questions to get a more comprehensive material. The questions used in the interviews are mainly open. This gives the interviewee more space to answer in his or her own way, and it also makes it easier to come up with follow up questions (Krag Jacobsen 1993, pp.18-19).

Similar questions are asked all the interviewees, some of them changing a little depending on the background of the interviewee.

According to Lantz, the respondent should be informed about all practical things, such as background, what type of documentation will be used and all terms and confidentiality of the interview (2007, pp.57-58). Therefore all interviews starts with a short introduction to the aim and purpose of the interview and the thesis, and information about how the answers might be used. The interviewees are then asked questions about their profession and involvement in the project, to give an idea of their point of view and position, from which interpretations could be made more easily.

### *2.1.2 Interview Questions*

The introducing questions are about the respondent and their role in the ETT-project. Part two of the interview focuses on their experiences, positive and negative of the project in general. Part three focuses on the ETT-vehicle in particular, starting with how much they have been in contact with the vehicle, and what properties it expresses and emotions it evokes visually. Further the questions focus on positive and negative experiences from the vehicle combination in the field tests, what has worked satisfactory, what has exceeded expectation, what has not worked satisfactory and what could be an issue for improvement? The following questions concern the possibilities and wishes if a new vehicle was to be built, both in a realistic and a futuristic perspective. The closing questions are about the future of the project and this kind of vehicles, possibilities and limitations associated with them.

## 2.2 Background Study

The first step in the thesis is to get a comprehensive knowledge about the project of which this thesis is a part. Basic facts about the vehicle industry, the forestry industry and legislations regarding the forest transport industry are clarified, to get the knowledge necessary to understand the conditions and limitations of the project and the vehicle.

Here the interviews with project members and experts in the areas of interest play an important role and is a main source of information about the ETT-project and ongoing research. By interviewing many people from different backgrounds and with different interests in the matter, a comprehensive knowledge about the project and its context is achieved. Further, research is made mainly from literature, articles and websites.

## 2.3 Concept Development Process

A product development process is a sequence of activities that include conceiving, designing and commercializing a product (Ulrich and Eppinger 2004 pp 12).

The research method used in this thesis is adapted from Ulrich and Eppinger’s *Generic Development Process* (2004, pp 12). This development process is divided into five phases shown in Figure 2.2. The focus of this thesis is phase 1 – *Concept Development* and therefore only this phase will be more thoroughly described in the following sections.

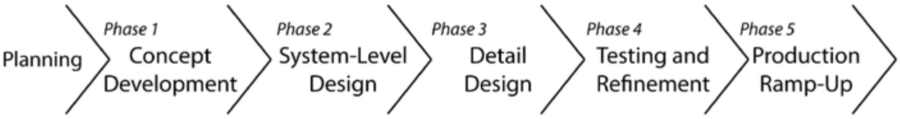

**Figure 2.2.** Generic Development Process (adapted from Ulrich and Eppinger, 2004, pp 9)

### 2.3.1 Planning

The planning precedes the actual development process and identifies the portfolio of products to be developed and also the timing for the market introduction. The first steps in the planning are to identify opportunities, evaluate and prioritize projects, allocate resources and plan timing (Ulrich and Eppinger 2004, pp 34-37). The planning process results in a *Mission Statement*, which includes a description of the product, clarification of the target market and also assumptions and constraints of the product (Ulrich and Eppinger 2004, pp 47). The process of this thesis starts with the formulation of a *Mission Statement*; the foregoing steps are not part of the thesis assignment.

### 2.3.2 Phase 1 – Concept Development

In the Concept Development phase the process is expanded into the *Front-End Process,* see Figure 2.3. This process is, with modifications specific to this project, divided into six sections; *Identifying Customer Needs*, *Product Specifications*, *Concept Generation*, *Concept Selection*, *Concept Testing* and *Selection of Final Concept* (Ulrich and Eppinger 2004 pp 9).

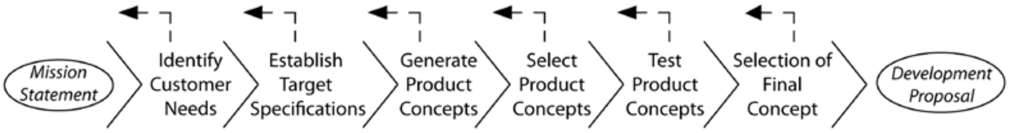

**Figure 2.3.** Front-End Process (adapted from Ulrich and Eppinger, 2004, exhibit 2-3 pp 16)

# 3 Frame of Reference

*In this chapter background information to the thesis is presented. To clarify expressions regarding the vehicle industry, some basic technology about trucks and trailers is presented. This is followed by legislations concerning the transport industry and also background information about the forestry- and transport industry in Sweden. Since the main goal for this thesis is to reduce fuel consumption, factors important to this is also described.*

## 3.1 Basic Truck Technology

There are various types of trucks depending on for what purpose they are built. Regarding towing trucks, two major types are used, the *tractor*, see Figure 3.1, and the *rigid*, see Figure 3.2. The tractor has no cargo space but is instead equipped with a fifth wheel to which trailers can be connected. Rigids have a fixed cargo space, but certain types of trailers are also possible to connect to this type.

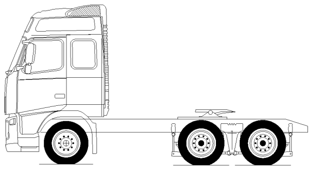

**Figure 3.1.** Tractor

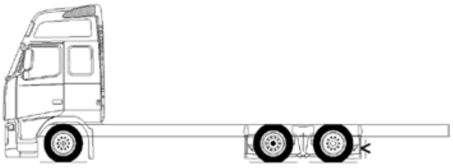

**Figure 3.2.** Rigid

The cab appears in mainly two types; *Normal-Control Cab*, see Figure 3.3, and *Forward-Control Cab*, see Figure 3.4. In the Normal Control cab, the engine is placed in front of the cab (Volvo Truck Parts Corporation 1991, pp 3-5, 145-147). This type is usually used for cargoes with a weight that is heavy in relation to its volume, e.g. for construction sites, and is also popular in the US where the length of the cab is not included in the legislation concerning total length of the vehicle (Hjelm & Bergqvist 2009, pp 470). The Forward-Control Cab is used when the cargo space must be as great as possible. It has the cab above the engine, and to facilitate service of the engine, the whole cab can be tilted forward (Volvo Truck Parts Corporation 1991, pp 145-147).

**Figure 3.3.** Normal Control Cab

**Figure 3.4.** Forward Control Cab

### *3.1.1 Driveline*

The driveline is a collective expression for the engine and the power transmission which includes the clutch, gearbox, propeller shaft and rear axle. The purpose of the power transmission is to transmit the power from the engine to the driving wheels (Volvo Truck Parts Corporation 1991, pp 367).

For heavy trucks, either a manual or an automatic gearbox can be used. One gearbox designed for heavy gross combinations, and well suited for long haul operations, is the I-shift. It is a 12-speed, electronically controlled, automatic mechanical transmission (Volvo Trucks 2009:1). The propeller shaft transmits the power from the gearbox and then angles the driving power 90 degrees through helical gears, i.e. the final drive, and onto the rear axle (Volvo Truck Parts Corporation 1991, pp 67). In case there are two driving rear axles, i.e. tandem drive, the power between the two drives is transferred by a short propeller shaft (Volvo Truck Parts Corporation 1991, pp 84). A truck with one front axle and one rear driving axle is often referred to as a 4x2 truck, and a truck with 2 driving rear axles a 6x4 truck. In case there are two rear axles but only one of them driving, it is called a 6x2 truck (Volvo Truck Parts Corporation 1991, pp 6). On some trucks it is possible to lift one of the rear axles in a bogie (double axles) which is called a bogie-lift.

## 3.2 Trailers

Behind the towing vehicle, rigid or tractor, trailers can be connected to increase the load. There are various types of different trailers and the combination of trailers is mainly depending on if a rigid or a tractor is used and how much load space is needed. In the European Modular System, four types of trailers are used; dolly, centre axle trailer, link and semi-trailer (EMS 2009). Below, a brief description of these three and also a non-modular trailer are presented.

### *3.2.1 Full-trailer*

The full-trailer has both front and rear axles (Wikipedia 2009:1). This type of trailer cannot be combined in a modular trailer system but is used as a single trailer. A full-trailer has a connecting rod and can be coupled to a rigid. One common full-trailer is the four axle trailer that can be seen in Figure 1.3.

### *3.2.2 Centre Axle Trailer*

A centre axle trailer, see Figure 3.5, is a trailer with the wheel axles at the centre of the cargo space. It can be coupled to a rigid, or a semi-trailer (Larsson[1]).

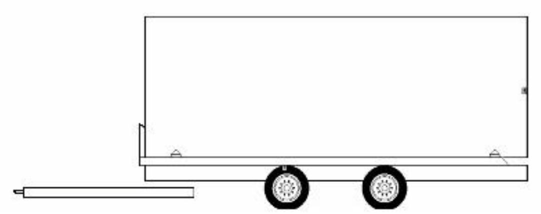

**Figure 3.5.** Centre axle trailer

### *3.2.3 Semi-trailer*

A semi-trailer, Figure 3.6, is a trailer without a front axle. Some of its weight is carried by a tractor vehicle or another trailer with a fifth wheel. Normally, a semi-trailer is equipped with a landing gear which supports the trailer when it has been disconnected from the tractor vehicle (Volvo Truck Parts Corporation 1991, pp 151), (Wikipedia 2009:2).

**Figure 3.6.** Semi-trailer

### *3.2.4 Dolly*

A dolly, Figure 3.7, is a trailer that can be coupled to either a rigid or a semi-trailer. The dolly is equipped with a fifth wheel onto which a semi-trailer or a link is attached (Wikipedia 2009:3).

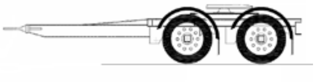

**Figure 3.7.** Dolly

### *3.2.5 Link*

A link, Figure 3.8, is used to link either a tractor vehicle or a dolly with a semi-trailer. The difference between a link and a semi-trailer is that the link, instead of full cargo space, has half the cargo space and a fifth wheel. Usually links have two wheel axles;

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[1] Larsson, Lena, , Technical Project Leader, Volvo 3P, conversation 2010-03-10

however there are links with three axles but then the semi-trailer in general has two wheel axles (Johansson[1]).

**Figure 3.8.** Link

### 3.2.6 Wheel Axle Configuration

The numbers of wheel axles varies depending on the cargo and the driving conditions. There are strict regulations regarding maximum axle load, and this is the reason why the axle loads, and thereby cargo weight is what regulates how many axles are used. The heavier cargo, the more axles are used. Wheel axles can be single, bogie (double) or triple axles, Figure 3.9.

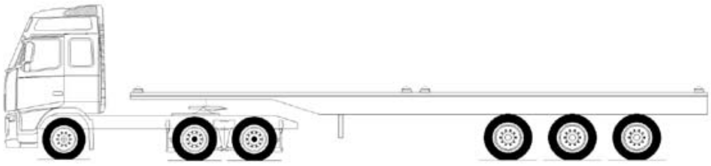

**Figure 3.9.** Single, bogie & triple axles

## 3.3 Laws, Dimensions- and Weight Restrictions

### 3.3.1 Road Classifications

All public roads in Sweden are, in accordance with Trafikförordningen (SFS 1998:1276), divided into three groups (bearing classes), BK1, BK2 and BK3, depending on their load capacity. If nothing else is mentioned, all public roads are within BK1, which is the group of roads with the highest capacity and which includes 92% of the Swedish roads. The ETT-vehicle only drives on BK1 roads, why the following restrictions are for BK1 roads only.

### 3.3.2 Driving Hours

Driving time for truck drivers are strictly regulated, and exceeding them can lead to fines. All newer heavy duty trucks have to have a digital tachograph that registers when the truck is driving, and when it is standing still. The daily driving time can be a maximum of 9 hours, but can be extended to 10 hours twice a week. During the break time no driving or other work should be performed, it should be solely dedicated to recovery. After driving four and a half hour, a break of at least 45 minutes is mandatory. This break can be divided into two parts during the four and a half hours, but then the first has to be at least 15 minutes and the second at least 30 minutes. After

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[1] Johansson, Alfred, Design Engineer, Epsilon, Gothenburg, e-mail 2009-09-29

the break, 45 min or 15+30 min, a new driving period starts automatically (Transportstyrelsen 2009).

### *3.3.3 Dimensions and Gross Combination Weight*

In Trafikförordningen (SFS 1998:1276), chapter 4, following restrictions according gross combination weight, dimensions and wheel axle loads are listed.

Vehicles in Sweden are not allowed to be longer than 24 metres. Exceptions exist for module systems that fulfil certain demands. These can be up to 25.25 metres and permitted width on these vehicles, including cargo, is 2.55 metres. Vehicles, less than 24 metres long and are driven on BK1 roads can have a maximum width of 2.60 metres. The gross combination weight, which includes both vehicle and cargo, depends on the distance from the front to the rear wheel axle on the vehicle. When this distance is 18 metres, or longer, the maximum allowed gross combination weight is 60 tons.

In most of Europe[2] maximum permitted gross combination weight is 40 tons and maximum length is 18.75 meters. The width can be 2.55 meters, and temperature controlled vehicles can be 2.60 meters wide (Rådets Direktiv 95/53/EG 1996).

### *3.3.4 Wheel Axle Load*

The maximum permitted load on a single wheel axle depends on if it’s a driving axle or not. Permitted load on a non driving axle is 10 tons and if it is a driving axle the maximum load is 11.5 tons

The maximum load on a bogie depends on the distance between the axles and can vary from 11.5 – 20 tons. As for a bogie, the maximum load for a triple wheel axle is depending on the distance between the axles and varies from 21 – 24 tons.

## 3.4 Road Transport in Sweden

At the end of 2008 there were about half a million trucks in use in Sweden, whereof 16 percent were heavy trucks (SIKA 2009, pp. 9). Heavy trucks are in Sweden defined as trucks with a gross combination weight over 3.5 tons, requiring a heavy truck driver’s licence (STR 2009).

The number of trucks in Sweden is increasing, but practically only the number of light trucks (gross combination weight under 3.5 tons). The heavy trucks however, instead increase in load capacity (SIKA 2009, pp. 10). The most common trucks have a loading capacity between 35-45 tons. 87% of the transportation (ton-kilometres) was in 2008 carried out by trucks with a total weight over 55 tons. Really heavy trucks with loading capacities over 50 tons, have however decreased since the year 2000, mainly due to restrictions in the EU (see chapter 3.3.2) (SIKA 2009, pp. 13).

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[2] Finland also has the same regulations as Sweden. Holland and Denmark are doing tests on heavier and longer vehicles and in Germany there are some tests being performed on these types of vehicles.

The total amount of transported goods in Sweden has been increasing almost every year for many years now (SIKA 2009, pp.3). Heavy trucks registered in Sweden with a maximum loading capacity of at least 3.5 tons, travelled 2900 million kilometres and transported 367000 million tons of cargo during the year of 2008. Each transport carried in average 15.5 tons load (SIKA 2009, pp.5).

An average heavy duty truck travels 52 000 km a year (2008), generally the higher the load capacity, the longer distance it travels (SIKA 2009, pp. 10). The most common number of wheel axles is seven, 75% of the cargo was transported in trucks with seven wheel axles or more (SIKA 2009, pp.13).

Soil, stone, gravel and sand made up a forth of the transported amount measured in tons, and other big parts include round wood, mixed cargo, groceries, drinks and tobacco (SIKA 2009, pp.5).

### 3.4.1 Trucks and Railway in Round Wood Transportation

Forest and forest industry transport make up about 25%, in ton-km, of all land transports in Sweden. About 50 million tons of round wood is transported each year with trucks, 7.5 million tons on railway and 2.1 million tons by boat (numbers are from 2006, but have been similar since). On road the average transport distance was 88 km and total transportation was 4 612 million ton-km in 2006. The total road network in Sweden is about 419 000 km; where about half of the roads are forest vehicle roads. The rail network is about 11 700 km. 2 000 km of forest vehicle road was built in Sweden in 2007 (Skogsstyrelsen 2009).

### 3.4.2 Environmental Objectives 2020

During 2008 EU decided the emissions of carbon dioxide should be reduced by 2020, to at least 20% below the levels of 1990. A mean to get there is to make the use of energy 20% more effective and increasing the share of renewable energy use (Miljömål 2010).

The main emissions from trucks are carbon dioxide ($CO_2$) and nitrogen oxides ($NO_x$). The carbon dioxide is increasing due to more and heavier trucks, but the nitrogen oxides are decreasing, however slowly, thanks to more advanced emission after treatment. (SIKA 2009 pp 10)

### 3.4.3 European Emission Standards

The European emission standards define the acceptable limits for exhaust from vehicles. For large goods vehicles, the emissions regulated by these standards are carbon monoxide (CO), hydrocarbons (HC), nitrogen oxides (NOx), particulate matter (PM) and smoke. There are in total seven standards; Euro 0 – Euro VI, however Euro VI is not standard until 2014, and Euro V just became standard in 2009. The chart below, Table 3.1, shows the limits for standard Euro IV, Euro V and EURO VI for heavy trucks (Gerson Lehrman Group 2010).

**Table 3.1.** European Emission Standards

| | Date applied | CO | HC | NOx | PM | Smoke |
|---|---|---|---|---|---|---|
| **Euro IV** | 2005 | 1.5 | 0.46 | 3.5 | 0.02 | 0.5 |
| **Euro V** | 2009 | 1.5 | 0.46 | 2 | 0.02 | 0.5 |
| **Euro VI** | 2014 | 1.5 | 0.13 | 0.4 | 0.01 | - |

## 3.5 Swedish Forest Industry

The forest industry[3] is one of Sweden's largest industries and very important to the economy due to high export rate. It accounts for 10-12 percent of total employment and turnover in Swedish industry, and 11 percent of exports. This makes it relatively large compared to other EU-countries, with the exception of Finland, who also has a permitted maximum load of 60 tons, and a large forest industry.

Sweden is a major player in the forest industry globally, and the second largest exporter overall of paper, pulp and sawn timber in the world. More than 85% of the produced pulp and paper is exported and 70% of sawn timber. Europe is the biggest market, with Germany, Great Britain and France as important customers. Sweden and Finland are leading the way in pulp and paper technology in Europe and the world.

The forest is not only important to the national economy, but also to the climate as it binds carbon dioxide, provides biofuel and recycled fibres that are increasingly important as raw material.

Sweden's largest forest companies (by turnover) are Stora Enso, SCA, Holmen and Billerud (Swedish Forest Industries Federation 2009:1).

### *3.5.1 The ETT-project's Importance to the Forest Industry*

The forest sector[4] is a powerful network in Sweden since it cooperates with many other sectors like machine industry, transport, chemical industry, construction and more. This cooperation includes research and education, such as the ETT-project, and leads to employment, knowledge and development within the industry.

A goal for the Swedish forest industry is to reduce its emissions of fossil $CO_2$ from transportation by 20 percent. Here longer, heavier and more fuel efficient timber shipments can play a large role in fulfilling the goal (Swedish Forest Industries Federation 2009). Another issue is that the value of the timber is very low compared to the transport costs hence there are high demands on transport efficiency in the forestry industry (Svensson[5])

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[3] The forest industry in this case includes the pulp and paper industry, the sawmill industry, the wood board industry, production of packaging from wood, paper and board, and the joinery industry. The single largest sector is the paper industry.

[4] The forest sector is defined here as forestry and the forest industry.

[5] Svensson, Gunnar, Researcher, Skogforsk, conversation 2009-03-05

## 3.6 Fuel Consumption of Heavy Trucks

The negative environmental effects and the likely increase of fossil fuel cost, puts high demands on increased fuel efficiency and alternative fuels for heavy vehicles such as trucks. To increase the fuel efficiency of diesel powered trucks there are several aspects that have potential to be improved, e.g;

- Maximise the payload
- Decrease rolling resistance
- Decrease aerodynamic drag
- Optimise the driveline
- Increase the efficiency of the logistics system

The single most important factor when considering fuel consumption per ton-km is the load. The more load carried on each vehicle, the more efficient the transport is. Aerodynamic drag and rolling resistance are normally the things contributing the most to the fuel consumption of heavy trucks with a fixed load capacity. However it is also affected by factors like the efficiency of the driveline, the logistics surrounding the transport, the driver behaviour, the inclination of the road, the number of accelerations and decelerations, the speed, the equipment and the weather (Volvo Trucks 2009:2).

### 3.6.1 Rolling Resistance

The wheels and tires play a crucial role in the operation of a vehicle, and have a big impact on the fuel consumption of heavy duty trucks. The vehicle-ground contact causes a rolling resistance that must be overcome by the driving torque, the load distributed over all the wheels must be carried and the inertia of the wheels must be overcome when accelerating and decelerating (Tire Rack 2009). Since the vehicle combination studied in this report has few stopping points on its service path, the inertia of the wheels has a negligible impact on its fuel consumption.

If wheels and roads were undeformable there would be no resistance between them, hence no tractive force would be necessary to keep the wheels rolling. However, there is no such thing as perfectly undeformable bodies. In the case of a pneumatic tire rolling on tarmac, almost the whole deformation is localised in the tire. The energy loss due to internal damping when the material deforms and springs back is what causes the rolling resistance. The friction in the hub, the aerodynamic drag on the disc and sliding between road and wheel, only bring a small contribution, a few percent, to the overall resistance (Genta 2006, pp 41).

The rolling resistance, $F_R$ is proportional to the load, hence the normal force acting on the tire, and is expressed as

$$F_R = C_R F_L \qquad \text{(Equation 1)}$$

where $C_R$ is a rolling coefficient and $F_L$ is the load. The rolling coefficient must be determined experimentally and depends on many parameters; the travelling speed, the inflation pressure, the normal force i.e. the load, the size of the tire and the contact zone, the pattern and the material, the temperature, road conditions and forces exerted by the wheel (Genta 2006, pp 43). The rolling resistance is proportional to the tire load, and hence if the rolling coefficient was constant, only the total weight and not the number of wheels would influence the total resistance. However, the properties of the tire and the rolling coefficient change with the load. A tire is normally more efficient when subjected to a higher load. The relationship between load and rolling coefficient is not linear, and varies between tires of different material and patterns. Measurements of the rolling coefficient on tires are performed after a standard where the tire is loaded with 85% of its maximal load and rolled on a drum, and the rolling coefficient is measured, see Figure 3.10.

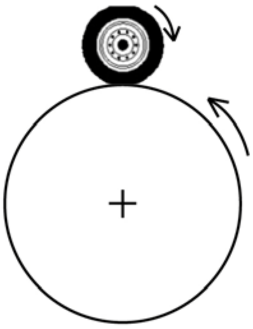

**Figure 3.10.** Drum test

The value measured on the drum must then be transformed into a value for flat road. This is done with the following formula:

$$C_{R,plan} = C_{R,drum} \cdot \left( \frac{1}{1 + \left( R_{tire} / R_{drum} \right)} \right)^{0.5} \qquad \text{(Equation 2)}$$

where $C_{R,plan}$ is the value of the rolling coefficient on flat ground, $C_{R,drum}$ the rolling coefficient from the drum measurement, $R_{tire}$ the radius of the tire and $R_{drum}$ the radius of the drum.

To see how the rolling coefficient varies depending on the axle loads, another formula can be used:

$$C_R = C_{R,ref} \cdot \left( \frac{Z}{Z_{ref}} \right)^{-0.1} \qquad \text{(Equation 3)}$$

where $C_R$ is the value of the rolling coefficient, $C_{R,ref}$ the rolling coefficient in the 85% load case, Z the load to study, and $Z_{ref}$ 85% of the load capacity of the tire. This formula has a validity field around the $Z_{ref}$-value of about ±15% (de Giacomoni[6]). Figure 3.11 shows a graph of how the rolling coefficient varies with the load.

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[6] de Giacomoni, Jacques, Technical Account Manager Trucks Original Equipment, Michelin Tires, Conversation/e-mail Nov-Dec 2009-12-04

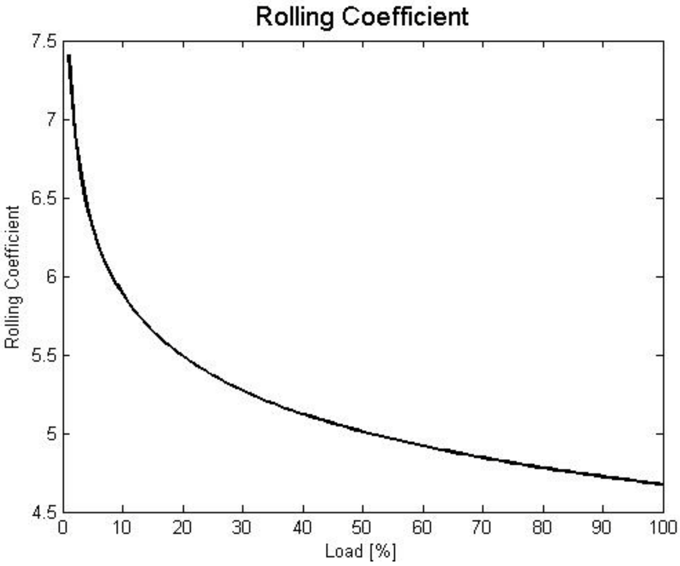

**Figure 3.11.** Rolling coefficient dependency on tire load

### *3.6.2 Aerodynamic Drag*

#### 3.6.2.1 Fluid Mechanics

Fluid mechanics is the study of the behaviour of fluids, in rest or in motion. A fluid is defined as a substance that will deform continuously (flow) when acted upon by a shearing stress; hence fluids are liquids and gases. When acted upon by a pressure, a liquid will not compress notably in opposite to gases that are highly compressible (Young et al. 2004, pp 9). Changes in gas density affect the pressure and temperature according to the Ideal Gas Law

$$p = \rho RT \qquad \text{(Equation 4)}$$

where p is absolute pressure, ρ is the density, R a gas constant and T the absolute temperature. The gas constant R depends on the particular gas.

#### 3.6.2.2 Viscosity

To describe the “fluidity” of a fluid the term viscosity $\mu$ is used. It describes the rate of angular deformation of a fluid when subjected to shearing stress. Fluids that have a linear relation between stress and deformation are called Newtonian fluids, and this includes most fluids. The viscosity is highly dependant on the temperature (Young et al. 2004, pp 11-12). For example at 15.0 °C, the viscosity of air is $1.81 \times 10^{-5}$ Ns/m$^2$, and at 100 °C it is $2.21 \times 10^{-5}$ Ns/m$^2$ (LMNO Engineering, 2003).

#### 3.6.2.3 Reynolds number

A parameter used to describe the relationship between the inertia force and the viscous force in a fluid, is Reynolds number, Re

$$\mathrm{Re} = \frac{\rho V l}{\mu} \quad \text{(Equation 5)}$$

where ρ is the fluid density, V the mean fluid velocity, $l$ the characteristic length and μ is the fluid viscosity (Young et al. 2004, pp 281).

The flow past a body depends strongly on Reynolds number. The higher the value of Reynolds number, the higher are the inertia forces and the lower the impact from viscous forces. When passing a body, fluids with low a Re get affected by the body far from the body in all directions and this distance is reduced with an increased Re, see Figure 3.12. Since the viscosity never is zero, the fluid velocity on the solid surface of the body is zero. The layer where the velocity changes from the stream velocity to the zero velocity on the body surface is called the boundary layer and this layer is increased with lowered Reynolds number. This layer is also affected by if the flow is turbulent or laminar, the more turbulent the flow, the wider the layer. The body has very little effect on the streamlines outside the boundary layer. However, the wake region behind the body is due entirely to the viscous interaction in this layer (Young et al. 2004, pp 367-370).

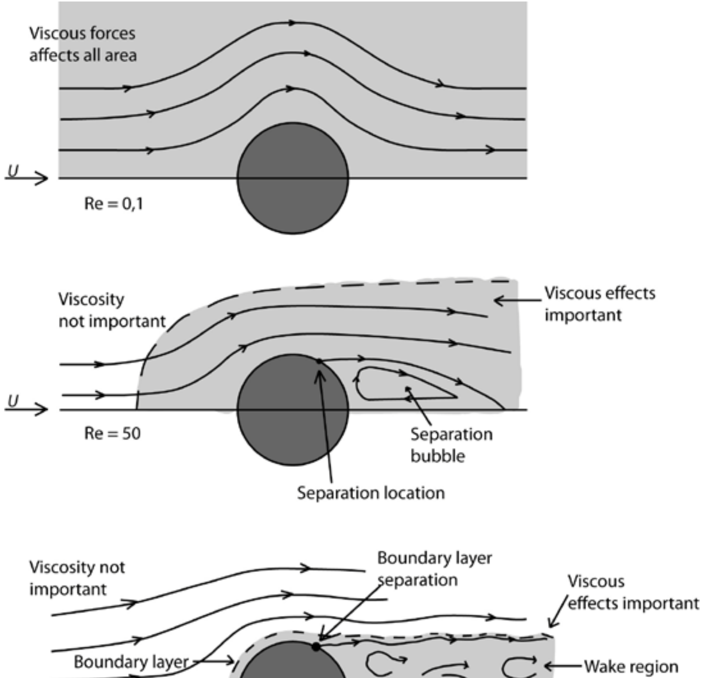

**Figure 3.12.** Character of flow past a body (adapted from Young et al, 2004, fig 9.5 pp 369)

### 3.6.2.4 Aerodynamics of Heavy Duty Trucks

The aerodynamics of commercial vehicles has been explored for over 70 years. In 1936 the Labatt Brewing Company developed a streamlined truck to be able to go faster and carry larger loads compared to conventional trucks at that time. The Labatt truck could go 24 km/h faster and carry 50% larger load. However, today the focus of aerodynamic drag reduction has changed from speed to fuel economy and emissions reduction (Cooper 2004, pp 9).

The Aerodynamic drag, D, is expressed as

$$D = C_D A \frac{\rho}{2} v^2 \qquad \text{(Equation 6)}$$

where $C_D$ is a non-dimensional drag coefficient, A is the projected frontal area, ρ the density of the air and v is the vehicle's speed relative to the air (Hucho 1998, pp 3). $C_D$ is a function of a number of parameters such as the shape, Reynolds number, the viscous effects and thereby the boundary layer, and the surface roughness (Young et al. 2004, pp 385-395). Parts of the vehicle important to the $C_D$ is the overall shape of the vehicle, both front, sides, top and rear, details such as mirrors and signs on the cab, gaps between truck and trailers and the surface of the vehicle. Gaps between truck and trailer, or trailers, should be less than 0.5 m wide not to affect the drag substantially (Tenstam[7]). Due to the complexity of aerodynamic drag it is difficult to make analytic calculations of the $C_D$ value, hence most information known about drag and different shapes are taken from a numerous of wind-tunnel tests (Young et al. 2004, pp 385), but also computational fluid dynamics (CFD) is a method used to approximate drag coefficient (Young et al. 2004, pp 259).

In the research to reduce drag resistance on heavy trucks, much effort has been put into the tractor. Reshaping the front of the truck is relatively easy and has given large drag reductions. Some effort has also been put into trailer modifications and devices. For example, rounded-edged truck bodies have now become standard. Tractor-trailer gap seals, trailer skirts, trailer boat-tailing and tractor-trailer integration have also been studied. However, aerodynamic devices are rarely used due to for example expensive investments but also lack of knowledge what it would do to the fuel consumption (Cooper 2004, pp 10). The aerodynamic drag increases significantly with increased speed, why air-drag reductions is of high importance for highway driven trucks (Hucho 1998, pp 415).

### *3.6.3 Optimising the Driveline*

A vehicle driveline is designed to meet specific performance criteria, and desirably, at the same time, be as fuel efficient as possible. Choice of engine, transmission, axle ratio, transmission shift points and ratios are important in this optimisation. Performance criteria are very much depending on the type of driving conditions and transport work that will be performed by the vehicle.

A diesel engine typically has an efficiency of about 35-45%, depending on its operational point considering torque and speed (Wikipedia 2010:1). The efficiency of a specific engine can be plotted in an engine efficiency plot, in Figure 3.13 this is done for the Volvo engine D16e660hp. As can be seen in this plot it is desirable that the

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[7] Tenstam, Anders, Team Leader Vehicle CFD, Volvo Technology, conversation 2009

engine as far as possible has a working point where the efficiency is high. In this particular case this is when the torque is about 3000Nm and the engine speed is around 1200 rpm.

Continuous development is made by vehicle manufacturers to improve the efficiency of engines and minimise the energy losses in the transmissions. It can however be troublesome to find an ultimate solution for many vehicles, since their operational conditions can be very varying.

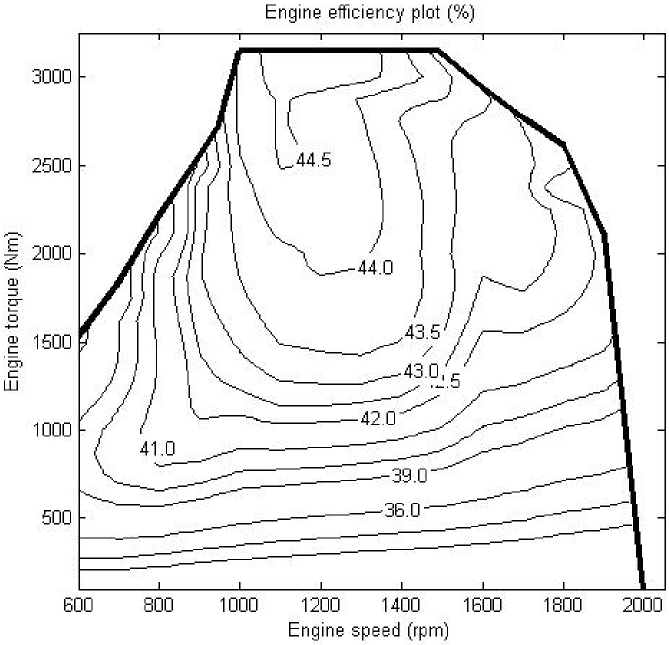

**Figure 3.13.** Engine efficiency plot for Volvo D16e660hp

### *3.6.4 Increasing the Efficiency of the Logistics System*

The logistics of goods transport is an important consideration when it comes to fuel efficiency and transport economy, especially when handling large vehicle fleet. In round wood transport it is very common that load is only transported half of the total travelled distance, the return trip, in most cases, is with empty vehicle. The trucks are especially built to carry round wood and the material flow is one-way, and therefore load is only carried out of the forest. This has a negative effect on the fuel efficiency.

Another obstacle in round wood transport is the varying quality of the roads that have to be travelled, and the activity of loading the timber onto the truck. The timber trucks often have to drive on small narrow forest roads, as well as paved high-ways, which complicates the choice of driveline, equipment and tires, since none are optimised for both purposes. The timber can be loaded onto the truck and trailers with a separate crane that is left in the forest, or with a crane that is permanently attached to the truck. The benefits of having a permanent crane are that the work is performed quickly and without having to move and attach the crane to a power source, but it adds to the weight of the vehicle, making the effective load smaller.

# 4 The ETT Vehicle

*The ETT-vehicle combination is the focus of this study, and a development concept will be the result. To be able to make a development concept, the present vehicle combination has to be clearly described, which is the aim of this chapter.*

**Figure 4.1.** The ETT-vehicle fully loaded on road

## 4.1 Technical Specification

The ETT-towing vehicle is a rigid Volvo FH16 660 hp 6x4. This means it has a high, front control cab with a 16 litres diesel engine and two out of three driving wheel axles, in this case the two rear axles.

### 4.1.1 Dimensions and Weight

The vehicle combination, Figure 4.1, towing vehicle and trailers, measures 29.4 metres, and is 2.60 metres wide. The maximum allowed height is 4.50 metres.

The tare weight of the vehicle is about 24 tons, and with a maximum gross combination weight of 90 tons it has a loading capacity of about 66 tons.

### 4.1.2 Trailers

The towing truck pulls three trailers; a dolly with a fifth wheel is connected to the rigid towing vehicle, a link with a second fifth wheel is connected to the dolly and a semi-trailer is connected to the link, see Figure 4.2 (1-3). One pile of timber is loaded onto the truck, one onto the link, and two onto the semi-trailer, see Figure 4.2 (4). The trailers are built by trailer manufacturer Parator[8], on the semi-trailer using the SSAB Domex 700 high strength steel quality, which is lighter than the steel regularly used in trailers. The use of this steel quality has reduced the weight of the vehicle with about 250 kg[9], compared to regular steel quality.

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[8] www.parator.com

[9] Olsson Per, CEO Parator, e-mail 2009-12-01

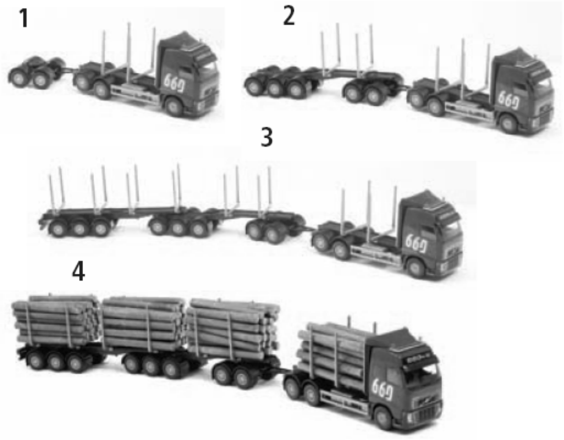

**Figure 4.2.** ETT-vehicle, with dolly (1), link (2), semi-trailer (3) and load (4)

### 4.1.3 Timber Equipment

The vehicle combination is equipped with a timber superstructure from BergsFegen[10], including timber bunks from ExTe[11]. There is a front wall behind the cab, to prevent the timber from hitting the back of the cab in case of a collision or malfunction of the load fastening equipment. The timber bunks are of the type A9, which are aluminium bunks, the lightest available on the market today. The load is fastened by a chain around the timber that is automatically strained by a pneumatic strainer. On the truck the strainers are of the type Luftman, and on the trailers of the type Grizzly.

### 4.1.4 Weight Distribution

The total weight is distributed on 11 wheel axles, which is four more than on a conventional timber truck that is 24 metres, has a gross combination weight of 60 tons and usually 7 wheel axles. Due to the increased number of axles compared to weight, and a carefully designed weight distribution, the axle loads are decreased, hence reducing the road wear. The average axle load will be 8.2 tons instead of 8.6 tons. The distances between wheel axles and trailer connections are determined so that the vehicle has optimal handling, stability, weight distribution and acceptable off tracking when loaded. Figure 4.3 below shows the approximate weight distribution in kg per axle in the loaded and unloaded case.

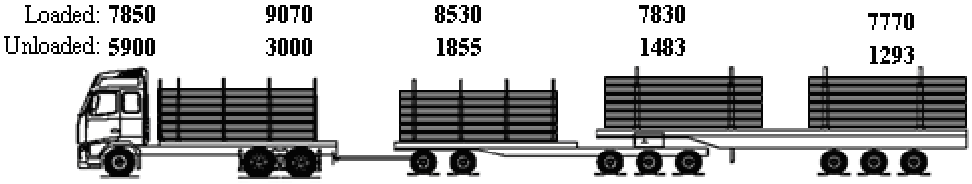

**Figure 4.3.** Weight distribution in kg per axle when the vehicle is loaded and unloaded

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[10] www.bergsfegen.se

[11] www.exte.se

### 4.1.5 Engine

The engine, D16E660 EU4, is a 16 litre, six cylinder engine that produces 660 hp and a maximum torque of 3100Nm. The emission level is standard Eu4[12].

The engine is equipped with VEB+ (Volvo Engine Brake), a high-efficiency engine braking system that can regulate the gas pressure inside the cylinders and produce an extremely high, smooth braking output. In combination with cruise control, VEB+ also gives better fuel economy and higher average speed (Volvo Truck Corporation 2009:1).

### 4.1.6 Power Transmission

The gearbox, ATO3112C, is a Volvo I-shift, an electronically controlled 12-gear automatic mechanical gearbox with overdrive. It has a fast gear changing system with minimum interruption in torque delivery and is dimensioned for 3100 Nm. The gears can also be changed manually (Volvo Truck Corporation 2009:2).

The driving rear axle, RTS2370A, is a tandem axle which is intended for heavy and demanding transport. Two driving wheel axles provides high driving force, high traction and low tyre wear (Volvo Truck Corporation 2009:3).

### 4.1.7 Suspension, Wheels and Tires

The front axle is mechanically suspended with a parabolic leaf spring, and the rear axles have air suspension. All the trailers have air suspension. On the rear bogie axle of the driving axles a bogie lift was installed in December 2009 to improve the grip. There are in total 26 wheels on the ETT-vehicle which are distributed over 11 wheel axles, see Figure 4.4.

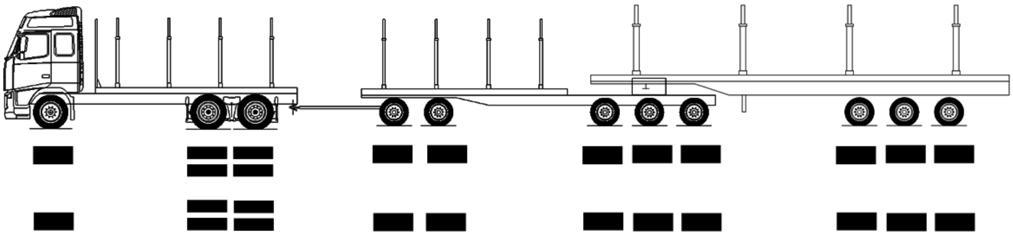

**Figure 4.4.** Wheel configuration on the ETT-combination

All tires are from Michelin and the tire specifications for the summer tires are listed in Table 4.1.

**Table 4.1.** Tire Specification Summer

| | Front axle | Drive axle | Dolly | Link | Semi-trailer |
|---|---|---|---|---|---|
| **Tire dim.** | 385/65R22.5 | 315/80R22.5 | 445/45R19.5 | 445/45R19.5 | 385/55R22.5 |
| **Tire Pattern** | XFA1+ | XDA2+ | XTA2 | XTA2 | XTE2 |

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[12] Eu5 was not yet standard when this vehicle was built

The driving wheels have an effective rolling radius of about 525 mm in the fully loaded case. The effective rolling radius is calculated from the actual distance the wheel has travelled in one revolution in operation and depends highly on the load (Genta pp. 38). The rolling radius of the driving wheels affects the engine's rotational speed.

### 4.1.8 Braking System and Weight Information

The ETT-vehicle combination is equipped with electronic braking system, EBS. The electronic activation of the braking components reduces the response time and reduces the braking distance with several meters. The system also has an integrated Anti-lock Braking System (ABS) that makes sure the wheels are never locked and ensures stability and steerability during braking (Wabco Automotive 2009:1).

The truck's braking control system is manufactured by Knorr[13] and the brake control system on the trailers comes from Wabco Automotive[14]. There is an automatic brake adjustment between the truck and the trailers to make sure the truck and trailers brake equally and at the same time (Volvo Trucks 2009:3). Since the ETT-vehicle has several trailers, Wabco Can Routers are used, since it allows the operation of two or more trailer EBS systems, communicating via CAN signals (Wabco Automotive 2009:2). This gives the ETT-vehicle combination a braking path length comparable to one of a 60 ton vehicle. The braking systems work according to ISO 11992, a CAN based vehicle bus standard for heavy duty truck industry, ensuring the compatibility between the different manufacturers (CiA 2010).

The braking modules on each axle group have a system for measuring the weight through a sensor in the air bellows. This weight information can be seen on a screen inside the cab and helps the driver to get the right gross combination weight, and to distribute the load so that correct axle loads are achieved. The braking modules use this information to adapt the brake force distribution to the load distribution.

### 4.1.9 Cab

The cab is a standard Volvo Globetrotter cab with four seats. It is equipped with a small roof wind deflector and side deflectors. There is an arch with four round spotlights on the roof, and grill arch with 4 round spotlights in the front. The headlights are xenon lights, which give the best light and colour reproduction. The cab is also equipped with a game fence, since there is a high risk of hitting reindeers and other wild animals on the path were the truck operates.

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[13] http://www.knorr-bremsecvs.com

[14] www.wabco-auto.com

**Figure 4.5.** Front view of the ETT-vehicle

## 4.2 Service Path and Fuel Consumption

The vehicle combination is a highway truck which does not drive on small forest roads; hence the timber is collected from the forest by a conventional truck with three piles of timber and a gross combination weight of 60 tons, and reloaded to the ETT-vehicle at a loading terminal in Överkalix. The ETT-vehicle then transports the timber from Överkalix to a sawmill in Piteå, a distance of about 160 km, see Figure 4.6 (Skogforsk 2009:4).

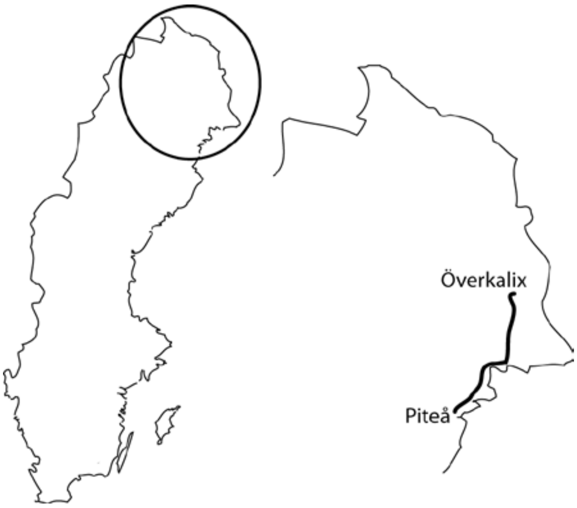

**Figure 4.6.** Service path of the ETT-vehicle

The topography of this service path is by Volvo defined[15] as predominantly flat, and the road surface is smooth. The route has a maximum gradient of 4% and maximum of 80 m height difference, as can be seen in Figure 4.7.

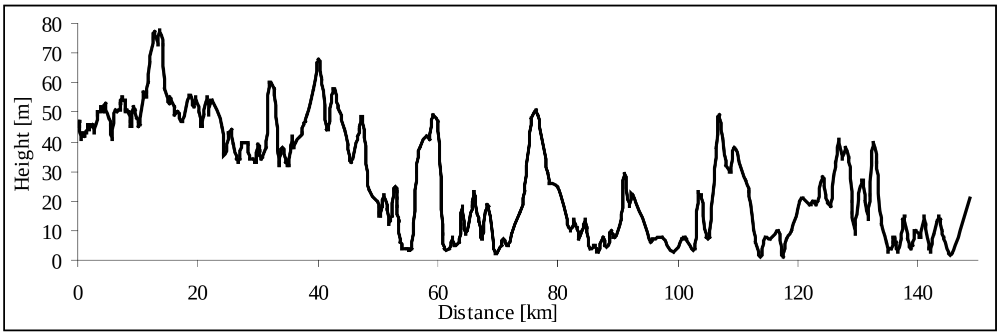

**Figure 4.7.** Topography of service path

The National Road Administration has issued a special regulation allowing the use of heavier and longer vehicles on this specific path. It includes certain restrictions, e.g. the vehicle's maximum possible speed is limited to 80km/h and the weight must be easy to check from inside the cab. The load on each axle group is within the limits of the current regulation, but the gross combination weight can exceed 60 tons. Especially important is the vehicle speed when crossing certain bridges, on one it cannot exceed 15 km/h. The vehicle must also have signs in the front and back with the text "Lång last", meaning "Long cargo" in English, see Figure 4.5 (VV 2008).

### *4.2.1 Dynafleet*

The ETT-vehicle is equipped with Dynafleet, Volvo Trucks' online Transport Information System. With Dynafleet you can see its current location, the fuel consumption, messages, driver times, driver activity, maps, service intervals and much more (Volvo Trucks 2009:4).

### *4.2.2 Fuel Consumption of the ETT-vehicle*

From measurements with Dynafleet during two weeks in June 2009, the fuel consumption for the ETT-vehicle has been estimated, see Table 4.2.

**Table 4.2.** Measured fuel consumption - ETT-vehicle [l/10km]

| | |
|---|---|
| Loaded (Överkalix-Piteå) | **7.22** |
| Unloaded (Piteå-Överkalix) | **3.64** |

Measurements on a reference 60 ton timber truck during the same weeks gave the fuel consumption results presented in Table 4.3.

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[15] According to Global Transportation Application

**Table 4.3.** Measured fuel consumption – 60 ton timber truck [l/10km]

| | |
|---|---|
| Loaded (Överkalix-Piteå) | **5.47** |
| Unloaded (Piteå-Överkalix) | **3.14** |

### 4.3 Safety

Safety is one of Volvo’s core values, and something that is never compromised. Volvo has several advanced safety systems available for trucks. The ETT-vehicle is equipped with some of them, and they are described here.

The cab is equipped with airbags and the seat belts have pretentioners, a powder charge that tenses the seatbelt in case of a collision. It makes the seat belt respond quicker and increases driver and passenger safety.

The vehicle has a speed limiter sensor that limits the speed of the vehicle to 80km/h and there is a smoke detector and alcohol-lock in the cab. The Lane Support system has a camera that watches the lane markings and warns the driver if he or she crosses one. It helps prevent off-roading accidents caused by fatigue or distraction.

The truck is equipped with a back-up monitor, a camera that helps the driver reverse. However it is on the ETT-vehicle mounted behind the truck, and not the last trailer, and the help is hence very limited when driving the full vehicle combination.

The link and semi-trailer have side under-run protection in the form of sheet metal between the wheels, and the towing truck has it in the form of two parallel horizontal beams (Wrige[16]).

---

[16] Wrige, Anna, Leader Volvo Trucks Accident Research Team, Volvo 3P, E-mail 2009-10-21

# 5 Concept Development Process

*The development process used in this thesis is adapted from the Generic Development Process described by Ulrich and Eppinger (2004). In this thesis the first step is a Mission Statement, which is followed by the Concept Development phase, where the Front-End Process is used.*

## 5.1 Concept Development – The Front-End Process

A concept development is a complicated process where activities often overlap and iteration is needed. The concept generation process applied in this study is adapted from the *Front-End Process* presented by Ulrich and Eppinger. The activities included are presented in fig Figure 5.1.

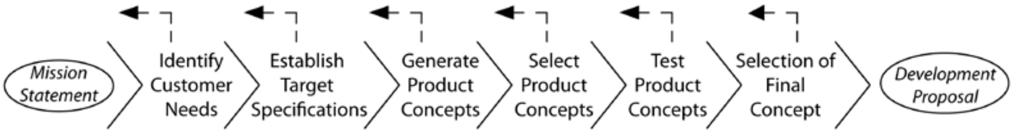

**Figure 5.1.** Front-End Process, Adapted from Ulrich and Eppinger (2004)

## 5.2 Mission Statement

To get a clear foundation for the concept generation phase, a detailed definition of the target market and the assumptions made for the product, i.e. a mission statement is formulated, see Table 5.1. Its content is adapted from Ulrich & Eppinger (2004 pp. 47-48).

**Table 5.1.** Mission Statement: More Efficient Timber Truck Concept

| | |
|---|---|
| **Product Description:** | ▪ **More efficient high-way timber truck with trailers from European Modular System** |
| **Concept Goals:** | ▪ Improve fuel efficiency with 25% compared to 60 ton truck<br>▪ Improve timber transport economy<br>▪ Strengthen product identity<br>▪ Improve safety<br>▪ Market introduction within 2-3 years |
| **Primary market:** | ▪ Swedish and Finnish timber-hauliers and drivers with long distance transports where railway is not an option |
| **Secondary market:** | ▪ Forest companies |
| **Assumptions and constraints:** | ▪ Modular system<br>▪ High-way application<br>▪ Timber superstructure<br>▪ Axle loads maximum 9 tons<br>▪ Longer and heavier than conventional timber trucks |
| **Stakeholders:** | ▪ Users; chauffeurs, hauliers, forest industry<br>▪ Government ($CO_2$, road wear & bridges)<br>▪ Other road users<br>▪ Vehicle manufacturers |

### *5.2.1 Assumptions and constraints*

It is assumed that the truck is a highway truck, supposed to be used on tarmac roads, and most of the time travels at a high speed, up to 80 km/h. It will transport at least four piles of timber, and include trailers that are part of the European Modular System.

The maximum axle load should not exceed 9 tons. It is assumed that the truck will be longer and heavier than a conventional vehicle combination allowed within the regulations today, which are 25.25 m and 60 tons gross combination weight, GCW.

The towing vehicle should as far as possible be a standard truck from Volvo. Parts in the driveline exist today or are planned for release within a year from Volvo Trucks Corporation. Road safety must not be compromised to any extent.

# 6 Identifying Customer Needs

*In this chapter the concept development is initiated with the activity of identifying customer needs. It begins with the targeting of customers, gathering of raw data from customers and interpreting the data into customer needs. The interpreted needs are then organised into a hierarchy of primary, secondary and tertiary needs, and finally the relative importance of the needs is established.*

## 6.1 The Process of Identifying Customer Needs

The process of identifying customer needs is a part of the *Front End Process*, see Figure 6.1.

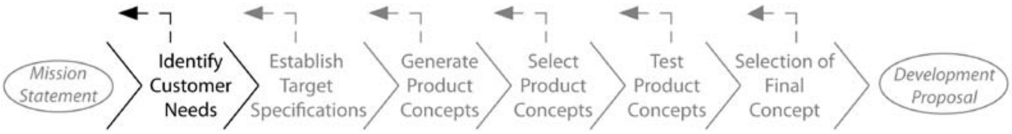

**Figure 6.1.** Identifying Customer Needs, adapted from Ulrich and Eppinger (2004)

It has in turn the following steps;

1. Targeting Customers
2. Gathering raw data from customers
3. Interpreting raw data into customer needs
4. Organising needs into a hierarchy
5. Establishing relative importance of needs

## 6.2 Targeting Customers

The ETT-project is a project with a limited number of involved people. So far there is only one four-pile timber vehicle in field test; hence the actual users are few. The project members are in this study chosen as the customers, since they are the ones with sufficient knowledge about the project and the vehicle. However, there are many potential customers to this vehicle, and in further research, if informed about the project, they could be included in this type of investigation.

### *6.2.1 Primary and Secondary Customers*

The ETT-vehicle's primary customers are the actual users of the vehicle, i.e. the timber hauliers and drivers. They are in close contact with the vehicle and are well informed about its strengths and weaknesses in operation.

The forest companies are secondary customers as the use of longer and heavier vehicles could improve productivity and cut costs. Hence they are also important customers, even though they often do not operate the vehicle itself. Several forestry companies are involved in the project, either in the project management committee or the operational group, usually with people from their transport or logistics departments.

### *6.2.2 Other Stakeholders*

Since the vehicle combination is not (yet) legal in Sweden, there are other important players in the introduction of this kind of vehicle on the market. To have a chance to accomplish the change of regulations, to allow heavier and longer timber trucks on Swedish roads, the legislators have to be informed and convinced of the environmental, economic and safety benefits of these kind of vehicles. One approach to achieving this is to create a vehicle that is optimised for its purpose, as fuel efficient as possible, safer than or at least as safe as a conventional timber truck and that causes less road wear. These benefits have to be thoroughly investigated, proven, and clearly communicated to the concerned legislators, and the public. Providing a vehicle that also visually communicates these benefits to the surrounding can be a step towards achieving the desired changes.

The vehicle and vehicle equipment manufacturers are also stakeholders in this project. Not only for the obvious reason of the possibility to be first on the market with products for this application and increase sales, but also to achieve environmental and productivity goals and be at the front edge of technical development.

## 6.3 Gathering of Raw Data – Interviews

In the collection of raw data for the interpretation into customer needs, interviews are performed with both primary and secondary customers i.e. drivers, timber hauliers and forest industry representatives. Project partners involved in the technical development of the vehicle combination, politicians and researchers within the area are also interviewed.

The haulier company and the drivers are the actual users of the vehicle, hence the most important customers. They know what works satisfactory on the vehicle combination and what does not, and concretely what they need for them to do their work efficiently.

The forestry companies’ representatives are interviewed to get their point of view on what is needed and what can be improved in the timber transportation.

Experts from areas like brakes, timber bunks, trailers, safety, vehicle construction and roads are interviewed to contribute with ideas and experience. Several of the experts are also in close contact with the drivers and get information about what does not work satisfactory within their area of expertise.

A few interviews are performed with people within the area infrastructural development, environmental research and politics to get their opinions on the requirements of the future vehicles that will be driven on Swedish roads.

## 6.4 Interpretation of Raw Data into Customer Needs

From the interviews, statements are taken and needs interpreted from them. The needs are then divided into categories, depending on what they affect. The categories are;

- Environmental impact
- Safety
- Transport Economy
- Driver environment
- Identity

Some of the needs correspond to two or more categories, but are included in the category where they are considered to have the greatest impact. In total 24 needs are formulated. Several of the needs are very extensive, and could be divided into several sub-needs. This is addressed later in the *Concept Generation* chapter.

### *6.4.1 Environmental Impact*

The statements and interpreted needs from the "Environmental Impact"-category are presented in Table 6.1. This category is closely linked to the "Transport Economy"-category, since the decrease in fuel consumption almost always affects the transport economy in a positive way as well. However, here the needs that have been categorised into "Transport Economy" are not primarily such that affect the fuel consumption.

**Table 6.1.** Statements and Interpreted Needs – Environmental Impact

| Statement | Interpreted Need | Clarification of need |
|---|---|---|
| The air could be channelled around the vehicle.<br>The aerodynamics are poor. | Reduced aerodynamic drag | The vehicle is aerodynamically designed. |
| The after treatment of emissions could be improved. | Lowered emissions | The vehicle has low emissions of e.g. NOx. |
| The tires on the trailers could have a lower rolling resistance, would save both tires and diesel. | Decreased rolling resistance | The vehicle tires have a low rolling resistance but good grip. |
| The driveline can be optimised.<br>Maybe 80km/h is not the best speed for fuel consumption. | Improved fuel efficiency | Less fuel is used to perform the same transport work. |
| We're at 50km/h in some slopes. | Improved average speed | The truck keeps a constant speed as often as possible. |

**Table 6.1.** continuing

| Statement | Interpreted Need | Clarification of need |
|---|---|---|
| A larger load on the truck makes the whole vehicle more stable.<br>There was one ton of ice on the vehicle.<br>If the whole vehicle combination was lighter it would enable a higher effective load. | Increased loading capacity | The effective payload of the vehicle combination is increased. |
| The truck is idling during loading/unloading; else the cab gets cold in winter or hot in summer. | Improved climate control in cab | The temperature is well preserved in the cab, both in cold and hot climate. |

### 6.4.2 Transport Economy

The needs corresponding to the category "Transport Economy" are presented in Table 6.2. Here needs affecting the logistics and reliability in use are included. The need "Reduced road wear" is included in this category, as it is considered the most suiting.

**Table 6.2.** Statements and Interpreted Needs - Transport Economy

| Statement | Interpreted Need | Clarification of need |
|---|---|---|
| The weight control system cannot be trusted. | Improved weight control | The load weight control is reliable and easy to check from inside the cab. |
| Driving into the forest will be difficult; there are places where there are problems already today.<br>You have to hold out in turns because it cuts corners. | Improved accessibility | The truck can be driven on narrower and more inclining roads and through sharper turns. |
| The electric system has been malfunctioning.<br>The cables have been troublesome; they've been jammed and pulled when turning.<br>Bad environment for the cables.<br>Connections on cables are bad. | Reliable electric cable solutions | The electrical cables work satisfactory. |
| The more the road wear is decreased the better. | Reduced road wear | Road wear is reduced through lower axle loads. |

### 6.4.3 Safety

The needs corresponding to the category “Safety” are presented in Table 6.3. Here safety for the driver as well as other road users is taken into account.

**Table 6.3.** Statements and Interpreted Needs - Safety

| Statement | Interpreted Need | Clarification of need |
|---|---|---|
| It side-slips when unloaded.<br>Starting when slippery is tricky.<br>Tap off air from the tires when there’s poor grip would help. | Improved traction | The startability on slippery road is improved and the risk of slipping is minmised. |
| Visibility aids are always needed.<br>Side windows and mirrors get covered with dirt. | Improved visibility for driver | The driver has satisfactory visibility from the cab in all weather conditions. |
| During winter the sign and lights in the back get covered with snow and you don’t see the truck as well and that it’s longer. | Improved visibility of truck | Other road users can easily see the truck from far away and that it is longer. |
| The game fence is definitely needed.<br>It’s too bad the truck is not equipped with all safety systems available.<br>Systems that make sure the driver is awake and sober should be standard equipment. | Improved safety for driver and other road users | Measures to decrease the risk of accidents as much as possible and limit the damage caused by accidents are taken. |
| An even better brake system is desirable. | Improved braking | The braking of the truck and trailers is even and effective, the braking distance is decreased. |

### 6.4.4 Driver Environment

Needs associated with the driver environment are presented in Table 6.4. Several needs in other categories also affect the driver environment, and vice versa.

**Table 6.4.** Statements and Interpreted Needs - Driver Environment

| Statement | Interpreted Need | Clarification of need |
|---|---|---|
| The tachograph steals time; it's hard to make the drive on legal time because of this. | More flexible driving hours | Enough time to drive back and forth without exceeding speed limits and driving hours legislations. |
| The chains are a problem when you are alone.<br>Timber might fall off.<br>The load fasteners work so-so when it's cold and don't tighten enough. | Improved loading and fastening | Loading/unloading and fastening of timber is quick, easy, has low energy consumption and no risk of injuries.<br>The timber has no risk of falling off. |
| A longer driver's space and more space around it. | Improved driver environment | The driver's environment is comfortable and safe to work in and fulfils the driver's requirements. |

### 6.4.5 Identity

The category "Identity" includes needs that affect how the vehicle is perceived, what impression it gives and its general appearance.

**Table 6.5.** Statements and Interpreted Needs - Identity

| Statement | Interpreted Need | Clarification of need |
|---|---|---|
| People see the vehicle as threatening and intimidating. | Improved safety impression | The vehicle looks safe and reliable. |
| A clearer profile, more homogeneous would be good.<br>The truck and the trailers should look like a transport solution. | Homogeneity | The vehicle combination looks like a transport solution, rather then random parts put together. |
| It should look more flexible. | Accentuated flexibility on road | The vehicle looks flexible and smooth while driving. |
| The benefits of the vehicle should be accentuated rather than its size. | Accentuated transport efficiency and environmental benefits | The vehicle itself looks efficient and environmentally friendly. |

## 6.5 Organisation of Needs into a Hierarchy

The interpreted needs are organised into a hierarchical list of importance; primary, secondary and tertiary. Here the ETT-project goals are used as foundation of the importance definition. Needs of primary importance are the once that have a substantial effect on fuel consumption, and hence transport economy as well. The secondary needs are such that they affect the fuel consumption to some extent, or have reduced fuel consumption as a side-effect. The needs of tertiary importance do not affect fuel consumption, but have other beneficial effects on the vehicle. The “Identity”-category is kept separate from this hierarchy as it is considered not applicable to the importance definition that mainly regards the fuel consumption. The hierarchical list is presented below.

Needs of primary importance – substantial effect on fuel consumption;

- Reduced aerodynamic drag
- Lowered emissions
- Decreased rolling resistance
- Improved fuel efficiency
- Increased loading capacity

Needs of secondary importance – some effect on fuel consumption;

- Improved average speed
- Improved climate control in cab
- Improved weight control
- Improved traction
- Flexible driving hours

Needs of tertiary importance – other beneficial effect;

- Improved accessibility
- Reliable electric cable solutions
- Reduced road wear
- Improved visibility for driver
- Improved visibility of truck
- Improved safety for driver and other road users
- Improved braking
- Improved loading and fastening
- Improved driver environment

## 6.6 Establishment of Relative Importance of Needs

The hierarchical list alone does not provide information about the relative importance of the different needs. The relative importance is necessary to make correct trade-offs in the product (Ulrich & Eppinger pp 66). The establishment of relative importance in this case is based on a mix of the assumed effect they might have, and the customer interviews.

The establishment is made by grading each need in four categories. The four categories are:

1. Frequency of mentioning in interviews
2. Assumed impact on fuel consumption
3. Assumed impact on safety
4. Contribution to strengthened identity

The grading is done with the gained knowledge from the interviews, literature and consultations with experts. Complete vehicle simulations are used to study what parameters have significant impact on fuel consumption. They indicate, as previously described, that aerodynamics, rolling resistance and loading capacity are the most influencing factors when looking to make big fuel savings. The vehicle simulations are further described in the concept testing, chapter 11.

The scale used is 1-3, where 1 point indicates no or small impact or low frequency, 2 points indicate average, and 3 points indicate a large impact or high frequency. The needs are then sorted after total points in each category. The results are presented in Table 6.6.

**Table 6.6.** Establishment of Relative Importance of Needs

| | 1. Interviews | 2. Fuel consumption | 3 Safety | 4. Identity | 5. Total score | 6. Importance |
|---|---|---|---|---|---|---|
| Reduced aerodynamic drag | 3 | 3 | 1 | 2 | **9** | 1 |
| Decreased rolling resistance | 3 | 3 | 2 | 1 | **9** | 1 |
| Improved fuel efficiency | 3 | 3 | 1 | 1 | **8** | 1 |
| Increased loading capacity | 3 | 3 | 1 | 1 | **8** | 1 |
| Lowered emissions | 1 | 2 | 1 | 1 | **5** | 1 |
| | | | | | | |
| Improved traction | 3 | 2 | 3 | 1 | **9** | 2 |
| Improved weight control | 3 | 2 | 3 | 1 | **9** | 2 |
| Improved average speed | 2 | 2 | 2 | 1 | **7** | 2 |
| Flexible driving hours | 2 | 2 | 1 | 1 | **6** | 2 |
| Improved climate control in cab | 1 | 2 | 1 | 1 | **5** | 2 |
| | | | | | | |
| Improved visibility of truck | 2 | 1 | 3 | 2 | **8** | 3 |
| Improved safety for driver and other road users | 2 | 1 | 3 | 2 | **8** | 3 |
| Improved loading and fastening | 2 | 2 | 1 | 2 | **7** | 3 |
| Improved visibility for driver | 1 | 1 | 3 | 1 | **6** | 3 |
| Improved braking | 1 | 1 | 3 | 1 | **6** | 3 |
| Reduced road wear | 2 | 1 | 2 | 1 | **6** | 3 |
| Reliable electric cable solutions | 2 | 1 | 2 | 1 | **6** | 3 |
| Improved accessibility | 2 | 1 | 2 | 1 | **6** | 3 |
| Improved driver environment | 1 | 1 | 2 | 2 | **6** | 3 |
| **Identity** | | | | | | |
| Homogeneity | 3 | 1 | 1 | 3 | **8** | |
| Accentuated transport efficiency and environmental benefits | 3 | 1 | 1 | 3 | **8** | |
| Accentuated flexibility on road | 3 | 1 | 1 | 2 | **7** | |
| Improved safety impression | 2 | 1 | 1 | 3 | **7** | |

The customer needs are now expressed in terms of what the customer wants or needs of the vehicle. These needs are later on in the process used as a base for the *Concept Generation*.

# 7 Establishment of Product Specifications

*In the previous chapter the relative importance of the expressed customer needs is established. The needs established as the most and second most important are in this chapter formulated into product specifications for the development concept, which describe in measurable detail what the product has to perform. Benchmarking of related products is performed and two reference vehicles defined to get an idea of the ETT-vehicles performance in relation to other long haul trucks. Target and marginally acceptable values for the specifications for development concept are set with help from the information gathered from the benchmarking.*

Translation of customer needs into product specifications is the second step of the *Front-End Process* by Ulrich & Eppinger see Figure 7.1, and is done in three steps;

- Preparing a list of metrics
- Collecting competitive benchmarking information
- Setting ideal and marginally acceptable target values

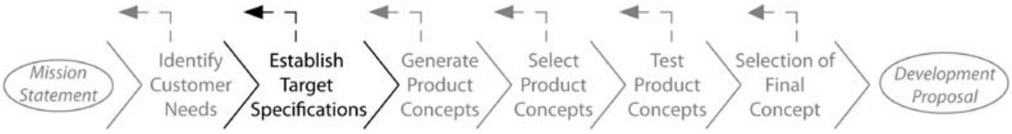

**Figure 7.1.** Establish Target Specifications, adapted from Ulrich and Eppinger (2004)

## 7.1 Focusing of Efforts

In this chapter the efforts will be focused on the needs that are in the previous chapter determined as the most and second most important. They are used to formulate the target specifications for the development concept which describe its performance. When the concept is finalised its performance is compared to the set targets.

The rest of the needs are not to be forgotten, they are discussed in Chapter 9 and 10, but are excluded from the activity of setting specifications. The needs “Flexible Driving Hours” and “Improved climate control in cab” are also left out in this part of the process, mainly because it has not been possible to find a suitable measurable metric that corresponds to the needs.

## 7.2 List of Metrics

The first step in establishing the target specifications is giving each of the eight remaining needs a describing measurable statement – a metric. The aim is that this metric reflects as directly as possible the customer need. The metrics corresponding to each need can be seen in the Needs-Metrics matrix in Table 7.1.

**Table 7.1.** Needs-Metrics matrix

| **Need** **Metric** | $C_D$-value [-] | A-value [$m^2$] | $C_R$ [N/ton] | Driveline efficiency [%] | Tare weight [ton] | Load / GCW [%] | Emission level | Drive axle load [ton] | Accuracy of scales [%] | Time in speed range [%] | Gradeability [s] |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Reduced aerodynamic drag | * | * | | | | | | | | | |
| Decreased rolling resistance | | | * | | | | | | | | |
| Improved fuel efficiency | | | | * | | | | | | | |
| Increased loading capacity | | | | | * | * | | | | | |
| Lowered emissions | | | | | | | * | | | | |
| Improved traction | | | | | | | | * | | | |
| Improved weight control | | | | | | | | | * | | |
| Improved average speed | | | | | | | | | | * | * |

In Table 7.2 the metrics are further explained or elaborated, if this is considered necessary.

**Table 7.2.** Explanations of metrics

| **Metric** | **Explanation** |
|---|---|
| Driveline efficiency | The percentage of energy, compared to the total energy content of the fuel that is transformed into work of the driveline. |
| Load /GCW | The amount of load compared to the Gross Combination Weight. |
| Tare weight | The weight of unloaded vehicle. |
| Emission level | A European Standard regulating the limits for exhaust emissions of new vehicles sold in the EU. |
| Drive axle load | The load on each driving axle when the vehicle is unloaded, measured in kilograms. |
| Accuracy of scales | The percentage accuracy the vehicle scales have when measuring the load. |
| Time in speed range | The percentage of time the vehicle keeps a velocity within a certain speed range. |
| Gradeability | Hill taking ability of the vehicle here defined as the time it takes to climb a 5 km long hill of the inclination 3 degrees. |

## 7.3 Collection of Competitive Benchmarking Information

To determine the positioning of the ETT-vehicle's performance in relation to other vehicles, a benchmarking is done. The approach is to determine and specify the performance of two reference vehicles, here considered as possible competitive products. The first reference vehicle is a 60 ton conventional timber truck, since this is the largest type of timber truck legal in Sweden today. Secondly, a tractor with a van body semi-trailer is used as reference, in order to get an idea of the difference in performance between this type of truck and a timber truck. Both reference vehicles are common on Swedish roads, and comparing the ETT-vehicle to these gives a sense of its performance in relation to regular long haul vehicles.

### *7.3.1 Description of Reference Vehicle 1 – 60 ton timber truck*

The first reference vehicle is a conventional timber truck today used in Sweden, both in highway and forest driving, see Figure 7.2. The towing vehicle is exactly the same as for the ETT-vehicle, and it pulls a full trailer with cargo space for two piles of timber. This vehicle is the same as the one used for the actual reference drives made with the ETT-vehicle, when fuel consumption measurements were made.

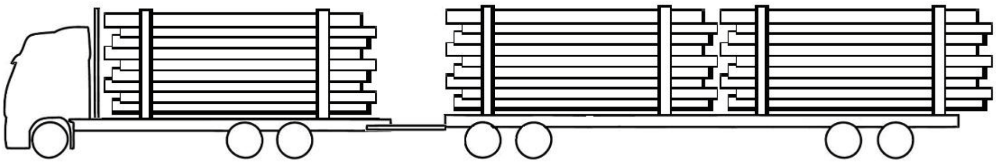

**Figure 7.2.** Schematic sketch of a 60 ton timber truck

In Table 7.3, the first reference vehicle is specified.

**Table 7.3.** Definition of reference vehicle 1, data from existing vehicle

| **Timber truck rigid + full trailer** | |
|---|---|
| Volvo FH16 | |
| GCW | 60 tons |
| Tare weight | 18 tons |
| Engine | D16 660hp Eu4 |
| Gearbox | I-shift overdrive |
| Final gear ratio | 3.19 |
| Number of wheels | 26 |
| $C_R$ (loaded) | 47,2 N/ton |
| Fuel consumption (loaded) | 5.47 l/10km |
| Fuel consumption (unloaded) | 3.14 l/10km |

### 7.3.2 Description of Reference Vehicle 2 – Tractor and Van Body Semi-trailer

The second reference vehicle is made to resemble a regular tractor and semi-trailer that today carries gods all over Sweden, see Figure 7.3 for a schematic picture.

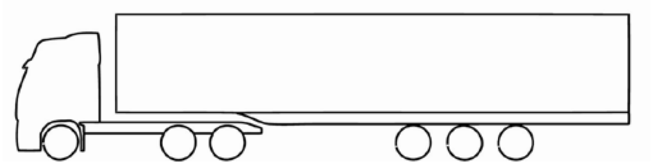

**Figure 7.3.** Schematic sketch of a tractor + van body semi-trailer

In Table 7.4 some core information about the second reference vehicle is specified, the data is collected from a simulation model in the Volvo model library.

**Table 7.4.** Definition of reference vehicle 2, data from simulation model

| **Tractor + van body semi-trailer** | |
|---|---|
| Long haul Volvo FH | |
| GCW | 40 tons |
| Tare weight | 14 tons |
| Engine | D13 460hp Eu5 |
| Gearbox | I-shift directdrive |
| Final gear ratio | 2.64 |
| Number of wheels | 16 |
| $C_R$ (loaded) | 46 N/ton |
| Fuel consumption (loaded) | 3.30 l/10km |
| Fuel consumption (unloaded) | 2.15 l/10km |

### 7.3.3 Benchmarking Chart

The information gathered about the reference vehicles is presented in a benchmarking chart, see Table 7.5. Division into loaded and unloaded case is done for two of the metrics, where the difference is considered important; $C_D$-value and rolling coefficient. It must be noted that these values are neither exact nor applicable in all cases; they are only a hint of what could be reasonable for the present vehicle configuration. Not all information is found, hence some squares are denoted N.A, not available.

**Table 7.5.** Benchmarking Chart, data from existing vehicles and simulation models

| **Metrics** | **ETT-vehicle** | **Timber truck 60 tons** | **Tractor + semi-trailer** |
|---|---|---|---|
| $C_D$ loaded | 1.5 | 1.3 | 0.623 |
| $C_D$ empty | 1.0 | 1.0 | 0.623 |
| A [$m^2$] | 11.45 | 11.10 | 10.23 |
| $C_R$ [N/ton] loaded | 42.99 | 47.2 | 46 |
| $C_R$ [N/ton] empty | 49.36 | 52.3 | N.A |
| Driveline efficiency [%] | 43.3 | 42.8 | 42.7 |
| Tare Weight [ton] | 24 | 18 | 14 |
| Load/GCW [%] | 73.3 | 70.0 | 65.0 |
| Emission level | Eu4 | Eu4 | Eu5 |
| Drive axle load [kg] | 3000/6880 | >4000 | N.A. |
| Accuracy of scales [%] | N.A. | N.A. | N.A. |
| Time over 75km/h [%] | 68.1 | 81.6 | 86.7 |
| Gradeability [s] | 451 | 340 | 361 |

The $C_D$-values for the timber trucks are very rough estimations since no wind tunnel or CFD-simulation data has been found for such vehicles. It is however certain that the aerodynamics of timber trucks is far worse than for a regular tractor-trailer combination. The A-value is here taken from measurements on the tractor-trailer combination, and adjusted considering the front wall and the increased area due to the timber piles.

The rolling coefficient, $C_{R,}$ is calculated with the tire data and formulas provided by Michelin. The high value for the 60 ton timber truck is a result of it having dual mounting on all trailer axles and the drive axles, giving each tire a rather low load.

The effective load ratio, *Load/GCW* is higher on the ETT-vehicle than the other two vehicles due to its relatively low tare weight and large loading capacity. The drive axle load is presented for engaged and disengaged bogie lift on the empty vehicle. Information about the accuracy of the vehicle scale has not been found.

The values of the last two metrics, *time over 75km/h* and *gradeability* are results from vehicle simulations.

The fuel consumption for the ETT-vehicle compared to the reference vehicles is presented in Table 7.6. The numbers for the ETT-vehicle and the 60 ton timber truck are from measurements, and the numbers for the tractor semi-trailer combination are results from simulations.

**Table 7.6.** Fuel consumption of the ETT-vehicle compared to the reference vehicles

| | **Weight loaded/unloaded [ton]** | **Fuel consumption (loaded) [l/10km]** | **Fuel consumption (unloaded) [l/10km]** |
|---|---|---|---|
| ETT-vehicle | 90 / 24 | 7.22 | 3.64 |
| 60 ton timber truck | 60 / 18 | 5.47 | 3.14 |
| Tractor & semi-trailer | 40 / 14 | 3.30 | 2.15 |

In table 7.6 it can be seen that the fuel consumption for the ETT-vehicle on the return trip is noticeable higher than for the loaded tractor and semi-trailer combination, even though the total weight of the tractor and semi-trailer is considerably higher. The 60 ton timber truck has also high fuel consumption numbers on the return trip. This indicates that timber trucks are inefficient when driving without load.

## 7.4 Setting Ideal and Marginally Acceptable Target Values

In this step the benchmarking values are reviewed to set target values for the new improved ETT-vehicle combination. Two types of values are set, an ideal and a marginally acceptable. The marginally acceptable value is the value that would barely make the product competitive to existing products, in this case the existing ETT-vehicle. The ideal value is the value to aim for in the development process, and is here derived with the help of the benchmarking information (Ulrich and Eppinger 2004, pp 79). The ideal and marginally acceptable target values are presented in Table 7.7. The acceptable values are in general the ones for the existing ETT-vehicle, meaning a change of the values in negative direction is not acceptable.

**Table 7.7.** Ideal and marginally acceptable target values

| **Metrics** | **ETT-vehicle** | **Ideal value** | **Acceptable value** |
|---|---|---|---|
| $C_D$ loaded | 1.5 | 1.0 | 1.5 |
| $C_D$ empty | 1.0 | 0.7 | 1.0 |
| A | 11.45 | 9.5 | 11.45 |
| $C_R$ [N/ton] loaded | 42.99 | 40 | 42.99 |
| $C_R$ [N/ton] empty | 49.36 | 45 | 49.36 |
| Driveline efficiency [%] | 43.3 | 44.0 | 43.3 |
| Load/GCW [%] | 73.3 | 77.0 | 73.3 |
| Tare Weight [ton] | 24 | 22 | 24 |
| Emission level | Eu4 | Eu5 | Eu5 |
| Drive axle load [kg] | 3000/6880 | 8000 | 6880 |
| Accuracy of scales [%] | N.A | 0 | 1 |
| % time over 75km/h | 68.13 | 87 | 70 |
| Gradeability [s] | 451 | 384 | 451 |

The ideal $C_D$-value and A-values for loaded truck is what is assumed to be possible to achieve on a vehicle as big and complex as the ETT-vehicle. This would however require major design changes.

By lowering the tare weight the load ratio could be improved. The value for the tare weight is however assuming the gross combination weight is unaffected.

The values for drive axle load are assumptions of what would be necessary in the present application. The most important issue is however that the drivers are satisfied and that safety is ensured.

Ideally the vehicle scales would show the exact weight of the load, but this is hard to achieve. With the current system and a proper calibration the error margin should be 1%[17].

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[17] Knutsson, Anders, Service Engineer, Wabco Automotive, conversation 2009-12-02

# 8 Concept Generation and Selection – Needs with Target Specifications

*In this chapter the activities of concept generation and selection are described, focusing on the eight needs that in the previous chapter are assigned target specifications. The remaining needs are addressed in chapter 9 and 10. The goal of the concept generation is to find solutions that fulfil the needs, wants and expectations expressed by the customers. Each customer need is treated separately and possible solutions explored systematically with ideas from both external and internal searches to find satisfying ways of obtaining the target specifications. Product concepts are presented for each need. These concepts are then evaluated based on defined criteria, and the concepts with the highest scores are selected and moved on to the concept testing.*

## 8.1 Concept Generation Process

Based on the identified customer needs and target specifications, several product concepts are generated for each need. From the concepts a selection is made. The concept generation phase in relation to the other activities of the concept development is shown in Figure 8.1.

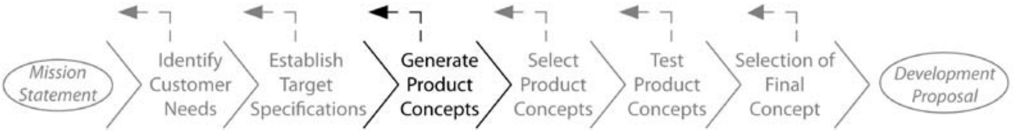

**Figure 8.1.** Concept Generation, adapted from Ulrich and Eppinger (2004)

### *8.1.1 The Four-step Method*

The concept generation is by Ulrich and Eppinger divided into four steps;

- Clarifying the problem
- External search
- Internal search
- Systematic Exploration

Good concept generation should mean that all alternatives have been explored, and greatly reduce the risk of finding a superior concept late in the process, or in the hands of a competitor. The use of the structured four-step method reduces these risks by encouraging gathering of information from many different sources, guiding through the exploration of alternatives, and providing a mechanism for integrating partial solutions. Although the method and results are presented in a linear sequence, the process is almost always iterative, and that is also the case in this thesis (Ulrich and Eppinger, 2004 pp 99).

#### 8.1.1.1 Clarifying the Problem

Decomposition by key customer needs is often used for products in which form, and not working principals or technology, is the primary problem (Ulrich and Eppinger, 2004 pp103). This is applicable in this case, since the aim of the concept development is an improvement of an existing product. The present situation concerning each need is first presented and briefly discussed, starting with the need established as the most important. Some of the needs are then decomposed into subproblems and the critical parts of each need are identified. The concept generation then focuses on the identified critical issues.

#### 8.1.1.2 External Search

The aim of the external search is to find existing solutions and technologies to the problems and subproblems identified. The use of existing solutions is often quicker and cheaper than developing new, and allows for time to focus on critical subproblems for developing new solutions where no satisfying can be found (Ulrich and Eppinger, 2004 pp 104). Interviews, literature search and benchmarking are the methods used in this thesis for the external search.

Interviews with users are performed and ideas for improvements or new solutions are gathered. Experts are interviewed to get ideas of which improvements are possible to achieve and to give opinions on solutions or product ideas. Experts in this case are people that participate or have knowledge of the project and/or extensive experience in the timber hauling industry, technical experts from vehicle manufacturing, researchers, staff from the National Road Administration and politicians. The advantage of consulting experts is that they have an extensive knowledge of what is possible, and developing technology within their area, which the customers perhaps have not heard or thought of yet.

Existing and competitive products and solutions are benchmarked to see if there is anything applicable to this specific case. Patents and literature are studied for further information on ways of solving the present problems.

#### 8.1.1.3 Internal Search

Internal search uses the knowledge and creativity of the people and team involved in the concept development (Ulrich and Eppinger, 2004 pp 107). It is carried out in this study individually and in group, with the main method being brainstorming. In the brainstorming phase all ideas that come to mind are written down, both realistic and unrealistic.

#### 8.1.1.4 Systematic Exploration

The result of the external and internal searches is a number of solutions to the subproblems that also can be seen as concept *fragments*. This step in the concept generation process aims to organise and view the possibilities with these fragments (Ulrich

&Eppinger, 2004 pp 110). This is done by organising the solutions into concept classification trees that divides possible solutions into independent categories. It gives a quick overview of the different solutions.

## 8.2 Concept Selection Process

The outcome of the *Concept Generation* is a large number of development concepts. No distinction of solutions from internal or external search is made in this thesis. In the *Concept Selection*, the concepts are evaluated and narrowed down to those chosen for further investigation (Ulrich and Eppinger 2004, pp 124). The Concept Selection in relation to other activities of the concept development is shown in Figure 8.2.

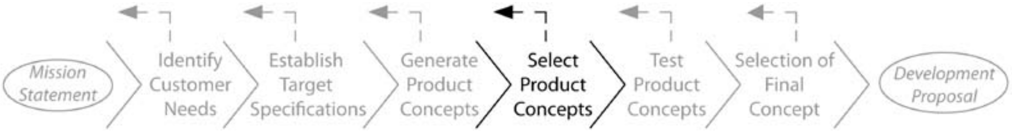

**Figure 8.2.** Concept Selection, adapted from Ulrich and Eppinger (2004)

A structured concept selection method has many potential benefits. Evaluating a concept based on customer-oriented criteria ensures a customer-focused product and comparing with existing products gives a competitive design. It also gives the information needed for effective decision making and communication. The documentation of the design process is a great help in assessing changes and involving new people in the project (Ulrich & Eppinger pp 128-129).

This evaluation can be carried out in several ways. Ulrich and Eppinger describe in more detail how to perform concept selection by creating decision matrices. This method is a two-step selection including *Concept Screening* and *Concept Scoring*, both of which consist of a decision matrix where the concepts get rated and ranked (2004, pp 125). The goal is to narrow the concept proposals down to a few, of which one is chosen through *concept testing*. In this thesis, the *Concept Screening* is replaced by discussions where unrealistic ideas are eliminated, which for example has been generated in the brainstorming. These ideas, eliminated in the discussion phase, are not being mentioned, and instead, effort is put to develop ideas that are more likely to be implemented, and conduct concept selection of these.

### *8.2.1 Concept Scoring*

Concept scoring is used to rate, rank and select the best concepts. All the alternatives are carefully considered, analysed and evaluated. Throughout the scoring process iterations may and should be performed with new or improved alternatives coming up due to new ideas or combinations of features from different concepts. The selection phase includes five steps;

- Prepare the selection matrix
- Rate the concepts
- Rank the concepts
- Combine and improve the concepts

- Select one or more concepts

The criteria used for the selection matrix are carefully adapted from the purpose and objective of the thesis and also from what customers and experts have expressed important. Importance weights are added to the criteria, by allocating 100 percentage points among them (Ulrich and Eppinger 2004, pp 135). The criteria and corresponding weights chosen for the concept scoring of the solutions in this thesis are presented in Table 8.1.

**Table 8.1.** Selection criteria and weights

| **Criteria** | **Weight (W)** |
|---|---|
| Fuel consumption | 0.35 |
| Reliability in use | 0.2 |
| Safety impact | 0.15 |
| Ease of use | 0.1 |
| Ease of implementing | 0.1 |
| Estimated cost | 0.1 |

All these six criteria are important to make a solution successful. However, in this thesis, *fuel consumption* is the most important criterion since this is the main goal of the final concept. The primary customers have expressed that the *reliability in use* is highly critical, why this is the second most important criterion. *Safety impact* is always critical and needs to be considered at all times, and finally *ease of implementing, ease of use* and *estimated cost* is the least important to this thesis. In *fuel consumption* the estimated impact on the fuel reduction is rated, and also if a solution adds any weight to the combination which increases the fuel consumption. For the criterion *ease of implementing* factors included are legislations affecting the ease of implementing these solutions, if there are existing solutions and if not, how easy it is to come up with working solutions and the ease of convincing customers and manufacturers to implement these solutions as well as the developing time. *Reliability in use* is how well the solution would work in use, meaning the durability or if it is possible to use this solution with any gain. *Ease of use* is how much effort the driver needs to put into the use of the solution, if it facilitates his/her job or makes it more difficult.

The rating system used for the selection criteria is a scale of 1-5, and the points are defined in Table 8.2.

**Table 8.2.** Definition of scores for concept rating

| Relative Performance | Rating (R) |
|---|---|
| Much worse than reference | 1 |
| Worse than reference | 2 |
| Same as reference | 3 |
| Better than reference | 4 |
| Much better than reference | 5 |

The reference is in this case the present ETT-vehicle. The concepts with the highest weighted scores (WS) move on to the concept testing, unless they are eliminated through a sensitivity analysis that implies that they are too sensitive to uncertainties in the solutions. The sensitivity analysis is performed through a closer discussion about some of the scores in the scoring matrix.

## 8.3 Focus of needs

The focus of this chapter is the eight needs for which target specifications were established in chapter 7. The needs are, in the order of relative importance;

- Reduced aerodynamic drag
- Decreased rolling resistance
- Improved fuel efficiency
- Increased loading capacity
- Lowered emissions
- Improved traction
- Improved weight control
- Improved average speed

## 8.4 Reduced Aerodynamic Drag

Aerodynamic drag is one of the main sources of fuel consumption on heavy trucks, especially for highway trucks travelling at high speed. The contribution from drag to the fuel consumption for highway trucks can be half or more than half. The drag is mainly formed by the irregular shapes protruding into the bypassing flow of the vehicle. The ETT-vehicle, with its 30 meters, four piles of timber and gaps between them, 26 wheels, timber bunks, rough timber surfaces and various details such as roof-lights and front wall, creates a lot of disturbance. This means it has a high $C_D$-value hence the aerodynamic drag is high. Some tests have shown that a conventional Volvo FH-truck with van body semi-trailer has a $C_D$-value of about 0.6-0.65; the $C_D$ of the ETT-vehicle is probably much higher. With this amount of disturbance in the air-stream, the boundary layer is very wide and the flow-field around and behind the vehicle is highly chaotic with large-scale turbulent motion. For the ETT-vehicle driven without cargo, the aerodynamic drag is considerably lower, since there are no timber piles with gaps in between. However, the timber bunks are, same number of wheels, and details such as roof-lights and front wall are still there to affect the drag[18]. On this particular vehicle the front wall exceeds the height of the roof spoiler with 150 mm, which disturbs the air flow.

The need, *Reduced aerodynamic drag*, is decomposed into subproblems that correspond to different parts of the vehicle. These parts are;

- Cab and front wall
- Trailers, chassis and wheels
- Cargo space
- Gaps between piles
- Rear of the vehicle

### 8.4.1 Cab and Front Wall

When determining the aerodynamic drag of an object the drag equation $D=C_D*A*0.5*\rho*v^2$ is used, see chapter 3.6.2.4. The two factors affected by changes on the object are A, the frontal area, and $C_D$, the drag coefficient.

#### 8.4.1.1 Solutions to Cab and Front Wall

The solutions regarding the cab and front wall are divided into those affecting A and those affecting $C_D$ as shown in Figure 8.3.

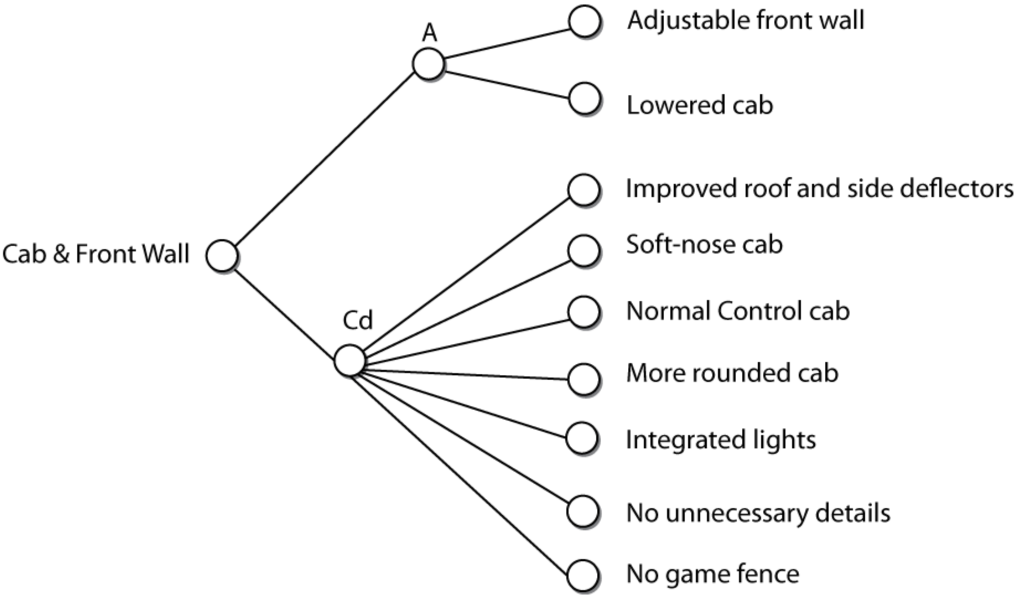

**Figure 8.3.** Classification tree *Cab and front wall*

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[18] Tenstam, Anders, Team Leader Vehicle CFD, Volvo Technology, conversation 2009-12-15

The solutions are explained further in Table 8.3.

**Table 8.3.** Solutions with brief explanations to *Cab and front wall*

| **Solution** | ***Explanation*** |
|---|---|
| **Adjustable front wall** | *An adjustable front wall for decreased drag* |
| **Lowered cab** | *When driving empty, the cab can be lowered* |
| **Improved roof deflector** | *An attachment, preferably adjustable, to lead the air over and around the cab, trailer gap and cargo* |
| **Soft -nose cab** | *The cab is extended with a nose about 0,5-1m in the front to decrease the front drag and to get a deformation zone in case of frontal collision* |
| **Normal control cab** | *To lower the front drag and to get a deformation zone in the front* |
| **More rounded cab** | *The corner radius on the cab should be at least 0.1 times the vehicle width for good aerodynamic properties (Tenstam[19])* |
| **Integrated lights** | *The roof lights could be integrated in the roof sign, or in the cab* |
| **No unnecessary details** | *Details such as Michelin men could be excluded* |
| **No game fence** | *Could be integrated in cab, or less wide* |

#### 8.4.1.2 Selection of Concepts

Each solution to Cab and front wall are rated according to the chosen criteria, the scores can be seen in the concept scoring matrix in Table 8.4. *R* is the rating, and *WS* is the weighted score.

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[19] Tenstam, Anders, Team Leader Vehicle CFD, Volvo Technology, conversation 2009-12-15

**Table 8.4.** Concept scoring matrix for *Cab and front wall*

| | | **Adjustable Front wall** | | **Lowered cab** | | **Improved Roof deflector** | | **Soft-Nose cab** | | **Normal control cab** | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Weight | R | WS | R | WS | R | WS | R | WS | R | WS |
| Fuel consumption | 0.35 | 4 | 1.4 | 4 | 1.4 | 4 | 1.4 | 3 | 1.05 | 3 | 1.05 |
| Reliability in use | 0.2 | 2 | 0.4 | 2 | 0.4 | 3 | 0.6 | 4 | 0.8 | 4 | 0.8 |
| Safety impact | 0.15 | 3 | 0.45 | 3 | 0.45 | 3 | 0.45 | 4 | 0.6 | 4 | 0.6 |
| Ease of use | 0.1 | 3 | 0.3 | 3 | 0.3 | 4 | 0.4 | 3 | 0.3 | 3 | 0.3 |
| Ease of implementing | 0.1 | 1 | 0.1 | 1 | 0.1 | 3 | 0.3 | 2 | 0.2 | 1 | 0.1 |
| Estimated cost | 0.1 | 2 | 0.2 | 1 | 0.1 | 3 | 0.3 | 2 | 0.2 | 2 | 0.2 |
| | **1** | | **2.85** | | **2.75** | | **3.45** | | **3.15** | | **3.05** |

| | | **More rounded cab** | | **Integrated lights** | | **No unnecessary details** | | **No game fence** | |
|---|---|---|---|---|---|---|---|---|---|
| | Weight | R | WS | R | WS | R | WS | R | WS |
| Fuel consumption | 0.35 | 4 | 1.4 | 4 | 1.4 | 4 | 1.4 | 4 | 1.4 |
| Reliability in use | 0.2 | 3 | 0.6 | 4 | 0.8 | 5 | 1 | 2 | 0.4 |
| Safety impact | 0.15 | 3 | 0.45 | 3 | 0.45 | 3 | 0.45 | 2 | 0.3 |
| Ease of use | 0.1 | 3 | 0.3 | 3 | 0.3 | 3 | 0.3 | 3 | 0.3 |
| Ease of implementing | 0.1 | 1 | 0.1 | 4 | 0.4 | 4 | 0.4 | 3 | 0.3 |
| Estimated cost | 0.1 | 2 | 0.2 | 3 | 0.3 | 5 | 0.5 | 2 | 0.2 |
| | **1** | | **3.05** | | **3.65** | | **4.05** | | **2.9** |

All solutions, except two, get four points for the criterion *fuel consumption*, since they are considered to have a substantial positive impact on this. The two exceptions, *Soft-nose cab* and *Normal control cab* do not affect the fuel consumption remarkably since the decrease in drag is small (Hjelm and Bergqvist pp 470) and there is an increase in weight, which affects the loading capacity. These two are however, rated four points in *safety impact*, because of the possibility of having a large deformation zone in front that decreases the damage of a frontal collision.

*Adjustable front wall* and *Lowered cab* are rated one point for *ease of implementing* because of the difficulty to come up with simple, reliable solutions that the customers would want to use. *Normal Control cab* was assigned one point in this category because of the strict length legislations in Sweden, having a *Normal Control cab* would cause a decrease in loading space since the nose takes up some of the length. A *More rounded cab* would have aerodynamic benefits, but the space in the cab is reduced and it is difficult even with the present cabs to fit all necessary parts into the limited space. *No game fence* would most likely reduce the drag, since the game fence used on the ETT-vehicle is quite wide and the air velocity increases around the cab corners. The game fence is however important due to the high risk of collisions with animals. However, according to Leuschen and Cooper, a properly designed and positioned deep bumper can provide a drag reduction (2009, pp 456).

The solutions are ranked and the results from the scoring are presented in Table 8.5.

**Table 8.5.** Concept scoring results to Cab and front wall

| | |
|---|---|
| No unnecessary details | 4.05 |
| Integrated lights | 3.65 |
| Improved Roof deflector | 3.45 |
| Soft-Nose cab | 3.15 |
| Normal Control cab | 3.05 |
| More rounded cab | 3.05 |
| No game fence | 2.90 |
| Adjustable front wall | 2.85 |
| Lowered cab | 2.75 |

The five solutions with the lowest scores are eliminated in this part of the concept generation. The reason why *Soft-nose cab* is put through to the testing phase, is that this is an interesting solution where the cab gets a deformation zone in the front, the drag is improved and the length is not affected at all as much as for a Normal control cab. The soft-nose would add about 300-600 mm and an idea of excluding the length increase from the regulations due to its safety benefits has been discussed. *No game fence* is eliminated and not discussed further but changing the design of the fence could reduce the drag marginally.

On trucks, there are often details such as signs, extra decorative lights, signal horns or Michelin men on the cab roof or front. This is often an unnecessary source of aerodynamic drag, and fuel could be saved by either eliminating these details, or somehow integrating them in the cab. The need *No unnecessary details* refers to this kind of added equipment. However, the ETT-vehicle is not equipped with such details, and the solution is hence eliminated at this point. The lights on the roof bar are included in the solution *Integrated lights.*

*Adjustable front wall* is eliminated, however on the ETT-vehicle the front wall is considered unnecessary high, and could be lowered.

### 8.4.2 Trailers, Chassis and Wheels

To minimise the impact of drag from the trailers, chassis and wheels of the vehicle aerodynamic devices can be added to the combination. This is a rather simple solution, but has limited impact. It is also possible to make extensive changes to the vehicle combination, like major design changes as a ways of solving the issue of drag. They are however often harder to implement, but could generate big savings in fuel.

#### 8.4.2.1 Solutions to Trailers, Chassis and Wheels

For *trailers, chassis and wheels,* the subproblems are *additional equipment* and *large modifications to the vehicle,* see Figure 8.4.

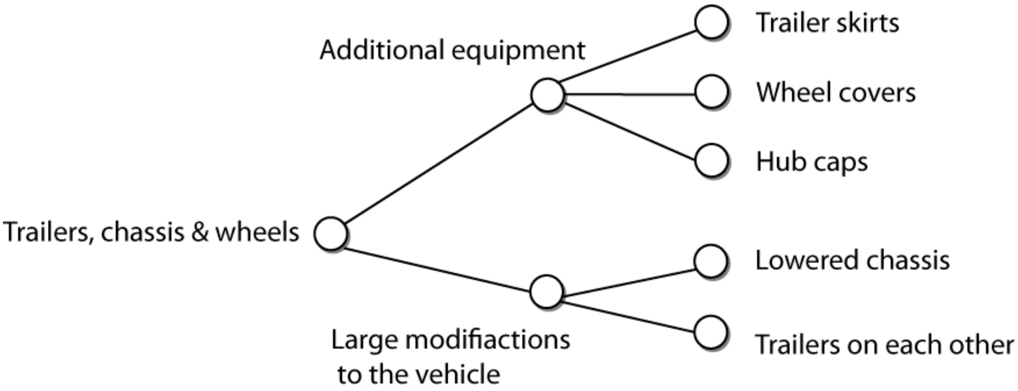

**Figure 8.4.** Classification tree *Trailer, chassis and wheels*

The solutions are explained in Table 8.6.

**Table 8.6.** Solutions with brief explanations to *Trailers, chassis and wheels*

| Solution | *Explanation* |
|---|---|
| **Trailer skirts** | *Covers on the sides of the chassis between wheels* |
| **Wheel covers** | *Covers on the wheels* |
| **Hub caps** | *Aluminium hub caps cover irregularities on the wheels* |
| **Lowered chassis** | *Lower chassis decreases the drag* |
| **Trailers on each other** | *When driving empty, the trailers could be put above each other to make the combination shorter* |

#### 8.4.2.2 Selection of Concepts

The solutions to *trailers, chassis and wheels* are rated in Table 8.7.

**Table 8.7.** Concept scoring matrix of *Trailers, chassis and wheels*

| | | **Trailer skirts** | | **Wheel Covers** | | **Hub caps** | | **Lowered chassis** | | **Trailers on each other** | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Weight | R | WS | R | WS | R | WS | R | WS | R | WS |
| Fuel consumption | 0.35 | 4 | 1.4 | 3 | 1.05 | 3 | 1.05 | 4 | 1.4 | 5 | 1.75 |
| Reliability in use | 0.2 | 2 | 0.4 | 2 | 0.4 | 4 | 0.8 | 3 | 0.6 | 2 | 0.4 |
| Safety impact | 0.15 | 4 | 0.6 | 4 | 0.6 | 3 | 0.45 | 3 | 0.45 | 4 | 0.6 |
| Ease of use | 0.1 | 3 | 0.3 | 3 | 0.3 | 3 | 0.3 | 3 | 0.3 | 1 | 0.1 |
| Ease of implementing | 0.1 | 4 | 0.4 | 1 | 0.1 | 5 | 0.5 | 2 | 0.2 | 1 | 0.1 |
| Estimated cost | 0.1 | 2 | 0.2 | 2 | 0.2 | 3 | 0.3 | 2 | 0.2 | 1 | 0.1 |
| | | | **3.3** | | **2.65** | | **3.40** | | **3.15** | | **3.05** |

The criterion *Safety impact* is here positively affected by *Trailer skirts* and *Covered wheels* as they prevent unprotected road users from being pulled in under the vehicle. The solution *trailers on each other*, is improving the safety as the combination is shortened and the accessibility is improved e.g. it is easier to take turns and round-abouts. *Wheel* covers might not be technically difficult to implement, but this solution is probably hard to convince customers to use, since the risk of dust and snow getting stuck increases and the fuel reduction is not significant. All solutions that include additional equipment mounted to the chassis have to be able to withstand large amounts of vibrations, making it something that might possibly break, hence lowering the *reliability* score. Table 8.8 presents the ranked results from the scoring.

**Table 8.8.** Concept scoring results to *Trailers, chassis and wheels*

| | |
|---|---|
| Hub caps | 3.40 |
| Trailer skirts | 3.30 |
| Lowered chassis | 3.15 |
| Trailers on each other | 3.05 |
| Wheel covers | 2.65 |

The only solution eliminated is *Wheel Covers* since all the others are considered interesting enough to evaluate in the *Concept Testing*.

### *8.4.3 Cargo Space*

The cargo space is where the cargo is placed; in this case timber is loaded onto a timber superstructure with timber bunks. The aerodynamic properties of the cargo space are very different depending on whether the truck is loaded or empty. On the return trip the timber bunks stand freely in the drag, adding to the aerodynamic resistance. In the loaded case the rough sides of the timber piles is a problem.

#### 8.4.3.1 Solutions to Cargo Space

This subproblem is divided into the categories *timber* and *timber bunks*, however some solutions overlap both categories but are put in the one considered more obvious, see Figure 8.5.

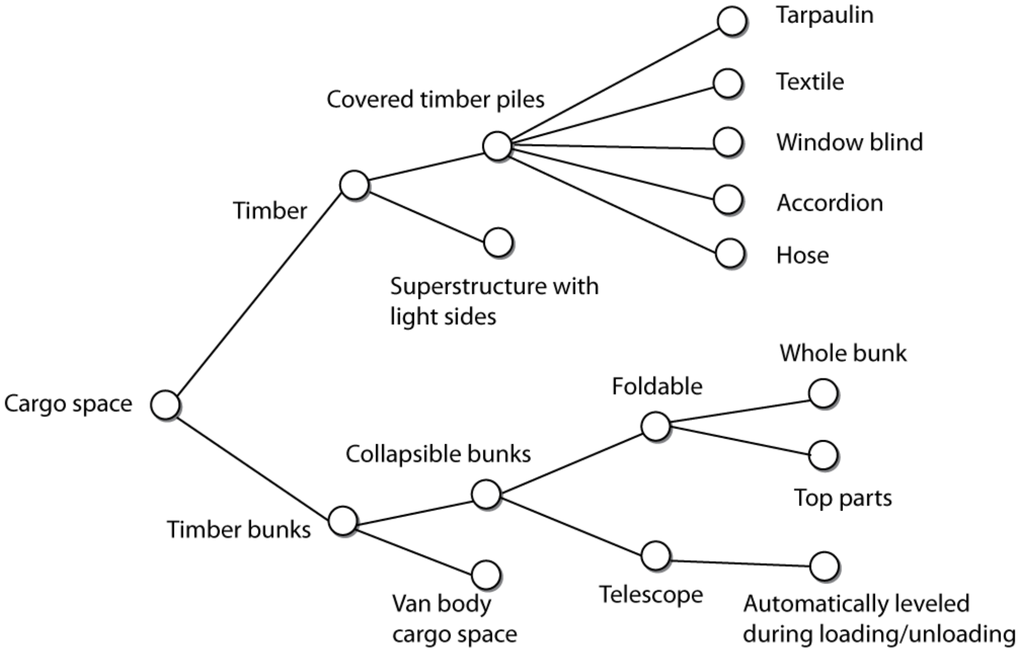

**Figure 8.5.** Classification tree *Cargo space*

Brief explanations to the solutions are found in Table 8.9.

**Table 8.9.** Solutions with brief explanations to *Cargo space*

| Solution | *Explanation* |
|---|---|
| **Covered timber piles** | *Cover the piles to get a smother surface* |
| **Collapsible bunks** | *Bunks that can be lowered or folded to facilitate loading and to decrease the drag when driving empty* |
| **Superstructure with light sides** | *Covers outside the timber bunks to get a smother surface* |
| **Van body cargo space** | *Van body cargo space to put the timber in instead of timber bunk* |

### 8.4.3.2 Selection of Concepts

The scores obtained by the *Cargo space*-solutions are presented in Table 8.10.

.

**Table 8.10.** Concept scoring matrix to Cargo space

| | | **Covered timber piles** | | **Collapsible bunks** | | **Superstructure with light sides** | | **Van body cargo space** | |
|---|---|---|---|---|---|---|---|---|---|
| | Weight | R | WS | R | WS | R | WS | R | WS |
| Fuel consumption | 0.35 | 4 | 1.4 | 5 | 1.75 | 4 | 1.4 | 4 | 1.4 |
| Reliability in use | 0.2 | 2 | 0.4 | 2 | 0.4 | 2 | 0.4 | 3 | 0.6 |
| Safety impact | 0.15 | 4 | 0.6 | 3 | 0.45 | 3 | 0.45 | 4 | 0.6 |
| Ease of use | 0.1 | 2 | 0.2 | 2 | 0.2 | 2 | 0.2 | 1 | 0.1 |
| Ease of implementing | 0.1 | 1 | 0.1 | 2 | 0.2 | 2 | 0.2 | 2 | 0.2 |
| Estimated cost | 0.1 | 1 | 0.1 | 2 | 0.2 | 2 | 0.2 | 2 | 0.2 |
| | | | **2.8** | | **3.2** | | **2.85** | | **3.1** |

None of the solutions to *Cargo space* is ending up with high total scores. The reason is partly because these solutions are not commonly used today. *Collapsible bunks* exist for example in Australia, and are used on the long road trains, but no application in conditions similar to north of Sweden has been found. Another reason for the low scores is that the reliability of the solutions is not very good, as it is additional or moving equipment involved. *Van body cargo space* are the most common cargo superstructure used today, but not for timber as they would highly complicate the loading and unloading._The solutions are ranked and the total weighted scores are presented in Table 8.11.

**Table 8.11.** Concept scoring results to *Cargo space*

| | |
|---|---|
| Collapsible bunks | 3.20 |
| Van body cargo space | 3.10 |
| Superstructure with light sides | 2.85 |
| Covered timber piles | 2.80 |

The only solution moving on to testing is *collapsible bunks* since this is used in certain areas today, and it is assumed that a lot of fuel can be saved when eliminating the drag from bunks when driving without cargo. The other three solutions are eliminated for the reasons mentioned above; the unreliability, the difficulty to come up with new, working designs, and the problem with convincing customers of using unfixed additional equipment when the fuel gain is not that high.

### *8.4.4 Gaps Between Piles*

Due to side winds and the high travelling speed of the vehicle, the gaps between the trailers and the piles add a lot to the aerodynamic drag. The gap between the truck and the dolly might even be the single most important issue to address in the aim of improving the aerodynamics of the ETT-vehicle. As described in earlier gaps between trailers has to be not more than 0.5 m not to add to the drag.

#### 8.4.4.1 Solutions to Gaps Between Piles

The problem *gaps between piles* could be solved by either covering the gaps, or eliminating them, why these two are the categories for the classification tree, see Figure 8.6.

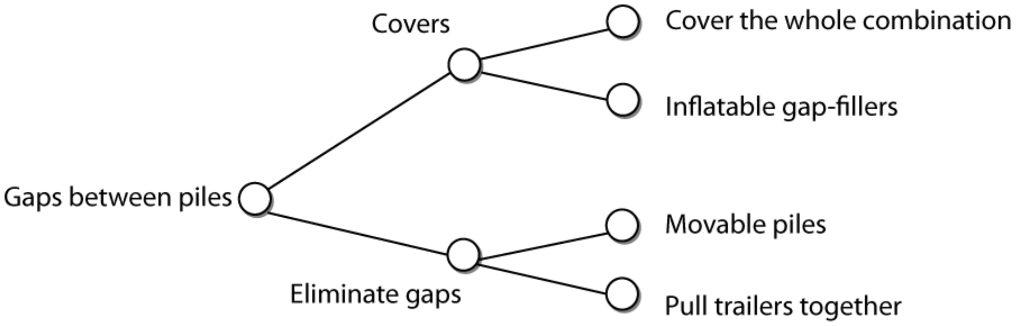

**Figure 8.6.** Classification tree *Gaps between piles*

In Table 8.12 brief explanations to the solutions are found.

**Table 8.12.** Solutions with brief explanations to *Gaps between piles*

| **Solution** | ***Explanation*** |
|---|---|
| **Pull trailers together** | *Automatically moveable feature that pulls the trailers together at a certain speed* |
| **Moveable piles** | *Automatically moveable feature that pulls the timber piles on the same trailer together at a certain speed* |
| **Cover the whole combination** | *Something to cover the truck and all the trailers* |
| **Inflatable gap fillers** | *Something inflatable to fill the gaps* |

#### 8.4.4.2 Selection of Concepts

The concept scoring matrix for the solutions to *Gaps between piles* is presented in Table 8.13.

**Table 8.13.** Concept scoring matrix to *Gaps between piles*

| | | **Pull trailers together** | | **Moveable piles** | | **Cover the whole combination** | | **Inflatable gap fillers** | |
|---|---|---|---|---|---|---|---|---|---|
| | Weight | R | WS | R | WS | R | WS | R | WS |
| Fuel consumption | 0.35 | 5 | 1.75 | 3 | 1.05 | 5 | 1.75 | 5 | 1.75 |
| Reliability in use | 0.2 | 2 | 0.4 | 2 | 0.4 | 2 | 0.4 | 2 | 0.4 |
| Safety impact | 0.15 | 3 | 0.45 | 3 | 0.45 | 4 | 0.6 | 3 | 0.45 |
| Ease of use | 0.1 | 3 | 0.3 | 3 | 0.3 | 1 | 0.1 | 2 | 0.2 |
| Ease of implementing | 0.1 | 1 | 0.1 | 1 | 0.1 | 1 | 0.1 | 1 | 0.1 |
| Estimated cost | 0.1 | 2 | 0.2 | 2 | 0.2 | 1 | 0.1 | 2 | 0.2 |
| | | | **3.2** | | **2.5** | | **3.05** | | **3.1** |

The main problem with the solutions to *Gaps between piles* is that there are no existing solutions in use today. However, the fuel reduction is significant for three of them, and even though it is difficult to implement and develop working solutions that will be reliable in use, a breakthrough with this would make a big difference to the timber hauling industry. The result from the scoring is presented in Table 8.14.

**Table 8.14.** Concept scoring results to Gaps between piles

| | |
|---|---|
| Pull trailers together | 3.20 |
| Inflatable gap fillers | 3.10 |
| Cover the whole combination | 3.05 |
| Moveable piles | 2.50 |

By solving the problem with the gaps, a great amount of fuel could be saved and it is therefore of high interest to evaluate these solutions further. The only solution eliminated here is *moveable piles* since this is only regarding the two piles on the semi-trailer, and the gap here is not as big as the ones between the trailers, and therefore the gain in moving these piles is not comparable.

### 8.4.5 Rear of the Vehicle

As mentioned in the beginning of this chapter, the wake behind a vehicle is a large source of drag. By guiding the air around the sides and hence decreasing the wake, the drag is decreased. This can be done by adding a device to the rear of the vehicle.

#### 8.4.5.1 Solutions to Rear of the Vehicle

The solutions to reducing the wake behind the vehicle combination are listed with short explanations in Table 8.15.

**Table 8.15.** Solutions with brief explanations to *Rear of vehicle*

| **Solution** | ***Explanation*** |
|---|---|
| **Boat tail** | *"Wings" at the back of the last trailer* |
| **Rounded** | *A feature that rounds the back of the last trailer* |
| **Drop-shape** | *A drop-shape feature at the back of the last trailer* |

For the ETT-vehicle the boundary layer is so wide when it reaches the end of the vehicle that a solution to this problem probably would not make a noticeable difference. Extensive changes to the overall drag must be made before the wake can be improved. Therefore the solutions to this problem are left out of the selection process, and the efforts focused on finding solutions that are more effective.

## 8.5 Decreased Rolling Resistance

The rolling resistance is one of the main contributors to fuel consumption of heavy trucks. There is a sometimes contradictive wish to have low rolling resistance, and at the same time a good grip. As described in chapter 3.6.1 the rolling resistance is highly dependant on the load of the tire. The rolling resistance increases proportionally with the load, but a higher load at same time gives a more efficient tire since the rolling coefficient decreases (De Giacomoni[20]). This means that the same total weight distributed on a decreased number of tires will result in a lower total rolling resistance. Having the right pressure in the tires and a correct wheel alignment also decreases the rolling resistance, as it minimises sliding of the tires.

### 8.5.1 Solutions to Decreased Rolling Resistance

The classification tree for *Decreased rolling resistance* is divided into two subproblems, *decrease rolling coefficient* and *increase axle loads*, see Figure 8.7.

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[20] De Giacomoni, Jacques, Technical Account Manager, Michelin, conversation 2009-11-18

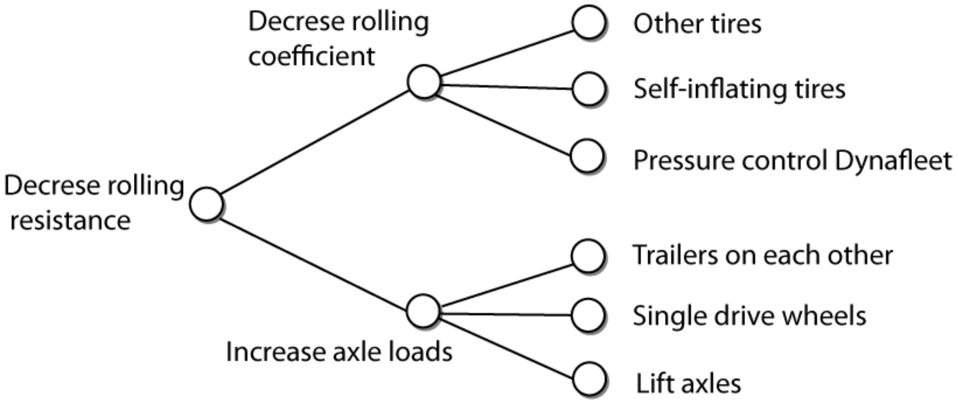

**Figure 8.7.** Classification tree *Decreased rolling resistance*

Brief explanations to the solutions are found in Table 8.16.

**Table 8.16.** Solutions with brief explanations to *Decreased rolling resistance*

| **Solution** | ***Explanation*** |
|---|---|
| **Other tires** | *Tires with less rolling coefficient than the ones used presently* |
| **Self inflating tires** | *Optimise tire pressure hence reduce the rolling coefficient with self inflating tires* |
| **Pressure control with vehicle information cluster** | *Information about the tire pressures in the vehicle information cluster, warning when not satisfying, manual inflation* |
| **Trailers on top of each other** | *Increase the axle loads, when driving empty, by loading the trailers on top of each other* |
| **Single mounting of wheels on drive axles** | *Increase the axle loads by using single mounting on drive axles* |
| **Lift axles** | *Increase the axle loads when driving empty by lifting one or more wheel axles* |

### *8.5.2 Selection of Concepts*

The rating of the solutions and the weighted scores for *Decreased rolling resistance* are presented in Table 8.17.

**Table 8.17.** Concept scoring matrix to Decreased rolling resistance

| | | **Other tires** | | **Self inflating tires** | | **Pressure control** | | **Single mounting on drive axle** | | **Lift axles** | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | *Weight* | R | WS | R | WS | R | WS | R | WS | R | WS |
| Fuel consumption | 0.35 | 4 | 1.4 | 4 | 1.4 | 4 | 1.4 | 4 | 1.4 | 5 | 1.75 |
| Reliability in use | 0.2 | 3 | 0.6 | 2 | 0.4 | 3 | 0.6 | 3 | 0.6 | 3 | 0.6 |
| Safety impact | 0.15 | 3 | 0.45 | 4 | 0.6 | 4 | 0.6 | 2 | 0.3 | 4 | 0.6 |
| Ease of use | 0.1 | 3 | 0.3 | 4 | 0.4 | 4 | 0.4 | 3 | 0.3 | 3 | 0.3 |
| Ease of implementing | 0.1 | 2 | 0.2 | 3 | 0.3 | 4 | 0.4 | 2 | 0.2 | 2 | 0.2 |
| Estimated cost | 0.1 | 3 | 0.3 | 2 | 0.2 | 3 | 0.3 | 3 | 0.3 | 2 | 0.2 |
| | | | **3.25** | | **3.3** | | **3.7** | | **3.1** | | **3.65** |

*Single mounting on drive axle* is rated low scores on *safety impact* and *ease of implementing*. The reason for this is due to the risk of a flat tire, and because of this, it is difficult to convince the customers to use single mounting on the drive axles. One possibility though is to use nitrogen filled tires instead, then the risk of a puncture is decreased and single mounting on drive axle could be used. This possibility is further investigated in chapter 9.4. Another problem with single mounted wheels on drive axles is that there are presently no axles built for this application (Johansson[21]).

*Other tires,* is rated quite average and there are many different types of tires to use. However, Volvo and Parator in cooperation with Michelin have put much effort in finding suitable tires for the purpose and this thesis does not include investigating different tires.

*Self-inflating tires* is a rather expensive solution but an easy and effective way to control the tire pressures. *Pressure control* is an easily implemented solution where the tire pressure is sent to the vehicle information cluster, and provides the driver with the information needed to keep the pressure acceptable at all times. The actual regulation of the pressure is in this solution done manually.

*Lifting wheel axles* is an effective way of increasing the axle loads. Since the load is divided over fewer axles, the load on each axle is increased and the tires become more effective. There are also other benefits with a decreased number of wheel axles. With more tires the inflation pressure and the wheel alignment is more likely to be faulty (Sandberg 2001, pp. 41). Turning is made easier and the side slipping of the tires is decreased, hence there is less abrasion on the tires and their life is prolonged. The riding comfort is increased due to the fact that the damping in the suspensions is dimensioned for loaded vehicle, and gets stiff when the truck drives unloaded due to much lower axle weights. Due to the positive effects of lifted axles, such as improved comfort, minmised vibration, and improved traction for the driving wheels ert[22]), the solution *lift axles* is rated highly as shown in the concept scoring matrix

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[21] Johansson, Alfred, Design Engineer, Epsilon, conversation 2010-03-08

[22] Peinert, Niklas, Senior Engineer, Chassis and Vehicle Dynamics, Volvo 3P, conversation 2009-12-02

above. *Ease of implementing* is rated two points because of the effort needed to add the equipment necessary for lifting axles, and not because it is hard to convince customers of the benefits. The solution *trailers on each other*, is discussed under aerodynamics.

The results of the concept scoring of solutions to *Decreased rolling resistance* are presented in Table 8.18.

**Table 8.18.** Concept scoring results to *Decreased rolling resistance*

| | |
|---|---|
| Pressure control | 3.70 |
| Lift axles | 3.65 |
| Self inflating tires | 3.30 |
| Other tires | 3.25 |
| Single mounting on drive axle | 3.10 |

As described above, *single mounting on drive axle* and *other tires* are eliminated in this step of the development process, and the three solutions with the highest scores are moved on to the testing phase.

## 8.6 Improved Fuel Efficiency

Fuel efficiency is here defined as the amount of fuel used per transport work. The fuel efficiency of a heavy truck depends on many factors. One very important factor is the amount of load carried, and this is further discussed under the need *Increased loading capacity*. The efficiency of the driveline is another important factor where savings often can be made. A vehicle driveline is often dimensioned for the toughest driving conditions it may operate in. This can result in an over-dimensioned driveline that is not optimised for the actual driving conditions in which the vehicle operates. In the case of round wood timber trucks, the return trip is often without cargo, making it a very different load case, for the ETT-vehicle 24 tons instead of 90, hence changing the operational point of the engine. This makes it particularly troublesome to optimise the driveline. The speed of the vehicle and the driver behaviour have also to a large extent an impact on the fuel efficiency. Alternative fuels and auxiliary drives are considered in the need *Lowered emissions*.

### *8.6.1 Solutions to Improved Fuel Efficiency*

The subproblems to the need *Improved fuel efficiency* are driveline and drivers, and these are used as categories in the classification tree, see Figure 8.8.

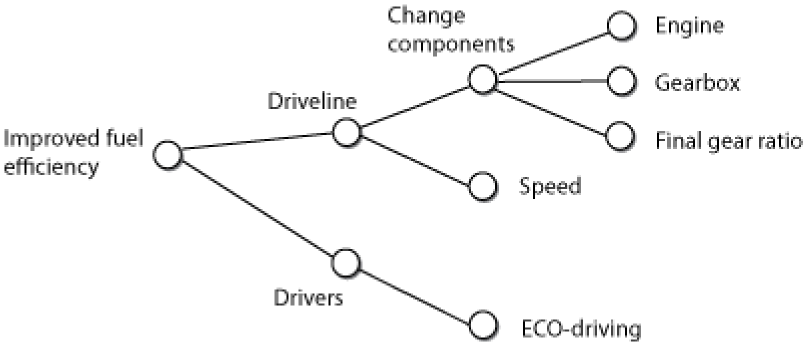

**Figure 8.8.** Classification tree *Improved fuel efficiency*

Table 8.19 presents the solutions with brief explanations.

**Table 8.19.** Solutions with brief explanations to *Improved fuel efficiency*

| Solution | *Explanation* |
|---|---|
| **Components** | *Increase the fuel efficiency by using the most optimised driveline, components analysed are; engine, gear box and drive axle (final gear ratio)* |
| **Speed** | *Use the most optimised speed for the driveline* |
| **ECO-driving** | *Educate and encourage drivers in ECO-driving, how to drive in the most fuel efficient way* |

### *8.6.2 Selection of Concepts*

For this need, *Improved fuel efficiency*, the solutions presented are not to be scored in a concept scoring matrix, but are instead to be tested in simulations in chapter 11, to measure the fuel consumption and effects of changes.

Additional to the driveline, the speed is also affecting the fuel consumption, and both higher and lower speed limits will be tested through simulations. Another way of reducing the emissions from vehicles, is to adapt ECO-driving, where the driver affects the amount of emissions in the way he or she is handling the vehicle. The drivers currently driving the ETT-vehicle have been educated in ECO-driving, and a continuation of this will be part of the final concept.

## 8.7 Increased Loading Capacity

The single most important factor affecting the fuel consumption per ton-km is the loading capacity. When increasing the load on each vehicle, the transport becomes more efficient. However, the gross combination weight is strictly regulated, and to increase it, legislations must be changed. The ETT-project is one step on the way to do this, by emphasizing the environmental, economic and safety benefits of heavier vehicles. Another way of increasing the loading capacity is to reduce the tare-weight. For example, on the ETT-vehicle, a light, high strength steel is used on the semi-trailer which reduces the tare weight with about 250 kg. The third way of improving the efficiency per ton-km, is to transport goods on the return trip as well, which in round wood transports, in most cases, is with empty vehicle. The subproblems to this need are therefore;

- Reduced tare weight
- Higher gross combination weight
- Return trips

### 8.7.1 Reduced Tare Weight

The subproblem *Reduced tare weight* can be solved by either using lighter alternative materials, or less material.

#### 8.7.1.1 Solutions to Reduced Tare Weight

*Alternative materials* and *less material* are the categories the solutions are divided into in the classification tree, see Figure 8.9.

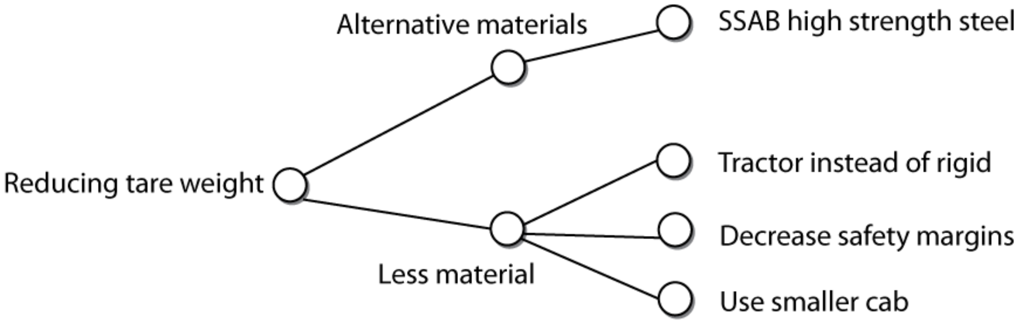

**Figure 8.9.** Classification tree *Reduced tare weight*

In Table 8.20 the solutions are presented with brief explanations.

**Table 8.20.** Solutions with brief explanations to *Reduced tare weight*

| **Solution** | ***Explanation*** |
|---|---|
| **SSAB high strength steel** | *Reduce the tare weight by using lighter materials, e.g. light high strength steel or aluminium in whole vehicle* |
| **Tractor instead of rigid** | *Save weight by using for example tractor and semi-trailer + dolly + semi-trailer or link + link + trailer and not have a timber superstructure on the truck* |
| **Decrease safety margins** | *Use less material overall by reducing the safety margins for the strength* |
| **Use smaller cab** | *Unnecessary with e.g. sleeping department* |

### 8.7.1.2 Selection of Concepts

The solutions to reduced tare weight are scored in the concept scoring matrix in Table 8.21.

**Table 8.21.** Concept scoring matrix to *Reduced tare weight*

| | | **SSAB - steel** | | **Tractor instead of rigid** | | **Decreased safety margins** | | **Use smaller cab** | |
|---|---|---|---|---|---|---|---|---|---|
| | *Weight* | R | WS | R | WS | R | WS | R | WS |
| Fuel consumption | 0.35 | 4 | 1.4 | 4 | 1.4 | 4 | 1.4 | 4 | 1.4 |
| Reliability in use | 0.2 | 3 | 0.6 | 3 | 0.6 | 3 | 0.6 | 3 | 0.6 |
| Safety impact | 0.15 | 3 | 0.45 | 3 | 0.45 | 2 | 0.3 | 3 | 0.45 |
| Ease of use | 0.1 | 3 | 0.3 | 3 | 0.3 | 3 | 0.3 | 3 | 0.3 |
| Ease of implementing | 0.1 | 3 | 0.3 | 3 | 0.3 | 2 | 0.2 | 3 | 0.3 |
| Estimated cost | 0.1 | 3 | 0.3 | 3 | 0.3 | 3 | 0.3 | 4 | 0.4 |
| | | | **3.35** | | **3.35** | | **3.1** | | **3.45** |

For the solution *alternative materials*, the use of the high strength steel on the entire ETT-vehicle, is rated in the concept scoring matrix as the solution *SSAB-steel*. This is an existing solution and therefore not difficult to implement or use, and is rated three points for all criteria except for fuel consumption which it improves.

*Tractor instead of rigid* is also an existing solution and reduces the weight and hence improves the fuel consumption. *Use smaller cab* is a possible solution and does not bring on many changes compared to the present cab, but is probably cheaper and reduces the weight. The results from the scoring matrix are shown in Table 8.22.

**Table 8.22.** Concept scoring results to *Reduced tare weight*

| | |
|---|---|
| Use smaller cab | 3.45 |
| SSAB - steel | 3.35 |
| Tractor instead of rigid | 3.35 |
| Decreased safety margins | 3.10 |

The two solutions eliminated are *tractor instead of rigid* and *decreased safety margins*. *Decreased safety margins* is not eliminated because of low scores, but instead because the safety is too important to neglect, and this would be a very expensive and time consuming process. *Tractor instead of rigid* is eliminated for the reason that it has to be investigated further before any decision can be made. In this thesis for example the stability and how well it takes turns etc, is not evaluated and hence a well informed decision cannot be made.

### *8.7.2 Higher Gross Combination Weight*

To increase the gross combination weight on heavy duty trucks, the legislations must be changed. If the ETT-project succeeds in convincing the legislators of the beneficial effects of heavier vehicles this might be a reality in the future. One important aspect to this is not to exceed the axle weights since this would increase the road wear significantly. If the regulation changes, it might not be limited to the regulations of the ETT-vehicle, but even longer and heavier vehicles could be a possibility. Solutions to efficiency in this case are for example to increase the gross combination weight to more than 90 tons, add a fifth pile of timber to the combination and add a third wheel axle to the rear bogie in order to increase the load on the truck.

#### 8.7.2.1 Solutions to Higher Gross Combination Weight

A heavier combination can either be achieved by making it longer or just heavier which are the two categories in the classification tree, see Figure 8.10 and Table 8.23 for solutions and brief explanations to them.

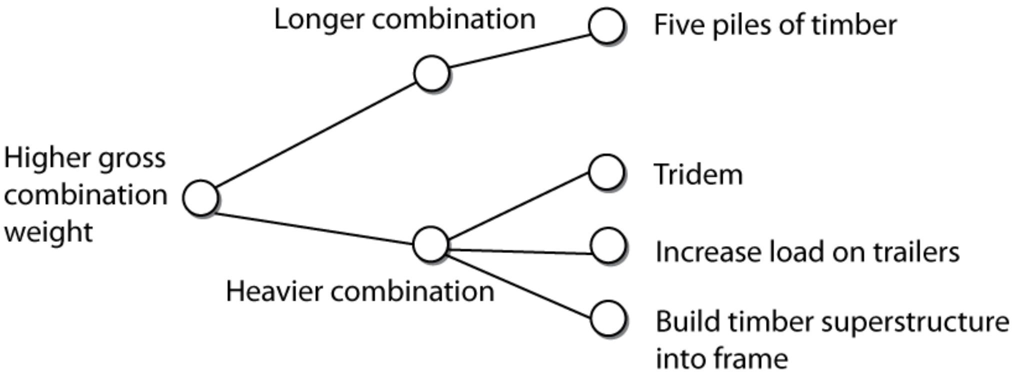

**Figure 8.10.** Classification tree *Higher gross combination weight*

**Table 8.23.** Solutions with brief explanations to *Higher gross combination weight*

| **Solution** | ***Explanation*** |
|---|---|
| **Five piles of timber** | *Increase the vehicle length and loading capacity by adding a fifth pile of timber* |
| **Tridem** | *Increase the load on the truck by using a four-axle truck i.e. a tridem* |
| **Increased load on trailers** | *Increase load on trailers by adding wheel axles* |
| **Build timber superstructure into frame** | *This lowers the centre of gravity and you can load higher (also good for safety and stability)* |

### 8.7.2.2 Selection of Concepts

The solutions to *Higher gross combination weight* are rated in the concept scoring matrix in Table 8.24.

**Table 8.24.** Concept scoring matrix to *Higher gross combination weight*

| | | **Five piles** | | **Tridem** | | **Increased load on trailers** | | **Building timber structure into frame** | |
|---|---|---|---|---|---|---|---|---|---|
| | *Weight* | R | WS | R | WS | R | WS | R | WS |
| Fuel consumption | 0.35 | 5 | 1.75 | 4 | 1.4 | 4 | 1.4 | 4 | 1.4 |
| Reliability in use | 0.2 | 3 | 0.6 | 3 | 0.6 | 3 | 0.6 | 3 | 0.6 |
| Safety impact | 0.15 | 2 | 0.3 | 4 | 0.6 | 2 | 0.3 | 3 | 0.45 |
| Ease of use | 0.1 | 2 | 0.2 | 3 | 0.3 | 3 | 0.3 | 3 | 0.3 |
| Ease of implementing | 0.1 | 1 | 0.1 | 4 | 0.4 | 2 | 0.2 | 2 | 0.2 |
| Estimated cost | 0.1 | 3 | 0.3 | 2 | 0.2 | 2 | 0.2 | 1 | 0.1 |
| | | | **3.25** | | **3.50** | | **3.0** | | **3.05** |

The criterion *safety impact* differs between the solutions whether the extra weight is added to the trailer or the truck. When added to the truck, the traction is improved, hence the safety is improved, but on the trailers the safety is reduced due to a higher centre of gravity or a longer vehicle. The solution *building timber structure into frame* results in a lower centre of gravity which benefits the safety, however by doing this it is possible to load higher and that decreases the safety, hence the rating three points.

**Table 8.25.** Concept scoring results to *Higher gross combination weight*

| | |
|---|---|
| Tridem | 3.50 |
| Five piles | 3.25 |
| Building timber structure into frame | 3.05 |
| Increase load on trailers | 3.00 |

The two solutions with the lowest scores are eliminated in this phase, see Table 8.25. The reason these two are not be put through to further testing, is that these are too difficult to implement and not as effective as the top two solutions regarding fuel savings.

### *8.7.3 Return Trips*

Since the return trips for round wood transportation in most cases are with empty vehicle, the total loading capacity of the transport would increase significantly by transporting goods on the return trip as well.

#### 8.7.3.1 Solutions to Return Trips

This subproblem is not further divided into categories, the solutions and brief explanations are presented in Table 8.26.

**Table 8.26.** Solutions with brief explanations to *Return trips*

| **Solution** | ***Explanation*** |
|---|---|
| **Adaptable superstructures** | *Superstructures which can adapt depending on what cargo is transported. For example collapsible bunks where something can be placed on top.* |
| **Van bodies** | *Adding van bodies to the timber superstructure to transport other cargo on the return trip* |

The issue with the return trips has a lot to do with the logistics of the transportation. Because of the limitations mainly due to time for this thesis, and that logistics is not main focus, no further investigation or comments will be included regarding carrying load on the return trips. However, the return trips without cargo are further investigated under other needs.

## 8.8 Lowered emissions

The European Union environmental objectives for 2020, states all emissions should be lowered with 20% before 2020 compared to the levels of 1990. To minmise the emissions from the transport industry, after treatment of for example nitrogen oxides are used according to the European emission standard system. The existing ETT-vehicle is using after treatment of standard Euro 4, but since this vehicle was built, Euro 5, which even further improves the after treatment of emissions, has changed to be the standard for vehicles produced 2009 and later. The reduction of carbon dioxide is mainly achieved by improved fuel efficiency. However, there are other ways to minmise the emissions of $CO_2$, for example by using alternative fuels, e.g. biofuel, or to use alternative auxiliary power sources.

The need *Lowered emissions*, can be divided into two subproblems;

- Emission after-treatment
- Alternative fuels and power sources

### 8.8.1 Solutions to Lowered Emissions

The solution that is most in hand to use, is to change Euro 4 to Euro 5. Euro 6 is expected to be standard in 2014.

To minimise the emission of $CO_2$, either alternative fuels or an auxiliary power sources can be used and these two are the categories in the classification tree for this problem, see Figure 8.11.

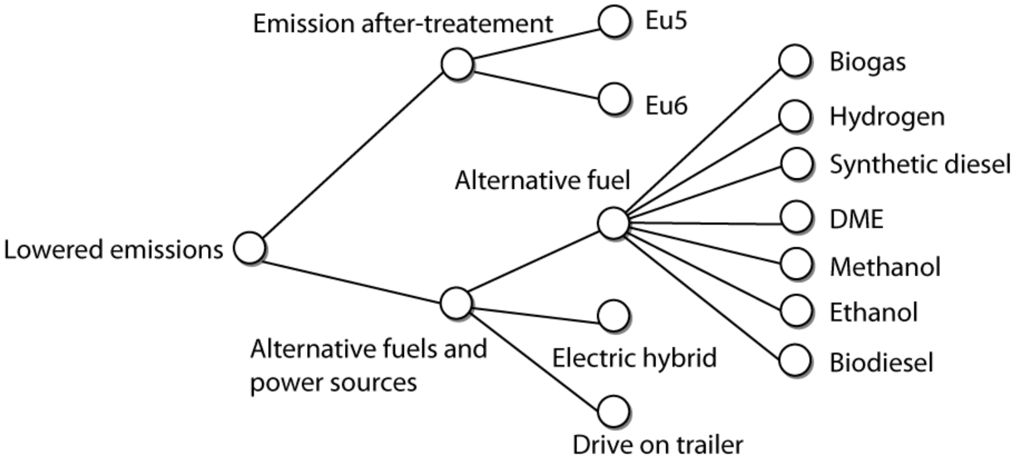

**Figure 8.11.** Classification tree *Lowered Emissions*

Brief explanations to the solutions are found in Table 8.27.

**Table 8.27.** Solutions with brief explanations to *Alternative fuels and power sources*

| **Solution** | ***Explanation*** |
|---|---|
| **Electric hybrid** | *Use electric power in combination with diesel power* |
| **Alternative fuels** | *Use alternative fuel e.g. solar energy, fuel cell, ethanol, bio diesel or DME* |
| **Drive on trailer** | *Make one or more axles on trailer(-s) driving* |

#### 8.8.1.1 Selection of Concepts

Since Eu5 is standard on vehicles built after 2008, it will move on to the final concept. To reduce the emissions of carbon dioxide, there are several alternative fuels that can be used. Much research is made in this area, and tests on for example DME are conducted at present time and will hopefully be a possibility within a few years. This thesis does not run any test on alternative fuels due to the limitations of the thesis and no further comments on the subject are included. The other two solutions, *hybrid* and *drive on trailer* are rated in Table 8.28.

**Table 8.28.** Concept scoring matrix to *Alternative fuels and power sources*

| | | **Hybrid** | | **Drive on trailer** | |
|---|---|---|---|---|---|
| | *Weight* | R | WS | R | WS |
| Fuel consumption | 0.35 | 3 | 1.05 | 3 | 1.05 |
| Reliability in use | 0.2 | 2 | 0.4 | 2 | 0.4 |
| Safety impact | 0.15 | 3 | 0.45 | 4 | 0.6 |
| Ease of use | 0.1 | 3 | 0.3 | 3 | 0.3 |
| Ease of implementing | 0.1 | 2 | 0.2 | 2 | 0.2 |
| Estimated cost | 0.1 | 1 | 0.1 | 2 | 0.2 |
| | | | **2.50** | | **2.75** |

Hybrids exists in passenger cars, and to some extent on heavy duty trucks, mainly operating in city traffic, and are therefore difficult to implement satisfactory in this application, but is worth mentioning as the technology is developing fast. Whether an auxiliary drive on one or more trailer axles would benefit the ETT-vehicle must be further investigated, but is left out of this thesis. None of the presented solutions will be moving on after this phase, as can be seen in Table 8.29.

**Table 8.29.** Concept scoring results to *Alternative fuels and power sources*

| | |
|---|---|
| Drive on trailer | 2.75 |
| Hybrid | 2.50 |

## 8.9 Improved Traction

The ETT-vehicle has had problems with the startability when it is empty, due to very low drive axle load, relatively high tare weight and many wheels to pull into motion. The problem is especially noticeable when road conditions are slippery. The bogie lift has had a positive impact on the drive axle load, but is not quite sufficient to ensure the startability. Traction can also be improved by driving on more than one axle, hence pulling or pushing the vehicle into motion. The need *Improved Traction*, is divided into the subproblems;

- Drive axle load
- Grip

### *8.9.1 Solutions to Improved Traction*

The classification tree to the need *Improved traction* is categorised into the subproblems *drive axle load* and *grip*, see Figure 8.12 for solutions, and Table 8.30 for explanations to them.

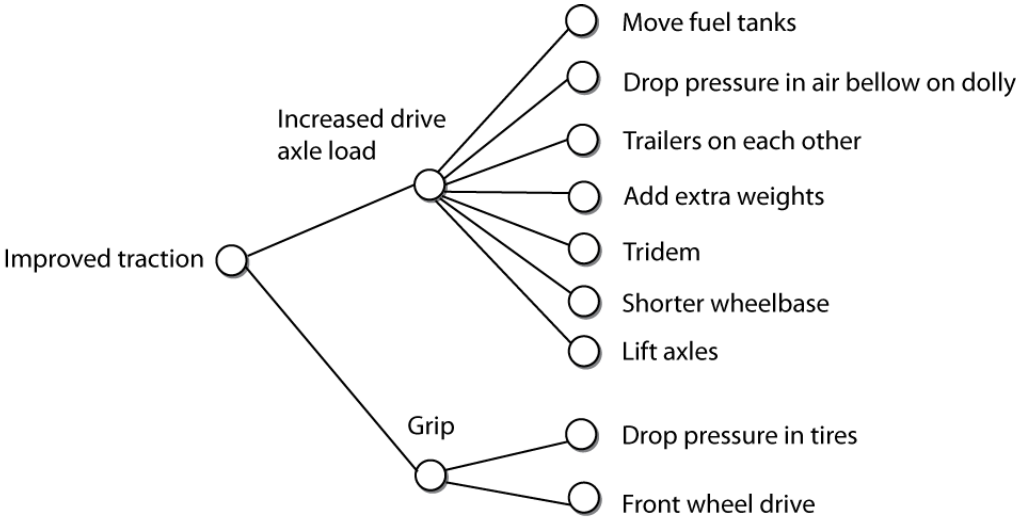

**Figure 8.12.** Classification tree *Improved traction*

**Table 8.30.** Solutions and brief explanations to *Improved traction*

| Solution | *Explanation* |
|---|---|
| **Move fuel tanks** | *Increase the drive axle load by moving the fuel tanks further back, or to another beneficial position* |
| **Drop pressure in air bellow on first axle on dolly** | *With less air in the air bellow on the first dolly axle when driving empty, more load is put on the drive axles* |
| **Trailers on each other** | *On the return trip, with the trailers on each other, more weight is put on the drive axles* |
| **Tridem** | *By lifting two axles on a tridem, more weight is put on the remaining drive axle* |
| **Add extra weights** | *By adding extra weights the load on the drive axles increases* |
| **Shorter wheelbase** | *With shorter wheelbase more load is put on the drive axle* |
| **Lift axles** | *Lowered rolling resistance and improved traction* |
| **Drop pressure in tires** | *Increase the grip by regulating the tire pressure, by e.g. an automatic pressure control system* |
| **Front wheel drive** | *Increase the grip by using front wheel drive. Could be done by e.g. hydraulic-, electric-, mechanic- or other drive* |

### *8.9.2 Selection of Concepts*

For the need *Improved* traction, three of the solutions, *trailers on each other*, *tridem* and *lift axles*, are rated in other chapters. The rest of the solutions are rated in Table 8.31.

**Table 8.31.** Concept scoring matrix to *Improved traction*

| | | **Move fuel tanks** | | **Drop pressure in air bellow on dolly** | | **Add extra weight** | | **Shorter wheelbase** | | **Front wheel drive** | | **Drop pressure in tires** | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *Weight* | R | WS | R | WS | R | WS | R | WS | R | WS | R | WS |
| Fuel consumption | 0.35 | 3 | 1.05 | 3 | 1.05 | 2 | 0.7 | 3 | 1.05 | 3 | 1.05 | 3 | 1.05 |
| Reliability in use | 0.2 | 3 | 0.6 | 3 | 0.6 | 3 | 0.6 | 3 | 0.6 | 2 | 0.4 | 2 | 0.4 |
| Safety impact | 0.15 | 4 | 0.6 | 4 | 0.6 | 4 | 0.6 | 3 | 0.45 | 4 | 0.6 | 4 | 0.6 |
| Ease of use | 0.1 | 3 | 0.3 | 3 | 0.3 | 3 | 0.3 | 3 | 0.3 | 3 | 0.3 | 3 | 0.3 |
| Ease of implementing | 0.1 | 2 | 0.2 | 3 | 0.3 | 4 | 0.4 | 3 | 0.3 | 2 | 0.2 | 3 | 0.3 |
| Estimated cost | 0.1 | 3 | 0.3 | 3 | 0.3 | 3 | 0.3 | 3 | 0.3 | 1 | 0.1 | 2 | 0.2 |
| | | | **3.05** | | **3.15** | | **2.9** | | **3** | | **2.65** | | **2.85** |

All of the solutions to *improved traction* have none or negligible affect on the fuel consumption and *ease of use* is not affected since nothing has to be done while driving, except for dropping the air in the bellows, but this could be handled easily from the cab.

The results from the scoring matrix are presented in Table 8.32.

**Table 8.32.** Concept scoring results to *Improved traction*

| | |
|---|---|
| Drop pressure in air bellow on 1st axle on dolly | 3.15 |
| Move fuel tanks | 3.05 |
| Shorter wheelbase | 3.00 |
| Add extra weight | 2.90 |
| Drop pressure in tires | 2.85 |
| Front wheel drive | 2.65 |

Only the two solutions with the top scores move on to the testing. This is mainly because these two are fairly easy to implement compared to the gain in traction as opposed to the bottom two solutions. The front wheel drive is more applicable in forest driving and very hilly conditions. A shorter wheelbase has to be evaluated considering stability and handling. Adding extra weight to the vehicle is an easy solution but has negative impact on the fuel consumption and is hence eliminated.

## 8.10 Improved Weight Control

In the regulations concerning the ETT-vehicle there are certain demands on the possibility of monitoring the weight from inside the cab. This weight system is controlled by the braking modules, and each axle group sends the information to a screen in the cab. This need is therefore closely connected to the need *Improved braking*, discussed in chapter 9.7. The driver should at all times be able to see the gross combination weight and load distribution so that correct axle loads are achieved. However the weight system cannot measure the weight during loading, as the air bellows are emptied.

There have been problems with this weight system and the drivers do not depend on the weights shown on the screen, as they are faulty, instead they use the weight information from the loading crane. Therefore this system has to be improved, and calibration is of high importance to make this system reliable, improve the safety and facilitate the driver's job. Another problem with the weight system is that it only shows the total weight in each axle group. In case the load on one of the axles in a group exceeds the limit, this does not show on the screen. It is desirable to get information about every wheel axle load, or even tire load to improve the weight distribution, the safety and the road wear.

### *8.10.1 Solutions to Improved Weight Control*

The classification tree to this need is not divided into further categories than the main need to *Improve the weight control*, see Figure 8.13.

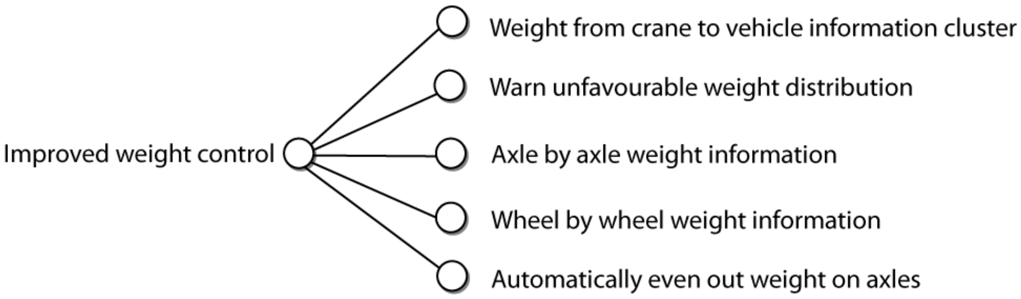

**Figure 8.13.** Classification tree *Improved weight control*

Explanations to the solutions are found in Table 8.33.

**Table 8.33.** Solutions with brief explanations to *Improved weight control*

| **Solution** | ***Explanation*** |
|---|---|
| **Weight from crane to vehicle information cluster** | *Weight information sent wireless from the crane to the vehicle information cluster to be compared with vehicle weight system* |
| **Warn unfavourable weight distribution** | *A system monitoring that the load is beneficially distributed over the axles, warns if it is not* |
| **Axle by axle weight** | *Information on the vehicle information cluster about each axle load separately* |
| **Wheel by wheel weight** | *Information on the vehicle information cluster about each wheel load separately* |
| **Even out weight** | *Even out each axle groups load by e.g. regulating the pressure in the air bellows* |

### 8.10.2 Selection of Concepts

The rating of the solutions to *Improved weight control* are presented in Table 8.34, and as can be seen here, the scores do not differ substantially between the different solutions.

**Table 8.34.** Concept scoring matrix to *Improved weight control*

| | | **Weight from crane to cluster** | | **Warn unfavourable weight distribution** | | **Axle by axle** | | **Wheel by wheel** | | **Even out weight** | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | *Weight* | R | WS | R | WS | R | WS | R | WS | R | WS |
| Fuel consumption | 0.35 | 3 | 1.05 | 3 | 1.05 | 3 | 1.05 | 3 | 1.05 | 3 | 1.05 |
| Reliability in use | 0.2 | 3 | 0.6 | 3 | 0.6 | 2 | 0.4 | 2 | 0.4 | 2 | 0.4 |
| Safety impact | 0.15 | 4 | 0.6 | 5 | 0.75 | 4 | 0.6 | 4 | 0.6 | 4 | 0.6 |
| Ease of use | 0.1 | 5 | 0.5 | 5 | 0.5 | 5 | 0.5 | 5 | 0.5 | 5 | 0.5 |
| Ease of implementing | 0.1 | 2 | 0.2 | 2 | 0.2 | 3 | 0.3 | 3 | 0.3 | 3 | 0.3 |
| Estimated cost | 0.1 | 3 | 0.3 | 3 | 0.3 | 3 | 0.3 | 3 | 0.3 | 3 | 0.3 |
| | | | **3.25** | | **3.4** | | **3.15** | | **3.15** | | **3.15** |

The solutions *axle by axle, wheel by wheel* and *even out weight* are rated 2 points for the criterion *Reliability in use* because of the problems with the present system and the unreliability of the signals between the truck and the trailers. However these three should not be difficult to implement since this is an already existing system and it is a matter of what signals to transform and show on the screen. The other two solutions, *Weight from crane to vehicle information cluster* and *Warn unfavourable weight distribution* are probably also not too difficult to implement, provided the weight system works.

The results from the scoring matrix are shown in Table 8.35.

**Table 8.35.** Concept scoring results to *Improved weight control*

| | |
|---|---|
| Warn unfavourable weight distribution | 3.40 |
| Weight from crane to vehicle information cluster | 3.25 |
| Axle by axle | 3.15 |
| Wheel by wheel | 3.15 |
| Even out weight | 3.15 |

All of these solutions are moving on to the final concept, for the reason that this is an important issue and the weight system has to be working, due to legislations, safety reasons and to make sure as much load as possible is carried. All these solutions are possible to implement simultaneously which would further improve the weight control system. The vehicle information cluster is a subject of discussion in the testing phase.

## 8.11 Improved Average Speed

A lot of the fuel used in the operation of a heavy vehicle combination like the ETT-vehicle, is used to accelerate the vehicle. The high loads put high demands on the driveline, and there is a lot of inertia to overcome. Minimising the accelerations and decelerations of the vehicle could save a lot of fuel and time, and the average speed is then increased. A stronger driveline decreases the losses in velocity that are caused by climbing inclining roads, and improves the acceleration time[23].

### *8.11.1 Solutions to Improved Average Speed*

The solutions to this need are shown in the classification tree, see Figure 8.14, and Table 8.36 for brief explanations.

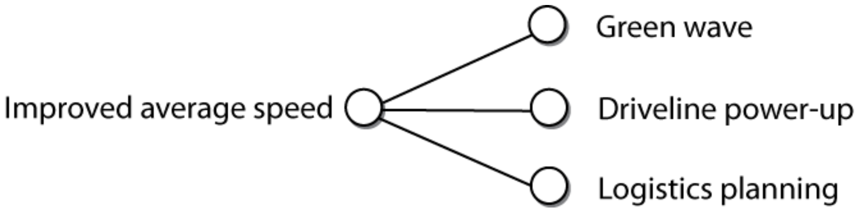

**Figure 8.14.** Classification tree *Improved average speed*

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[23] A short acceleration time is not necessarily decreasing the fuel consumption, but might be a consideration of time versus fuel.

**Table 8.36.** Solutions and brief explanations to Improved average speed

| **Solution** | ***Explanation*** |
|---|---|
| **Green wave** | *Logistics system that knows when a heavy duty truck is on the way towards a traffic light and switches to green automatically* |
| **Driveline power-up** | *Stronger driveline that can keep the desired speed* |
| **Logistics planning** | *Plan ahead to prevent acceleration/deceleration* |

The solutions to *Improved average speed* will not be rated and ranked, since *green wave* and *logistics planning* are outside the limitations of this thesis, and are only commented on in this chapter. *Driveline power-up* will be tested in the simulations in chapter 11.4, where different drivelines are compared regarding gradeability and how well they keep the speed on the actual service path of the ETT-vehicle, as well as fuel consumption.

# 9 Concept Generation and Selection – Needs without Target Specifications

*In this chapter the concept generation and selection continues with the needs without target specifications. These needs have no, or very limited impact on the fuel consumption, but have instead other beneficial effects. The goal of the concept generation is to find solutions that fulfil the needs, wants and expectations expressed by the customers. Solutions are presented for most of the needs; some needs are left out because of the limits of this thesis. The scoring matrices and results from the scoring are presented with discussions about the solutions and the process.*

The four-step method described in 8.1.1, and the scoring matrix described in chapter 8.2.1, is applied to this chapter. All needs are also discussed, and concept generation and selection for them is performed to a limited extent. The needs are, in the order of relative importance;

- Flexible driving hours
- Improved climate control in cab
- Improved visibility of truck
- Improved safety for driver and other road users
- Improved loading and fastening
- Improved visibility for driver
- Improved braking
- Reduced road wear
- Reliable electric cable solutions
- Improved accessibility
- Improved driver environment

## 9.1 Flexible Driving Hours

As mentioned in chapter 3.3.2, drivers must take a break of at least 45 minutes after four and a half hours of driving, otherwise they risk fines. The distance the ETT-vehicle is driving is about 160 km one way, and the drivers barely make it back and forth within this time limit. With this kind of pressure, the risk of unnecessary stress puts a risk to the traffic safety, and limits the possibility to practise economical driving. It is therefore desirable with some flexibility in the driving hours' legislation in order to keep the safety and environment highest priority. Another solution is to carefully plan the logistic flow and place the loading places on appropriate distances.

However, since this is mainly a question of legislation, this issue falls outside of this thesis work, and is not discussed further.

## 9.2 Improved Climate Control in Cab

Since the ETT-vehicle is driven in the north of Sweden, where the cold weather is a fact during the long winter, the climate control in the cab needs to be efficient at all time. In order to keep the heat, or in summer to keep the cab cool, the truck is idling while loading and unloading, which consumes fuel.

### 9.2.1 Solutions to Improved Climate Control in Cab

Solutions that aim to minmise the idling time are presented in Table 9.1, for example an external drive on the climate control could be used. Brief explanations of the solutions are also included in the table.

**Table 9.1.** Solutions with brief explanations to *Improved climate control in cab*

| **Solution** | ***Explanation*** |
|---|---|
| **Conserve energy from loading** | *Convert potential energy from the timber crane into electric energy* |
| **Conserve the braking energy** | *Convert braking energy into electric energy* |
| **Solar cells** | *Solar cells on the vehicle load batteries* |
| **Wind generator** | *While standing still, convert the wind into electric energy* |
| **Insulation** | *Improved insulation in cab* |

### 9.2.2 Selection of Concepts

The concept scoring matrix, where all the solutions are rated according to six criteria, are shown in Table 9.2. In the criterion *reliability in use*, what the chances are to use the different solutions are considered. For example, to use solar cells it needs to be sunny, while the solution *conserve energy from loading* can be used every time during loading or unloading.

**Table 9.2.** Concept scoring matrix of *Improved climate control in cab*

| | | **Conserve energy from loading** | | **Conserve braking energy** | | **Solar cells** | | **Wind generator** | | **Insulation** | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | *Weight* | R | WS | R | WS | R | WS | R | WS | R | WS |
| Fuel consumption | 0.35 | 4 | 1.4 | 4 | 1.4 | 4 | 1.4 | 4 | 1.4 | 4 | 1.4 |
| Reliability in use | 0.2 | 3 | 0.6 | 2 | 0.4 | 1 | 0.2 | 1 | 0.2 | 3 | 0.6 |
| Safety impact | 0.15 | 3 | 0.45 | 3 | 0.45 | 3 | 0.45 | 3 | 0.45 | 3 | 0.45 |
| Ease of use | 0.1 | 3 | 0.3 | 3 | 0.3 | 3 | 0.3 | 3 | 0.3 | 4 | 0.4 |
| Ease of implementing | 0.1 | 1 | 0.1 | 2 | 0.2 | 2 | 0.2 | 1 | 0.1 | 1 | 0.1 |
| Estimated cost | 0.1 | 2 | 0.2 | 1 | 0.1 | 1 | 0.1 | 1 | 0.1 | 1 | 0.1 |
| | | | **3.05** | | **2.85** | | **2.65** | | **2.55** | | **3.05** |

The results from the scoring matrix are sorted and presented in Table 9.3.

**Table 9.3.** Concept scoring results to *Improved climate control in cab*

| | |
|---|---|
| Conserve energy from loading | 3.05 |
| Insulation | 3.05 |
| Conserve braking energy | 2.85 |
| Solar cells | 2.65 |
| Wind generator | 2.55 |

The three solutions with the lowest scores will not move on to the testing phase, since these are considered too unreliable or ineffective to use in field. The wind generator will probably not generate enough energy to cover the increased weight and cost, and in operation in the north of Sweden the sun is not a reliable source of power. *Conserving braking energy* could be an option but is probably to expensive to be satisfactory. *Insulation* and *Conserve energy from loading*, ended up with the same score but only *Conserve energy from loading* will be moving on to the testing since *Insulation*, to the degree needed to keep the heat in the cab during the very cold winters, is considered too difficult to implement.

## 9.3 Improved Visibility of Truck

When driving in the dark, it can be hard for other road users to acknowledge timber trucks from behind. Trucks with covered cargo often have lights at the top of the cargo space, and this indicates to drivers behind the truck that it is a tall vehicle. Since timber trucks lack the space to put lights high up in the back, there is a risk of following traffic mistaking the truck for a passenger car or other smaller vehicle.

When there is a lot of snow, as is the case several months a year in the ETT-vehicle’s operational area, signs and lights easily get covered with snow, see Figure 9.1. This obstructs the other road users to see and form a correct estimation of the ETT-vehicles size for example before an overtaking.

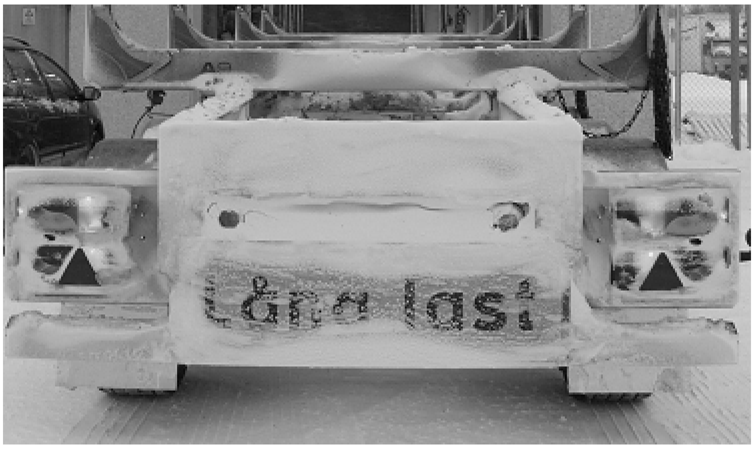

**Figure 9.1.** Sign and lights on the ETT-vehicle partially covered in snow

### *9.3.1 Solutions to Improved Visibility of Truck*

Solutions that are aimed to improve the visibility of the truck and hence make it more visible to other road users are presented in Table 9.4, and are also briefly explained.

**Table 9.4.** Solutions with brief explanations to *Improved visibility of truck*

| **Solution** | ***Explanation*** |
|---|---|
| **LED-sign** | *LED-sign at the back of the combination with exchangeable text that can display e.g. length, speed, and weight of the combination. It has wireless connection to the vehicle information cluster, can be updated automatically and is powered by a battery.* |
| **Reflector tapes** | *Reflector tape on timber bunks and/or wheels.* |
| **Lights on timber bunks** | *Extra lighting on the top-end of the timber bunks* |

### *9.3.2 Selection of Concepts*

The solutions for *Improved visibility of truck* are rated according to the chosen criteria in the concept scoring matrix in Table 9.5.

**Table 9.5.** Concept scoring matrix of *Improved visibility of truck*

| | | **LED-sign** | | **Reflector tapes** | | **Lights on timber bunks** | |
|---|---|---|---|---|---|---|---|
| | *Weight* | R | WS | R | WS | R | WS |
| Fuel consumption | 0.35 | 3 | 1.05 | 3 | 1.05 | 3 | 1.05 |
| Reliability in use | 0.2 | 2 | 0.4 | 5 | 1 | 2 | 0.4 |
| Safety impact | 0.15 | 5 | 0.75 | 4 | 0.6 | 4 | 0.6 |
| Ease of use | 0.1 | 5 | 0.5 | 5 | 0.5 | 5 | 0.5 |
| Ease of implementing | 0.1 | 2 | 0.2 | 5 | 0.5 | 2 | 0.2 |
| Estimated cost | 0.1 | 3 | 0.3 | 3 | 0.3 | 2 | 0.2 |
| | | | **3.2** | | **3.95** | | **2.95** |

The results from the scoring matrix are listed in Table 9.6.

**Table 9.6.** Concept Scoring results to *Improved visibility of truck*

| | |
|---|---|
| Reflector tapes | 3.95 |
| LED-sign | 3.20 |
| Lights on timber bunks | 2.95 |

For this need, all solutions got fairly high scores, except *Lights on timber bunks*, since it is considered to be quite difficult and expensive to implement. No such existing solution has been found. However this solution is not yet eliminated but investigated further in the concept testing, since it is still considered an interesting and effective solution. Reflector tapes are an easy, effective, cheap and already existing solution and have achieved very high scores in the evaluation.

## 9.4 Improved Safety for Driver and Other Road Users

A timber truck, or any heavy duty truck, can be hazardous to other road users causing much damage, and increased weight leads to higher impact in case of collision. Therefore, everything that can be done to improve the safety for all road users should be done. For example, there are several safety systems available that helps the driver in case of emergency and warn if an accident is near. The safety of the driver is also an important issue, single accidents with heavy cargo could have fatal outcome.

### 9.4.1 Solutions to Improved Safety for Driver and Other Road Users

Solutions that improve the safety for the driver and the surrounding traffic is presented and explained in Table 9.7.

**Table 9.7.** Solutions with brief explanations to *Improved safety for driver and other road users*

| Solution | *Explanation* |
|---|---|
| **Safety systems that alert the driver** | *Warning for **slippery roads***<br>***Eye scanners** that scan the driver's eyes to determine their degree of awareness and alerts to prevent him/her from falling asleep*<br>***DAS** – Driver Alert Support – monitors the vehicle's motion in the driving lane and evaluates the driver's alertness, warns suspected tiredness and distraction*<br>*Warning **system connected to the road network**, alerts audible or visually when sharp curves, roundabouts, crosswalks etc are coming up and the vehicle has an inappropriate speed*<br>***LCS** – Lane Change Support – radar detects vehicles in the blind spot when blinkers are activated.* |
| **Safety systems that adjust the driving automatically** | ***ACC -** adaptive cruise control that keeps the distance to traffic in front*<br>***Anti side-slip system** when starting*<br>***Motion detector** that scans an area in front of the truck, the vehicle responds automatically for example by braking when something is detected* |
| **Nitrogen filled tires** | *To prevent accidents from exploding tires* |
| **Trailer skirts** | *Covers between wheels to prevent other road users to get stuck under the truck/trailers* |

### 9.4.2 Selection of Concepts

Not all solutions to *Improved safety for driver and other road users* is evaluated in the scoring matrix, Table 9.8. All the safety systems, both the ones that alert the driver and those adjusting the driving automatically, will be suggestions in the final concept, since the safety is such an important issue, and all safety measures available should be used. Most of them exist already, at least for passenger cars, and the transition is considered manageable within a near future. The anti-side slip system has however not been found, and could be difficult to implement, but would be a great help when starting on slippery roads. The warning system connected to the road network should be able to operate together with the vehicle information cluster that has GPS-connection.

Such systems exist, one example is E-horizon[24]. The trailer skirts are left out in this matrix since this solution is rated under aerodynamics.

**Table 9.8.** Concept Scoring Matrix of *Improved safety for driver and other road users*

| | | **Nitrogen filled tires** | |
|---|---|---|---|
| | *Weight* | R | WS |
| Fuel consumption | 0.35 | 3 | 1.05 |
| Reliability in use | 0.2 | 4 | 0.8 |
| Safety impact | 0.15 | 4 | 0.6 |
| Ease of use | 0.1 | 2 | 0.2 |
| Ease of implementing | 0.1 | 3 | 0.3 |
| Estimated cost | 0.1 | 3 | 0.3 |
| | | | **3.25** |

The scoring only includes *Nitrogen filled tires* that achieves a total score of 3.25. It scores high in the criteria reliability because this solution is assumed to keep the pressure in the tires better than air, and reduce the risk of exploding tires. This solution moves on to the concept testing, where it is further investigated.

## 9.5 Improved Loading and Fastening

The loading of timber on the ETT-vehicle is done by a separate crane that needs to lift the timber over the timber bunks and place it between, since the timber bunks cannot be lowered. The fastening is done by the driver who throws the chains over the piles and fastens them. These chains are automatically strained by a pneumatic strainer. However, the throwing means a risk of injuries for the driver.

### 9.5.1 Solutions to Improved Loading and Fastening

Solutions facilitating or improving the loading, unloading and load fastening are presented and briefly explained in Table 9.9.

**Table 9.9.** Solutions with brief explanations for *Improved loading and fastening*

| **Solution** | ***Explanation*** |
|---|---|
| **Collapsible timber bunks** | *Makes the loading easier by not having to lift the timber as high, e.g. telescope bunks that unfold during loading.* |
| **Com90**[25] | *Timber bunk with automatic fastener.* |
| **Reinforced fabric belts** | *Belts of metallic- or glass fibre reinforced fabric that the crane can lift around the timber pile.* |

---

[24] Cider, Lennart, Project Manager, Volvo Technology, conversation 2010-03-08

[25] Com90 is a timber bunk from manufacturer ExTe that with the use of hydraulics automatically fastens the load leaving the use of chains unnecessary. They can be lowered to about half their height, but are relatively heavy in comparison with other timber bunks (www.exte.se).

### *9.5.2 Selections of Concepts*

For the need *Improved loading and fastening*, one of the solutions – *Collapsible timber bunks*, is rated under aerodynamics, so it is not included in Table 9.10, where the other two solutions are rated.

**Table 9.10.** Concept scoring matrix of *Improved loading and fastening*

| | | **Com90** | | **Reinforced fabric belts** | |
|---|---|---|---|---|---|
| | *Weight* | R | WS | R | WS |
| Fuel consumption | 0.35 | 2 | 0.7 | 3 | 1.05 |
| Reliability in use | 0.2 | 3 | 0.6 | 3 | 0.6 |
| Safety impact | 0.15 | 4 | 0.6 | 3 | 0.45 |
| Ease of use | 0.1 | 5 | 0.5 | 4 | 0.4 |
| Ease of implementing | 0.1 | 2 | 0.2 | 3 | 0.3 |
| Estimated cost | 0.1 | 2 | 0.2 | 2 | 0.2 |
| | | | **2,8** | | **3** |

The scoring leaves *Com90* with quite low scores. Many of the customers have requested Com90, but since this solution is heavy, the fuel consumption is increased, and this is why Com90 is eliminated in this step of the concept selection. The result from the scoring is shown in Table 9.11.

**Table 9.11.** Concept Scoring results to *Improved loading and fastening*

| | |
|---|---|
| Reinforced fabric belts | 3.0 |
| Com90 | 2.8 |

There are belts in use on timber trucks, but these are rarely used in the north of Sweden due to the amount of snow and ice on the timber which makes the belts slip easier. Since this is an existing solution it moves on to the testing phase.

## 9.6 Improved Visibility for Driver

The visibility from the cab is limited in some directions. Mirrors solve some of the problems, but additional mirrors is often optional equipment and not standard. A problem encountered by the drivers of the ETT-vehicle is that the side windows and mirrors are in wet weather sometimes covered up with dirt, highly reducing the visibility sideways.

### 9.6.1 Solutions to Improved Visibility for Driver

Solutions to improve the visibility from the cab are presented and briefly explained in Table 9.12.

**Table 9.12.** Solutions with brief explanations to *Improved visibility for driver*

| **Solution** | ***Explanation*** |
|---|---|
| **Cameras** | *Cameras with wipers around the vehicle so the driver easily can see everywhere* |
| **Rinsing of side windows and mirrors** | *Rinsing and wiping system for side windows and mirrors, similar to the one on the windshield* |
| **Larger window pane** | *Both front window and side windows are made bigger* |

### 9.6.2 Selection of Concepts

The different solutions to this problem are rated in Table 9.13.

**Table 9.13.** Concept Scoring Matrix of *Improved visibility for driver*

| | | **Cameras** | | **Rinsing of side windows and mirrors** | | **Larger window pane** | |
|---|---|---|---|---|---|---|---|
| | *Weight* | R | WS | R | WS | R | WS |
| Fuel consumption | 0.35 | 3 | 1.05 | 3 | 1.05 | 3 | 1.05 |
| Reliability in use | 0.2 | 2 | 0.4 | 3 | 0.6 | 2 | 0.4 |
| Safety impact | 0.15 | 4 | 0.6 | 4 | 0.6 | 4 | 0.6 |
| Ease of use | 0.1 | 4 | 0.4 | 4 | 0.4 | 4 | 0.4 |
| Ease of implementing | 0.1 | 2 | 0.2 | 2 | 0.2 | 1 | 0.1 |
| Estimated cost | 0.1 | 3 | 0.3 | 2 | 0.2 | 1 | 0.1 |
| | | | **2.95** | | **3.05** | | **2.65** |

Since they have no impact on fuel consumption, all three solutions get three points for this criterion. Only *Rinsing of side windows and mirrors* get three points for reliability, since this is considered working as well as rinsing of the front window. The other two solutions get two points for this criterion since cameras are an additional feature that might break, and a larger window pane decreases the stability of the cab.

The result of the scoring shows that *Larger window pane* is eliminated in this step, Table 9.14. The other two are moving on for further investigation.

**Table 9.14.** Concept Scoring results to *Improved visibility for driver*

| | |
|---|---|
| Rinsing of side windows and mirrors | 3.1 |
| Cameras | 3.0 |
| Larger window pane | 2.7 |

## 9.7 Improved Braking

The braking system on the ETT-vehicle is an electronic braking system, EBS, which reduces the response time and the braking distance. Every trailer brakes itself and CAN-routers are used for the communication between the trailers. This is the first vehicle in the world with an EBS system built for braking more than one trailer, and the drivers have been very satisfied with the braking. However, the automatic brake adjustment between the truck and the trailers can be further improved, resulting in for example an even shorter braking distance and lower and more even wear on the brakes.

### 9.7.1 Solution to Improved Braking

Some solutions on how to improve the braking system are presented in Table 9.15. Brief explanations are found in this table as well. To make these solutions work, the communication and cooperation between brake system manufacturers must be improved, since there are different manufacturers for the brake system on the truck, and the brake system on the trailers. The merging of these two systems has caused some difficulties and unsatisfactory operation.

**Table 9.15.** Solutions with brief explanations to *Improved braking*

| **Solution** | ***Explanation*** |
|---|---|
| **Communication truck-trailer** | *Improve the communication between the truck and the trailers to get accurate braking force on each wheel* |
| **Standard CAN-links** | *CAN-links that implement the ISO 11992*[26] *better* |
| **Connect braking system with safety systems** | *E.g. the vehicle automatically brakes when the motion detector senses something coming from the side* |

The solutions to *Improved braking* are considered very important, and the cooperation between truck and trailer system manufacturers has to be improved. The solutions are however not further discussed in this thesis, except the third that is also mentioned in the *Improved safety* needs.

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[26] http://www.can-cia.org/index.php?id=489

## 9.8 Reduced Road Wear

The road wear has been one of the main reasons for the opposition against heavier vehicles. The road wear is dependent on the wheel axle loads, and with an increased number of axles, the axle load is reduced and so is the road wear. The distance between the axles in each axle group also has an impact on the wear and should be considered in the design of heavy combinations. The effect of the ETT-project's vehicles on the roads is investigated in other parts of the project, and is not commented on further in this thesis.

## 9.9 Reliable Electric Cable Solutions

The environment for the electrical cables on the vehicle is not optimal. There are a lot of cables, it is a long vehicle and it is often very cold, icy, and snowy. This has caused some trouble with the reliability in the electrical cabling. The tough conditions should be considered in the design of the cabling, but will not be discussed further in this thesis.

## 9.10 Improved Accessibility

Problems with the ETT-vehicle may occur due to its length, if it in the future will drive on narrower roads, through small roundabouts or into the forest where it has to turn on small turning areas. Climbing hills with large inclination might be necessary if it is to operate in other parts of Sweden. Facilitated reversing could be useful in case the cargo is something else then round wood, which has to be loaded or unloaded from the back. However, a limitation to this thesis is that the ETT-vehicle only drives on paved larger roads, it is mainly a highway truck, hence the solutions presented in this chapter focus on this.

### *9.10.1 Solutions to Improved Accessibility*

Solutions concerning the accessibility of the vehicle are presented in Table 9.16.

**Table 9.16.** Solutions with brief explanations to *Improved accessibility*

| **Solution** | ***Explanation*** |
|---|---|
| **Wabco OptiTurn**[27] | *System that facilitates turning by automatically lifting axles if necessary while turning* |
| **Trailers on each other (roll out when loading)** | *Shorter combination facilitates driving and turning on narrow roads* |
| **Steerable trailer axles** | *Facilitates turning* |

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[27] OptiTurn is system from brake system manufacturer WABCO that automatically lifts axles on trailers when driving through narrow turns. This improves the accessibility and reduces the tire wear (WABCO 2010)

### *9.10.2 Selection of Concepts*

In the scoring matrix for accessibility, Table 9.17, the solution *Trailers on each other*, is not included since this is rated in chapter 0.

**Table 9.17.** Concept Scoring Matrix of *Improved accessibility*

| | | **Wabco Opti-Turn** | | **Steerable trailer axles** | |
|---|---|---|---|---|---|
| | *Weight* | R | WS | R | WS |
| Fuel consumption | 0.35 | 3 | 1.05 | 3 | 1.05 |
| Reliability in use | 0.2 | 3 | 0.6 | 3 | 0.6 |
| Safety impact | 0.15 | 3 | 0.45 | 3 | 0.6 |
| Ease of use | 0.1 | 4 | 0.4 | 4 | 0.4 |
| Ease of implementing | 0.1 | 3 | 0.3 | 2 | 0.2 |
| Estimated cost | 0.1 | 3 | 0.3 | 1 | 0.1 |
| | | | **3.1** | | **2.80** |

The results of the scoring are presented in Table 9.18. *Steerable trailer axles* is eliminated in this step of the concept generation, due to an estimated high cost, and otherwise quite low scores.

**Table 9.18.** Concept Scoring to *Improved accessibility*

| | |
|---|---|
| Wabco OptiTurn | 3.1 |
| Steerable trailer axles | 2.8 |

## 9.11 Improved Driver Environment

A comfortable and safe environment for the driver brings benefits like improved work satisfaction and healthier drivers. The fastening of the timber is not optimal and puts the drivers at risk for e.g. shoulder injuries. The fastening is further discussed under the need *Improved fastening and loading.* More space around the driver seat and more comfortable cab would also benefit the driver's environment, however none of the drivers have expressed any needs for this and therefore this will not be further investigated.

# 10 Concept Generation and Selection – Identity

*The concept generation continues here with the needs specific for the identity of the vehicle. The goal of the concept generation is to find solutions that fulfil the needs, wants and expectations expressed by the customers. Each need is discussed and explained along with the solutions to the need. The identity of the vehicle is treated separately in this thesis and the Concept Selection differs from the selections in chapter 8 and 9 in the sense that the solutions are chosen through discussions and analysis rather than by concept scoring and ranking.*

The category “Identity” is defined as features that affect how the vehicle is perceived, what impression it gives and its general appearance. In more detail this includes the combination of aesthetics, usability, function, form and ergonomics. One part that is emphasised is the connection between product and user, and in this case also the viewer, meaning other road users and the public in general. Styling of the vehicle, proportions, shape, colours, materials and surfaces are very important to the impression the vehicle evokes and the experience it offers. The goal in this thesis is to optimise the function, value and appearance of the product for the mutual benefit of users, the public and the manufacturers.

Even though the *Identity* needs have no impact on fuel efficiency, the project would benefit from accentuating some properties, for example the environmental benefits, transport efficiency and safety issues, and make these more visible. This could facilitate the acceptance and the introduction of vehicles of this kind on the Swedish roads.

## 10.1 Concept Generation

The four-step method described in 8.1 is used as in previous chapters; however the external search in this area has not contributed with as many solutions as for other needs, why the internal search has been expanded into both brainstorming and mood boards.

The needs in the *Identity* category are, in order of relative importance;

- Homogeneity in appearance
- Accentuated transport efficiency & environmental benefits
- Accentuated flexibility on road
- Improved safety impression

### *10.1.1 Homogeneity*

The ETT-vehicle is part of a modular system with four separate parts. There are different manufacturers for the truck and the trailers hence the appearance of the truck and the trailers is not homogenous. Wishes from the customers have been expressed that the vehicle should be seen as a complete transport solution as opposed to different parts put together. The solutions primarily corresponding to the *Homogeneity*-category are presented and briefly explained in Table 10.1.

**Table 10.1.** Solutions with brief explanations to *Homogeneity*

| Solution | *Explanation* |
|---|---|
| **Homogeneity in colours** | *All the parts of the vehicle are united by using the same colour palette* |
| **Homogeneity in form** | *Proportions and shapes are recurring in the vehicle* |
| **Lights with same shape** | *The lights on the vehicle have the same form* |

### *10.1.2 Accentuated Transport Efficiency & Environmental Benefits*

The purpose of the ETT-project is to emphasise and visualise the environmental and transport efficiency benefits with longer and heavier vehicle combinations, in order to affect the legislators, the transport industry and the public, to accept them on Swedish roads. Therefore the ETT-combination should accentuate these benefits in its appearance, so that people, when seeing this vehicle on the road, are reminded about the positive effects. The fact that the vehicle carries natural raw material to the benefit of the general public, the environment and the Swedish industry is a property that could be enhanced. The solutions corresponding to the *Accentuated transport efficiency and environmental benefits*-category are presented and briefly explained in Table 10.2.

**Table 10.2.** Solutions with brief explanations to *Accentuated transport efficiency and environmental benefits*

| Solution | *Explanation* |
|---|---|
| **Hub caps & trailer skirts** | *Covers on uneven shapes enhance the efficiency and aerodynamic benefits* |
| **Visible solar cells** | *Using renewable energy is environmentally friendly, and visual solar cells accentuate the impression of this* |
| **No unnecessary details** | *A clean look gives aerodynamic benefits and associations to a clean environment* |
| **“Swedish forest on the way”** | *Spelling out a message on the truck can evoke positive feelings and associations* |

**Table 10.2.** continuing

| **Solution** | ***Explanation*** |
|---|---|
| **Smooth surfaces** | *Enhances efficiency and aerodynamic benefits* |
| **Forest colours** | *Forest colours like moss green, brown and beige on the vehicle gives it an impression of being environmentally friendly* |
| **Natural materials** | *By using natural materials the environmentally friendly impression is strengthened* |

### *10.1.3 Accentuated Flexibility on Road*

Even though the ETT-vehicle is longer and heavier than conventional timber trucks, it has equal handling in roundabouts and turns. This is an important quality of the combination which should be accentuated in its appearance. The modular system is an important part of the vehicle concept, and its flexibility should be enhanced. The solutions corresponding to the *Accentuated flexibility on road*-category are presented and briefly explained in Table 10.3.

**Table 10.3.** Solutions with brief explanations to *Accentuated flexibility on road*

| **Solution** | ***Explanation*** |
|---|---|
| **Make lift axles a lighter colour** | *A lighter colour gives an impression of lighter weight and easier operation* |
| **Accordion to show where the vehicle bends** | *In case the combination is covered, accordions showing where it bends adds to the flexibility impression* |
| **“Cotton-like” surface for light look** | *Cotton-like surfaces give the impression of a light and flexible vehicle* |
| **Train feeling with cover** | *Making the vehicle more train-like enhances its smoothness in driving as well as environmental issues* |
| **Pull trailers together** | *A shorter combination looks more flexible* |
| **Puzzle pieces indication for modular system** | *Graphical symbols showing how the modular system can be combined* |
| **Accentuating modular system coupling possibilities with colour** | *Colours indicating what combination possibilities the modular system has* |

### 10.1.4 Improved Safety Impression

One of the most important aspects of the ETT-project is to show that the ETT-vehicle is safer to use on public roads than conventional timber trucks. One aspect to the safety is what impressions other road users get since it affects how people behave when interacting with it on the road. Therefore the safety impression of the ETT-combination is an important identity issue and the safety needs to be accentuated in the appearance. The solutions corresponding to the *Improved safety impression*-category are presented and briefly explained in Table 10.4.

**Table 10.4.** Solutions with brief explanations to *Improved* ***safety impression***

| **Solution** | ***Explanation*** |
|---|---|
| **Visible fastening belts for timber piles** | *Clearly visible fastening belts (perhaps with reflector tapes) that hold the timber in place instead of almost invisible chains improves the safety impression* |
| **Cover all timber piles** | *Not seeing the timber makes it feel safer* |
| **Reflector tapes** | *Making the vehicle visible in the dark adds to safety* |

## 10.2 Concept Selection

The *Concept Selection* for the identity-concepts differs from the other categories. The criteria used in the concept scoring matrices are not applicable for the solutions to the identity and therefore no matrices nor ranking of these concepts are presented. The selection is instead performed through discussions and analysis of what each solution would do to the identity, and also how easy these are implemented. The discussions are based on what customers and experts have expressed in the interviews. Since the needs in the identity category concern how the vehicle is perceived and what impression it gives, solutions to these needs often overlap and affect more than only one need. For example, one solution to *Accentuated environmental benefits* is to have a homogeneous vehicle with no unnecessary details, which also benefits *Homogeneity* and *Improved safety impression*. There are no classification trees for this category, all the needs are instead presented in a figure along with the solutions. In Figure 10.1 there is a symbol corresponding to each need and these symbols are listed in front of each solution to indicate what needs the solution affects. . For example, the solution *Hub caps & trailer skirts*, affects transport efficiency since this solution provides the vehicle with a more aerodynamic appearance. It also affects the safety impression with the covers between and on the wheels, and the homogeneity is improved by using same-shaped trailerskirts and hub caps. This is visualised in figure 10.1 by a circle, a square and a diamond.

| | | | |
|---|---|---|---|
| Homogeneity | ◆ | ◆ ■ ● | Homogeneity in colours |
| | | ◆ ■ ● | Homogeneity in form |
| | | ◆ | Lamps with same shape |
| Transport Efficiency & Environmental Benefits | ● | ● ■ ◆ | Hub caps & trailer skirts |
| | | ● | Visible solar cells |
| | | ● ■ ★ | No unnecessary details |
| | | ● | "Swedish forest on the way" |
| | | ● ■ ★ | Smooth surfaces |
| | | ● ◆ | Forest colours |
| | | ● | Natural materials |
| Accentuated Flexibility | ★ | ★ ● | Make lift axles a lighter colour |
| | | ★ ■ | Accordion to show where the vehicle bends |
| | | ★ ● | "Cotton-like" surface for light look |
| | | ★ ■ ● | Train feeling with cover |
| | | ★ ■ | Pull trailers together |
| | | ★ | Puzzle pieces indication for modular system |
| | | ★ | Accentuating modular system coupling possibilities with colour |
| Safety Impression | ■ | ■ | Visible fastening belts for timber piles |
| | | ■ ● ★ ◆ | Cover all timber piles |
| | | ■ | Reflector tapes |

**Figure 10.1.** The effect of solutions on the different identity needs

The first group of solutions, *lights with same shape, homogeneity in colour* and *homogeneity in form* are all likely to be rather easy to implement and are put through to the testing phase. The lights could easily be designed to achieve similar shapes and the colour of the vehicle is possible to change into colours accentuating for example the environmental benefits of the ETT-vehicle. The form is slightly more difficult to make more homogeneous but this can be achieved by, for example using the same trailer-skirts and the same surface finishing on the vehicle and trailers.

In the second group of solutions, the concepts proceeding to the testing phase are; *hub caps and trailer skirts*, *"Swedish forest on the way"* and *forest colours*. All these three are easy to implement and quite effective in accentuating the benefits of the ETT-vehicle. The rest of the concepts in this group are eliminated for different reasons; solar cells has a large initial investment cost and the payback is hard to achieve in the north of Sweden due to the long hours of darkness. There are no, here considered, *unnecessary details* disturbing the airflow around the cab on the ETT-vehicle presently, why this solution would not make any difference and is therefore eliminated. *Smooth surfaces* and *natural materials* are eliminated because these are too difficult to implement; the surfaces of the timber cannot be changed unless they are covered with another material (which is a separate solution) and the use of *natural material* would be hard to implement without risking the strength of the construction.

The third group of solutions are those that accentuate the flexibility. Here, *make lift axles in a lighter colour* is eliminated because the axles are hidden underneath the chassis and by the wheels, why changing the colours of these would not be visible. *Accordion to show where the vehicle bends* could be solved by using fabric or plastic material and this solution is moving on to the testing phase since the solution *cover the whole combination* in chapter 8 is, and these two solutions are used in combination. *"Cotton-like" surface for light look* is eliminated because this is an unrealistic solution that would be too difficult to implement. Both *train feeling with cover* and *pull trailers together* are proceeding since these already moved on to the testing from the aerodynamics in chapter 8. *Puzzle pieces indication for modular system* would be hard to implement and hard to make understandable to the user, and is therefore eliminated. Instead, *accentuating modular system coupling possibilities with colour* is moving on as a solution to accentuate the modular system and thereby the flexibility, since this is assumed to be easier achieved and more accessible than puzzle pieces.

In the last group of the solutions, all three are put through to the testing, since these are improving the safety impression, which is highly important. *Visible fastening belts for timber piles* and *reflector tapes* are also solutions to the safety need in chapter 9, which is a second reason why they are not eliminated here. *Cover all timber piles,* is not easy to implement, and does not improve the aerodynamics as much as covering the whole combination, and is therefore eliminated in this step of the process.

The solutions to the Identity needs proceeding to the testing phase are collected and presented in Table 10.5.

**Table 10.5.** Solutions to Identity needs moving on to testing

| |
|---|
| Homogeneity in colours |
| Homogeneity in form |
| Lights with same shape |
| Hub caps & trailer skirts |
| "Swedish forest on the way" |
| Forest colours |
| Accordion to show where the vehicle bends |
| Train feeling with cover |
| Pull trailers together |
| Accentuating modular system coupling possibilities with colour |
| Visible fastening belts for timber piles |
| Reflector tapes |

# 11 Concept Testing

*In this chapter the Front-End process continues with the Concept Testing phase. The concepts chosen for further testing in Concept Selection are in this chapter evaluated in simulations, where the fuel consumption is measured, and by sketches and 3D-models. Here discussions are the method of reasoning what concepts are the most suitable. The simulations are described, how they work and how they are used. Every solution is presented with estimated fuel reduction, illustrations or a discussion.*

The *Concept Testing* phase in relation to other phases in the *Front-end Process* is shown in Figure 11.1.

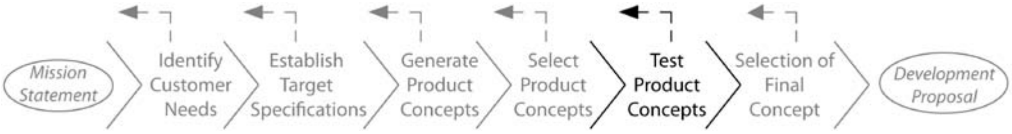

**Figure 11.1.** Test product concepts, adapted from Ulrich & Eppinger 2004

The testing is divided into sections of solutions to different needs. Some solutions affect several needs that are closely linked, and these are grouped when considered applicable. When possible, fuel consumption or other interesting property, is measured through simulations. For solutions where simulations are not possible testing is instead performed throughout discussions and consultations with experts. The needs relevant to the identity of the vehicle are tested with the help of sketches and 3D-illustrations to come up with the most suitable solutions.

## 11.1 Simulations

Simulations are in this thesis used for several reasons;

- Building a model of the studied vehicle and verifying the model by comparing the fuel consumption with the measurements made on the actual ETT-vehicle
- Testing of which parameters have significant impact on fuel consumption, and hence where the efforts should be concentrated (see chapter 7)
- Testing and evaluation of product concepts
- Determining product specifications

### 11.1.1 Global Simulation Platform

The platform used for the simulations in this thesis is GSP – Global Simulation Platform, containing a model library for simulations based on MATLAB and Simulink. It is a Volvo proprietary complete vehicle performance simulation environment and is mainly used to study fuel consumption and the behaviour of vehicles.

One simulation here consists of a vehicle concept that is simulated to drive in a specified environment and application, i.e. specified outer conditions and a specified driving path. A vehicle concept is created by modelling the vehicle based on its physical properties, it can be created either by combining models from a component library or by modelling them, or a combination of the two. The vehicle concept is divided into *powertrain* and *chassis* that together with a *driver* and the *road and environment* make up the configuration of a simulation, see Figure 11.2.

Mechanics of a vehicle are rather simple to model, since the physics are well known; however modelling the control systems and driver are much more difficult as they cannot be described as accurately mathematically.

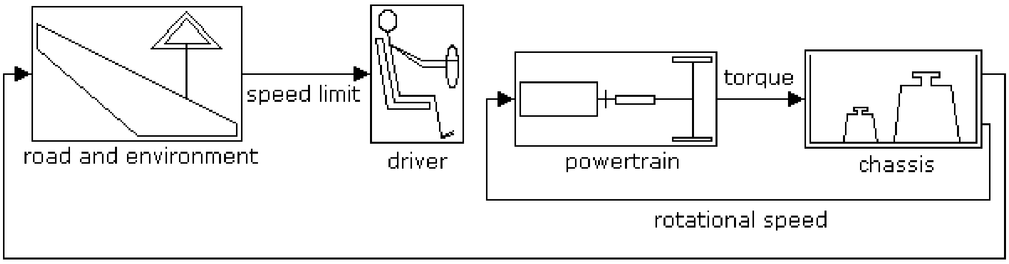

**Figure 11.2.** Simulation setup in GSP – Global Simulation Platform

Parameters of the models can be changed, and the effect of the changes studied. Simulations are useful for several reasons. Firstly, a simulation is much faster and more economical than doing measurements on a real vehicle and drive cycle. Secondly, the effects of small changes can be studied as the exact same conditions can be repeated, that would disappear in the error margins in a field test.

### 11.1.2 Approach

The approach used in this thesis for the simulations is to create a virtual model of the actual ETT-vehicle, and use it to see what impact modifications would have. The vehicle is built by combining existing models of the components in the ETT-vehicle, and by determining vehicle specific parameters. Two cases are studied, the loaded truck driving from Överkalix to Piteå, and the empty vehicle on the return trip.

A road file is created from data including the GPS coordinates, level over sea, and speed limits from the actual service path. To duplicate the drive cycle as carefully as possible, the drivers were asked how many times per drive cycle they had to brake into almost standstill and the number of stops then added to the road file. This is done since the acceleration of a heavy combination like the ETT-vehicle means a significant increase in fuel consumption. A conventional driver model is picked from the component library.

The engine and gearbox models are collected from a component library. The final gear ratio of the ETT-vehicle is known, and the final gear inertia and efficiency are collected from the supplier Arvin Meritor.

The chassis model includes for example the mass of the vehicle, the wheel model, the aerodynamic parameters A and $C_D$ and the brakes. To get the right input parameters for the wheels and tires, help was provided from the tire supplier Michelin that also provided a formula for calculating the rolling coefficient depending on the axle loads.

The aerodynamic properties are an uncertainty in the vehicle model since no CFD-simulations (computational fluid dynamics) have been performed at Volvo with a timber truck, not to mention a four pile timber truck. A and $C_D$ -values were provided by Volvo from wind tunnel tests on a regular FH16 tractor with a semi-trailer, and this is used as a starting point with modifications due to the front wall and increased area because of the gaps between the piles and the timber bunks.

Average values for mechanical auxiliary equipment energy consumption for a long haul truck are used. In the mechanical auxiliaries the air compressor, steering pump, coolant pump, oil pump, alternator, fan, and AC-compressor are included.

The verification of the model is done by comparing fuel consumption results from the simulations with the actual fuel consumption that has been measured in field tests, comparing the speed profile and by consulting experts in different areas to see that the input variables are reasonable. The simulation show very similar results in term of overall fuel economy especially when fully loaded. For performance measure, hill climbing showed a speed drop to 55 km/h in simulations, logged data was 53 km/h. This verification was appropriate for the purpose.

## 11.2 Aerodynamics

Some tests have shown that a conventional Volvo FH-truck with a van body semi-trailer has a $C_D$-value of about 0.6-0.65; the $C_D$ of the ETT-vehicle is probably much higher. To improve the aerodynamics of a vehicle like the ETT-vehicle, the improvements must be made in a certain order to have an impact on the overall drag coefficient.

On a statistical average, the side wind is usually about 4-5 degrees on the Swedish Road net, and therefore gaps between trailers are a huge contributor to aerodynamic drag. On the ETT-combination, the second gap, between the truck and the dolly, is the one contributing the most to the drag, since this is the widest and one of the first gaps[28]. Sealing a gap in the back without improving this one first has low impact on the overall drag since the turbulence is already high and the boundary layer thick from the wide gap.

Second most important, are the other two gaps. In accordance with improving the gaps between the piles, the timber bunks can be modified, since these are an obstacle in the free air-stream along the trailer sides. The third area to reshape is the flow over

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[28] The first gap, between the cab and the first pile, is small enough not to affect the drag.

the cab roof; here a roof deflector could be used to lead the air above the front wall and over the trailers. After these improvements the next step is to use trailer skirts.

Improvements on the cab changes the $C_D$-value of a few hundreds, and since all these other changes could lower the $C_D$-value much more radically, changes on the cab have little impact on the total drag of the vehicle in comparison to the changes of the trailers.

In the following sections, all solutions regarding aerodynamics are explained along with figures or illustrations, and the impact on the aerodynamic drag is roughly estimated. The results from the tests performed through simulations are presented after all the solutions are discussed. Some of the references are from tests performed at 100km/h. This leads to a higher $C_D$-value than at 80km/h, and this has been taken into consideration for the estimated impact on the drag on the ETT-vehicle.

### 11.2.1 Integrated Lights

According to Leuschen and Cooper, one OEM fender mirror in the free air stream, adds about 0.010 in $C_D$, when driving at 100km/h (2007 pp 453). No exact conclusion for the contribution in $C_D$ of roof details can be drawn from this, however it indicates in what range details like this might contribute to the drag. Most trucks have lights on the cab roof which add to the aerodynamic drag. Lights can obviously not be eliminated because of safety reasons, but they could be integrated in the cab roof or, on the ETT-vehicle in the sign on the top front of the cab to minmise the drag, see Figure 11.3.

**Figure 11.3.** Integrated lights

The contribution of the lights to the $C_D$-value is here assumed to be comparable to the OEM fender mirror, as the lights are larger in area, but not placed in an area of total free air stream. The ETT-vehicle is driven at maximum 80 km/h and this is taken into consideration.

### 11.2.2 Improved Roof Deflector

The roof deflector used on the ETT-vehicle is not adjustable, starts quite far back on the roof and is 15 centimetres lower than the front wall. The position and difference in height between the deflector and the front wall disturbs the flow over the roof and increases the drag, practically making the deflector useless. To improve this, the deflector should be adjustable and cover a bigger area of the roof, see Figure 11.4.

**Figure 11.4.** Improved roof deflector

Leuschen and Cooper show in wind tunnel tests that a correctly adjusted roof deflector can lower the $C_D$-value by 0.072 when driving at 100km/h (2007, pp 453). Since this is just an indication of what impact a deflector has on the drag, and the ETT-vehicle is not driven faster than 80km/h, this is assumed as an indication of what impact correctly adjusted roof deflectors could have on the drag of the ETT-vehicle.

Lowering the front wall with 100 mm leads to a $0.26m^2$ decrease in the front area, A.

### 11.2.3 Soft-Nose Cab

The difference in $C_D$-value between a normal control cab and a front control cab is in the order of 0.05 (Hjelm and Bergqvist pp 470) and this indicates that a soft nose cab which is much smaller than a normal control cab, would not contribute significantly to drag reduction on the ETT-vehicle. Another aspect is the deformation zone a soft-nose contributes with. However, a heavy vehicle such as the ETT-vehicle would not increase the safety sufficiently for other road users with a deformation zone, but could instead contribute to increased reparation costs in case of a collision with for example a large animal. Since animals are a big issue in the part of Sweden where the vehicle operates, a short-nose is instead preferable. A short-nose is of the same shape as a soft-nose but does not have a deformation zone and hence decreases the risk of collision damage to the truck. Other benefits with a short-nose are that the cooling of the engine is improved and it is possible to integrate lights etc. in it. Figure 11.5 shows a sketch of what a short-nose cab might look like. As can be seen in this sketch, a short-nose cab gives a streamlined impression which adds to the identity need, *accentuated transport efficiency*.

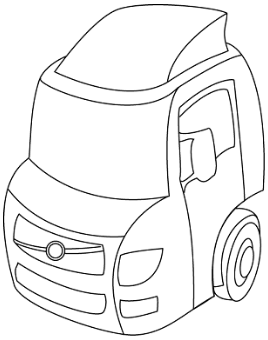

**Figure 11.5.** Short-nose cab

### 11.2.4 Hub Caps

Hub caps have no significant impact on the aerodynamic drag as shown in wind tunnel tests by Leuschen and Cooper (2007 pp 453). Even if aluminium hub caps are used, which are relatively light, they still add weight to the vehicle, without giving enough drag reduction to compensate for the lost loading capacity. The solution *Hub caps* was scored 3.40 in the *Concept Scoring matrix*, higher than the other solutions for *trailers, chassis and wheels*. But since fuel consumption is the most important factor for the concepts, this solution will not continue, even though this is a common and easily implemented detail on wheels.

### 11.2.5 Trailer-Skirts

The area between the wheels is an important contributor to aerodynamic drag. Some sort of under-run protection between the wheels is often standard on trucks, usually consisting of two horizontal beams, or a sheet metal. On the ETT-vehicle there are horizontal beams on the truck, and rather short trailer-skirts on the link and the semi-trailer.

Fully covering tank and side skirts on the truck has been shown in a wind tunnel test to reduce the $C_D$-value with 0.027 on a normal control Volvo tractor at a speed of 100km/h. Trailer-skirts on a 12.2 m long trailer improved the $C_D$-value with about 0.035-0.045 depending on the shape and ground clearance (Leuschen and Cooper, 2007 pp 453).

The ETT-vehicle has many trailers, and the gaps between the wheels contribute to the drag resistance. A problem area where it is difficult to fit trailer skirts is between the truck and the dolly, and also to get a good coverage on the rest of the trailers. Another difficulty with trailer skirts is that snow and ice could easily get stuck on the inside and add extra weight to the combination. An example of what it might look like with trailer skirts on the ETT-combination is shown in Figure 11.6.

**Figure 11.6.** The ETT-vehicle equipped with extended trailer skirts

The effect of trailer-skirts on the ETT-vehicle is assumed to be equal to the effect on the 12.2 m trailer; that is, lowering the $C_D$-value with about 0.035-0.045.

### 11.2.6 Lowered Chassis

One area causing aerodynamic drag is under the vehicle. For this, trailer-skirts can be used, see previous section. Another way of solving this problem is to lower the chassis. CFD-simulations have showed that lowering the chassis on a tractor with 0.04 metres lowered the $C_D$-value with about 2% (Tenstam[29]). This test was made on a tractor with one semi-trailer, and for the ETT-vehicle, this number is used as an indication of what lowering all the chassis could do for the $C_D$-value.

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[29] Tenstam, Anders, Team Leader CFD, Volvo Technology, E-mail 2009-12-17

### 11.2.7 Trailers on Each Other

The drag on the ETT-vehicle is large also without cargo. One way of reducing the drag when driving with empty vehicle is to load the trailers on each other. In Australia there are solutions where trailers are pulled up on each other, but there they use trailers that are specifically designed for this purpose and not part of the European Modular System, which is an assumption in this thesis. A solution to this concept including the modular system is to bring down or tilt the timber bunks and load the front of the link on top of the cargo-space of the truck and the back on the dolly, and the semi-trailer on top of the link, see Figure 11.7. The crane that is used for loading the timber can easily lift the link and semi-trailer, however fastening of the trailers might be difficult to achieve.

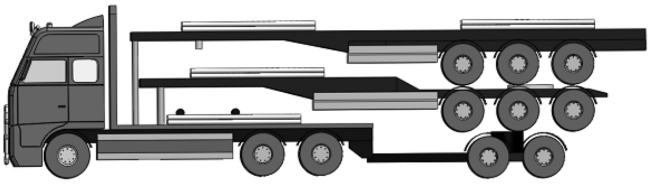

**Figure 11.7.** Trailers on each other

The possible drag reduction from placing the trailers on top of each other on the return trip is hard to estimate. Wind tunnel tests or CFD-calculations have to be performed to get an idea of the potential savings.

### 11.2.8 Collapsible Bunks

When driving with empty vehicle the timber bunks are standing in the free air stream. There are 16 poles and these are assumed to be a substantial reason for the drag on the return trip. If these were collapsible, fuel could be saved on the return trip. The timber bunk manufacturer for the ETT-vehicle, ExTe, have this solution is use in South Africa. However, in Sweden, there are no existing solutions, and the quite extreme weather in the north of Sweden with several months of snow, ice and low temperatures could cause problems. See Figure 11.8, for an example of how it might look like with the timber bunks collapsed.

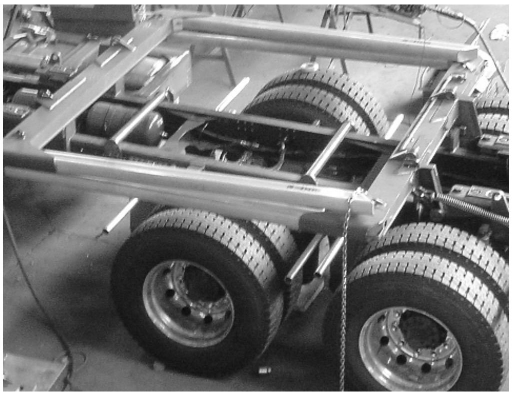

**Figure 11.8.** Collapsed timber bunks

The savings that can be made with collapsed timber bunks is investigated through simulations. The drag is calculated from the equation $D=C_D*A*0.5*\rho*v^2$ and it is $A*C_D$ that impacts the aerodynamic change from collapsing the bunks. Since the $C_D$ is difficult to approximate, all the contribution from this solution is put in the parameter A. The assumptions made on these values have great uncertainties and are only very rough estimations. The first A-value, in Table 11.1 comes from comparison of the simulated fuel consumption results and the measured. The second A-value, the one for the collapsed timber bunks, is a value provided for a regular FH16 tractor-trailer combination that has been modified due to the increase the front wall causes.

**Table 11.1.** Results from simulations of tests with collapsed timber bunks

| | **$C_D$-value** | **A-value** | **Fuel consumption [l/100km]** | **Diff [%]** |
|---|---|---|---|---|
| With timber bunks | 1.0 | 11.100 | 36.48 | 0 |
| Collapsed timber bunks | 1. | 10.586 | 35.41 | -2.93 |

The tests indicate a possible fuel saving of about 3% on the return trip.

### 11.2.9 Pull Trailers Together

As mentioned in the beginning of chapter 11.2, the gaps between the timber piles are one of the main reasons for the aerodynamic drag. The drag is negligible when driving slowly, and the gaps are necessary when turning and driving in roundabouts etc. However, when on a straight road at high speed, the gaps are a crucial issue, and one way of solving this problem is to pull the trailers together at a certain speed to decrease the gaps, see Figure 11.9 for an illustration.

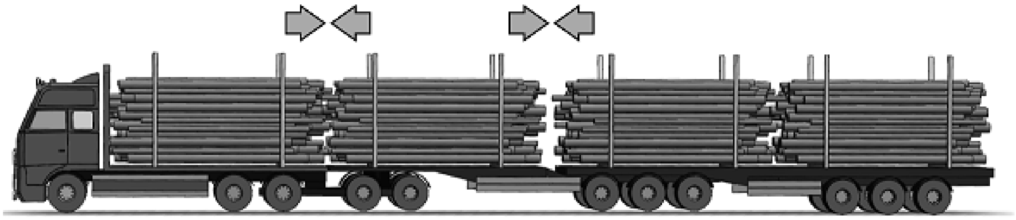

**Figure 11.9.** Trailers pulled together

There are a number of issues needed to be solved for this to work. The first problem is to get legal approval for an automatically moveable connecting rod or fifth wheel. Secondly, the system would probably need hydraulics, which adds quite a lot of weight to the vehicle. Most vehicles do not have hydraulics and then a separate electrical driven hydraulic system would be needed. The dolly could be moved by pulling the connecting rod forward which does not jeopardize the weight distribution, and technically this is possible to implement. On the link, the fifth wheel could be moved forward, but then the system must control the weight distribution so that the weight is not increased on some wheel axles during the move. Both moveable fifth wheels and connecting rods exist on vehicles today, using compressed air to power the move, but this is used only when the vehicle is still (Olsson[30]).

A way of pulling together and extending the trailers is to use the kinetic energy the trailers already have. By slightly braking certain trailers more than others and at the same time releasing the connections, they can be moved closer together or further apart. This solution requires very careful monitoring of braking power and can be quite difficult to implement on a vehicle driving at high speed, but it would have the benefit of not having to use any hydraulics.

The impact on the $C_D$-value from pulling the trailers together is difficult to estimate, it depends on how much smaller the gap is, which gaps can be reduced, the speed at which it is reduced etc. However, especially if it is possible to reduce the first wide gap on the ETT-vehicle, the one between the truck and the dolly, major fuel savings could probably be made. According to Hucho, a one metre decrease in gap reduces the $C_D$ with about 0.07 (1998, pp 432). For the ETT-vehicle, it is estimated that the $C_D$-value could be decreased with between 0.07-0.15 by pulling the dolly connection and the fifth wheel on the link forward at higher speeds.

### 11.2.10 Inflatable Gap Fillers

Another way of eliminating the gaps between the piles is to fill them with an inflatable material, see Figure 11.10. Desirably, the gap filler fills the whole gap, but as long as the gap is less than 0.5 metres wide, the drag is significantly reduced. There are patents regarding inflatable gap fillers for pickup trucks, between the cab and the cargo space, however no existing solution has been found for gaps between two trailers, and not for tractor-trailers gap for timber trucks. The problem with timber trucks is that there is no, for example, fixed van body to attach the material in, why this could be a difficult solution to implement. A system for inflating the gap fillers is also necessary for this solution.

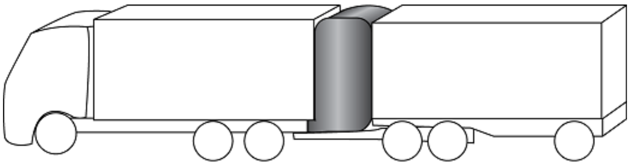

**Figure 11.10.** Inflatable gap filler

The gap-fillers are assumed to have approximately the same effect on the $C_D$-value as pulling the trailers together.

### 11.2.11 Cover the Whole Combination

The final solution regarding the gaps between the piles is to cover the whole combination, which is also good for other drag sources for example the rough surface of the timber and the protruding timber bunks,. The cover needs to be flexible over the gaps for the vehicle to be able to turn and drive in roundabouts, but still not too loose, in order to reduce the drag at high speed. The cover could for example be attached at the

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[30] Olsson, Per, CEO, Parator, E-mail, 2009-12-10

front wall and pulled over all the piles after loading. Another solution is to drive the vehicle through a "cover-tunnel" where the cover is put on and the air eliminated to create vacuum under the cover. Figure 11.11 shows a sketch of what the cover could look like. This concept could save a lot of fuel by reducing the aerodynamic drag significantly, but is however quite unrealistic at the time and will not continue to the final concept proposal.

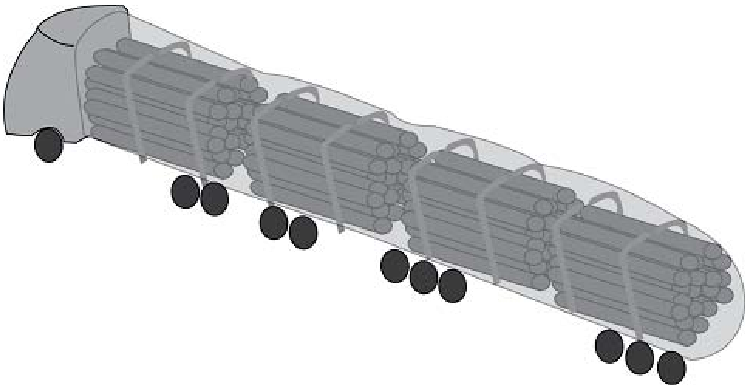

**Figure 11.11.** Whole combination covered

### 11.2.12 Summary and Testing of Assumed Effects on Aerodynamics

The effect of the $C_D$-value on the fuel consumption is studied in simulations, both for the loaded and unloaded vehicle. The solutions to improved aerodynamics and their assumed effect on the $C_D$-value (A-value on the return trip alternative) and fuel consumption are summarised in Table 11.2. The assumed effects of different changes are listed in the table, however, the total combined effect is very hard to predict. As mentioned earlier, the overall effect on the aerodynamic drag depends highly on in what order the changes are made. It should also be noted that the numbers presented here are very rough estimations, and few conclusions can be drawn from this without making CFD-simulations or wind tunnel tests.

**Table 11.2.** Solutions to Improved aerodynamics and assumed effect on the $C_D$-value

| **Solution** | **$\Delta C_D$** | **Assumed fuel reduction [%]** |
|---|---|---|
| Integrated lights | 0.007-0.015 | 0.15-0.35 |
| Improved roof deflector | 0.05-0.1 | 1.1-2.2 |
| Soft-nose cab | ~ 0.01 | ~ 0.2 |
| Tank, truck and trailer-skirts | 0.035-0.045 | 0.75-1.0 |
| Lowered chassis | 0.02-0.03 | 0.45-0.7 |
| Pull trailers together | 0.07-0.15 | 1.5-3 |
| Inflatable gap fillers | 0.07-0.15 | 1.5-3 |
| Cover whole combination | 0.3-0.4 | 6.5-8.9 |
| **Return trip** | **$\Delta A$** | |
| Collapsed timber bunks | 0.5 | 3.0 |
| Trailers on each other | unknown | unknown |

The results for the effect of the $C_D$-value on the fuel consumption on loaded vehicle are visually presented in Figure 11.12. The mark indicates the estimated current $C_D$-value.

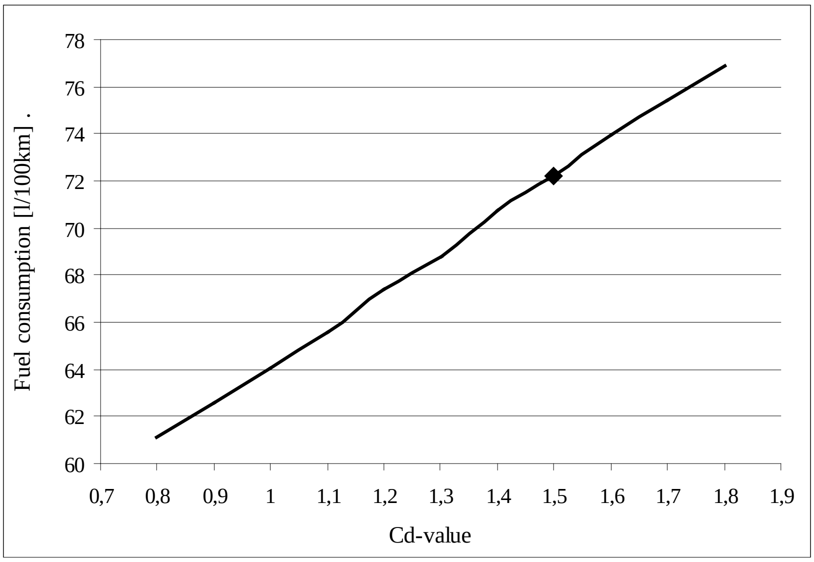

**Figure 11.12.** $C_D$-value effect on fuel consumption from simulations, loaded truck

The results indicate a linear relationship between the $C_D$-value and the fuel consumption, with a rather steep inclination.

The results from studies on the unloaded vehicle are presented in Figure 11.13.

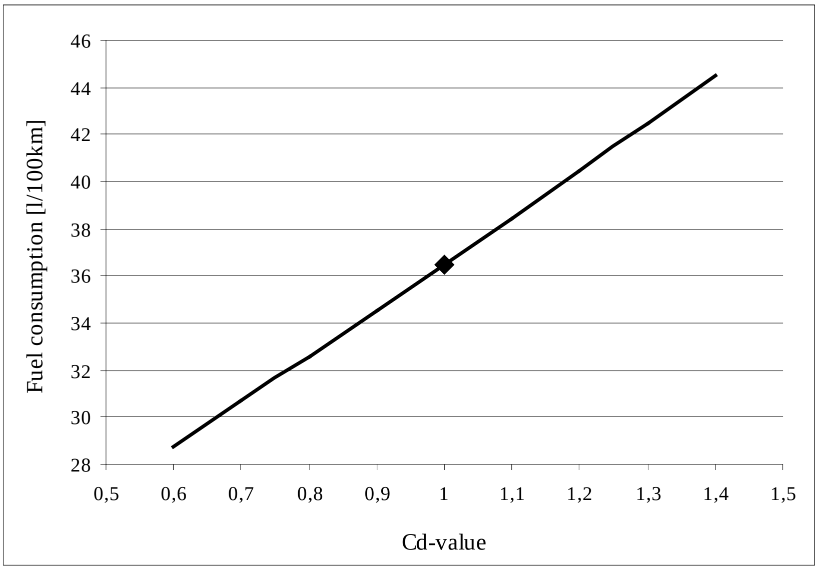

**Figure 11.13.** $C_D$-value effect on fuel consumption from simulations, return trip

Even though any conclusions about the effect of a single or multiple changes to the vehicle are difficult to make, one thing that is very clear, is that a lot of fuel can be saved by having a more aerodynamic vehicle. This applies in the loaded, as well as the unloaded case. It is not only the $C_D$-value that should be looked over; the A-value has equal impact on the aerodynamic drag, and could be lowered by for example having a lower front wall or smaller cab.

## 11.3 Rolling Resistance and Traction

The solutions that moved on to testing from the needs *Decreased Rolling Resistance* and *Improved Traction* were pressure control, lift axles and self inflating tires from *Rolling resistance*, and drop pressure in air bellow on first axle on dolly and move fuel tanks from *Traction*. Here, three of them are tested, and pressure control and self inflating tires are discussed later in *Braking and Weight Control.*

### *11.3.1 Lift Axles*

A way of decreasing the rolling resistance is by lifting wheel axles, making the axle loads higher and the tires more effective. On the ETT-vehicle this solution is highly applicable since the vehicle combination has many wheel axles and a relatively low tare weight, resulting in inefficient tires on the return trip. Except for this the tire wear is decreased, the comfort improved, vibration minmised, and traction improved for the driving wheels. This makes lifting axles a very interesting solution for the ETT-vehicle.

The easiest way of achieving an axle lift is to assemble braking cylinders to the axle that pushes the axle upwards. Another solution is to add an extra bellow that is situated in front of the axle and pushes it upwards with a lever arm. In both cases the air suspension to the axle is blocked, the pressure in the bellows dropped, and the axle lifted (Olsson[31]).

Normally the chassis does not have to be higher in order to lift axles, it depends on the suspension and the driving conditions. Since the ETT-vehicle drives on level roads it should not be necessary, which is fortunate since the timber bunks would then exceed the height limit of 4500 mm.

The lifting can be controlled automatically, by a button in the cab, or by load, speed, gear etc, there are several options (Olsson[32]).

Axles on the ETT-vehicle can only be lifted on the return trip, or else maximum axle loads are exceeded. There are a number of different scenarios to the solution of lifting axles, mainly concerning how many and which axles to lift. The question of which axles to lift is not further investigated in this thesis due to the time limit, since calculations concerning vehicle stability and dynamics are necessary. Considering how many axles to lift, four scenarios are investigated to see the effect on fuel consumption. These are;

1. No lifted axles
2. Only bogie-lift
3. Bogie-lift and one lifted axle on each trailer
4. Bogie-lift, one lifted axle on the dolly, two each on the link and semi-trailer

The four scenarios are illustrated in Figure 11.14.

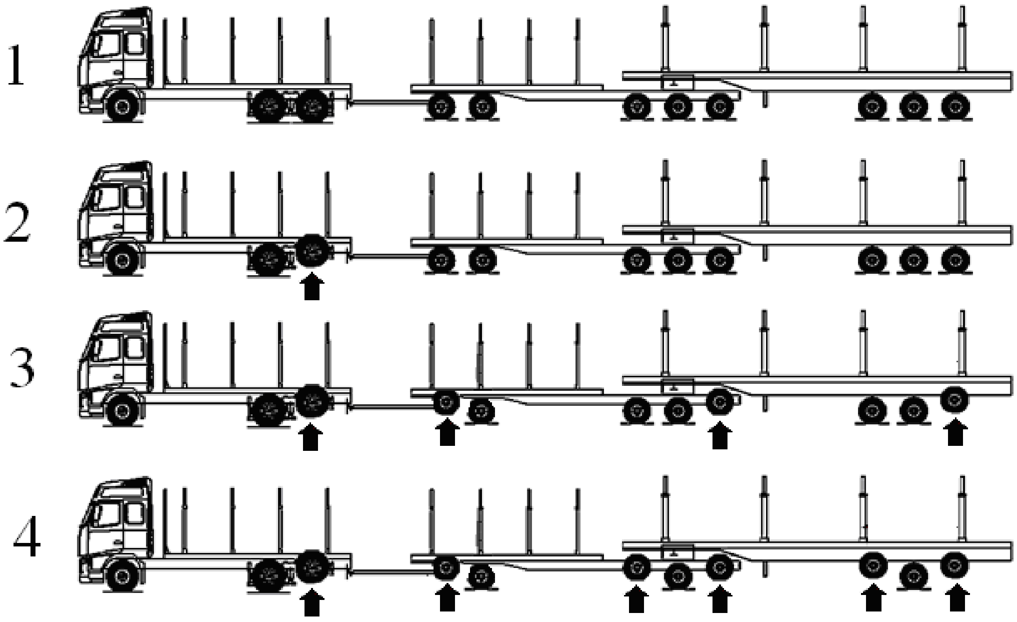

**Figure 11.14.** Lift axle scenarios

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[31] Olsson, Per, CEO, Parator, e-mail 2009-12-14
[32] Olsson, Per, CEO, Parator, e-mail 2009-12-16

The different scenarios result in different load distribution on the remaining tires in ground contact. The more axles are lifted, the higher the load on the remaining tires, and hence they are more effective. The load on each tire in kilograms for each scenario has been calculated and is presented in Table 11.3.

**Table 11.3.** Load on each tire in kilograms for the different scenarios of lifting axles

| | **Front tires** | **Drive tires** | **Dolly and link tires** | | **Semi-trailer tires** |
|---|---|---|---|---|---|
| 1. Unloaded | 2950 | 750 | 927 | 742 | 646 |
| 2. Bogie-lift | 2510 | 1720 | 927 | 742 | 646 |
| 3. One lifted axle/unit | 2510 | 1720 | 1855 | 1112 | 970 |
| 4. Two lifted axles on link + semi-trailer | 2510 | 1720 | 1855 | 2225 | 1940 |

The equipment necessary for the bogie-lift weights about 60 kilograms and the equipment for each trailer axle lift about 30 kilograms. The vehicle is equipped with a bogie-lift, but during the fuel measurements used in this thesis it was not, hence the first scenario is included without an increased weight. The rolling coefficient for each tire calculated, and an average rolling coefficient for the whole combination has been calculated considering how many tires of each kind are in ground contact. The effect on the rolling coefficient ($C_R$) and the weight of the combination for each scenario is presented in Table 11.4.

**Table 11.4.** Rolling coefficient and gross combination weight, GCW for lift axle scenarios

| | **$C_{R,avg}$ [N/ton]** | **Diff, $C_{R,avg}$ [%]** | **Extra weight [kg]** | **GCW [kg]** |
|---|---|---|---|---|
| 1. Unloaded | 49.36 | 0.00 | 0 | 23940 |
| 2. Bogie-lift | 47.78 | -3.20 | 60 | 24000 |
| 3. One lifted axle/unit | 46.34 | -6.12 | 150 | 24090 |
| 4. Two lifted axles on link + semi-trailer | 45.55 | -7.72 | 210 | 24150 |

The effect of lifting axles on the fuel consumption is shown in Table 11.5.

**Table 11.5.** Effect of lifting axles on fuel consumption, FC, on the return trip

| | **FC l/100 km** | **Diff [%]** |
|---|---|---|
| 1. Unloaded | 36.39 | 0 |
| 2. Bogie-lift | 36.18 | -0.58 |
| 3. One lifted axle/unit | 35.94 | -1.24 |
| 4. Two lifted axles on link + semi-trailer | 35.79 | -1.65 |

The results indicate a possibility of saving 1.65% fuel per 100km on the return trip by lifting six wheel axles. In total, both loaded and unloaded, the gain from lifting axles can be about 0.55% in fuel reduction per 100km. However the loading capacity is decreased slightly in the cases where the weight of the timber is limiting and not the space, for example when the timber is wet. In the *unloaded* and *bogie lift* scenarios the axle weights are very low, bringing uncertainty to the calculated $C_R$-value since equation 3 only has validity for load cases between 70-100% of the maximum tire load. The $C_R$-value might be a bit high and thereby indicating a larger fuel saving than is accurate. However, the fact remains that fuel is saved, and the more axles lifted the better. With the other benefits that come with lifting axles, this is a highly recommended solution for the ETT-vehicle. It should be noted that the payload is decreased in the loaded case due to the extra weight from the lifting equipment, hence bringing a minor fuel loss when driving a loaded vehicle.

### 11.3.2 Drop Pressure in Air Bellows on the First Dolly Axle

By dropping the pressure in the air bellows on the first axle on the dolly, the weight is redistributed, adding weight to the driving wheels which improves the traction. In Figure 11.15, the relative weight distribution before the pressure drop is shown.

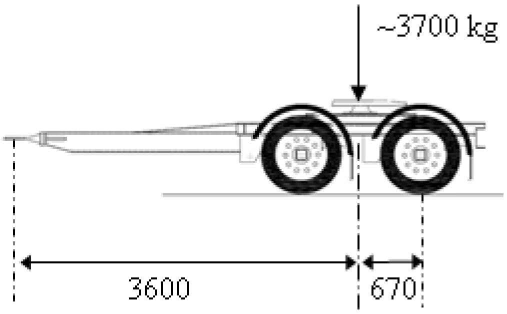

**Figure 11.15.** Weight distribution on dolly without pressure drop

In Figure 11.16 the weight distribution after the pressure drop is shown, adding about 580 kg to the coupling of the dolly, hence the driving wheels. Even better is to lift the axle, and at the same time eliminate its contribution to rolling resistance.

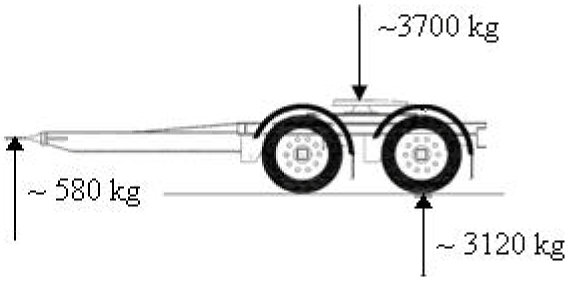

**Figure 11.16.** Weight distribution on dolly after pressure drop

What needs to be done to achieve the pressure drop is to assemble a valve to each bellow that shuts the air suspension and drops the pressure in the bellows on the first axle. One or two conductors from the valve to the cab are needed and a button in the cab for activation (Olsson[33]). Since it is better for the rolling resistance to lift the axle, this alternative is desirable. However, when it is slippery, many tires add to the grip, hence both options should be available.

### 11.3.3 Move Fuel Tanks

The ETT-vehicle has a 500 litre fuel tank situated at the right side of the chassis, just behind the rear wall of the cab, see Figure 11.17. Moving it to a place behind the driving axles would redistribute the weight on the wheel axles, adding the weight of the tank and fuel to the driving axles. This could add in average 250 kg to the drive axles, assuming the tank is in average half full. The solution would require a different chassis packing, but is considered possible to achieve, however there might be some safety issues.

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[33] Olsson, Per, CEO, Parator, e-mail 2009-12-10

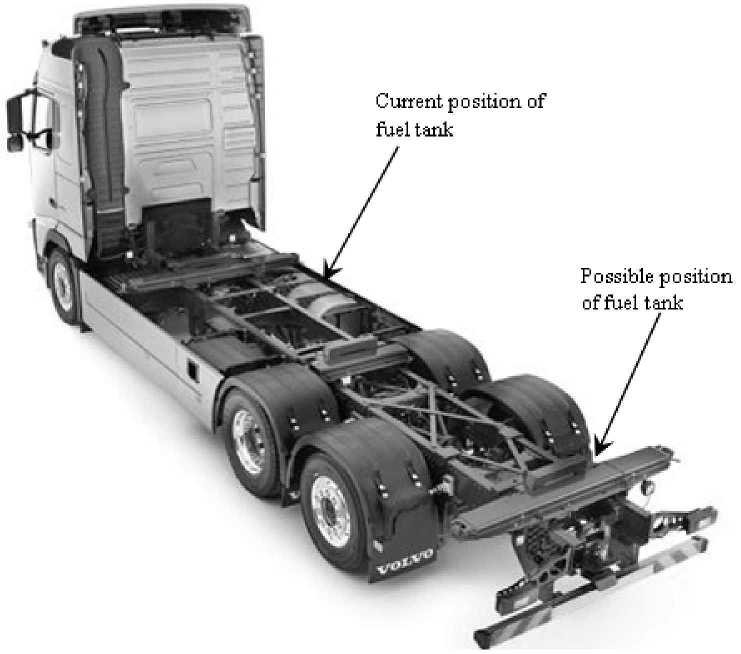

**Figure 11.17.** Current and possible position of fuel tank

## 11.4 Driveline

In this section, the solutions regarding the driveline are discussed and tested in simulations. The solution *Conserve energy from loading* is also discussed in this section, since it is considered closely linked to the driveline.

### *11.4.1 Components Tests*

For a driveline to be as fuel efficient as possible, it should be optimised for its purpose. For the ETT-vehicle, different engines, gear boxes and final drive ratios are tested in simulations to measure the effect on fuel consumption. Four different engines, all with emission standard Eu5 are tested in combination with two gearboxes, the existing with overdrive, and one with direct drive. The engines that are compared to present engine are three 16 litre engines with 540hp, 600hp and 700hp, and one 13 litre engine with 540 hp. All results are in comparison to the existing components, a 660hp Eu4 engine and an I-shift with overdrive.

The fuel consumption is measured, as well as how the vehicle keeps its speed during the drive cycle. On about 80% of the road the speed limit is 80 km/h, and a percentage of how long time the vehicle has a velocity over 75 km/h is presented. Further the gradeability is tested through measuring the time it takes the vehicle to accelerate on a one kilometre long flat road to climb a 5 km hill with an inclination of 3 degrees. The latter two values are not presented for the return trip, as they are not considered interesting during such low load conditions. The engine efficiency is however presented for both loaded and unloaded vehicle. In Table 11.6 the results of the engine and gearbox test are presented for loaded vehicle, and in Table 11.7 results from the return trip are presented.

**Table 11.6.** Results from simulations with tests of engines and gearboxes with loaded vehicle

| | **FC [l/100km]** | **Diff [%]** | **% over 75km/h** | **Time in 3° hill [s]** | **Engine efficiency [%]** |
|---|---|---|---|---|---|
| **Overdrive** | | | | | |
| ***D16 660hp Eu4*** | ***72.27*** | ***0*** | ***59.5*** | ***451*** | ***43.0*** |
| D16 540hp Eu5 | 69.80 | -3.42 | 55.3 | 531 | 43.4 |
| D16 600hp Eu5 | 70.41 | -2.57 | 56.7 | 491 | 43.5 |
| D16 700hp Eu5 | 71.84 | -0.60 | 60.3 | 440 | 43.3 |
| D13 540hp Eu5 | 70.93 | -1.85 | 54.3 | 514 | 43.1 |
| **Direct drive** | | | | | |
| D16 540hp Eu5 | 70.08 | -3.03 | 55.9 | 527 | 43.4 |
| D16 600hp Eu5 | 70.72 | -2.15 | 57.5 | 513 | 43.5 |
| D16 700hp Eu5 | 72.04 | -0.32 | 60.3 | 442 | 43.3 |
| D13 540hp Eu5 | 70.88 | -1.92 | 56.1 | 515 | 43.1 |

**Table 11.7.** Results from simulations with tests of engines and gearboxes on the return trip

| | **FC [l/100km]** | **Diff [%]** | **Engine efficiency [%]** |
|---|---|---|---|
| **Overdrive** | | | |
| ***D16 660hp Eu4*** | ***36.39*** | ***0*** | ***41.11*** |
| D16 540hp Eu5 | 36.02 | -1.02 | 41.29 |
| D16 600hp Eu5 | 36.06 | -0.91 | 41.32 |
| D16 700hp Eu5 | 36.11 | -0.77 | 41.27 |
| D13 540hp Eu5 | 35.52 | -2.39 | 41.97 |
| **Direct drive** | | | |
| D16 540hp Eu5 | 36.58 | 0.52 | 40.47 |
| D16 600hp Eu5 | 36.58 | 0.52 | 40.47 |
| D16 700hp Eu5 | 36.59 | 0.55 | 40.45 |
| D13 540hp Eu5 | 35.10 | -3.55 | 42.26 |

The results clearly show that the overdrive gearbox provides lower fuel consumption than the direct drive gearbox. The weaker the engine, the better the fuel consumption is also a fact that can be established from the results, however the 13 litre 540 hp engine shows considerably lower fuel reductions than the 16 litre equivalent when the truck is loaded. It is therefore eliminated from the possible choices, even though it is the most efficient on the return trip. The three 16 litre engines have similar fuel consumption results from the return trip, varying from a 0.77% reduction on the 700 hp engine to 1.02% on the 540 hp engine. This leaves the results from the loaded case tests as the primary selection criteria.

Time is an essential aspect to the transport industry, and the weaker the engine, the longer a certain distance takes to drive. In the loaded case the choice is between performance and fuel reduction. The 700 hp engine is superior to the other alternatives in keeping velocity and a low gradeability time; it is the only engine that improves in these performance criteria compared to the present engine. However the fuel reduction is at least 2% less than for both the 600 hp and 540 hp engines. The engine efficiency is not changing dramatically, but is improved in all alternatives, with the best result for the 600 hp engine.

Some of the fuel savings achieved with the tested engines are due to the fact that they are of a newer model then the one in the ETT-vehicle, and of a newer emission standard. How much of the effect that is caused by this fact is unknown.

The available final gear ratios for the rear axle in the ETT-vehicle are also tested considering fuel consumption with the engine and gearbox in the present ETT-vehicle. The results show that the current ratio, 3.19 is the most fuel efficient with this component combination. But since these results are very case specific this should be investigated for the engine and gearbox that is finally chosen. The results from the test of the ETT-vehicle components are not presented here as they are not interesting in the selection of the development concept.

### 11.4.2 Speed Test

The vehicle speed is another important factor in fuel efficiency, as it highly affects the drag resistance and the driveline efficiency. Generally, the lower speed of the truck, the lower is the fuel consumption. Naturally it is often a consideration of fuel versus time, where most hauliers choose time. It is however interesting to see the effect of the top speed limit on the fuel consumption and simulations are made considering this on the loaded ETT-vehicle. The ETT-vehicle is limited to maximum 80 km/h, why both lower and higher top speed limits are set in simulations; the fuel consumption, time to complete a drive from Överkalix to Piteå and the engine efficiency are investigated. The results are presented in Table 11.8.

**Table 11.8.** Results for the ETT-vehicle from speed limit simulations

| Speed limit [km/h] | FC [l/100km] | Diff [%] | Time [s] | Diff [min] | Engine efficiency |
|---|---|---|---|---|---|
| 70 | 67.41 | -6.75 | 8620 | 13 | 42.73 |
| 72 | 68.41 | -5.37 | 8504 | 11 | 42.71 |
| 74 | 69.08 | -4.44 | 8335 | 8 | 42.84 |
| 76 | 70.06 | -3.09 | 8133 | 5 | 42.94 |
| 78 | 71.11 | -1.63 | 7984 | 2 | 43.01 |
| 80 | 72.29 | 0.00 | 7839 | 0 | 43.05 |
| 82 | 73.57 | 1.77 | 7724 | -2 | 43.07 |
| 84 | 74.65 | 3.27 | 7687 | -3 | 43.15 |
| 86 | 76.07 | 5.23 | 7557 | -5 | 43.14 |
| 88 | 76.95 | 6.45 | 7373 | -8 | 43.25 |
| 90 | 77.90 | 7.76 | 7333 | -8 | 43.22 |
| 92 | 78.68 | 8.84 | 7210 | -10 | 43.35 |

The results indicate that a lot of fuel can be saved by applying a lower speed limit than 80 km/h. By just lowering it 2 km/h a fuel saving of 1.63% is achieved while the drive takes approximately two minutes longer. The large engine however works more efficiently with a higher load.

Fuel consumption versus time is illustrated in Figure 11.18 for the present ETT-vehicle. The larger data points indicate the present situation.

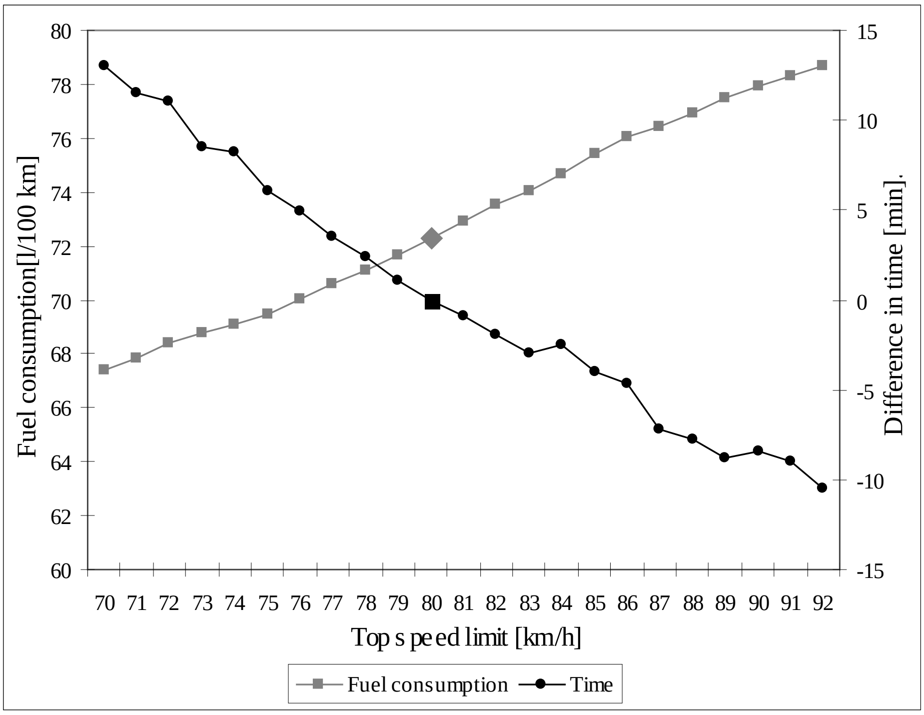

**Figure 11.18.** Speed limit effects on fuel consumption and time for the present ETT-vehicle

### *11.4.3 Conserve Energy from Loading*

In order to decrease the use of diesel, energy used to heat or air condition the truck during loading and unloading could be taken from the crane that loads and unloads the timber, see Figure 11.19. The potential energy the timber has when lifted, is now wasted when it is lowered down on the truck or ground, and could instead be used to charge a battery that supplies energy to the climate control in the cab. The energy equation is used to calculate the potential energy from lifting the timber;

$$W = mgh \quad \text{(Equation 6)}$$

where *m* is the mass, *g* the gravity and *h* is the height the timber is lowered (Ingelstam et al. 1971, pp 73). The timber is lowered approximated from 5 meters as the timber bunks are 4.5 meters high, to 1.5 meter that is the approximate height of the timber superstructure. The timber is hence lowered an average of 2 meters during loading. From this, following results are calculated;

Potential energy of 1 ton of timber lowered 2 meters: W = 20 kJ

Potential energy of 66 tons of timber (whole truck): W = 1.3 MJ = 0.36 kWh

**Figure 11.19.** Loading of the ETT-vehicle

The efficiency of a diesel engine is about 40%, and the energy content of one litre diesel is 36.4 MJ, hence the useable energy from one litre diesel is 14.6 MJ (ORNL 2010). From this follows that, lowering 730 tons of timber or loading a full ETT-vehicle 11 times could save energy corresponding to one litre diesel. There is a potential of saving even more energy when unloading, depending on at what level the timber is placed.

## 11.5 Loading Capacity

Increasing the loading capacity is an effective way of reducing the fuel consumption per ton-km. It can be done by either reducing the tare weight, and in that way making it possible to load more cargo onto the vehicle, or by exceeding the 90 ton limit. The first two solutions aim to reduce the tare weight, and the following two to increase the gross combination weight.

### *11.5.1 Smaller Cab & SSAB High Strength Steel*

The cab on the ETT-vehicle is a Volvo Globetrotter (L2H2) with four seats. The two extra seats were added because this is a test vehicle and space for extra passengers was considered appropriate for educational purposes. For another vehicle driving this distance, extra seats might not be necessary, and since it is only 160 km one way, a sleeping department (which the two seats can be replaced with) is not necessary either. Therefore a smaller cab could be used, and this could reduce the tare weight and save fuel due to higher effective load. How much the tare weight could be reduced by using a smaller cab is unknown, since no cabs without sleeping department are at the moment available for the FH16 truck model. Changing to the smallest available cab (L2H1) would mean a reduction of weight with only 80 kilograms[34]. This solution is

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[34] Volvo Weight Information System, 2010-03-10

however not an option in the north of Sweden, since the air volume inside the cab is needed to keep the temperature at a satisfying level for the drivers[35].

The light, high strength steel from SSAB used on the semi-trailer on the ETT-vehicle could be used on the rigid, dolly and link as well. This could reduce the tare weight with about one ton compared to the existing ETT-vehicle (Sundell[36]).

The fuel consumption per ton-km and possible savings that could be made with increased effective load is presented in Table 11.9. The gross combination weight is assumed to be 90 tons. 66 tons is the present loading capacity of the ETT-vehicle.

**Table 11.9.** Fuel consumption with increased effective load, from simulations

| Load [ton] | Fuel consumption [l/ton-km] | Diff [%] |
|---|---|---|
| ***66.0*** | ***0.01096*** | ***0*** |
| 66.5 | 0.01087 | -0.76 |
| 67.0 | 0.01079 | -1.50 |
| 67.5 | 0.01071 | -2.22 |
| 68.0 | 0.01063 | -2.95 |
| 68.5 | 0.01056 | -3.65 |
| 69.0 | 0.01048 | -4.35 |
| 69.5 | 0.01040 | -5.04 |
| 70.0 | 0.01033 | -5.71 |

The results indicate that the single measure of replacing the steel could save about 1.5% fuel when driving with load. It also would mean savings on the return trip since the vehicle would be lighter, resulting in an even higher fuel reduction.

The results show a linear relationship between the load and the fuel consumption. This is illustrated in Figure 11.20.

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[35] Larsson, Lena, Technical Project Leader, Volvo 3P, 2010-03-17

[36] Sundell, Börje, Engineering Consultant, SSAB, e-mail 2010-02-04

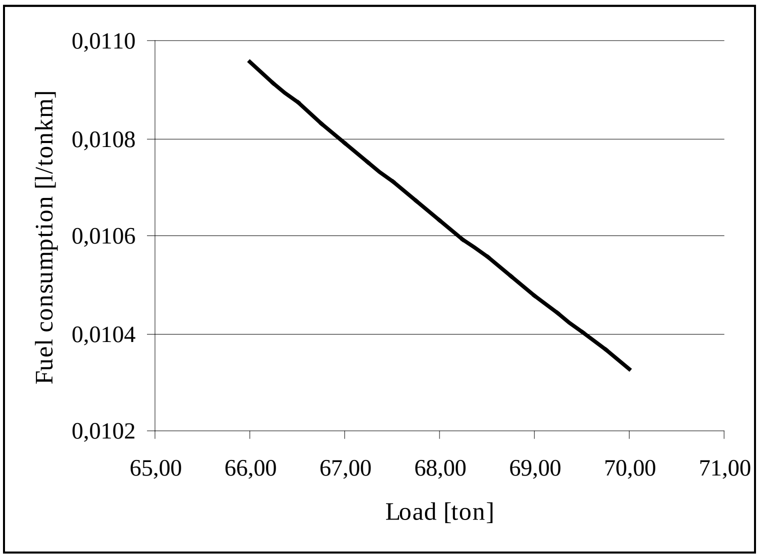

**Figure 11.20.** Relationship between fuel consumption and effective load

The fuel consumption and savings that could be made on the return trip are shown in Table 11.10, and are a result of simulations with reduced tare weight.

**Table 11.10.** Tare weight effect on fuel consumption on return trip, from simulations

| Tare weight [ton] | Fuel consumption [l/100km] | Diff [%] |
|---|---|---|
| 24.0 | 36.42 | 0 |
| 23.5 | 36.15 | -0.74 |
| 23.0 | 35.90 | -1.43 |
| 22.5 | 35.60 | -2.25 |
| 22.0 | 35.37 | -2.89 |
| 21.5 | 35.11 | -3.60 |
| 21.0 | 34.85 | -4.31 |
| 20.5 | 34.60 | -5.00 |
| 20.0 | 34.33 | -5.74 |

Here as well, a linear relationship between tare weight and fuel consumption is the result.

### 11.5.2 Tridem

By using a truck with a triple axle in the back, i.e. a tridem, the load on the truck can be increased. Maximum allowed gross combination weight for a tridem truck in Sweden is 32 tons (Yrkestrafiken 2010). The tare weight of a tridem is here approximated to 13.5 tons, one and a half extra ton for the extra axle and wheels, which means this can be loaded with 18.5 tons of timber without exceeding the maximum 32 tons. Compared to the ETT-vehicle, this is an increase of about four and a half tons of timber giving the whole vehicle combination a gross combination weight of approximately 96 tons.

The fuel consumption of the tridem is tested in simulations and the results of the fuel consumption can be seen in Table 11.11. The increase in rolling resistance due to the increased number of wheels has been considered.

**Table 11.11.** Fuel consumption of the ETT-vehicle compared to a tridem

| | **GCW [ton]** | **Effective load [ton]** | **Fuel consumption [l/100 km]** | **Fuel consumption [l/ton-km]** | **Diff [%]** |
|---|---|---|---|---|---|
| **Loaded** | | | | | |
| ETT-vehicle | 90 | 66 | 72.3 | 0.0110 | |
| Tridem | 96 | 70.5 | 74.9 | 0.0106 | |
| **Return trip** | | | | | |
| ETT-vehicle | 24 | - | 36.4 | - | |
| Tridem | 25.5 | - | 37.3 | - | |
| **Average** | | | | | |
| ETT | | 66 | 54.4 | 0.0082 | 0 |
| Tridem | | 70.5 | 56.1 | 0.0080 | -3.3 |

It should be noted that the extra one and a half ton in tare weight on the tridem increases the fuel consumption slightly on the return trip, but the increased effective load still makes the total fuel saving per transported ton-km considerably lower.

### 11.5.3 Five Piles

One way of increasing the load on the combination is to add a fifth pile of timber, and by for example having a tractor pulling three links and a semi-trailer this could be achieved.

Here the trailer combination is not further considered, only the fuel consumption that would be a result of the fifth pile. On the existing ETT-vehicle, the first pile on the semi-trailer, which mainly causes the load on the link axles, weighs 17.5 tons, why this is supposed to be an appropriate load on the fifth pile. The tare weight of the link is approximately 4.5 tons and thereby, the extra gross combination weight from a fifth pile is 22.0 tons. This results in a total tare weight of 28.5 tons, and a gross combination weight of 112 tons. Except for this, at least four more wheel axles are added to the combination affecting the rolling resistance, and the $C_D$-value is assumed to increase with about 0.1 due to the air resistance of the fifth pile.

The five piles solution is tested in simulations and the fuel consumption studied on loaded vehicle, empty vehicle, and the lift axle scenarios (including the extra trailer) presented in the lift axle solution. The results are presented in Table 11.12.

**Table 11.12.** Results from fuel consumption simulations with five pile timber truck

| | **GCW [ton]** | **$C_R$ [N/ton]** | **Fuel consumption [l/100km]** | **Diff [%]** |
|---|---|---|---|---|
| 1. Loaded | 112 | 42.924 | 81.90 | - |
| 2. Unloaded | 28.50 | 49.225 | 41.59 | 0 |
| 3. Bogie lift | 28.56 | 47.964 | 41.42 | -0.41 |
| 4. One axle per trailer | 28.68 | 46.573 | 41.21 | -0.91 |
| 5. Two axles per trailer | 28.74 | 45.287 | 40.89 | -1.68 |

The effective load on the loaded five pile timber truck is 83.5 tons, resulting in a fuel consumption of 0.0098 l/ton-km, compared to 0.0111 l/ton-km for the ETT-vehicle. This indicates a possible fuel saving of about 11% by adding a fifth pile. However there are several issues concerning safety and roads to overcome before this could be realised.

## 11.6 Tires, Weight Control and Vehicle Information Cluster

Several of the proposed solutions are closely linked to the tires, the weight information system, and the vehicle information cluster, and these are here grouped together. The solutions discussed in this section are;

- Pressure control
- Self-inflating tires
- Nitrogen filled tires
- Warn unfavourable weight distribution
- Weight from crane to vehicle information cluster
- Axle by axle
- Wheel by wheel
- Even out weight
- Wabco Opti-turn

### 11.6.1 Pressure Control, Self-inflating Tires and Nitrogen Filled Tires

To improve the inflation pressure, and with that improve handling, fuel consumption and safety, a few solutions are proposed. The first is a rather simple one and includes the monitoring of the tire pressures by the vehicle information cluster, and a system to alert the driver when it is unfavourable. This could be done by placing sensors in each tire and sending the pressure information to the vehicle information cluster. The adjustment of the pressure is not included in this solution, and would in case of an alert, have to be adjusted manually.

A more convenient, but also much more complicated and expensive solution is to have self-inflating tires that regulate the pressure automatically, for example CTIs (*Central Tire Inflating system*). Here the tire pressure can easily be regulated considering the load on the vehicle and the condition of the road (TPC International 2010).

By filling the tires with nitrogen instead of air, the risk of exploding tires is probably reduced. In air there can be water vapour, and when it transforms from liquid to vapour, it expands in volume causing a risk of explosion inside the tire. The vapour also acts as a catalyst for rust and corrosion of the rubber and the steel cords inside the tire. Air consists of about 21% oxygen, and oxygen can also be very reactive under high temperatures and pressures, fuelling potential flames if a tire catches on fire. Dry nitrogen is used in race car tires and air craft tires because of the extreme conditions that may occur, but the benefits under the conditions of a highway truck are not evidential. It is also claimed that the pressure in nitrogen filled tires is kept longer, since air permeates through rubber faster (Get Nitrogen Institute, 2010).

### 11.6.2 Weight Control in Vehicle Information Cluster

Some of the solutions are improvements to the information displayed by the vehicle information cluster considering the weight distribution. It is suggested that the system should warn the driver if the weight distribution is unfavourable. The risk of this is rather small in round wood transportation as the vehicles are often fully loaded, but when transporting general cargo accidents have occurred where trailers have rolled over due to uneven loading. The warning system would increase the safety of heavy combinations.

The driver can at the moment not see the weight information during loading, due to the fact that the air bellows are emptied to cope with the fast variations in load. The loading crane has a scale that is used to make sure the right amount of cargo is loaded onto the truck. It would be convenient if the information from the crane could be transferred to the vehicle information cluster, so that the loading could be monitored from the cab as well. The weight information from the crane and the one from the vehicle can then be compared when the loading is finished and the air bellows filled up, providing an extra control of the accuracy of the systems.

The weight distribution is currently displayed per axle group, making sure they don’t exceed the limits. A small and quite simple improvement would be to display the distribution not only per axle group, but also axle by axle and even tire by tire, making sure the distribution in each group is even, and none of the axles exceed the permitted limits. Figure 11.21 shows a suggestion of the interface in the vehicle information cluster, displaying the weight distribution per axle and per tire.

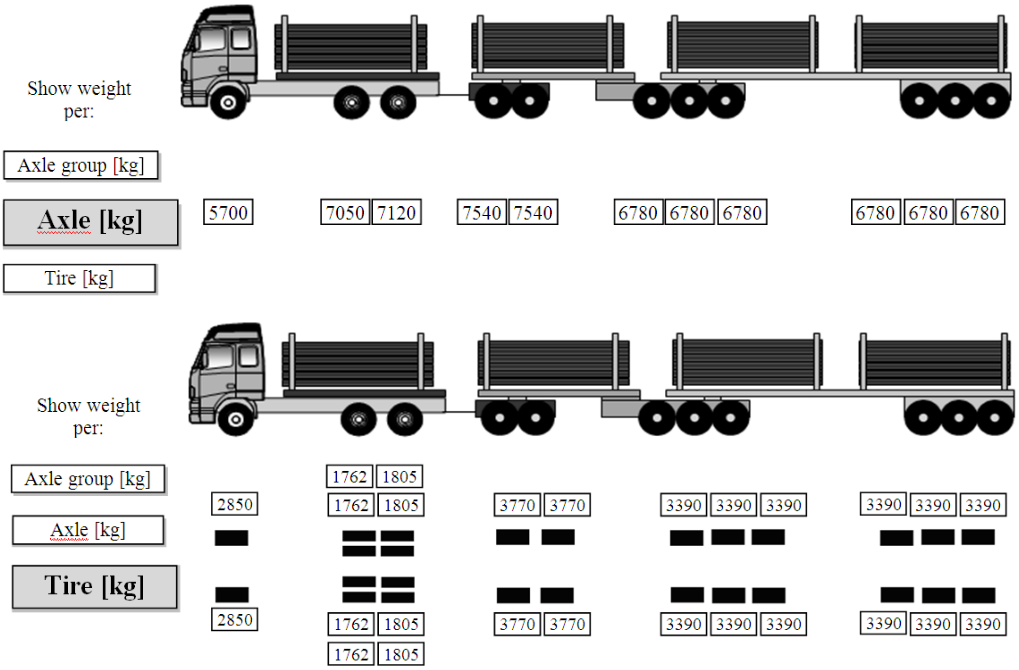

**Figure 11.21.** Suggestion of the vehicle information cluster Interface

### *11.6.3 Even Out Weight and Wabco Opti-turn*

By even out weight, it is meant that the weight on one axle group is automatically distributed evenly over the axles. This is achieved by regulating the air pressure in the air bellows. This system works together with the weight information system and the vehicle information cluster to check that the right distribution is achieved. This is beneficial for the safety, the road wear and the tires.

Wabco Opti-turn is a system that automatically lifts axles during turning to improve the turning radius and hence the accessibility. This is however not very applicable on the ETT-vehicle, since when the truck is loaded the axle weights will be exceeded if axles are lifted. In the case of driving with empty vehicle, the axles could in most cases be lifted the whole time.

## 11.7 Safety

Improving the safety on the ETT-vehicle is an important issue to increase the likelihood of it being able to drive on more roads in the future. The solutions selected from the concept generation phase are not specific for this vehicle, but can be applied to all timber trucks, and in some cases all trucks. Seven solutions for improved safety are tested here;

- Reflector tapes
- LED-sign
- Lights on timber bunks
- Reinforced fabric instead of chains
- Rinsing of side windows and mirrors
- Cameras

These are not the only solutions affecting the safety of the vehicle, but other improving features like soft-nose cab and nitrogen tires are discussed earlier in this chapter.

### *11.7.1 Reflector Tapes*

Improving the vehicles visibility in the dark is easily and cheaply achieved by adding reflector tapes somewhere on the vehicle. It is a very small investment that does not affect the reliability in any way. By putting them on the timber bunks the information that it is a timber truck is effectively communicated at the same time, therefore this is considered a very good solution.

### *11.7.2 LED-sign*

A LED-sign in the back of the vehicle has several benefits. In winter it has a greater chance of being seen through any snow that blows over it, and it can even be heated if necessary. But most of all, a sign with exchangeable text can provide more extensive and accurate information than one with a fixed text. There are several occasions when it could be useful for the ETT-vehicle to display other information than “Long vehicle”. For example it has low speed limits on some bridges, and it would improve safety for other road vehicles it they could read it during and a while in advance of the bridge that it is slowing down. The possibility of displaying the actual length of the vehicle could improve safety in overtaking situations. The high weight could be displayed, which is also a good reason not to load it too heavy. The idea is that the sign is wirelessly connected to the vehicle information cluster that also automatically monitors the text, and changes it when something comes up. There should also be a way for the driver to change the text, in case of for example an accident. An example of what the sign might look like is shown in Figure 11.22.

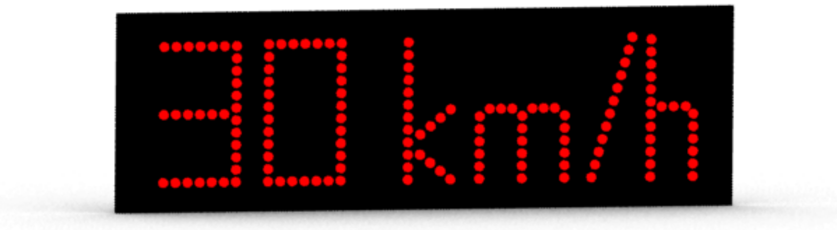

**Figure 11.22.** LED-sign proposal

This is considered a very promising solution that could improve the safety for the other road users in interaction with the ETT-vehicle. Some development has to be done, both with hardware and software but it is still considered a rather simple solution.

### *11.7.3 Lights on Timber Bunks*

Improving the visibility of the truck in darkness, and enhancing the fact that it is a timber truck, can be done by placing lights at the top of every timber bunk. It not only indicates the height of the vehicle, but also the length and gives it a more appealing appearance. A picture of what it might look like is shown in Figure 11.23.

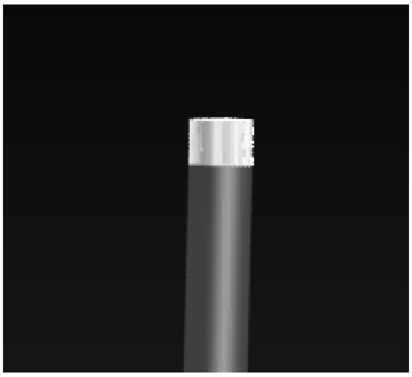

**Figure 11.23.** Light on timber bunk

The problems with the lights on the top of the bunks is that they might be broken if logs hit them during loading and unloading. Further they need to be powered by electricity, meaning wires might have to go through the timber bunks or batteries have to be used. The use of LED-lights is however very energy efficient.

### *11.7.4 Reinforced Fabric Belts*

Something that came up several times during the interviews was that timber trucks can seem intimidating, since it looks like timber might fall off. Fastening belts are more visible than chains, but these are rarely used when there is a high risk of snow and ice on the timber, because they slip easier. Therefore this solution has additional attributes; it has reflector tapes to improve the visibility in the dark, it is equipped with a rough inside with a good grip on the slippery timber, and the belt is extra reinforced to make it as strong as possible. These belts fasten and tighten the timber in the same way as conventional fastening belts. The solution can be seen in Figure 11.24.

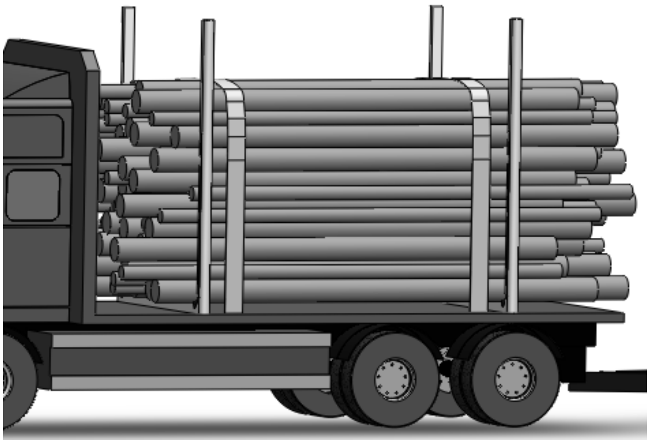

**Figure 11.24.** Reinforced fabric belts for timber fastening

The solution is simple, and the thought is that the belts should also be able to be lifted with the timber crane, so no throwing is necessary. This minimises the injury risk for the driver. A fitting material needs to be found and a way of automatically tensioning the straps needs to be figured out for the solution to work in the field.

### *11.7.5 Rinsing of Side Windows and Mirrors*

A desirable solution to the dirt getting stuck on the side windows and mirrors is to be able to rinse them as is done with the windshield. It is a very important safety issue, and not having enough side view could cause serious accidents in for example lane changing situations.

### *11.7.6 Cameras*

Cameras surrounding the whole vehicle could be very helpful, especially in case it is necessary to back up the ETT-vehicle. However in the current application reversing is quite unusual.

## 11.8 Identity

As mentioned earlier, the project would benefit from making some properties of the vehicle more visible. For example the environmental benefits, transport efficiency and the safety impression should be accentuated in the perception of the ETT-vehicle. The perception is all up to the viewer and is therefore individual. However, there are aspects that are considered to accentuate certain properties, for example that the colour green brings the mind to environmentally friendly products, and that a streamlined body looks efficient and flexible. When discussing the solutions to the need of improved identity, assumed perceptions from the public are taken into consideration, as well as what customers and experts have expressed, but also subjective opinions on different solutions are part of the decision making process, as they are hard to exclude in this aspect of the concept.

Some of the solutions that suggestively improve the identity of the vehicle might also improve other aspects, for example the aerodynamics of the vehicle. In these cases, the effect the solutions might have on the fuel consumption or safety is considered more relevant to the final concept than improved identity, and is therefore discussed more thoroughly in the respective sections.

The concepts left from the concept selection are in following sections more thoroughly described, discussed and some visualized with sketches and pictures.

### 11.8.1 Homogeneity in colours

For the ETT-vehicle to be perceived as one complete transport solution the colours on truck and trailers should be from the same colour palette. Also details such as timber bunks, game fence and signs should have colours from a certain palette to accentuate the homogeneity of the vehicle. To enhance the homogeneity, the truck, trailers and the trailer-skirts should have the same colour. There are legislations about what colour for example the sign indicating “long cargo” must have, but perhaps this colour can be adapted to other signs or details to enhance the homogeneity.

### 11.8.2 Homogeneity in form

The form of different parts of the vehicle is another area that could be made more homogenous. For example, the trailer-skirts could have the same design, both on truck and trailers, and the surfaces could be the same on all parts. Apart from the trailer-skirts being of the same design, this solution is rather difficult to implement.

### 11.8.3 Lights with same shape

On the ETT-vehicle, there are different types of lights on the front of the cab, both square shaped and circle shaped ones. This might give an impression of inhomogeneity, and using lights of the same design might reduce this feeling. However, one other aspect is how well the lamp blends in to the location it is placed on the cab, and therefore it is not certain that same-shaped lights would enhance the homogeneity.

### 11.8.4 Hub caps & trailer skirts

Hub caps and trailer-skirts reduce uneven surfaces and improve the aerodynamic drag. The feeling of a smooth surface enhances the efficiency and the aerodynamic benefits. However, hub caps and trailer-skirts do not contribute a large amount to the efficiency impression, and what is more relevant is their contribution to the improved aerodynamic drag, which is discussed in other sections.

### 11.8.5 “Swedish forest on the way”

Spelling out a message on the truck can evoke positive feelings and associations. The fact that the vehicle carries natural raw material is emphasised by the message “*Swedish forest on the way*”. A unique message on the ETT-vehicle also emphasises the project and makes it recognisable to the public.

### *11.8.6 Forest colours*

By using forest colours on the ETT-vehicle, the environmental benefits are accentuated. The ETT-vehicle has presently a green truck but with a cold tone, and blue trailers. This particular tone of green is not as associated with forest colours as, for example, a warmer green such as moss and leaf green. Changing the colour of a vehicle is easy implemented.

### *11.8.7 Accordion to show where the vehicle bends*

In case the whole combination is covered with a material, there must be some flexible material over the gaps for the vehicle to be able to turn. To increase the flexible impression, and also the safety impression, these parts of flexible material should be visible, in the shape of for example an accordion-like form. This solution is however connected to the solution *Cover the whole combination*, and is only put through to the final concept in case the cover-solution is put through.

### *11.8.8 Train feeling with cover*

Another way of enhancing the flexibility impression is to cover the whole combination in a cover, which makes it feel more train-like. This is discussed further in section 11.2.11, where the solution *Cover the whole combination* is discussed regarding improved aerodynamic drag.

### *11.8.9 Pull trailers together*

By pulling the trailers together the length of the combination is shortened, which enhances the flexibility and safety impression. This solution is discussed under aerodynamics in section 11.7.5.

### *11.8.10 Accentuating modular system coupling possibilities with colour*

One part of the project is the use of the European modular system, which increases the flexibility of the combination. By indicating with for example different colours which couplings go together, this modular system is emphasised and the flexibility impression increased. However, it is uncertain how well this solution actually would work, and also the lack of space on where to put the colour indication is the reason why this solution is eliminated.

### *11.8.11 Visible fastening belts for timber piles*

As mentioned in section 11.7.5, the impression of a timber truck can be intimidated. By using visible fastening belts for the timber piles, this frightening feeling could be reduced. One other aspect is that in the dark, chains are hardly visible, but on the fastening belts, reflector tapes can be attached to improve the visibility in the dark as well.

### *11.8.12 Reflector tapes*

If a large and heavy vehicle is hard to see in the dark, the safety for other road users is at risk. By using reflector tapes on as many places as possible on the ETT-vehicle, the safety impression is increased and thereby also the safety of other road users.

# 12 Selection of Final Concept

*In this chapter the final concept is selected. In the testing the solutions were evaluated individually. Here the most interesting solutions are revised considering fuel savings, safety, identity and feasibility, made certain that they are compatible together and chosen to be part of the final concept. New tests of the combined solutions are then performed to determine the product specifications defined in chapter 7.*

The *Selection of Final Concept*-phase in relation to other phases in the *Front-end Process* is shown in Figure 12.1.

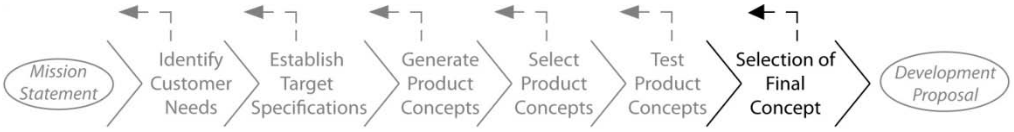

**Figure 12.1.** Front-End process, adapted from Ulrich and Eppinger 2004

## 12.1 Selection of Concept Parts

### 12.1.1 Aerodynamics

Three aerodynamic modifications to the cab are suggested, *integrated lights*, *improved roof deflector* and *soft-nose cab*. The lights and the deflector are rather simple solutions having a substantial effect on the flow around the cab, and are moving on to the final concept. These are solutions that are applicable on all long haul trucks, and that offer easy fuel savings. The improved deflector is assumed to add about 10 kg to the tare weight, while the integrated lights do not affect the weight. The front wall is lowered 100 mm, since it is not considered necessary to have it exceeding the height of the cab as much as it is on the present ETT-vehicle. This affects the A-value as the frontal area is decreased with 0.26 $m^2$.

The *soft-nose cab* moves on to the final concept mainly because of the safety benefits it would bring to incorporate a deformation zone in the extended part of the cab. There are potential aerodynamic benefits as well, but on a vehicle like the ETT-vehicle it is subordinated. The soft-nose cab is assumed to add about 100 kg to the tare weight of the vehicle.

Extended trailer-skirts are also chosen to be part of the final concept. The existing trailer skirts are extended as much as possible as long as they don’t disturb the turning of the vehicle. The trailer-skirts of the concept are also possible to fold up, so that any snow or ice that gets stuck inside the skirt is easily removed. The additional weight is estimated to 100 kg.

Considering improved aerodynamics specifically on the return trip, two suggestions are discussed in the previous chapter. Placing the trailers on each other is considered a far too complicated solution for the trailers on the ETT-vehicle that would probably require a complete redesign of the trailers. Collapsible bunks are also a quite complicated solution, but there are some existing solutions in use in Australia and South Africa that could perhaps be modified to suit the current conditions. The estimated potential fuel saving of about 3% on the return trip is so high that it is worth a try, and the solution moves on to the final concept. Each arrangement for folding the timber bunk is assumed to weigh about 20 kg, making the total contribution of weight to 160 kg.

As described, the gaps between the trailers are a significant reason for aerodynamic drag on the ETT-vehicle, and three solutions are presented to minimise the gaps. The first is to fill the gaps with an inflatable material, the second to pull the trailers together when driving at a certain speed and the third to cover the whole combination. All solutions are rather complicated and demand advanced systems to work, but the potential fuel savings are on the other hand major. The solution chosen for the final concept is to pull the trailers together, as the inflatable gap filler is hard to incorporate on a timber vehicle and is better suited for a truck with van bodies that are fixed, and to cover the whole combination is at this time too hard to realise due to technical difficulties. How the mechanism of pulling the trailers together is supposed to work is not further discussed. It is however assumed that some extra equipment will be necessary, and the weight of the extra equipment is estimated to 100 kg.

Wind tunnel tests indicate a fuel saving potential in lowering the chassis and since the ETT-vehicle mainly drives on level roads this is considered a possibility. With a redesign of the suspension it is assumed that the chassis can be lowered 40 mm when driving at higher speeds, lowering the $C_D$-value with up to 2%.

### 12.1.2 Loading Capacity

As mentioned earlier, the loading capacity can be changed by either reducing the tare weight or by increasing the total gross combination weight. In the first option, reducing the tare weight, two solutions have been tested: to use a smaller cab and the use of SSAB high strength steel. As a smaller cab turned out to only decrease the tare weight with about 40 kg, this solution will not move on to the final concept. Replacing the steel in the ETT-vehicle by SSAB high strength steel would decrease the tare weight with about 1000 kg. This would, as showed in the simulations in Table 11.10 reduce the fuel consumption with about 1.5% when driving with cargo due to 1 ton higher loading capacity, and on the return trip, the fuel consumption will be reduced with about 1.43%. This solution will therefore be part of the final concept.

The two solutions that were tested in chapter 11 regarding increased total gross combination weight were tridem and adding a fifth pile of timber. Adding a fifth pile would reduce the fuel consumption remarkably per transported ton timber, however this solution is still rather difficult to achieve and a lot more issues regarding safety and roads needs to be overcome before this can be a reality. The solution moving on to the final concept is therefore a tridem, which is an already existing solution that could reduce the fuel consumption with about 3.3%. The use of a tridem also brings the opportunity to lift two axles on the truck on the return trip, which would increase the traction even more when driving without cargo.

### 12.1.3 Rolling Resistance and Traction

Lifting wheel axles on the return trip reduces the rolling resistance as well as improving the traction. For the final concept as many axles as possible are lifted, meaning seven. With the tridem configuration two axles can be lifted on the truck, one on the dolly, and two on each trailer. The effect on the fuel consumption per ton-km for the loaded and the unloaded trip together is presented in Table 12.1. The numbers differ from the ones presented in the previous chapter, as they only concerned the return trip.

**Table 12.1.** Effect of lifting axles on fuel consumption, FC, per ton-km both ways

| | FC l/ton-km | Diff [%] |
|---|---|---|
| 1. Unloaded ETT-vehicle | 0.00823 | 0 |
| 2. Six lifted axles on ETT-vehicle | 0.00819 | -0.49 |
| 3. Unloaded tridem | 0.00795 | -3.40 |
| 4. Seven lifted axles on tridem | 0.00792 | -3.77 |

The equipment for lifting the axles still means a weight increase of 210 kg, as the lift for the tridem axle is included in the 1500 kg increase that came with it.

Even though the axles on the empty vehicle in most cases will be lifted, including the first dolly axle, the pressure drop without lifting the axle is still chosen to be a part of the final concept. The reason is that it can be necessary to drive with wheels in the ground in very slippery conditions as the tire side provides side stability for the vehicle. However the simultaneous increase in traction that the pressure drop provides could then be of good use. Moving the fuel tanks is however left out, as the already mentioned measures are considered enough to ensure satisfying traction at all time.

### 12.1.4 Driveline

When it comes to the driveline of the development proposal, several concepts advance to the final concept. The new engine is of emission standard Eu5, and has 700hp. The main reason for this choice is the increased load that comes with the tridem configuration. Further other aspects than fuel efficiency are considered, such as the ability to keep the speed during the drive cycle and the gradeability. The 700hp engine is the only engine that does not worsen these properties substantially. Another thought on the matter is the potential possibility of driving four pile timber trucks in more hilly areas of Sweden, were more power could be absolutely necessary. The engine is coupled with an overdrive I-shift gearbox as it shows the best fuel consumptions. The final gear ratio is investigated through simulations to find the most fuel efficient alternative. The fuel consumption depending on the final gear ratio is illustrated in Figure 12.2, which shows that 3.06 is the most fuel efficient alternative. It is hence selected for the final concept.

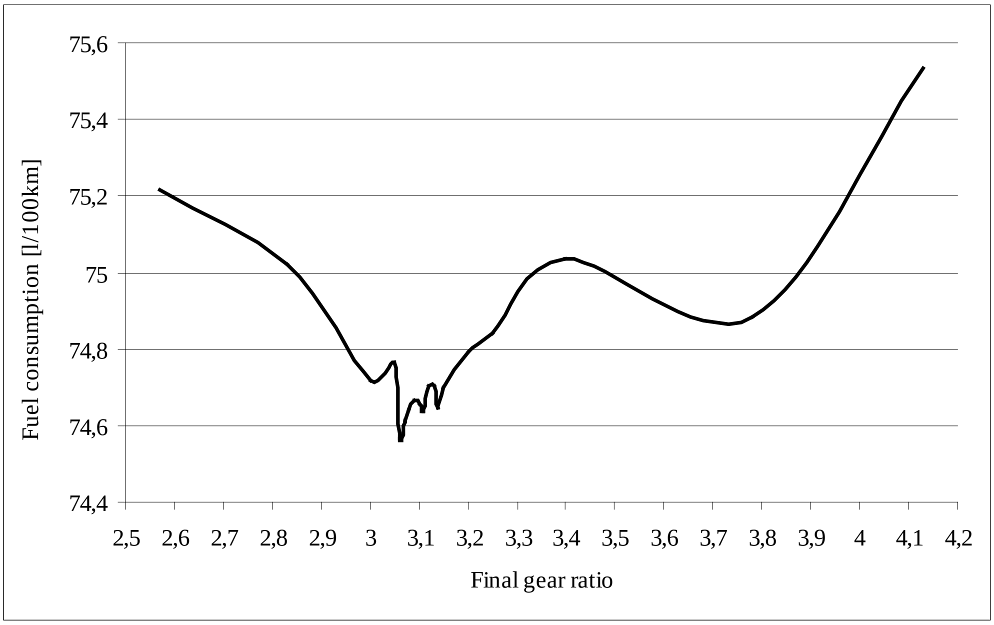

**Figure 12.2.** Final gear ratio effect on fuel consumption, from simulations

Included in the final concept is a course in Eco-driving for all drivers of the vehicle as the driving style has substantial impact on fuel economy.

The solution where energy is conserved from the loading and unloading of the timber is however left out since it is considered not to have enough potential saving possibilities.

### *12.1.5 Tires, Weight Control and Vehicle Information Cluster*

The suggestions tested in chapter 11 for the proposed improvements considering the weight control in the vehicle information cluster, like the display of weights axle by axle, move on to the final selection. They are considered rather simple to implement, and important to achieving the best weight distribution possible.

Also the suggestion of monitoring the pressure in the tires via the vehicle information cluster moves on. It is a convenient solution for the driver, especially on a vehicle combination with as many wheels as the ETT-vehicle. The suggestion means manual adjustment of the pressure, the system only warns when it drops below acceptable levels. Self-inflating tires are eliminated due to the high investment cost. This kind of system is more applicable for a vehicle that drives into the forest where a variable pressure could be used to increase the accessibility and reduce the road wear.

The information found about nitrogen filled tires has no clear indication to that it would actually mean a reduced risk of exploding tires in the application of a highway truck. Further research in the matter is necessary before a decision to use it can be made, and the possibility of filling up the tires with nitrogen has to be provided at gas stations.

The solution that evens out the weight on the axles in an axle group with the pressure in the air bellows is selected for the final concept. The OptiTurn that automatically lifts axles to improve turning radius is left out because of the supposed few possibilities to use it as the empty vehicle will drive with lifted axles at most times.

### *12.1.6 Safety*

Some safety systems that warn the driver and that adjust the driving automatically are suggested in chapter 9, and all of these are chosen to be a part of the final concept. The safety is considered very high in importance, and every available system should be used to increase it. Examples of the mentioned systems are; slippery road warning, lane change support and adaptive cruise control.

Four solutions to improve the visibility of the truck were tested. Two of them are absolutely considered to be part of the final concept; the reflector tapes and the LED-sign. The reflector tapes are a simple and effective solution, and the LED-sign a good way of displaying information that is otherwise hard to communicate to other road users. The LED-sign is however assumed to add about 10 kg extra weight. The text on the “Lång last”-sign is changed to “Fordon 30m” since this is considered to be clearer to other road users, that it is a 30 metre long vehicle.

To have lights at the top of the timber bunks is another solution, with the benefit of making it visible to other road users when it is dark that it is a tall and long vehicle that is approaching. Concerns exist however about the risk of breaking the lights during loading and unloading of the timber, but the solution is considered important and rather easy to implement, so it is chosen for the final concept as well. The lights will possibly also contribute to the identity of the vehicle, making it stand out a bit and look more appealing. Since the timber bunks are folded on the return trip, lights are also put on the back of the front wall, so that the height of the vehicle is seen in this case as well.

By fastening the timber piles with clearly visible belts instead of chains, the safety impression is increased. Depending on the tensile strength of the belt, the safety could also be improved, as chains have broken when trailers have tipped over. However the main benefit of the reinforced belts is the impression it gives, the benefits to the vehicle identity, the possibility to lift them with the crane over the timber, and hence moves on to the final concept.

Rinsing of side windows and mirrors moves on to the final concept with the arguments that it is of highest importance with good visibility for the driver, and the assumption that it is manageable to install. The same arguments apply to cameras that are also included in the final concept. The solutions are estimated to add around 10 kg.

### *12.1.7 Identity*

From the discussions and analysis of the solutions to the identity of the vehicle, four solutions proceed to the final concept. These are homogeneity in colour and form, “Swedish forest on the road” and forest colours. Apart from these, there are a few more solutions which have other impact than only to the identity, that move on to the final concept and these are; trailer-skirts, pull trailers together, visible fastening belts for timber piles and reflector tapes. These are further discussed under respective section. The only solution not proceeding only affecting the identity is lights with same shape. The reason this is eliminated is because of the uncertainty that this would actually improve the identity since the design of the cab has much impact on how the lights are to be designed.

Improved homogeneity is one aspect mentioned in many interviews, and is therefore considered an important part of the identity. The easiest way to achieve this is by using unanimous colours throughout the combination, and also using the same design on all trailer-skirts. To use a slogan on the truck is also something mentioned in the interviews and the slogan proceeding to the final concept will be in Swedish saying “Svensk skog på väg”, which means Swedish forest on the way. This slogan will be situated on the cab at a location where it is visible and well adapted.

## 12.2 Summary of Effects of the Chosen Concepts

The selected concepts have impact on the vehicle properties, such as the aerodynamics, weight and rolling resistance.

Each aerodynamic solution chosen for the final concept is in chapter 11 presented with the approximated contribution in drag reduction, both a minimum and a maximum scenario. To estimate the total drag reduction for the final concept, these numbers are added together. For the loaded case, the solutions altogether provide a reduction in $C_D$ with a minimum of about 0.18, and in the unloaded case this number is about 0.14. Since these numbers are of high uncertainty, a smaller change in $C_D$ will be used for the concept proposal; 0.15 in the loaded case and 0.1 in the unloaded case, giving them $C_D$-values of 1.35 and 0.9 respectively. Since the front wall is lowered 10 centimetres, A is reduced from 11.45 to 11.19, which also reduces the drag resistance.

The weight of the final concept is affected by the selected changes. The effect of the different changes is presented in Table 12.2.

**Table 12.2.** Effects on the weight of the vehicle

| **Solution** | **Additional weight [kg]** |
|---|---|
| Improved roof deflector | 10 |
| Soft nose | 100 |
| Extended trailer skirts | 100 |
| Collapsible bunks | 160 |
| Pull trailers together | 100 |
| Tridem | 1500 |
| SSAB-steel | -1000 |
| Lift seven wheel axles | 210 |
| LED-sign | 10 |
| Rinsing of side windows and cameras | 10 |
| **Total** | **+1200** |

The tare weight is increased with 1.2 tons and the empty vehicle hence has a weight of 25.2 tons. The tridem enables an increase in the gross combination weight with 6 tons to 96 tons, giving the concept vehicle an effective load of 70.8 tons.

The rolling resistance is affected by the changed load distribution, resulting in an average rolling resistance of 43.9 for loaded vehicle, and 45.2 for unloaded vehicle with seven lifted axles. The total number of wheels on the vehicle is increased from 26 to 28, due to the added tridem axle.

# 13 Development Proposal

*In chapter 12 the chosen solutions are presented. In this chapter all these are combined into one final concept. The total fuel reduction and vehicle specifications are presented as well as illustrations of the final concept and the chosen features. The results are discussed and analysed.*

The Development Proposal that is the result of the *Front-end Process* is presented in this chapter. As shown in figure 13.1 this is the final step in the development process.

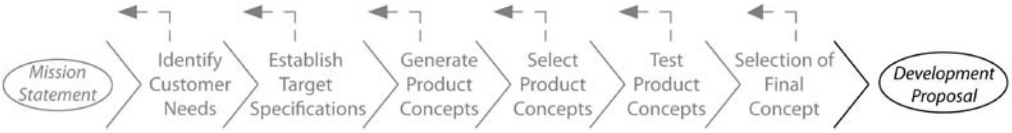

**Figure 13.1.** Development Proposal, adapted from Ulrich and Eppinger 2004

## 13.1 Presentation of Development Concept

The results of the development concept indicate a potential fuel saving per ton-km of about 10% compared to the existing ETT-vehicle, which is a result of simulations made with the chosen solutions. Compared to a conventional 60 ton timber truck, this number is 28%. The final concept also presents improvements regarding the safety and the identity of the vehicle which hopefully improves the public's impression of the vehicle.

In following pages, the development concept and the improved solutions are visualized in 3D-illustrations. The first illustration, Figure 13.2, shows the fuel consumption and load capacity of the development concept compared to the existing ETT-vehicle, in both the loaded and unloaded case. In the second illustration, Figure 13.3, the concept vehicle is presented in unloaded and loaded case as well as loaded with the trailers pulled together. The driveline specific solutions and some of the solutions regarding the cab are presented in Figure 13.4, where the vehicle is shown from the front. The rest of the solutions to the cab and the truck are visualised in Figure 13.5. The vehicle driving without cargo in the dark is shown in Figure 13.6, where the solutions specific to this are presented. Finally the safety systems chosen for the development concept are presented in Figure 13.7.

**ETT-vehicle**

**Unloaded**
Mass: 24 ton
Fuel Consumption: 36.4 l/100km

**Loaded**
Mass: 90 ton
Effective load: 66 ton
Fuel Consumption: 72.2 l/100km

**Total Fuel Consumption: 0.008227 l/tonkm**

**Concept Vehicle**

**Unloaded**
Mass: 25.2 ton
Fuel Consumption: 32.9 l/100km

**Loaded**
Mass: 96 ton
Effective load: 70.8 ton
Fuel Consumption: 71.8 l/100km

**Total Fuel Consumption: 0.007393 l/tonkm**

**Difference: - 10.1 %**

Difference compared to 60 ton timber truck: -28 %

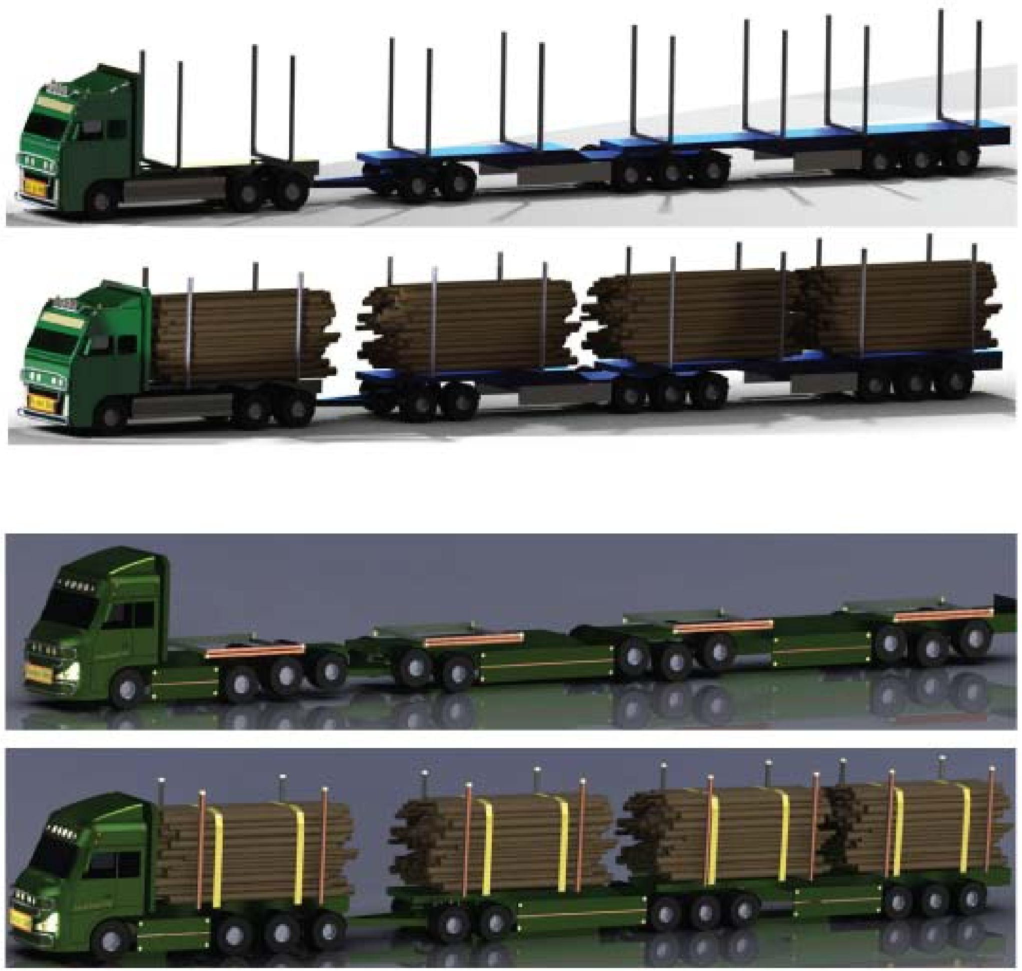

**Figure 13.2.** Fuel consumption and loading capacity of concept vehicle compared to the ETT-vehicle

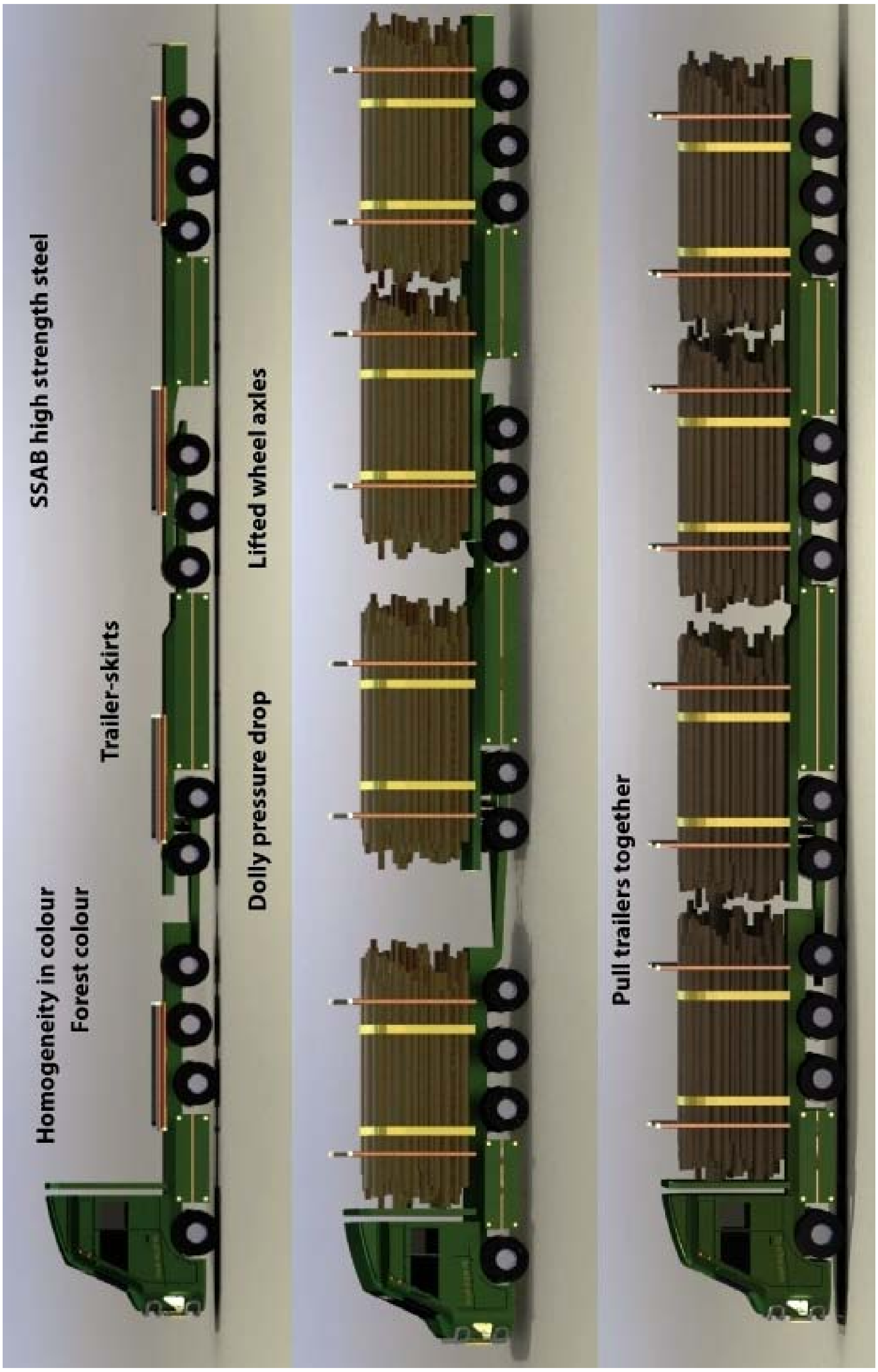

**Figure 13.3.** Concept vehicle unloaded, loaded and pulled together

**Figure 13.4.** Driveline and cab features of the development concept

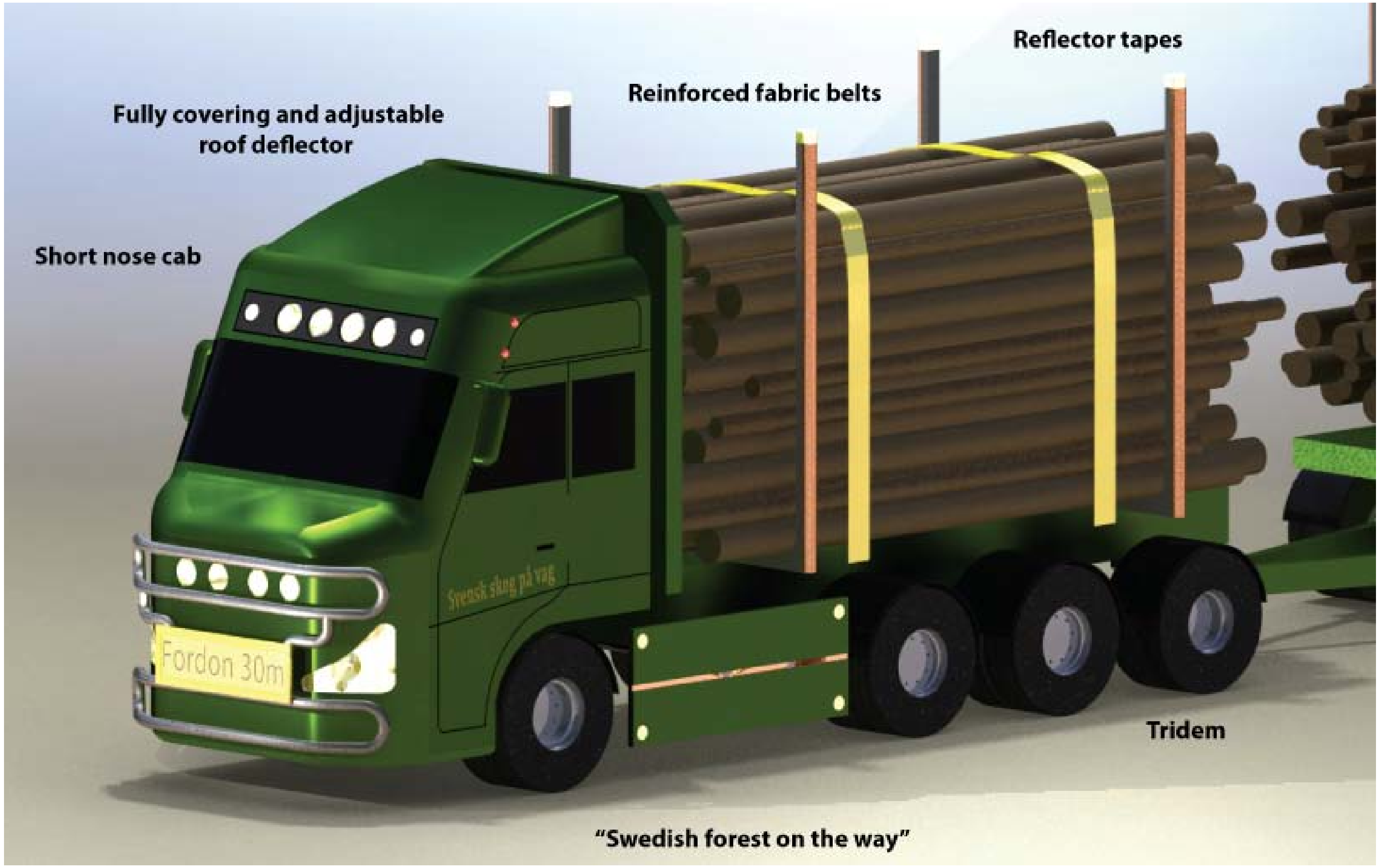

Figure 13.5. Solutions to the cab, truck and load fastening on the development concept

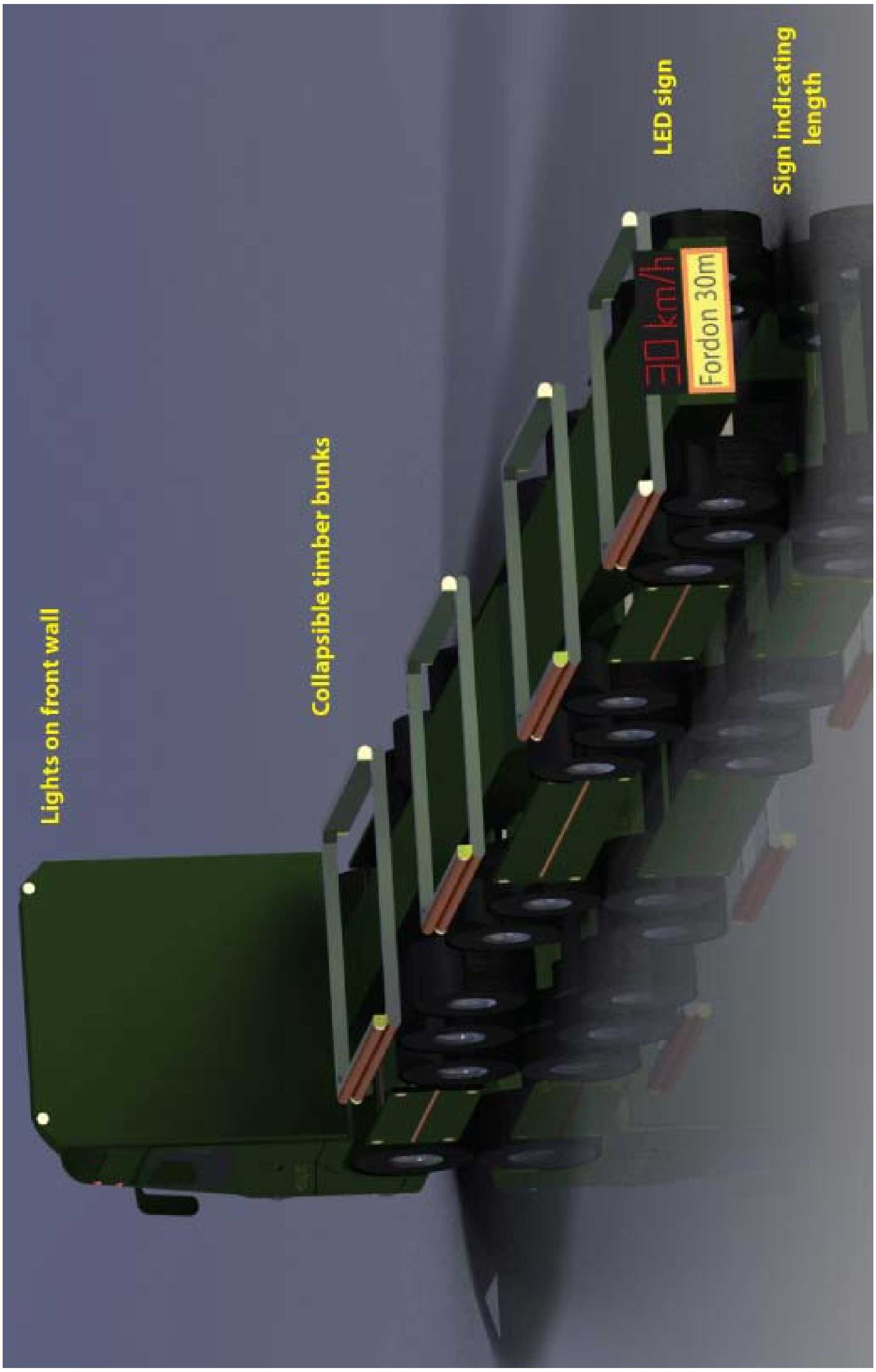

**Figure 13.6.** Solutions to empty vehicle, and driving in the dark

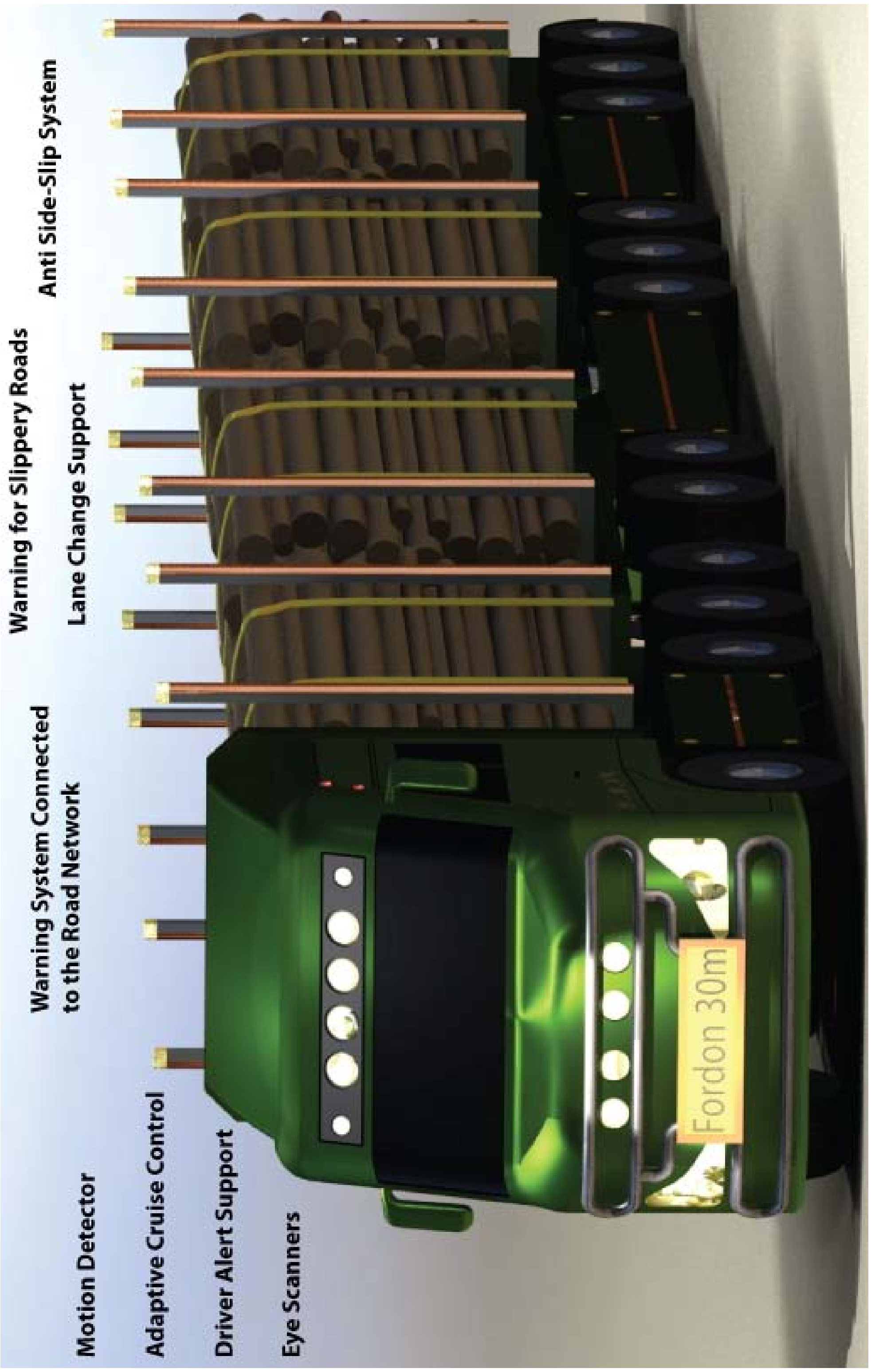

**Figure 13.7.** Safety solutions in development concept

## 13.2 Development Concept Specification

In chapter 7, the target specifications for the development concept with marginally acceptable and ideal values are listed, where the desired performance of the concept vehicle is described. The actual specifications for the development concept are in presented together with the target values Table 13.1.

**Table 13.1.** Vehicle specifications for development concept

| **Vehicle Specifications** | **Development Concept** | **Ideal value** | **Acceptable value** |
|---|---|---|---|
| $C_D$ loaded | 1.35 | 1.0 | 1.5 |
| $C_D$ empty | 0.9 | 0.7 | 1.0 |
| A [$m^2$] | 11.19 | 9.5 | 11.45 |
| $C_R$ [N/ton] loaded | 43.9 | 40 | 43.0 |
| $C_R$ [N/ton] empty | 45.2 | 45 | 49.4 |
| Driveline efficiency [%] | 43.3 | 44.0 | 43.3 |
| Load/GCW [%] | 73.8 | 77.0 | 73.3 |
| Tare Weight [ton] | 25.2 | 22 | 24 |
| Emission level | Eu5 | Eu5 | Eu5 |
| Drive axle load [kg] | 8440 | 8000 | 6880 |
| Accuracy of scales [%] | 1 | 0 | 1 |
| % time over 75km/h | 59 | 89 | 70 |
| Gradeability [s] | 457 | 384 | 451 |

An illustration of the vehicle specifications for the development concept compared to the ideal and marginally acceptable target values is shown in Figure 13.8.

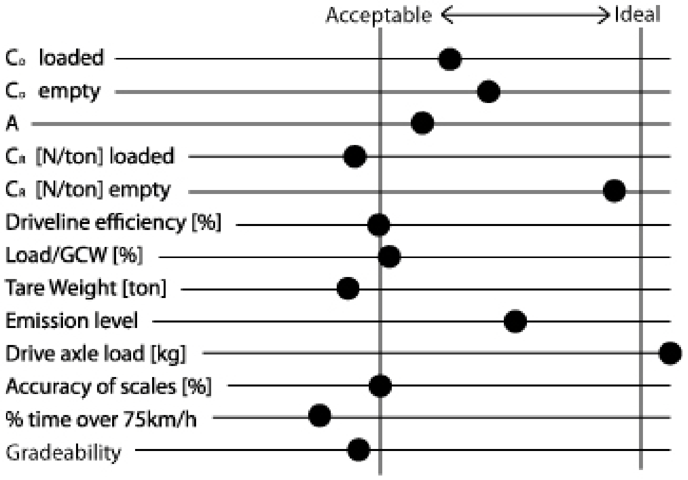

**Figure 13.8.** Vehicle specifications in relation to target specifications

As can be seen here, some of the specifications for the development concept end up below the acceptable value. The reason for this result is mainly due to the increased gross combination weight, which decreases the percentage in time over 75km/h, the rolling coefficient on loaded vehicle, and the gradeability. The increase in tare weight is also connected to the increased loading capacity since the tridem axle increases the tare weight with 1500 kg. The use of a tridem however decreases the fuel consumption per ton-km remarkably and therefore the result is considered acceptable. The rest of the specifications are at least equal to or over the acceptable value, with the drive axle load even exceeding the ideal value thanks to the possibility of lifting two axles on the truck on the return trip. The rolling coefficient on empty truck is improved dramatically as a result of the lifted axles.

## 13.3 Fuel Consumption Results

Table 13.2 shows the differences in fuel consumption between the reference truck with a gross combination weight of 60 ton, the 90 ton ETT-vehicle and the concept vehicle with a GCW of 96 ton. The table presents the fuel consumption per ton-km versus the load fuel efficiency which is measured in ton-km per litre. The relative difference between the three vehicles is also presented below each scenario.

**Table 13.2.** Fuel consumption and load fuel efficiency

| | **Gross Combination Weight [ton]** | **60** | **90** | **96** |
|---|---|---|---|---|
| | **Effective load [ton]** | **42** | **66** | **70,8** |
| **Fuel Consumption** | Loaded [l/10km] | 5.47 | 7.22 | 7.18 |
| | Unloaded [l/10km] | 3.14 | 3.64 | 3.29 |
| | Loaded [l/ton-km] | 0.0103 | 0.0082 | 0.0074 |
| | compared to 60 ton | 100% | 80% | 72% |
| | compared to 90 ton | 125% | 100% | 90% |
| | compared to 96 ton | 139% | 111% | 100% |
| **Load Fuel Efficiency** | Loaded [ton-km/l] | 97.6 | 121.5 | 135.2 |
| | compared to 60 ton | 100% | 125% | 139% |
| | compared to 90 ton | 80% | 100% | 111% |
| | compared to 96 ton | 72% | 90% | 100% |

Some modifications have greater impact on the fuel consumption of the proposed concept than other. On the concept compared to the ETT-vehicle the aerodynamic properties, the loading capacity, the rolling resistance and the driveline are the modifications that affect the fuel consumption the most. The contribution from each of these is illustrated in Figure 13.9 and discussed further, as well as the maximum speed limit.

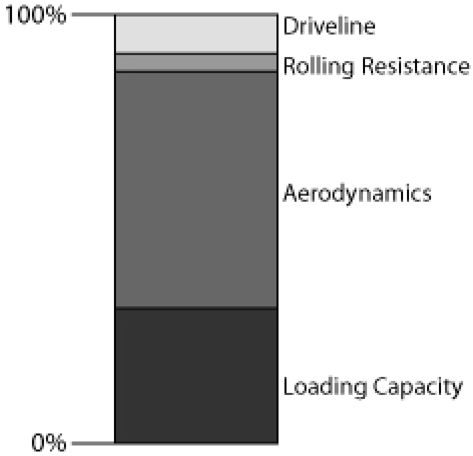

**Figure 13.9.** Contribution from different modifications to the total fuel reduction

### *13.3.1 Aerodynamic Effect on Fuel Consumption*

The assumed $C_D$-value is 1.35 for loaded vehicle and 0.9 for unloaded vehicle. They are however very uncertain, and a parameter study to show the effect of the $C_D$-value on the fuel consumption is presented in Figure 13.10 and Figure 13.11.

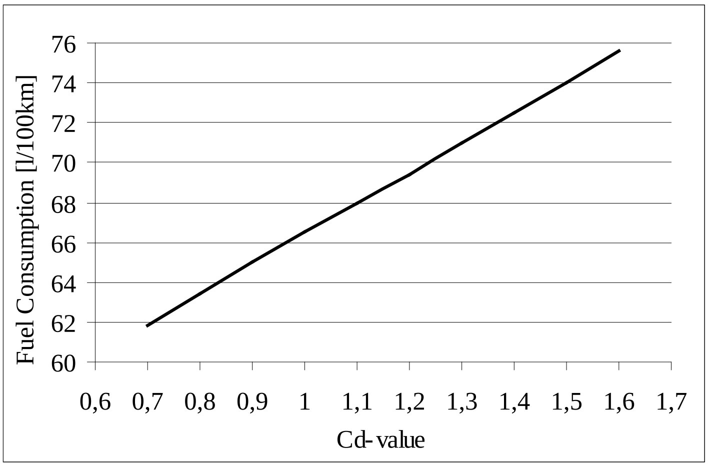

**Figure 13.10.** The effect of the $C_D$-value on the fuel consumption of loaded concept vehicle, from simulations

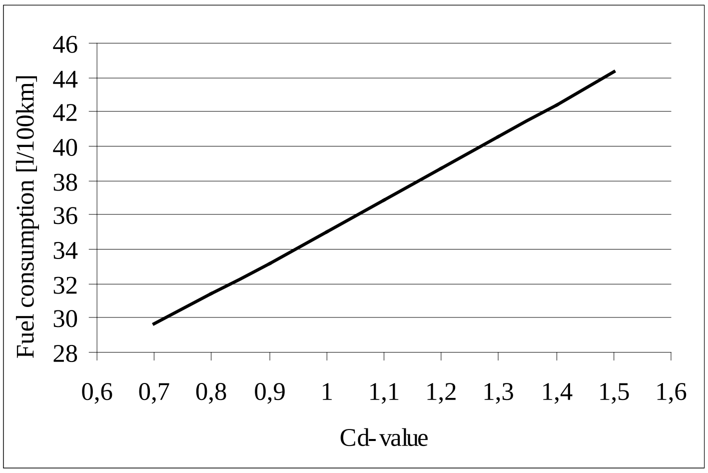

**Figure 13.11.** The effect of the $C_D$-value on the fuel consumption of unloaded concept vehicle, from simulations

As can be seen in the figures, the $C_D$-value has a substantial impact on the fuel consumption, and a lot of fuel can be saved by having an aerodynamic vehicle. With the $C_D$-value assumed to 1.35 and the A-value to 10.33, the aerodynamic improvements account for about 5% of the 10% fuel reduction.

### 13.3.2 Rolling Resistance Effect on Fuel Consumption

When the concept vehicle is loaded, the total rolling resistance compared to the loaded ETT-vehicle is increased slightly, mainly due to the added axle. On the return trip however, the rolling resistance is decreased significantly from 49.4 N/ton to 45.2 N/ton, as a result of the seven lifted axles. This decrease in rolling resistance accounts for about 0,5% of the fuel saving.

### 13.3.3 Loading Capacity Effect on Fuel Consumption

The perhaps largest modification done to the original vehicle is that the loading capacity is increased with the help of a tridem axle. The effect on the fuel consumption of the increased effective load compared to if it would not be used is shown in Table 13.3.

**Table 13.3**. Effect of increased effective load on fuel consumption

| **ETT-vehicle** | | **Diff [%]** |
|---|---|---|
| Effective load | 66 tons | |
| Loaded | 72.2 l/100km | |
| Unloaded | 36.4 l/100km | |
| Average | 0.008227 l/ton-km | |
| **Concept 90 tons** | | |
| Effective load | 66.3 tons | |
| Loaded: | 69.0 l/100km | |
| Unloaded | 32.2 l/100km | |
| Average | 0.007631 l/ton-km | **-7.3** |
| **Concept 96 tons** | | |
| Effective load | 70.8 tons | |
| Loaded | 71.8 l/100km | |
| Unloaded | 32.9 l/100km | |
| Average | 0.007393 l/ton-km | **-10.1** |

The results indicate that the tridem lowers the fuel consumption per ton-km with almost 3%, meaning the other modifications account for about 7% in fuel reduction.

### 13.3.4 Driveline Effect on Fuel Consumption

The engine in the concept vehicle is a 700hp Eu5, and the final gear ratio 3.06, to compare with the 660 hp Eu4 and final gear ratio of 3.09 on the ETT-vehicle. This affects the fuel consumption, and the change accounts for about 1% of the total fuel saving of 10%.

### 13.3.5 Maximum Speed Effect on Fuel Consumption

The speed of the vehicle also has an important impact on the fuel consumption, as discussed in chapter 8 under the need *Improved Fuel Efficiency*. To illustrate this, the fuel consumption of the final concept with a maximum speed of 80km/h is compared to the same with a maximum speed of 78 km/h. With the lower speed the fuel consumption is reduced with another 1.57%, and the total time of driving from Överkalix to Piteå and back increases with four minutes.

# 14 Conclusions and Recommendations for Further Studies

*In this chapter conclusions regarding the results are presented and recommendations suggested for further studies in the subject.*

## 14.1 Conclusions

The results indicate substantial potential fuel savings for timber trucks. The two most important factors to consider, affecting the fuel consumption per ton-km on the studied timber truck, are the aerodynamics and the loading capacity. The use of longer and heavier vehicles is an efficient way in improving the efficiency of long hauling trucks, but several modifications to the vehicles can be done to improve it further.

The problem statement for this thesis includes four questions;

- What can be done to save even more fuel?
- How much is the fuel consumption reduced by various modifications?
- What can be done to improve safety?
- How can the identity of the vehicle be strengthened and the benefits of the concept communicated in a more effective way?

The solutions in the concept aim to answer these questions. Fuel can be saved by improved aerodynamics, increased effective load, a more optimised driveline and decreased rolling resistance. The impact on the fuel consumption from several modifications is presented for the development concept in chapter 13. The safety is improved by more warning and driver support systems as well as an improved visibility of the truck. The identity is strengthened by for example presenting a more homogeneous vehicle that accentuates transport efficiency, and a vehicle that more clearly communicates its safety benefits. The combination of these three areas creates a relatively complete concept that shows the possibilities in further development of timber trucks. If any of these were to be left out, the concept would not communicate its benefits to the desired extent. The calculations and simulations verifying the fuel reductions add credibility to the effect of the modifications and can be used in further development.

## 14.2 Recommendations

Since this thesis is conducted within a limited period of time and the efforts focused on those subjects affecting in foremost the fuel consumption, the safety and the identity of the vehicle, there are areas that are not covered within this report. There are a number of subjects that could be focus of further studies within the ETT-project or within other areas of research. There are also room for a lot more research within the subjects of this thesis, and the results presented could be verified with further studies and investigations.

### *14.2.1 Aerodynamics, stability and logistics*

The aerodynamic of vehicles is a difficult subject and the assumptions of the drag of a vehicle are always of high uncertainties. CFD-calculations or wind tunnel tests are needed to achieve fairly correct estimations. There are wind tunnel tests and CFD-calculations made regarding the aerodynamics of trucks with trailers with covered cargo, but conclusions regarding timber trucks from these results are vague and no calculations or tests have, in this thesis, been found about timber trucks. This is why the results presented in this thesis only can be seen as rough assumptions and further research should be made in this area, in order to establish the actual parameters of the aerodynamics. The fuel consumption of a 40 ton loaded semi-trailer with covered cargo can be lower than the fuel consumption of an empty 24 ton ETT-vehicle, as well as the unloaded Concept proposal. This could indicate that the aerodynamic drag on the empty ETT-vehicle is an area where a lot can be done to improve the fuel consumption. Since there are large improvements made on the unloaded concept regarding the aerodynamics, the resulting drag might be even lower than what is approximated in this thesis. Field tests where the timber bunks are detached and folded down should be performed to measure the fuel reduction. This is a relatively simple and inexpensive way of measuring the potential in collapsible timber bunks.

### *14.2.2 Logistics of the ETT-vehicle*

One area where further research can, and should be made, is regarding the logistics of the ETT-vehicle. The ETT-vehicle is a highway truck and there are now specific regulations of where this vehicle is allowed. However, if this project is to be continued and expanded, the possibilities of using longer and heavier vehicles further into the forest should be investigated. During the interviews the opinions differed regarding this; some said there would be no problems in using this kind of vehicle further into the forest, while others emphasised the difficulties, and that a lot of work have to be done to roads to make this a reality.

One obstacle the drivers expressed are the time limit they have before they need a break, and it is difficult to drive all the way and back again within this time. One aspect to this is the logistics, and the locations where the timber is collected and delivered could be investigated, and then maybe make the driving distance shorter to prevent exceeding the legal time limit. Another aspect to the logistics is the return trip. This is now conducted with an empty vehicle which results in a much lower efficiency than if cargo were to be transported both ways. This is a difficult issue, and to solve this, the vehicle needs to be modified to be able to transport other cargo than round wood, and a lot of effort must be put into making the logistics work.

Possible implementation to other applications than timber for ETT-vehicles should be investigated. Re-loading is then no issue, as it is for timber that comes from the forest, and the efficiency can be even further improved. Cargo can also be transported on the return trip and the fuel consumption per ton-km improved.

### 14.2.3 Stability

The stability and dynamics of the ETT-vehicle was thoroughly investigated during the development of the vehicle. However, in this thesis, no further calculations regarding this have been performed, which might have an impact on for example which wheel axles to lift, the extra axle on the truck and the effect of pulling the trailers together. In order to implement the final concept, the effects on the stability and dynamics need to be firmly established, why more work in this area needs to be performed.

The stability and dynamics is also an important issue when considering adding another pile of timber to the vehicle. In Australia long road trains, trucks with several trailers operate, and are regulated through e.g. maximum values on the rearward amplification[37]. Such calculations could be performed on different combinations of trailers carrying five piles of timber.

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[37] National Transport Commission Australia, http://www.ntc.gov.au/filemedia/Reports/PBSSchemeStandsVehAssRule24Nov08.pdf

# 15 References

Bergs Fegen (2009). *Välkommen till Bergs Fegen* (Online) Available at: <http://www.bergssmide.se> 2009-09-09

Bilprovningen (2009). *Bilprovningen in Brief* (Online) Available at: <http://www.bilprovningen.se> /English 2009-09-09

CiA (2010) CAN in Automation (Online) Available at: http://www.can-cia.org/index.php?id=489, 2010-02-22

Cooper, KR (2004). *Commercial Vehicle Aerodynamic Drag Reduction: Historical Perspective as a Guide.* McCallen, Browand, Ross (Eds.) The Aerodynamics of Heavy Vehicles: Trucks, Buses, and Trains. Springer, Berlin, Germany

EMS (2009) *European Modular System.* (Online) Available at: <http://www.modularsystem.eu/> 2009-11-02

Epsilon (2009). *Epsilon* (Online) Available at: < http://www.epsilon.nu/> 2009-09-09

ExTe (2009). *ExTe* (Online) Available at: <http://www.exte.se/eng/> 2009-09-09

Genta, G (2006). *Motor Vehicle Dynamics*. World Scientific Publishing CO, Toh Tuck Link, Singapore

Gerson Lehrman Group (2010). *Incentivising Euro VI: the Impact on the European Heavy Truck Market* (Online) Available at: <http://www.glgroup.com/News/Incentivising-Euro-VI--the-Impact-on-the-European-Heavy-Truck-Market-26015.html> 2010-01-20

Get Nitrogen Institute (2010). *Should you stop putting air in your tires* (Online) Available at: <http://www.getnitrogen.org/pdf/print_articles/Bridgestone_FirestoneCommercialTruckTires.pdf> 2010-02-22

Hiab (2009). *Om oss* (Online) Available at: <http://www.hiab.se/Om-oss/oversikt-av-bolaget/> 2009-09-09

Hjelm, L & Bergqvist, B (2009). *European Truck Aerodynamics - A comparison Between Conventional and CoE Truck Aerodynamics and a Look into the Future Trends and Possibilities.* McCallen, Browand, Ross (Eds.) The Aerodynamics of Heavy Vehicles II: Trucks, Buses and Trains. Springer, Berlin, Germany

Holmen (2009). *Holmen in brief* (Online) Last update: 1 Sept 2009. Available at: <http://www.holmen.com>/The Group/Holmen in brief. 2009-09-08

Hucho, W-H (1998). *Aerodynamics of Road Vehicles*. Society of Automotive Engineers, Inc. Warrendale, USA.

Ingelstam et al. (1971). *TEFYMA, Handbok för teknisk fysik, fysik och matematik,* Sjöbergs förlag, Sverige.

Krag Jacobsen, Jan (1993). Intervju, Konsten att lyssna och fråga. Hans Reitzels Forlag, Köpenhamn, Danmark.

Lantz, Annika (2007). Intervjumetodik. Studentlitteratur. Polen

Larsson L (2009) *ETT-Modulsystem för skogstransporter* (Online) Presentation Mittia Convention 2009-08-14, Ljusdal, Sweden. Available at: <http://www.skogforsk.se/upload/Dokument/Presentationer/Lena-Larsson-Volvo.pdf>. 2009-09-21

Leuschen, J & Cooper, K R (2007). *Summary of Full-Scale Wind Tunnel Tests of Aerodynamic Drag-Reducing Devices for Tractor-Trailers*. The Aerodynamics of Heavy Vehicles II: Trucks, Buses and Trains, August 26-31, Lake Tahoe, California, pp 451-462)

LMNO Engineering (2003) *Gas Viscosity Calculator* (Online) Available at: <http://www.lmnoeng.com/Flow/GasViscosity.htm>, 2009-09-15

Löfroth C, Skogforsk (2009). *ETT-Modulsystem för skogstransporter* (Online) Presentation Mittia Convention 2009-08-14, Ljusdal, Sweden. Available at: <http://www.skogforsk.se/upload/Dokument/Presentationer/Claes-Lofroth-Skogforsk.pdf>. 2009-09-25

Löfroth, C & Svensson G (2008). *Resultat från Skogforsk Nr 17 2008.* Skogforsk, Gävle.

Michelin 2010, The Michelin Group (Online) Available at: <http://www.michelin.com/corporate/front/templates/affich.jsp?codeRubrique=2&lang=EN> 2010-03-17

Miljömål (2009). *Utsläpp av växthusgaser (2020)* (Online) Available at: <http://www.miljomal.se/1-Begransad-klimatpaverkan/Delmal/Utslapp-av-vaxthusgaser-2020/> 2010-01-12

Näringsdepartementet (2009). *Trafikförordningen*. Stockholm: Sveriges Riksdag. (SFS 1998:1276)

ORNL (2010) *Bioenergy Conversion Factors* (Online) Available at: <http://bioenergy.ornl.gov/papers/misc/energy_conv.html>. 2010-03-01

Parator (2009). *Welcome to Parator* (Online) Available at: <http://www2.parator.com/pages.asp?id=11&meny=11> 2009-09-09

Reaxcer (2009). *Reaxcer* (Online) Available <http://www.reaxcer.se/> 2009-09-09

REV (2009). *REV, för vem?* (Online) Available at: <www.revriks.se/>/Om REV & Enskilda Vägar/REV, för vem?. 2009-09-09

Rådets Direktiv 95/53/EG 25 July 1996 (online) Available at: <http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CONSLEG:1996L0053:20020309:SV:PDF> 2009-12-03

Sandberg, Tony (2001). Heavy Truck Modelling for Fuel Consumption Simulations and Measurements. Thesis No. 924. Department of Electrical Engineering, Linköping University, Linköping

SCA (2009). *SCA in Brief* (Online) Available at: <http://www.sca.com/en/About_SCA/SCA_in_Brief>. 2009-09-07

SIKA – Statens Institut för kommunikationsanalys (2009). *Lastbilstrafik 2008 helår*. Östersund: SIKA: 2099:12 pp. 3-15.

Skogforsk (2009:1). *ETT (One more pile) project.* (Online) Available at: <http://www.skogforsk.se/>/English/About us/Collaboration/ETT. 2009-09-17

Skogforsk 2009:2 (2009:2). *Flexibla virkesfordon drar mindre bränsle.* (Online) Last updated: 2009-08-14. Available at: <http://www.skogforsk.se/sv/Pressrum/Pressmeddelanden-2009/Flexibla-virkesfordon-drar-mindre-bransle/>. 2009-09-21

Skogforsk (2009:3). *About Skogforsk* (Online) Available at: <http://www.skogforsk.se>/About Skogforsk>. 2009-09-07

Skogforsk (2009:4). *ETT – En Trave Till.* (Online) Available at: <http://www.skogforsk.se/upload/48254/ETT-broschyr.pdf>. 2009-09-17

Sveriges Åkeriföretag (2009). *Welcome to Sveriges Åkeriföretag* (Online) Available at: <http://www.akeri.se/english> 2009-09-08

Swedish Forest Industries Federation (2009:1). *The Swedish Forest Industries, Facts and Figures 2008.* (Online) Available at: <http://www.skogsindustrierna.org/>/In English/Documentation/Facts and figures/The Swedish Forest Industries - Facts and figures 2008 (pdf 3,6 MB)). 2009-12-03

Swedish Forest Industries Federation (2009:2). *About us* (Online) Available at: <http://www.skogsindustrierna.org>/About us. 2009-09-08

Skogsstyrelsen (2009). *Kort fakta om virkestransporter* (Online) Available at: <*http://www.skogsstyrelsen.se/episerver4/templates/SNormalPage.aspx?id=15204*>

SSAB (2009). *About SSAB* (Online) Available at: < http://www.ssab.com/en/About-SSAB1/About-SSAB/> 2009-09-09

Stora Enso (2009). *Stora Enso in brief* (Online) Last update: 11 June 2009. Available at: <http://www.storaenso.com/about-us/stora-enso-in-brief/Pages/stora-enso-in-brief.aspx>. 2009-09-08

STR – Sveriges trafikskolors Riksförbund (2009). *C Tung lastbil.* (Online) Available at: http://www.str.se/Korkort/Korkortsguide/Forarbehorigheter/Tung-lastbil/ 2009-12-03

Sveaskog (2009). *About Sveaskog* (Online) Available at: <http://www.sveaskog.se/en/About-Sveaskog/>. 2009-09-08

Södra (2009). *About Sodra* (Online) Available at: <http://www.sodra.com/en/About-Sodra/>. 2009-09-08

Tire Rack (2009). *Tire Rolling Resistance Part 1: Understanding Corporate Average Fuel Economy.* (Online) Available at: <http://www.tirerack.com/tires/tiretech/techpage.jsp?techid=29 2009-11-20> 2009-12-04

TLV (2009). *Om företaget* (Online) Available at: <http://www.tlv.nu/default.asp?page.id=003>. 2009-10-12

TPC International (2010). *Tire pressure control* (Online) Available at: <http://www.tirepressurecontrol.com>. 2010-02-22

Transportstyrelsen (2009). *Kör- och vilotider. Regler och vägledning september 2009 (Online) Available at:* <http://publikationswebbutik.vv.se/upload/1831/kor_o_vilotider_upplaga02.09.pdf> 2009-10-05

(Volvo Group (2009:1). *Volvo Technology.* (Online) Available at: <http://www.volvogroup.com>/About us/Our Companies/Volvo Technology. 2009-09-17

Volvo Group (2009:2) *Volvo 3P – an innovative force*. (Online) Available at: <http://www.volvo.com/group/global/en-gb/volvo+group/our+companies/volvo3p/volvo3p.htm > 2009-10-15

Volvo Group(2009:3). *A group of high-power companies* (Online) Available at: <http://www.volvo.com/trucks/global/en-gb/company/about_volvo_group/about_volvo_group.htm> 2009-10-15

Volvo Group (2009:4) *Volvo Group business structure.* (Online) Available at: <http://www.volvo.com/group/global/en-gb/volvo+group/our+companies/business_structure.htm> 2009-10-15

Volvo Trucks 2009:1 *I-shift*. (Online) Available at: http://apps.volvotrucks.com/I-Shift/en-gb/i-shift.html 2009-09-29

Volvo Trucks (2009:2). *Så här optimeras bränsleförbrukningen.*(Online) Available at: <http://www.volvo.com/trucks/sweden-market/sv-se/aboutus/Environment/fuel_consumption.htm> 2009-12-04

Volvo Trucks (2009:3). *Bromsarna* (Online) Available at: <http://www.volvo.com/trucks/sweden-market/sv-se/trucks/Volvo-FH16/productPage.htm?TAB=2-1> 2009-10-22

Volvo Trucks (2009:4). *Dynafleet – the online tool for improved profitability* (Online) Available at: <http://www.volvo.com/trucks/uk-market/en-gb/services/Transport+information+system+Dynafleet/dynafleet_online_main.htm> 2009-10-15

Volvo Trucks (2009:5) *Total Solution Provider*. (Online) Available at: <http://www.volvo.com/trucks/global/en-gb/company/company.htm > 2009-10-12

Volvo Truck Corporation (2009:1). *Fact Sheet – Engine brake type EBR-VEB+*. (Online) Available at: <http://productinfo.vtc.volvo.se/files/pdf/lo/EBR-VEB+_Eng_05_647962.pdf> 2009-10-05

Volvo Truck Corporation (2009:2). *Fact Sheet - Gearbox ATO3112C.* (Online) Available at: <http://productinfo.vtc.volvo.se/files/pdf/lo/ATO3112C_Eng_01_953845.pdf> 2009-10-05

Volvo Truck Parts Corporation (1991). *Basic vehicle technology Trucks*. Gothenburg, Sweden

VTI (2009). *About VTI* (Online) Available at: <http://www.vti.se/templates/Page____2783.aspx> 2009-09-09

VV (2008) *Vägverkets föreskrift 2008:418* (Online) Available at: <http://www20.vv.se/vvfs/lagrum_dokument_historik.asp?dokumentbeteckning=2008:418>

VV (2009). *Welcome to the Swedish Road Administration* (Online) Available at: <http://www.vv.se/Andra-sprak/English-engelska/> 2009-09-09

WABCO (2009:1) *Electronic Braking System EBS* (Online) Available at: <http://www.wabco-auto.com/products_wabco/brake-stablity-control/electronic-braking-system-ebs>

WABCO (2009:2) *Wabco Can Router* (Online) Available at: <http://www.wabco-auto.com/products-wabco/brake-stablity-control/electronic-braking-system-ebs/canrouter> 2010-01-15

Wabco (2009:3). *Wabco* (Online) Available at: <http://www.wabco-auto.com/> 2009-09-09

Wabco (2010). *Wabco* (Online) Available at: <http://www.wabco-auto.com/index.php?id=346> 2010-03-01

Wikipedia (2009:1), Full-Trailer (Online) Avaliable at: <http://en.wikipedia.org/wiki/Trailer_(vehicle)#Full-trailer>. 2009-09-19

Wikipedia (2009:2), Semi-Trailer (Online) Available at: <http://en.wikipedia.org/wiki/Semi-trailer>. 2009-09-15

Wikipedia (2009:3), Dolly (Online) Avaliable at: <http://en.wikipedia.org/wiki/Dolly_(trailer)>. 2009-09-15

Wikipedia (2010:1), Diesel Engine (Online) Avaliable at: <http://en.wikipedia.org/wiki/Diesel_engine>. 2010-03-01

Young et al. (2004). *A Brief Introduction to Fluid Mechanics.* John Whiley & Sons, Inc. Crawfordsville, USA.

Yrkestrafiken (2010). *Bruttovikter för fordon* (Online). Available at: http://www.yrkestrafiken.se/Transportsaljare/Godstransporter/Matt-och-vikt/Bruttovikter-som-inte-far-overskridas 2010-02-08

# 16 Appendix A – Abbreviations and Words

## 16.1 List of abbreviations

| | |
|---|---|
| GCW | Gross combination weight |
| $C_R$ | Rolling coefficient |
| $C_D$ | Aerodynamic drag coefficient |
| A | Frontal area of vehicle which affects the Aerodynamic drag |

## 16.2 List of words

| | |
|---|---|
| Tractor | A towing vehicle without cargo space and instead equipped with a fifth wheel to which different types of trailers can be connected. |
| Rigid | A towing vehicle with a fixed cargo space. Trailers can be connected to this type via a dolly. |
| Dolly | A small trailer which can be coupled to a rigid or a semi-trailer. Equipped with a fifth wheel on which a semi-trailer or a link is attached. |
| Link | Is used to link either a tractor or a dolly with a semi-trailer. Has a cargo space and one fifth wheel. |
| Semi-trailer | A trailer without a front wheel axle and is coupled to a tractor, dolly or a link. Has a full cargo space. |
| Full-trailer | A four wheel axle trailer. Can’t be combined in a modular system but is used as a single trailer. |
| Bogie | Double wheel axles. |
| Wheelbase | Distance between the centres of the front wheel and the front driving wheel. |
| Front wall | Protection to the cab in case the timber would slip forward |
| Timber bunks | The poles that holds the timber in place |

| | |
|---|---|
| Forward Control Cab | The cab is placed above the engine and the whole cab can be tilted forward to facilitate service. This type is used when the cargo space must be as great as possible. |
| Normal Control Cab | The engine is placed in front of the cab. This type is usually used for cargoes with a weight that is heavy in relation to its volume. |
| Gross combination weight | The total weight of the vehicle including cargo |
| Tare weight | The weight of the vehicle without cargo |

# 17 Appendix B – Fuel Consumption Calculations

## 17.1 Presented Calculations

In chapter 13.3, Table 13.2, the fuel consumption is presented for a conventional 60 ton timber truck, the present 90 ton ETT-vehicle and the 96 ton development concept. The measures used here is the average consumption [l/10km], the fuel consumption [l/ton-km] and load fuel efficiency [ton-km/l].

The fuel consumption [l/ton-km] is calculated by adding the average consumption [l/10km] for the loaded to average consumption [l/10km] for the unloaded trip and dividing this by two and the effective load.

$$Fuel\ consumption\ [l/tonkm] = \frac{FC_{load,avg} + FC_{unload,avg}}{2} / effective\ load$$

The load fuel efficiency is the inverse of the fuel consumption.

## 17.2 Alternative Calculations

An alternative way of calculating the fuel consumption [l/ton-km] is to add the total fuel consumption [l] for the loaded and unloaded trip, divide with the distance driven with load [km], i.e. half the total driven distance, and then divide this with the effective load [ton].

$$Fuel\ consumption, alt\ [l/tonkm] \frac{FC_{load,tot} + FC_{unload,tot}}{distance\ with\ load} / effective\ load$$

By doing so the efficiency of the transport is made clearer, since it shows the fuel efficiency for the actual work performed, since no transport work is performed on the return trip. The fuel used for this is instead transferred to the transport work performed on the loaded trip. The load fuel efficiency is here the inverse as in previous case.

In Table 17.1 the fuel consumption for a conventional 60 ton timber truck, the 90 ton ETT-vehicle and the 96 ton concept vehicle, calculated in the alterative way, is presented.

**Table 17.1.** Alternative fuel consumption and load fuel efficiency calculations

| | **Gross Combination Weight [ton]** | **60** | **90** | **96** |
|---|---|---|---|---|
| | **Effective load [ton]** | **42** | **66** | **70,8** |
| | **Driven distance, loaded [km]** | **160** | **160** | **160** |
| | **Driven distance, unloaded [km]** | **160** | **160** | **160** |
| **Fuel Consumption** | Loaded [l] | 87.5 | 115.5 | 114.9 |
| | Unloaded [l] | 50.2 | 58.2 | 52.6 |
| | Loaded [l/ton-km] | 0.0205 | 0.0165 | 0.0148 |
| | compared to 60 ton | 100% | 80% | 72% |
| | compared to 90 ton | 125% | 100% | 90% |
| | compared to 96 ton | 139% | 111% | 100% |
| **Load Fuel Efficiency** | Loaded [ton-km/l] | 48.8 | 60.8 | 67.6 |
| | compared to 60 ton | 100% | 125% | 139% |
| | compared to 90 ton | 80% | 100% | 111% |
| | compared to 96 ton | 72% | 90% | 100% |

# 18 Appendix C – Interviewees

## 18.1 Primary customers:

| | | |
|---|---|---|
| Kent Bjälmsjö | Bjälmsjö skog & transport | Haulage Contractor/Driver |
| Lena Bjälmsjö | Bjälmsjö skog & transport | Economic Director |
| Johanna Funck | Bjälmsjö skog & transport | Driver |
| Torbjörn Pettersson | Bjälmsjö skog & transport | Driver |

## 18.2 Secondary customers:

| | | |
|---|---|---|
| Jan Åhlund | Holmen Skog | Technical Director Forest |
| Thomas Hedlund | SCA | Director of Transport |
| Claes Löfroth | Skogforsk | Technical Development, Initiator of ETT |
| Staffan Thonfors | Skogsindustrierna | Director of Transport |
| Anders Örtendahl | StoraEnso | Planning Manager |
| Anders Järlesjö | Svea Skog | Logistics Manager |

## 18.3 Tertriary customers/experts:

| | | |
|---|---|---|
| Magnus Jönsson | Bergsfegen | Design Engineer |
| Alfred Johansson | Epsilon | Design Engineer |
| Mikael Halvarsson | Exte | Development Manager |
| Per Olsson | PARATOR | CEO, Owner |
| Reidar Thunell | Reaxcer | Technical Manger Transport |
| Börje Sundell | SSAB | Technical Advisor |
| Johan Ericsson | VTI | Researcher |
| Anders Lindén | Volvo | Field Test Supervisor |
| Anna Wrige | Volvo | Accident Research Team |
| Lena Larsson | Volvo | Tech. Project Leader Vehicle Development |
| Lennart Cider | Volvo | Project Leader Vehicle Development |
| Niclas Karlsson | Volvo | Brakes – Communication Engineer |

# 17. Appendix C – Interviewees

| | | |
|---|---|---|
| Johan Lang | Vägverket | Coordinator |
| Thomas Asp | Vägverket | Road Technique West |
| Anders Berndtsson | Vägverket | Development Strategist |
| Anders Knutsson | WABCO Automotive | Service Engineer |
| Joakim Jönsson | WABCO Automotive | Service Engineer |
| Karin Svensson Smith | Miljöpartiet | Politician Swedish Parliament |
| Lars Hansson | Miljöinstitutet i Lund | Researcher |

# 19 Appendix D – About the ETT-Project Members

## 19.1 Forest Industry

### *19.1.1 Skogforsk – The Forest Research Institute of Sweden*

The Forest Research Institute is the central research body for the Swedish forestry sector. It is financed by the government and the members, and pursues research within a wide variety of fields. These include forest technology, raw-material utilization, environmental impact and conservation, forest tree breeding, organisational structures, etc. (Skogforsk 2009:4).

Skogforsk leads the “One More Pile”-project, and will study cost, productivity, fuel consumption, vibrations and environmental impact ($CO_2$, $NO_X$) of the longer and heavier logging shipments (Löfroth & Svensson 2008, pp 2).

### *19.1.2 SCA*

SCA offers personal care products, tissue, packaging, publication papers and solid-wood products in more than 90 countries, with Europe as its main market. Sweden is the fifth largest market. They work with continuous efficiency enhancements and a desire to contribute to a sustainable development. Equal quantities of recycled and fresh wood fibres are used in production (SCA 2009).

### *19.1.3 Stora Enso*

Stora Enso is a global paper, packaging and forest products company. They produce newsprint, book, magazine and fine paper, consumer board, industrial packaging and wood products. Sustainability – meaning economic, social and environmental responsibility – underpins the thinking and approach of the Stora Enso way of doing business (Stora Enso 2009).

### *19.1.4 Södra*

Södra is an economic association for forest owners in southern Sweden, that work in areas ranging from forestry management and environmental conservation to accounting, sales and product development. The Group has four business areas that produce sawn and planed timber goods, interior products, paper pulp and biofuel, and has also become a large producer of electricity (Södra 2009).

### *19.1.5 Holmen*

Holmen is a forest products group, manufacturing printing paper, paperboard and sawn timber. The Group also owns forests and power stations. Europe is by far the largest of Holmen's markets, accounting for around 90 per cent of its turnover and Holmen is the fifth largest producer of printing paper in Europe. The largest individual markets are Great Britain, Germany, Spain and Sweden (Holmen 2009).

### *19.1.6 Svea Skog*

Sveaskog is the largest forest owner in Sweden and leading supplier of timber, pulpwood and biofuel. The company works with land sales, caters for hunting and fishing and provides land for local entrepreneurs within eco-tourism. Sveaskog works towards achieving sustainable development, as well as economic growth, a healthy environment and social development (Sveaskog 2009).

### *19.1.7 Skogsindustrierna – The Swedish Forest Industries Federation*

The Swedish Forest Industries Federation is the trade and employers' organisation of the pulp, paper and wood mechanical industries. It represents pulp and paper mills, sawmills, and companies close to the production of pulp, paper and sawn timber. The Federations role is to foster competitiveness among the members, promote greater use of wood-based products, and is also involved in Swedish and European industrial policy (Swedish Forest Industries Federation 2009:2).

## 19.2 Haulage Contractor Companies

### 19.2.1.1 *Sveriges Åkeriföretag - The Swedish Association of Road Haulage* Companies

The Swedish Association of Road Haulage Companies is the trade association of the haulage industry, and it represents around 9,300 members operating a total of around 37,000 vehicles. They support their members with business development, public opinion and lobbying (Sveriges Åkeriföretag 2009).

### *19.2.2 Bjälmsjö Skog och Transport AB*

Bjälmsjö Skog och Transport is the haulage company that drives the ETT-vehicle. They are situated in Överkalix and have 15 employees, whereof 13 are full-time employed. The fleet includes the ETT-vehicle, two conventional timber vehicles, one vehicle combination which can transport both round wood timber and other tree parts, loaders and a group of forest machines. Kent Bjälmsjö is the owner of both the main company and one underlying company. The main commissioning body is SCA Skog AB[38].

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[38] Bjälmsjö, Lena, Economic Director, Bjälmsjö Skog och Transport A, e-mail, 2010-02-09

### *19.2.3 TLV*

TimmerLogistikVäst AB (TLV) was founded in early 2003, to supply Dalsland, Bohuslän and Västra Götalands districts in the forest industry. In total there are 11 haulage contractors and 16 vehicles on the roads within TLV. Offices are in Uddevalla and in Åmål. TLV drives the ST-vehicles for Stora Enso during the projects testing period (TLV 2009).

## 19.3 Vehicle Builders

### *19.3.1 The Volvo Group*

The Volvo Group is one of the world's leading manufacturers of heavy commercial vehicles. The Volvo Group offers complete transport systems for urban traffic, e.g. heavy trucks and buses. They offer construction equipment and drive systems for marine and industrial applications, aerospace components and financial services, insurance, leasing and service.

In 1927 the first series-manufactured Volvo car rolled off the production line in Gothenburg. It has grown from being a small local industry to one of the largest of its kind in the world. The Volvo Group has today approximately 72 000 employees, production in 25 countries and sales in more than 185 countries (Volvo Group 2009:2).

### *19.3.2 Volvo Group business structure*

The Volvo Group is organised in business areas and business units. The business areas are companies that are product-related and work with a brand towards the final customer. The business units support the business areas in different key areas such as; product development, research, purchasing, product planning and other business services. This organisation allows close contact with the customer and an efficient utilisation of the resources in the Group. (Volvo Group 2009:4).

### *19.3.3 Volvo Trucks*

Volvo Trucks is a business area and a brand within the Volvo Group. It is the second-largest heavy-duty truck brand in the world after Mercedes. The trucks are sold and serviced in more than 140 countries all over the world. Volvo Trucks strives to be a Total Solution Provider, offering not only the truck itself, but also aftermarket, service and extended offers based on the customer needs. The focus and the core values in the organisation are Quality, Safety and Care for the Environment (Volvo Trucks 2009:5).

### *19.3.4 Volvo 3P*

Volvo 3P is a business unit and the product development company for the four truck companies within the Volvo Group; Volvo Trucks, Renault Trucks, Mack Trucks and Nissan Diesel. The areas 3P is responsible for are: Product planning, purchasing, Global Vehicle Development, global engineering and Product Range Management (Volvo Group 2009:4).

Volvo 3P leads the development of the vehicles in the ETT-project, with research support from Volvo Technology.

### 19.3.5 Volvo Technology

Volvo Technology (VTEC) is a research, innovation and development company supporting all Volvo Group companies with research and development of soft as well as hard products. Volvo Technology participates in research programmes involving universities, research institutes and other companies. Areas of expertise are for example logistics, ergonomics, combustion and mechanics. They also offer services within intellectual property to the rest of the Volvo Group (Volvo Group 2009:1).

### 19.3.6 Bergs Fegen

Bergs Fegen is Sweden’s largest manufacturer specialising solely in timber superstructures, and has provided the superstructure on the ETT-vehicle (Bergs Fegen 2009).

### 19.3.7 ExTe

ExTe is the world’s leading manufacturer and supplier of timber bunks and automatic tensioners for the safe and profitable transportation of timber by road and rail (ExTe 2009).

### 19.3.8 Hiab

Hiab is a part of Cargotec, and the global leader in on-road load handling. They produce e.g. truck cranes, hook lifts, tail gate lifts and wood cranes (Hiab 2009). Hiab has built the crane for the ST-crane truck.

### 19.3.9 Parator

Parator manufactures heavy vehicle trailers like timber trailers, box trailers, machine transporting, tip trailers, flatbed trailers, B-double, and switch bodies. They design each object according to customer needs and have close cooperation with the leading European subcontractors supplying components for trailer vehicles (Parator 2009).

Parator has built the trailers for the ETT-vehicle.

### 19.3.10 SSAB

SSAB is a Swedish steel manufacturer and global leader in value added, high strength steel (SSAB 2009). They have provided the latest steel qualities for the ETT-vehicle to keep the weight down and still maintain the strength.

### *19.3.11 Wabco*

WABCO Vehicle Control Systems is a supplier of safety and control systems for commercial vehicles. They work with electronic, mechanical and mechatronic technologies for braking, stability, and transmission automation systems to commercial truck, trailer, and bus manufacturers (Wabco 2009:3).

### *19.3.12 Michelin*

Michelin manufactures and sells tires for all kinds of vehicles, publishes maps and guides and operates a number of digital services in more than 170 countries (Michelin 2010). The tires used in the ETT-project have been chosen by Volvo in cooperation with Michelin.

### *19.3.13 Epsilon*

Epsilon is a consultancy in technology and systems development (Epsilon 2009). They have contributed to the ETT-project with technical expertise.

## 19.4 Logistics

### *19.4.1 Reaxcer*

Reaxcer offers logistical solutions within the forest industry and transport and machinery solutions within construction industry (Reaxcer 2009).

## 19.5 Authorities

### *19.5.1 Vägverket – The Swedish Road Administration*

The Swedish Road Administration is the national authority assigned the overall responsibility for the entire road transport system that works to develop a safe and efficient road transport system with directions from the Swedish Government and Parliament (VV 2009).

The Swedish Road Administration will within the ETT-project study the traffic safety, road wear and how the public responds to longer and heavier vehicles.

### *19.5.2 Riksförbundet Enskilda Vägar – National Association for Private Roads*

The National Association for Private Roads represents and assists the private road maintenance and owners (REV 2009).

The association will together with the Swedish Road Administration and Skogforsk study the consequences of heavier vehicles on private roads.

### 19.5.3 VTI

VTI, Swedish National Road and Transport Research Institute, is an independent research institute within the transport sector. VTI carries out applied research and development in relation to all modes of transportation (VTI 2009).

### 19.5.4 Bilprovningen - Swedish Motor Vehicle Inspection Company

The Swedish Motor Vehicle Inspection Company is solely responsible for inspecting all vehicles registered in Sweden. They work for an increased road safety, a decreased environmental influence of traffic and an improved vehicle economy for private motorists and companies (Bilprovningen 2009).