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A Reference Architecture for Fuel-based Carbon Management Information Systems in the Logistics Industry

Master thesis

Michel Steenwijk

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Author:

Name:	Michel Steenwijk
Programme:	Business Information Technology
Institute:	University of Twente
E-mail:	m.steenwijk@alumnus.utwente.nl

Graduation committee:

University of Twente:	
First supervisor:	dr. Maria-Eugenia Iacob
Second supervisor:	dr. ir. Marten van Sinderen
CAPE Groep:	
External supervisor:	Marcel de Haas

On behalf of:

CAPE Groep B.V.
Kosteeweg 13
7447 AJ Hellendoorn
Phone: +31 (0)548 65 60 65
Web: www.capegroep.nl

Abstract

The carbon footprint is a measure of the amount of greenhouse gas emissions caused by an activity or over the life stages of a product. Logistical service providers have various reasons to attempt to gain insight in the carbon footprint of their transport services. Clients may ask for a report on the emissions caused by a transport order and forthcoming legislation may demand carbon management from the transport industry. Furthermore insight in emissions provides insight in reduction opportunities. In the transport industry, the dominant driver of carbon emissions is fuel combustion. Reducing carbon emissions thus means reducing fuel consumption. This yields financial savings, which is another incentive to adopt carbon management.

Carbon footprinting is a relatively new phenomenon. Numerous protocols from various organizations have emerged over the past years, and calculation methods are still under development. The current practice is to calculate transport emissions distance-based, i.e. based on distance travelled, using long-term averages to estimate fuel consumption per kilometre. Fuel consumption may actually vary over time, because of differences in road characteristics, traffic situations, driving behaviour, etc. Therefore distance-based emission calculations are not accurate. Without accurate insight in carbon emissions, it is difficult for LSPs to start with carbon reduction initiatives.

Our approach is to calculate transport emissions fuel-based by obtaining the actual fuel consumption during trips via board computers installed in vehicles. Transport services may stretch over multiple, sometimes multimodal, legs. While crossing warehouses, multiple shipments are often consolidated in one freight unit. Altogether calculating transport carbon emissions is a complex task. To automatically gather relevant data and consequently calculate emissions, an information system is necessary. Several Carbon Management Systems have recently emerged on the market. However, the current state of the art of these applications goes little further than corporate carbon footprints for the average company.

This thesis presents a reference architecture for fuel-based Carbon Management Information Systems in the logistics industry. The reference architecture integrates the business process and information technology environment of typical logistics service providers. More specifically, integrating Transport Management System and board computers with a Carbon Management System allows for real-time monitoring of fuel consumption during trips. Consequently it enables calculating detailed and accurate product carbon footprints of transport services. Analysis of data on emissions and emission drivers collected over time, may serve as starting point for carbon reduction initiatives. When a transport company achieves reduction of its emissions, this makes a small contribution to reducing global warming.

We verify the reference architecture with a prototype that is capable of calculating emissions based on actual fuel consumption by linking incoming board computer XML messages with trip plannings received from a TMS earlier. The calculation method includes an algorithm to allocate emissions to shipments consolidated in one freight unit. A test case validates the correct behaviour of the prototype, proving that our aim of real-time fuel-based carbon footprinting of transport services is feasible.

Acknowledgements

This master thesis is the result of my graduation research carried out at CAPE Groep. It has been a long ride, both the final project and my total study time. I guess the personal carbon footprint of my study time exceeds that of most fellow students. Almost a year after starting this research, I have now reached the final destination. While finishing this thesis, I complete the Master Business Information Technology at the University of Twente. I would not have been able to achieve this without the help of several people.

First I have to thank Maria Iacob, my first supervisor from the University of Twente. Maria initially established the contact with CAPE Groep, so without her I would not have conducted this research at all. I would also like to thank my second supervisor, Marten van Sinderen. During the project their mixture of critical approach and enthusiasm, on the research subject and my research approach, yielded valuable reflection and insights. Furthermore their feedback on my thesis helped me to better structure it, and keeping in touch when I was struggling at two occasions supported me to keep pushing.

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Finally, many thanks go to my parents for their support during my study; for their nearly endless patience but at the same time encouragement to continue; for letting me live my own life.

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1 Introduction

This chapter provides an outline of the thesis and describes the research conducted. First we explain the motivation for the research, followed by the research objective. Section 1.3 presents the research questions, after which we discuss the research approach. Finally, the structure of the report is listed in section 1.5.

1.1 Motivation

Global warming is a hot topic in society. It concerns the recent increase of the global average surface and near-surface air temperature. The Intergovernmental Panel on Climate Change observed that the increase amounts 0.74 (+/- 0.18) degrees Celsius over the last 100 years (IPCC, 2007a). Between 1956 and 2005 the warming trend was 0.13 (+/- 0.03) °C per decade. The IPCC has also researched the causes of the temperature increase. It concludes that most of the warming in the last five decades is very likely due to an increased concentration of greenhouse gases emitted by human activity. Greenhouse gases (GHGs) are gases causing the greenhouse effect by trapping heat ascending from the Earth's surface in the atmosphere, while it would normally escape into space (Schneider, 1989). The effects on the global climate system, according to the IPCC amongst others more extreme weather and sea level rise, worry both society and politicians.

The European Union is committed to reducing greenhouse gas emission with 20% by 2020, compared to 1990 (European Commission, 2008a). Economic sectors will be allocated emission quota one by one. The quota are currently being regulated by an Emission Trading System (ETS), which became law in 2003 (European Parliament and Council, 2003) and is basically a cap and trade system. Financial consequences and bonuses are attached to carbon dioxide (CO_2) emission, since CO_2 is the most important anthropogenic GHG (IPCC, 2007a). An overall cap is assigned to an industry after which companies within the industry are allocated emission rights. Companies may trade these allowances on the market, according to their demands or surpluses. From the start the ETS covers large installations in the energy and industrial sector responsible for almost half of the CO_2 emission in the EU (European Commision, 2008b).

As a result, companies obliged to the ETS will need to gain insight in their carbon emission. However, the desire to reduce CO_2 emission is not only enforced by law. Companies following the principles of social entrepreneurship or striving for a green image may already be aiming for less CO_2 (or GHG in general) emission. Consequently they may ask their suppliers about the carbon emission of the supplied goods or services or even desire the supply to cause as least emission as possible. The total amount of GHG or CO_2 emission caused by a product or activity is often called a carbon footprint (Wiedmann & Minx, 2008). The term carbon may refer to either only CO_2 or all GHGs. Consequently we use this term when specification is reckoned unnecessary.

After the energy industries, the second largest contributor to carbon emission is transport. In the EU its combined GHG emission share is 19% and, opposed to all other sectors, transport showed an increase of emission between 1990 en 2006 (Huggins, 2009). Globally, transport has a 23% share when counting CO_2 emission only (IEA, 2009). This can be explained by CO_2 being released as result of the chemical reaction occurring during fossil fuel combustion. Focusing on transport it turns out that road transport is the biggest contributor to carbon emission. Based on earlier reports from the IEA, Chapman accounts road transport for 65% of CO_2 emission caused by transport (Chapman, 2007). Still looking at transport only, he concludes that road transport is the biggest contributor to climate change, followed by aviation. Zooming in further, Chapman also concludes that road freight is responsible for almost half of the road transport total. Because of its large share the transport and logistics sector is likely to face legislation on CO_2 emission soon as well. Aviation will be included in the ETS as of 2012 (EPC, 2009). Road transport may follow after 2013, when the EU intends to put more sectors under legislation.

The urgency for logistics service providers (LSPs) to adopt a carbon footprint calculation system is twofold. Legislation will demand it within a short term and with their variety of clients it may be asked from that side even sooner. When insight in emission has been reached, this will show opportunities for reduction as well. Since CO_2 emission of transportation is almost completely caused by fuel burning (U.S. EPA, 2010), reduction will come together with financial savings. This will be another incentive to reduce CO_2 emission.

CAPE Groep (2011) is a consultancy and system integration company with many clients in the transport and logistics industry. It intends to develop an information system (IS) that provides clients insight in their carbon footprint. With the so called Carbon Reduction Suite clients will learn the carbon emission caused by the transport of a shipment, but also what the carbon footprint of the corporate as a whole is. Based on historical data, the system should be able to forecast the emission of a transport as well. The final aim of the system is to show carbon reduction opportunities.

1.2 Objective

Summarizing the motivation, for various reasons companies want to know what their carbon footprint is and subsequently reduce their carbon emission. However, the carbon footprint concept has only recently emerged with several organizations proposing calculation methods. Many standards and protocols with different origins, both on product and on corporate level, are available (Finkbeiner, 2009) and thus used (Andrews, 2009). So a prerequisite for composing a reliable footprint is to determine the most appropriate protocol.

As input for the calculation companies need to collect data from activities containing emission sources. For the logistics sector in particular, the challenge is to acquire accurate information on fuel usage per transport and per good shipped. Here we face some practical problems. Fuel bills may seem a simple source for fuel usage. However, carbon emission may vary during transports, e.g. between highway and urban areas and due to congestions. Furthermore, one vehicle may carry loads for a number of clients with several dropping and loading points; how to allocate the right amount of emission to each shipment or client? These problems have not been completely solved yet. The current practice is to calculate transport emissions based on distance travelled, using historical average fuel consumption figures to estimate the emissions per km.

We aim to improve this practice by researching fuel-based calculation, resulting in more accurate footprints. To define actual fuel consumption amounts, data from board computers or even motor management systems may be more suitable than fuel bills. But transport is more than moving vehicles. What about emissions caused by trailers' refrigeration units or by transport related activities in warehouses or offices? How to count and allocate those emissions? To harvest these data and automatically perform the required calculations a logical solution is to implement an information system tailored to the company's characteristics. Finally, just presenting a footprint has little value when a company has no idea what action to take next. Therefore it is desirable such an IS also gives insight in opportunities to reduce carbon emission.

Since the challenge is relatively new for transport companies, only little progress on footprint calculation has been made within the sector. LSPs are generally aware of the issue and notice the growing demand for emission information. However, they have hardly started quantifying their footprints, as became clear during client contacts and market research by CAPE Groep. It also appears that no carbon management information systems specifically aimed at the transport sector are available on the market. Watson et al. claim that the IS academic community in general has been slow to acknowledge the environmental sustainability problem and call for more research that demonstrates how IS can help to build an ecologically sustainable society (Watson, Boudreau, & Chen, 2010). Particularly for LSPs no general information technology solution to calculate the carbon emission of a transport service seems to be known in the literature.

Such a general solution could be provided in the form of a reference architecture, which gives, for a certain domain, a generic structure of system elements and their functions and interfaces. It may serve as a starting point for creating a software architecture of a specific IS, which then is an instance of the reference architecture (W3C, 2004). One can draw a reference architecture by exploring common functions and configurations of IS in the domain. Here we face several knowledge problems. In the transport carbon footprint domain understanding is required about:

- typical transport activities and their related carbon emissions
- what the various carbon footprint protocols prescribe and have in common
- functionalities existing carbon management software packages have in common
- IS typically present at transport companies and able to provide data on emissions

The challenge of developing a reference architecture is to conduct research on the topics listed above and based on the findings derive key functional requirements and a common architecture for carbon management IS.

Altogether, while footprint calculation is complex, there are many protocols but no custom IS solutions at hand. Therefore it is clear that the desire to learn and reduce the amount of carbon emission is difficult to fulfil for logistics service providers. The problems causing this can be modelled in a problem bundle. This is a causal graph of experienced problematic phenomena (nodes) and believed causal relationships (arrows):

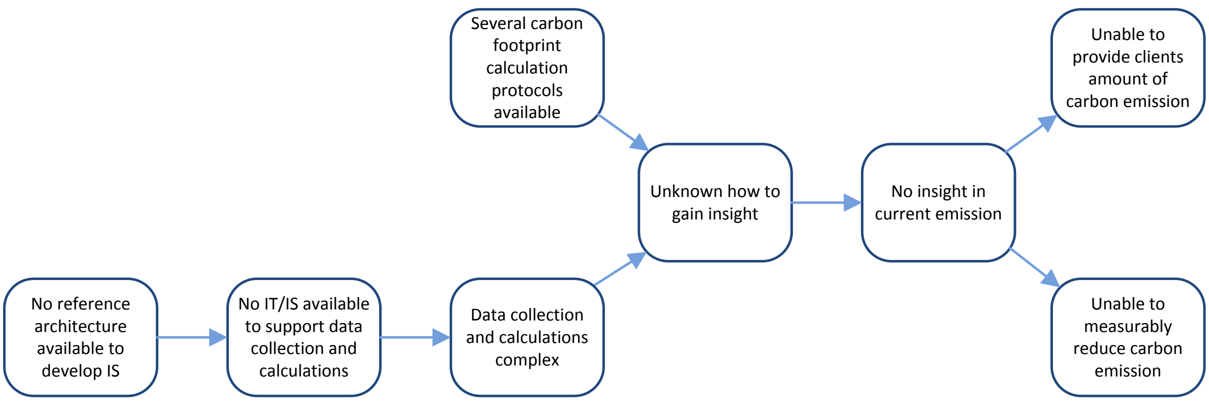

Figure 1: Problem bundle of carbon footprint phenomena.

The problems at the right end of the bundle have noticeable impacts on a business. In order to solve these problems, this research focuses on the root causes. The main research objective is:

To develop a reference architecture for fuel-based carbon management information systems, which ultimately supports logistics service providers in calculating and reducing their carbon emissions.

To verify the reference architecture and to respond to demand from practice we aim to develop an instance of the reference architecture as well. By implementing a prototype (CAPE Groep's Carbon Reduction Suite) the instance (software) architecture can be validated.

The social relevance of this research consists of addressing part of the global warming problem. The information system to be designed calculates carbon emission caused by a transport and shows opportunities to reduce emission. When a company takes such an opportunity less CO_2 is emitted. This makes a small contribution to reducing global warming.

The scientific relevance of this research lies in the development of an IS reference architecture for calculating carbon footprints in the field of transport and logistics, which has not emerged yet in literature. Furthermore, the fuel-based approach to emission calculation, as directed in the architecture, improves the accuracy of transport carbon footprints, since the current state of the art is distance-based calculation using long-term averages of fuel consumption.

1.3 Research questions

In order to reach the objective presented in the previous section this research is conducted according to the following main research question:

What reference architecture can best provide a basis for the design of an information system that allows logistics service providers to gain insight in their carbon emission and how to reduce it, by integration of relevant systems and fuel-based calculation of the emissions during transport services?

The main research question contains three fields of research, namely on the concept of carbon footprints, on architecture and on design. After dividing the research in these three sections the following research questions can be formulated, each consisting of a small constellation of sub questions. This thesis provides answers to these questions in order to meet the objective.

Carbon footprint

RQ1. What forms a carbon footprint on both product and corporate level for logistics service providers?

a) What are the best standards for calculating a carbon footprint on product and corporate level?
b) What activities do LSPs perform and which corresponding data is necessary as input for an information system calculating carbon footprints for LSPs?
c) How to calculate a carbon footprint from this data?

Architecture

RQ2. What reference architecture can best provide a basis for the design of a carbon management information system for logistics service providers?

a) What are the architectural standards of and functionalities provided by comparable information systems?
b) What does the IS landscape at LSPs typically look like?
c) What reference architecture can be developed for a carbon management IS for LSPs?

Design

RQ3. How to design an information system that allows logistics service providers to gain insight in their carbon emission and how to reduce it?

a) How to apply the reference architecture to develop a functional design for a carbon management information system?
b) How to obtain data from peripheral systems like board computers and motor management systems?
c) Does the realised implementation provide its users insight in their carbon emission and opportunities to reduce it?

1.4 Research approach

In short our research approach is to first study the carbon footprint and transport field from both a business and an information technology perspective. The results of this study form the input to develop the reference architecture. Then we specify requirements for the design of an IS as instance of the reference architecture. Finally we develop a prototype and perform a small test case after which we draw our conclusions. The research approach is modelled in Figure 2. The numbers in the boxes refer to the chapter that handles the topic:

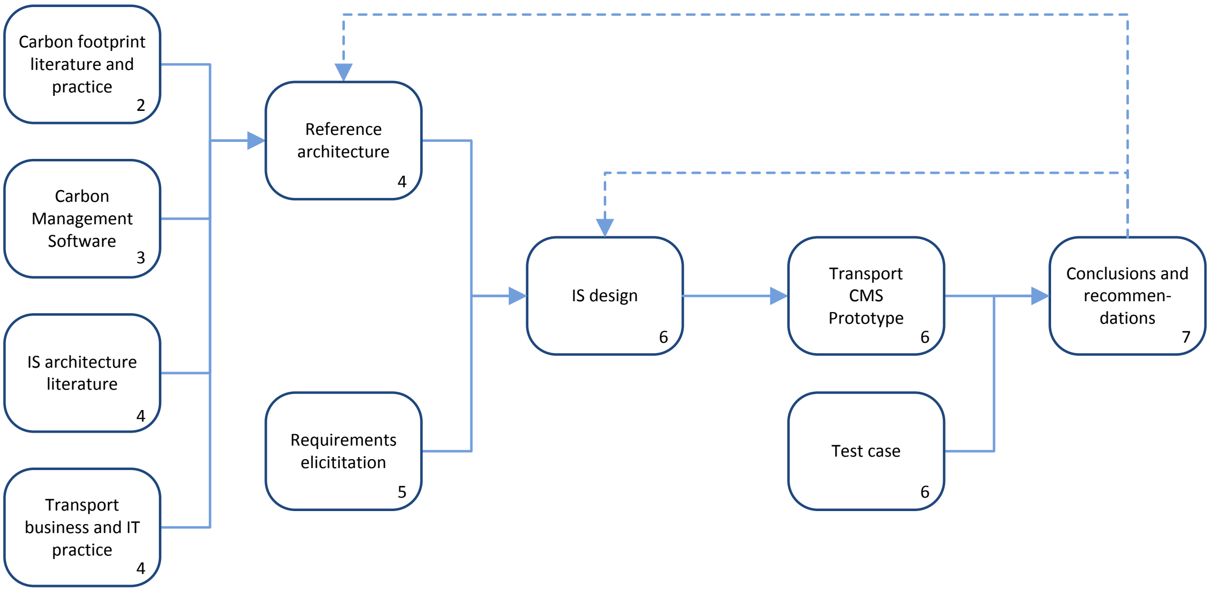

Figure 2: Research approach.

The research starts with gaining background information on the current state of carbon footprint calculation from both the business and information technology perspective. The carbon footprint literature and practice exploration includes its concept and contents and the numerous protocols available to compose footprints. Next we study the field of green information systems including a survey of existing carbon management software solutions. At this stage research questions 1a and 2a are answered.

Together with a literature exploration about IS architecture and requirements derived from an in-depth review of the business and information technology characteristics of the transport industry (answering research questions 1b and 2b) this forms the input for the development of a reference architecture for a transport carbon management IS. The reference architecture provides a theoretical answer to research question 1c, and answers 2c.

Then the design part of this research commences, for which the reference architecture is a starting point. CAPE Groep provides the facilities for the system design. Its intended carbon management IS is an instance of the reference architecture. Using input from customers interested in carbon management software and CAPE Groep's knowledge of the logistics industry, requirements for the IS design can be collected. These requirements form the final input to arrive at the design of our carbon management IS. At this stage research questions 3a and 3b are answered.

The final part of this research is the validation. According to the design a prototype is implemented, The prototype offers the functionality to calculate product carbon footprints of transport services fuel-based using data retrieved from Transport Management Systems and board computers. Thus at this stage research question 1c is answered practically as well. A test case is carried out with simulated, though realistic, order, transport and board computer data. With the results of this test we validate the design, answering research question 3c.

Normally, such results would lead to a following iteration of system design, or even adjustment of the reference architecture. However, such an iterative approach lies beyond the scope of this research. We finish our research with conclusions and recommendations, which may be used to improve the reference architecture or Carbon Reduction Suite in the future.

1.5 Structure report

To summarize the research approach and give a clear overview of the structure of this thesis, the list below shows the chapters that follow:

- Chapter 2: A Carbon Footprint
- Chapter 3: Green Information Systems
- Chapter 4: Transport Carbon Management IS Reference Architecture
- Chapter 5: Requirements for a fuel-based transport CMS
- Chapter 6: Transport CMS Prototype
- Chapter 7: Conclusions and recommendations

2 A Carbon Footprint

In this chapter we dig into the concept of a carbon footprint. Before being able to compose a footprint, it is important to have a clear definition of what it is and to select a proper method for performing the footprint calculations. The next section discusses the origin of the term and the ongoing track towards a clear definition. Then we cover some aspects of a carbon footprint, starting in section 2.2 with a description and comparison of carbon footprints for corporations and products. Section 2.3 analyses the relevancy of various greenhouse gases and considers the scope of emissions to include in a carbon footprint. Section 2.4 explains the concept of emission factors and argues what the best functional unit for footprint calculation of transports is. The second part of this chapter (section 2.5) provides an overview of initiatives to develop standards, protocols or emission factor databases for footprint calculation. Finally, the last section presents the chosen standards for our IS.

2.1 Towards a definition

Ever since global warming became an issue the term “carbon footprint” gained popularity as some kind of measure of one’s contribution to climate change. Basically, it is a derivation of the term “ecological footprint”, which represents the area of biologically productive land and sea required to regenerate the resources consumed by a human population and assimilate the corresponding waste, using prevailing technology (Wackernagel & Rees, 1996).

But while the ecological footprint is clearly defined by the proposers of the concept, the origin of the term carbon footprint is unclear and its concept is ambiguous. In a column published in the New York Times (Safire, 2008), Wackernagel explains that the term was strongly boosted through a BP media campaign on the carbon footprint in 2005. The fact that the phrase has emerged through business rather than science and has been spread more by media than by scientists may be a reason for the lack of a clear definition.

Variation in definitions may lead to unreliable carbon footprints. Johnson (2008) compares the footprints of electric and LPG forklifts under various definitions. He finds conflicting results. In some cases the electric forklift has a smaller footprint, while in other ones the LPG forklift prevails. Reviewing the cases, Johnson concludes that the source of conflict is not the data used, but the definitional differences.

Finkbeiner (2009) mentions several issues to consider when defining a carbon footprint, for example the scope of emissions, life cycle stages and other system boundaries, data sources and capital goods. Wiedmann and Minx (2008) recognized the absence of common academic understanding as well and tried to find an answer for some similar questions. They conducted a survey on both scientific journals and grey literature. Based on the most commonly accepted principles and approaches, they propose the following definition:

"The carbon footprint is a measure of the exclusive total amount of carbon dioxide emissions that is directly and indirectly caused by an activity or is accumulated over the life stages of a product."

In order to decide whether this is a sound definition suitable for this research, it is evaluated on both what it measures and in what unit. Concerning the “what” it is necessary to understand the various levels of carbon footprinting, e.g. for a single parcel transport or for a whole company. Concerning the unit it is necessary to dig into the relevancy of various greenhouse gases.

2.2 Corporate versus product level footprint

Wiedmann and Minx (2008) propose to measure emissions directly and indirectly caused by an activity or accumulated over the life stages of a product. They state that the activity may be of individuals, companies, processes etc. Furthermore the product can be a good or service. The distinction between activities in general and product specific emissions is important, since two types of carbon footprints have emerged.

The first approach provides an overview of all emissions an organization is responsible for. It is the sum of all emissions directly caused by the organization's activities and all emissions indirectly caused, for example electricity used for office lighting, employees' travelling and waste disposal. This high level footprint is usually called a corporate carbon footprint (CCF) or business carbon footprint. Companies calculate their footprint to show how seriously they take their aim for sustainable business development. They usually present their CCF in an annual report written for shareholders, partners or any other individual interested.

Personal or household footprints, often calculated by simple tools provided by environmental organizations, also belong to this category. Padgett et al. (2008) discuss and examine such carbon calculators. However, this research excludes them, since it focuses on transport companies. Various protocols for composing a CCF are available and discussed in section 2.5.

The second approach provides the emission caused by a single product or service. This footprint is usually called a product carbon footprint (PCF). Companies may calculate a footprint of a certain product to gain insight in their own processes. Usually however, the footprint is asked for by a client or the company wants to promote its sustainable character by labelling its products with a carbon footprint. Table 1 compares the two footprint levels.

Footprint level	Corporate	Product
Scope	Activities per organization	Activities per product chain wide
Time window	Calendar year	Lifecycle
Communication medium	Sustainability report	Product label
Target group	Shareholders and stakeholders	Client, consumer, internal
Protocol (example)	GHG Protocol	PAS 2050
ISO standard	ISO 14064 and 14069	ISO 14040/14044 and 14067

Table 1: Corporate versus Product level carbon footprint (adapted from Van Dijk (2009)).

A main issue in scientific debate concerns system boundaries, especially in the field of PCFs (Weidema, 2008; McKinnon, 2010; Matthews, 2008). According to Wiedmann and Minx (2008) a PCF should take the whole life cycle into account. This means starting at design and manufacturing, via distribution to and usage by the consumer ending with the waste disposal. Therefore it comes close to the practice of life cycle assessment (LCA). Actually, climate change caused by anthropogenic gas emissions is a standard category of impact assessment in performing an LCA (Guinée (ed.), 2002).

Hence some members of the LCA community argue that current LCA standards are sufficient to address the impact of GHG emissions from products or services (SETAC Europe LCA Steering Committee, 2008). Schmidt (2009) adds to this critique that consumer behaviour influences the footprint. He also states that a single PCF label has little meaning to the consumer and may confuse him with regard to other labels (e.g. energy consumption labels). Schmidt concludes that PCF as single indicator is the wrong track for sustainable production and use.

However, Weidema et al. (2008) note that the carbon footprint has, more than LCA, caught public attention. Therefore it carries more potential for increasing awareness of the environmental impact of products. They also point at the vagueness of existing ISO LCA standards. Some rules are open and can be easily misinterpreted while others are largely treated and complicated. For this reasons Weidema et al. welcome carbon footprinting standards, provided that they define clear LCA system boundaries. The SETAC Europe LCA Steering Committee (2008) shares this requirement. In this context Weidema et al. mention the British PAS 2050 PCF standard, and conclude that an ISO PCF standard should be considered. Currently the latter is indeed under development. Sections 2.5.2 and 2.5.3 discuss both initiatives.

Looking back at the proposed definition, the conclusion is that it suffices for the aspects discussed until now. When interpreting corporate footprints as a collection of activities, it covers footprints on both levels. Furthermore, concerning life cycle boundaries, the definition is clear and in agreement with other literature. In the next section we discuss whether it also suffices concerning the GHGs.

2.3 Scope of emissions

Another main topic of debate concerning the definition of a carbon footprint is the scope of emissions (Finkbeiner, 2009; Schmidt, 2009). Probably due to its name, many people associate the footprint with carbon dioxide only. A commonly used logo also contains the term CO_2 (see Figure 3). Because of practical, but as well linguistic reasons, Wiedmann and Minx (2008) propose to measure the total amount of carbon dioxide emissions. This means that other GHGs are excluded, although several others are relevant to climate change as well. The Kyoto Protocol (United Nations, 1998) regulates six GHGs: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF_6).

Figure 3: Common CF logo.

In order to compare the impact of GHGs the IPCC has developed the Global warming potential (GWP) concept (IPCC, 1990). It is the ratio of heat trapped by a given mass of a certain GHG compared to that of the same mass of CO_2 over a specific time interval. Because every GHG has a certain lifetime the GWP values change over time. Using GWPs it is possible to express the impact of any GHG in CO_2 impact. The carbon dioxide equivalent unit (CO_2e) gives the mass of CO_2 released into the atmosphere that would have the same GWP as a given mass of another GHG. CO_2e units are generally based on 100 year GWP values. Since the GWP of CO_2 has been defined as 1, the CO_2e is the product of mass and GWP. This allows for reporting in a single unit while all GHGs are taken into account.

The GWPs of other GHGs exceed that of CO_2 by far (IPCC, 2007b). This raises the question whether it is right to exclude them from the carbon footprint. On the other hand, the amounts emitted of other GHGs come nowhere near the emission of CO_2. In 2004 CO_2 represented 77% of the total anthropogenic GHG emissions (IPCC, 2007b). Since this figure is in CO_2e units, its share in kg was over 99%.

Within the transport sector, CO_2's share is even higher. Transport GHG emissions consist of hardly any other gas than CO2, since it is a main product resulting from fuel combustion in engines emitted through the exhaust. Other exhaust gas constituents, such as nitrogen oxides (NO_x) and hydrocarbons (HCs), may be polluting, they do not contribute to the greenhouse effect. However, in some circumstances, they may react to form N_2O or CH_4, accounting for small but measurable shares of GHG emissions (U.S. EPA, 2010). Finally, HFCs are used as refrigerants in mobile air conditioning systems and freight cooling. Leakage of these gases, of which HFC-134a is mostly used, contributes to the greenhouse effect. Although the amounts leaked are very small, its very high GWP makes HFC-134a relevant. Swiss studies estimate its share at up to 2%, measured in CO_2e (Stemmler, 2004).

Table 2 provides an overview of the six main greenhouse gases. Since there is a wide range of HFC and PFC compounds, the table lists the most common one as example for each fluorocarbon. The global and transport shares are the sums of all HFCs, PFCs and SF_6, though. Clear transport emission figures or shares of HFC-134a could not be found and have thus been omitted.

Greenhouse gas	Chemical formula	Lifetime (years)	GWP 20 yr	GWP 100 yr	GWP 500 yr	Global share (% in CO_2e)	Transport share (% in CO_2e)
Carbon dioxide	CO_2	variable	1	1	1	76,7	98,45
Methane	CH_4	12	72	25	7,6	14,3	0,11
Nitrous oxide	N_2O	114	289	298	153	7,9	1,44
HFC-134a	CH_2FCF_3	14	3830	1430	435	1,1	0,0
PFC-14	CF_4	50000	5210	7390	11200		
Sulphur hexafluoride	SF_6	3200	16300	22800	32600		

Table 2: GHG properties and shares. Sources of figures: IPCC (2007b) and (last column) U.S. EPA (2010).

From a mathematical viewpoint, limiting the footprint to CO_2 seems acceptable for transport companies. However, Schmidt (2009) demands to take all relevant GHGs into account. In current practice, men has opted the other way as well. The EU ETS may currently demand CO_2 accounting only, The Netherlands have already opted in N_2O and from 2013 this will be followed EU wide for certain sectors (European Commision, 2008b). Furthermore, most carbon footprint standards and protocols take more GHGs into account, as we describe in section 2.5. Finally, Wiedmann himself changed his mind and recently stated that a carbon footprint should capture the full amount of greenhouse gas emissions (Wiedmann, 2009). Therefore the conclusion is that counting CO_2 only is not the right track. A carbon footprint should take at least the six main GHGs into account. Expressing them in CO_2e allows reporting in single and comparable units.

2.4 Emission factors

Agreement on CO_2e or CO_2 as metric is not enough. For calculating a footprint one needs to know how much gas is emitted by performing a certain activity. How much CO_2 emission is related with 1 kWh of electricity used? What is the emission of a light duty vehicle delivering goods powered by diesel? And what if the engine uses LPG? For a company or individual it is not feasible to reliably measure these amounts by themselves. Therefore institutions perform field studies or experiments to determine standard values, which are called emission factors. A certain factor stands for the average amount of a specific GHG released into the atmosphere by a certain activity. An emission factor can be expressed in the weight of the pollutant per unit of volume or weight of the source substance, or per unit of distance or time associated with the activity.

For mobile combustion sources (e.g. fuel combustion in a truck's diesel engine), two types of emission factors to calculate the CO_2 emission are common (Zadek & Schulz, 2010):

- Fuel-based: kg CO_2 / litre.
- Distance-based: kg CO_2 / km.

The latter is often adapted to include the cargo quantity, in which case also called activity-based:

- Distance-based (alternative): kg CO_2 / quantity * km, with quantity as e.g. weight in ton kgs.

The chemical reaction occurring during fuel combustion is the prime source of CO_2 emission. Therefore CO_2 / litre factors are the most reliable figures for carbon footprint calculation. The GHG Protocol (see section 2.5.1) for example prescribes this approach (2005). Distance-based factors can be used when fuel consumption data is not available. However, such figures are calculated using several assumptions. Aspects that influence the ultimate fuel usage and thus emission include road type, traffic situation, meteorological conditions, driver behaviour and characteristics of vehicle, engine and load (Palmer, 2007). Distance-based factors use estimates or long term averages for these aspects and are thus less accurate than fuel-based (also referred to as energy-based) factors. For a global overview in the CCF of an average company, this may suffice. But for detailed PCF calculations for an LSP, fuel-based factors are required.

2.5 Footprinting methodology

Similar to the fact that no single definition of a carbon footprint is in use, several standards and protocols for composing both CCFs and PCFs have been developed. Some aim for global standardization, others are intended for national or even sector specific use. Just for carbon emission caused by transport already a handful of methodologies are available. The developers are governmental institutions, not for profit organizations, commercial groups or a collaboration of them. The purpose varies from defining a standard on what the contents of a carbon footprint should be to protocols describing how to compose one. Finally, some organizations provide a collection of standard emission factors. Their aim is to harmonise calculations so that figures reported in different footprints are comparable.

On a more theoretical level, two approaches on carbon footprinting can be distinguished (Wiedmann, 2009). The first is a top-down approach based on the theory of input-output analysis. This is a technique modelling the relations between economic entities on macro level, e.g. industry sectors. A variant is to quantify environmental impacts of activities. When the total production level of a sector is known and statistics on total GHG emissions from that sector are available as well, one can allocate emissions to products. A disadvantage is that processes or emissions may be aggregated, but overall they cover the complete amounts. It is thus especially appropriate for CCF calculations, and several attempts to calculate footprints of nations, sectors or organizations have been described in the literature (Minx, et al., 2009).

The second approach is bottom-up, based on process analysis. This method is used to quantify (in this case) environmental impacts of individual products or processes and thus appropriate for PCFs. It is more detailed, but also easily too narrowly scoped, taking only first-order processes and impacts into account. Therefore a third, hybrid approach has emerged. This allows for detailed calculation of core processes, while less significant processes, or activities elsewhere in the supply chain, can be covered by input-output analysis (Wiedmann, 2009).

Such an approach comes close to the theory of activity based costing (ABC). This method allocates costs of secondary activities (overhead) to the primary activities, providing a complete cost price for a product. Mamouni Limnios et al. (2009) describe an ABC method for product ecological footprints. Focussing on GHG emissions, one could think of the term activity based carboning. Probably because it is an established and well known method, in practice several methods take an approach that could be seen as ABC.

The following sections provide an overview of relevant corporate and product footprinting initiatives. We consider relevant:

- Global initiatives – GHG protocol, PAS 2050 and ISO standards (sections 2.5.1 - 2.5.3)
- National initiatives from The Netherlands and large surrounding countries (2.5.4)
- Initiatives focusing on the European road transport sector (2.5.5)

2.5.1 Greenhouse Gas protocol

The GHG protocol is an early high level approach to carbon footprinting on corporate level. It has been developed by the World Business Council for Sustainable Development and the World Resource Institute with input from several other organizations and multinationals. Due to its global view and early presence, the protocol has been widely adopted (Rich, 2008). It covers the six main GHGs presented before. The protocol divides the emissions in three scopes:

1. Direct emissions from sources owned or controlled by the company.
2. Indirect emissions from the generation of purchased electricity consumed by the company.
3. Emissions of all other indirect sources.

Reporting of scope 3 is voluntary. It contains emissions that are a consequence of a company's activities, but occur from sources not owned or controlled by it. Figure 4 gives an impression of the

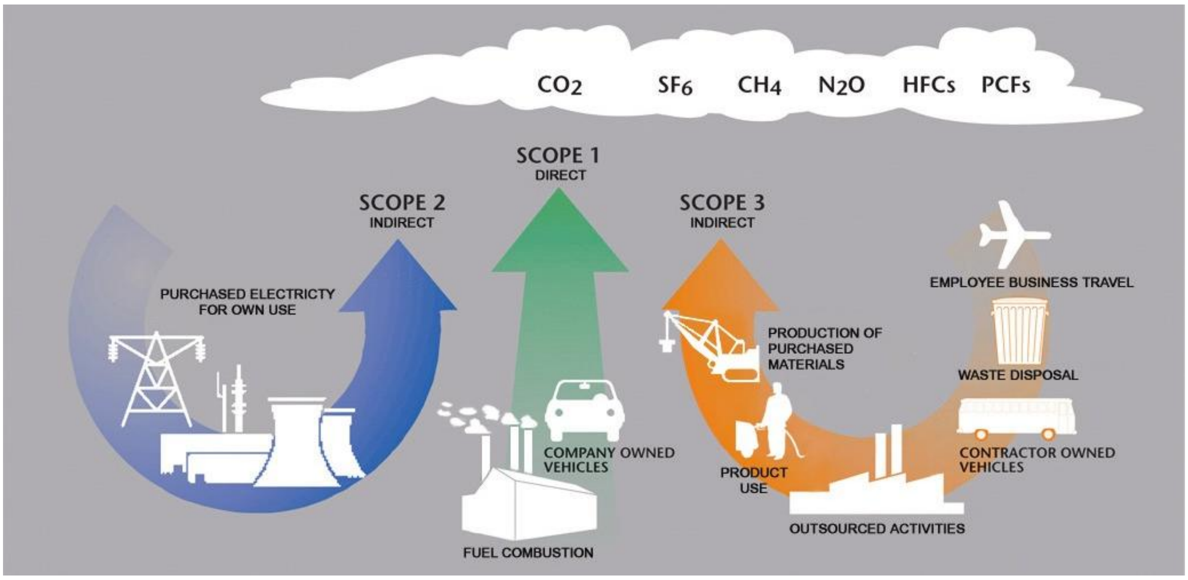

Figure 4: GHG protocol scopes and sources.

three scopes and their GHG sources.

The WBCSD and WRI are currently working on a PCF standard as well, called the Product Life Cycle GHG Accounting & Reporting Standard. It guides a company in preparing an inventory of emissions associated with a product across its life cycle. The goal is public disclosure of the footprint, helping users in their decisions on what products they choose. The WBCSD and WRI have already released a draft version of the standard, and expect to publish the final version in December 2010 (Rich, 2008). Finally, a protocol for scope 3 accounting is under development, which may follow the principles of input-output analysis (Minx, et al., 2009).

2.5.2 PAS 2050

The British Standards Institution developed this Publicly Available Specification for the assessment of the life cycle greenhouse gas emissions of goods and services (BSI, 2008) at the request of DEFRA and Carbon Trust. These three organizations also collaborated to publish the Guide to PAS 2050, which assists in composing a PCF according to the specification. Built upon earlier work from Carbon Trust, it is the first international standardized PCF method. The specification is based on the ISO 14040 standard, limiting it to GHG emission inventory. Compared to LCA, PAS 2050 simplifies the assessment. It also provides clarification on several issues, like system boundaries and elements to include in the impact assessment (Sinden, 2009). These include overhead activities, using an ABC approach to allocate them to core processes.

2.5.3 ISO standards

The International Organization for Standardization is a non-governmental organization formed by members of national standards institutes. It is the world’s main standards developer active in all sectors. ISO standards are widely known and accepted as a guarantee for quality of products or processes. In the field of carbon footprints, the ISO lags a little bit behind the standards emerged from practice. It has published a CCF specification standard, but others are still on their way.

- ISO 14064 and 14069. Concerning the CCF category the ISO has developed the 14064 standards for greenhouse gas accounting and verification. Most important is Part 1: *Specification with guidance at the organization level for the quantification and reporting of greenhouse gas emissions and removals* (ISO, 2006). The ISO decided to maintain consistency with the GHG protocol, the existing best practice (Chan & Boehmer, 2006). Part 1 provides overall norms on the contents of a CCF report, but does not prescribe how to draw one. Additional guidance for applying ISO 14064-1 will be provided in ISO 14069. This technical report is currently under development. Publication is not expected before 2012.
- ISO 14040/14044 and 14067. The ISO has not yet published a carbon footprint standard on product level. It is working on ISO 14067 - Carbon footprint of products, consisting of two parts: quantification and communication. The first part sets norms on what topics have to be covered when measuring the lifecycle emissions of products. It is based on the ISO Environmental management - Life cycle assessment standards, respectively 14040 – Principles and framework and 14044 – Requirements and guidelines. These LCA standards are sometimes referred to as guidelines for performing PCF calculations, which form part of an LCA. The communication part of ISO 14067 provides guidelines on labelling products. The ISO targets early 2012 for publication of the 14067 standard, which is currently in draft status.

2.5.4 Local initiatives

Besides the global initiatives described in the previous sections, on a national level various organizations have published standards as well:

- DEFRA. The British Department for Environment, Food and Rural Affairs provides a clear manual for UK based companies on how to measure and report GHG emissions on corporate level. It is based on, but adds little to, the GHG protocol. DEFRA's main contribution lies in the emission factors it provides.
- Bilan Carbone. The developer of this method is the French governmental agency ADEME. It is a CCF method intended for companies and local authorities. Bilan Carbone takes direct as well as indirect GHG emissions into account and is compatible with ISO 14064 and the GHG protocol. Besides the CCF method, ADEME also provides a simple PCF tool and an extensive emission factors document.
- ProRail CO_2 performance ladder. ProRail is a Dutch company which maintains the national rail network. As part of its CO_2 reduction programme ProRail wants to stimulate its suppliers to offer sustainable products. The performance ladder is a CCF standard compliant with ISO 14064 and prescribes the GHG protocol. It is not just intended for measurement of CO_2 emission, but really aims at reduction. ProRail audits its suppliers on four aspects: insight, reduction, transparency and collaboration. The better a company scores on these criteria, the higher its position on the ladder, which is advantageous in tendering procedures. ProRail also provides emission factors based on data from CE Delft and DEFRA.
- Milieubarometer. The Dutch foundation Stimular has developed a CO_2 calculator as part of its environmental barometer. It is a rather simple tool, but the more interesting is their publically available list of emission factors. Ranging from several kinds of transport modes to electricity, water, paper and refrigerants, the list appears to be comprehensive enough for companies in the transport industry. Last updated early 2011, based on Dutch circumstances, it is very useful for Dutch companies with the desire to gain insight in their carbon footprints.

This list is far from exclusive, with initiatives from several other countries being excluded. Unfortunately the responsible organizations seem to put little effort in collaboration or synthesis.

2.5.5 Transport initiatives

Finally, some organizations have performed studies specifically in the field of transportation:

- ARTEMIS and COPERT. Two projects funded by the European Union. The ARTEMIS project aims to build a database with emission factors for transport. Working groups conducted field studies on vehicle emission and developed models taking into account vehicle, road, traffic and driving characteristics. Both research fields combined, ARTEMIS provides emission factors in g/km units for several transport modes. The project ran from 2000 to 2004, with its final report published in 2007 (Boulter P. & McCrae, 2007). The COPERT project goes further. It incorporates emission factors collected through own field studies, but also from other sources like ARTEMIS, into a method for calculation of road transport emissions. It is intended for use at a national level. A COPERT software application is available as well to assists users with the calculation (Ntziachristos, 2009). The European Environment Agency uses results from both projects for its air pollutant emission inventory guidebook (EEA, 2009). This book provides methodologies and emission factors for EU wide use of high level emission calculation, e.g. as reference for governments complied to certain conventions.

- HBEFA. The German Handbook Emission Factors for Road Transport contains GHG g/km emission factors. It actually offers factors for various types of emissions, e.g. for both "hot" and "cold start" emissions. Furthermore, HBEFA provides them for many vehicle categories in various traffic situations. Updated every few years, the latest release was in 2010.
- STREAM. The abbreviation stands for Study on Transport Emissions of All Modalities (Boer, Brouwer, & Essen, 2008). The Dutch consultancy and research organization CE Delft has conducted this study commissioned by Dutch ministries. It provides CO_2 emission factors for several transport modalities, specifically for Dutch circumstances. Although CE Delft provides a simple roadmap for calculating a PCF for a certain transport service, its main contribution consists of the emission data. These data are based on field studies. It takes amongst others transport mode, road type, nature of cargo and estimates of load factor into account as well as emissions between well and tank, in order to arrive at well to wheel gram CO_2 emitted per km data. This means that the emission factors are useful when calculating a footprint for transport activities over a certain time with little information available. However, when actual fuel consumption figures are known, STREAM has less value.
- NTM. The NTM methodology has been developed by the Swedish not for profit organization Network for Transport and Environment. The method primarily evaluates the environmental impact of transports. NTM provides average values for vehicle types, motor specifications, fuel usage and load factors. The user may use these for the footprint calculation. However, the method allows for entrance of self-provided values. The more the user specifies, the higher the accuracy level of the result. NTM does not provide own emission factors. For road transport, the method uses values retrieved from HBEFA and ARTEMIS.

Summarizing, these studies have resulted in valuable emission factors and methods for calculating PCFs of transports. Especially when an organization wants to compose a footprint of its total transport activities over a certain time they are very useful. However, we intend to calculate the emission of single transports, with fuel data at hand. These transport methods are not detailed enough or already contain too much assumptions on circumstances to be useful for our information system. Furthermore the provided emission factors are too narrowly scoped. For composing a CCF one would need another source for the factors, which is not desirable for consistency reasons.

2.6 Selection of standards

We intend to develop an information system with the purpose of calculating both corporate and product footprints for LSPs. In order to make the resulting footprints reliable and comparable to other footprints, they need to comply with the appropriate standards. After analyzing several aspects of carbon footprints, it becomes clear that the standards should meet the following criteria:

Section	Aspect	Criteria
2.2	Corporate level	globally supported, intended for businesses
2.2	Product level	globally supported, including complete lifecycle
2.3	Scope of emissions	accounting for at least the six main GHGs
2.4	Emission factors	providing factors for several activities providing fuel-based emission factors for mobile combustion

Table 3: Carbon footprint methodology selection criteria.

Based on these criteria we select the following standards:

CCF: ISO 14064 standard and the GHG protocol. ISO standards are respected worldwide. The GHG protocol is globally the most used protocol and well-known. Since ISO has developed its standard in consistency with the GHG protocol, both can be used together. Requiring reporting of the six Kyoto GHGs, both meet the scope of emissions criterion.

PCF: PAS 2050. Although rooted in Great Britain, this protocol aims at global use and indeed appears to be accepted worldwide. Based on LCA it provides a clear guidance for calculating a PCF for both goods and services. For transport services in particular, aspects such as system boundaries, allocation issues and data units are well defined, which makes PAS 2050 a solid choice. Local initiatives on PCF on the other hand, are mostly simple tools that have not reached a desirable level of maturity. We intend to comply with the forthcoming ISO 14067 standard. This standard is not expected to deviate much from PAS 2050, although minor future modifications to the IS have to be anticipated. No effort is put in partial compliance with ISO 14040 standard, since it will have little meaning after publication of ISO 14067.

Emission factors: Milieubarometer. Stimular's list of emission factors is rather short. Actually, several other emission factor publications are far more comprehensive. However, Milieubarometer provides exactly the factors that are useful for our intended use. It meets the criterion on emission per litre fuel data. More specific this concerns a so called well-to-wheel factor, which matches the PAS 2050 LCA principle (also see Appendix B). Furthermore it contains emission factors for several other activities taking place in typical service companies. Using the same factors for both PCFs and CCFs assures consistency between the two. Finally, its recent update in 2011 is an advantage.

2.7 Conclusion

The introduction to the carbon footprint field shows that it is immature. Both in science and practice no single definition of the concept has been widely accepted. Sections 2.2 until 2.4 dig into three aspects of a carbon footprint, providing partial answer to the first research question on what forms a carbon footprint. These can be composed on corporate level and on product level, with a service interpretable as product. Based on literature we conclude that for product level footprints a full life cycle approach is preferred. Section 2.3 researches the various greenhouse gases. It reveals that while CO2 emissions are abundant in practice, other GHGs have more impact and should therefore be included in the scope of a carbon footprint. Emission factors are the units to convert emission sources to emission amounts. For our research it is important to use fuel-based emission factors, since these translate transport movements into carbon emissions most accurately.

The immaturity of carbon footprinting is also expressed in the numerous standards and protocols developed for composing footprints, as section 2.5 showed. Organizations with different origins propose various protocols and in many countries domestic institutions have defined local emission factors. Little synthesis between them is visible, while consolidation would greatly improve the reliability, transparency and comparability of carbon footprints of different organizations and products. To answer research sub question 1a), for our own architecture we select the GHG Protocol and PAS 2050, both complying to ISO standards, as best alternatives. They have global impact and meet the carbon footprint content criteria. As source for emission factors the Milieubarometer is considered the best alternative, as it provides all factors relevant in the logistics industry.

3 Green Information Systems

This chapter discusses the theory and applications of Green information systems. It starts with the historical evolution of green thinking and sustainable business. Section 3.2 handles the application of IT and IS as applications of green business practices. We dig into the literature on the adoption of Green IT/IS in section 3.3. What are the drivers for organizations to “go green” as expected by academics and as explained by practitioners? Section 3.4 shortly presents some expected benefits of Green IT/IS, particularly in the field of smart logistics. In section 3.5 we analyze the adoption potential for Carbon Management Software (CMS, a typical example of Green IS) in the transport industry. We finish the chapter with an overview of CMS available on the market in section 3.6.

3.1 Green business

Since people started to regard being sustainable as a quality, it became popular to attach the label ‘green’ to just about everything. In the 1970s green was linked to social and political movements, with ecological thinking slowly gaining ground in society. In the late 1980s companies became aware of growing environmental concerns of large groups of consumers, as a stream of articles on green business appeared in several business magazines (Vandermerwe & Oliff, 1990). Companies responded to this consumer shift and adjusted their strategy on marketing, manufacturing and R&D level.

However, these initiatives were later often regarded as piecemeal. It was rather marketing “green washing” the company than really making the company’s operations more sustainable. It took more than another decade of green thinking gaining global momentum through society and politics before businesses started to take their responsibilities more seriously. Nowadays not only a wide range of “green” products and services are available on the market. More and more companies really embrace environmental strategy throughout their business (Prothero, McDonagh, & Dobscha, 2010).

Bansal and Roth examined why companies “go green” (Bansal & Roth, 2000). They conducted a qualitative survey to identify motivations for initiatives to mitigate the corporate environmental impact. Such initiatives may take place on product, process or policy level. Based on the survey results, Bansal and Roth distinguish three motivations: competitiveness, legitimation and ecological responsibility.

In this context competitiveness means the potential to improve profitability with green initiatives, profitable innovations that yield competitive advantage. Examples are energy reduction, waste management, green marketing and development of eco-products. Legitimation embraces initiatives to adapt the firm to established environmental regulations, norms and values. Reactive behaviour satisfying stakeholders should lead to the firm’s survival. This includes ensuring compliance to actual legislation, but also consulting an environmental committee or the local community. Ecological responsibility is the concern for social obligations and values, rather ethical than pragmatical. Proactive behaviour according to ecological ideals benefits the society and can result in a high corporate morale. Examples are establishing green product lines, even if they are less profitable, lifecycle analysis and recycling office supplies.

While the green goals mentioned by Bansal and Roth (2000) are mostly exemplary and derived from participants’ answers, Dyllick and Hockerts (2002) conceptualized these goals in the broader context of corporate sustainability. They distinguish three dimensions of sustainability: economic, social and environmental. Companies often tend to maximize the business (economic) case and consider themselves sustainable when they simultaneously take the societal and natural cases into account. Dyllick and Hockets state that such an approach does not suffice for true sustainability. They provide six criteria to satisfy in order to reach sustainability in all three dimensions. This framework is depicted in Figure 5. The idea is that firms not only use resources efficiently, but also use their business case to effectively improve the natural and societal cases. Furthermore, some balance between the latter two is desired. For our research, especially the ecological criteria are relevant. Chen, Boudreau and Watson (2008) present them as more concrete goals to reach ecological sustainability. Based on both papers, the three goals can de defined as:

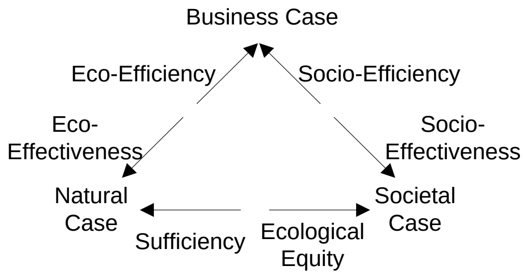

Figure 5: Corporate Sustainability framework.

- Eco-efficiency: consuming less non-renewable resources to reach desired production levels.
- Eco-equity: distributing natural resources fairly within and between generations.
- Eco-effectiveness: ending practices that cause ecological degradation.

According to Chen et al., eco-efficiency is often the foremost goal in line with the business case, while eco-effectiveness can be considered the ultimate solution. Linking them to the motivations explained by Bansal and Roth, the first will probably be driven by competitiveness, while for the second some ecological responsibility may be required. The next paragraph discusses IT practices that aim for ecological sustainability and links them to the general theory of corporate sustainability.

3.2 From Green IT to Green IS

Within the IT sector the first initiatives for more sustainability were taken at the infrastructure level. This field is often referred to as Green IT. Mann et al. (2009) define Green IT as:

The strategic deployment of operations and information technology to dynamically, sustainably and responsibly align business-oriented goals with green objectives for the entire duration of operations.

Green IT can be applied both client and server side, using techniques focused on energy saving and sustainable use of materials. Murugesan (2008) divides Green IT practices into reducing energy consumption by PCs and greening data centres. Examples of the first are power management, turning off PC's outside office hours and using thin clients. Examples of the second are low-energy hardware and cooling systems, eco-friendly design and construction, and virtualization. Mann et al. (2009) mention Software-as-a-Service (SaaS) solutions as well. By deploying software on a remote server, making it accessible via web browsers, no local servers are needed. Together with virtualization and thin clients significant savings on hardware usage and energy consumption can be realized. Finally, both articles add recycling of hardware to the list of sustainable IT practices. Altogether the sustainability of IT can be improved in all stages of its lifecycle; green design, manufacturing, use and disposal of IT.

However, infrastructural improvements are not the only way IT can aid to sustainable business. Murugesan (2008) explains IT can also support environmental initiatives by offering tools for e.g. environmental impact analysis, energy and emission monitoring, and urban planning. Although

Murugesan does not coin the term, he refers to what others consider Green IS. Watson et al. (2008) define Green IS as:

The design and implementation of information systems that contribute to sustainable business processes.

The difference between Green IS and Green IT is that IT is part of the problem, while IS contributes to the solution (Chen, Watson, Boudreau, & Karahanna, 2009). Green IT typically improves IT efficiency, making the IT infrastructure itself more sustainable, and thus reduces the problem. Green IS uses IT to make the whole business more effective and thus creates solutions. Therefore Green IT relates to eco-efficiency and Green IS to eco-effectiveness. Although a clear distinction between IT and IS can be made according to the definitions above, these terms are used interchangeably and differently (Ijab, Molla, Kassahun, & Teoh, 2010).

Brooks, Wang and Starker (2010) performed a literature review on Green IT, in which they include Green IS. Like the statements by Watson, Boudreau and Chen (2010), their main conclusion is that the academic research on Green IT is immature. In line with the evolving ideas about Green IT & IS, most articles found belong to the eco-efficiency category with IT topics. More theoretically oriented papers often discuss why companies should an do adopt Green IT/IS and what their strategic considerations are. Since our research topic is Green IS we dot no dig into Green IT any further. However, insight in motivations for Green IS adoption and the expected benefits is worthwhile. In the next paragraph we review the academic literature on this topic to find out if there is a solid basis for the adoption of carbon management software.

3.3 Adoption of Green IT/IS

Chen et al. have drawn a conceptual paper in which they investigate the roles of IS in the pursuit of ecological sustainability (Chen, Boudreau, & Watson, 2008). They reckon automation, information and transformation as the three roles of IS. Furthermore, Chen et al. rely on institutional theory to distinguish different pressures that act as drivers for implementing Green IS. The theory holds that different organizations over time start to look alike (i.e. institutionalize) in their behaviour. Three kinds of pressures make them consider similar behaviour legitimate:

- Mimetic: imitating successful competing organizations' behaviour, e.g. to cope with strategic uncertainty.
- Normative: meeting cultural expectations from society or professional expectations from affiliates, e.g. to foster relationships.
- Coercive: complying to laws and regulations from government or powerful stakeholders, e.g. to avoid sanctions.

In their model, Chen et al. relate the IS roles and institutional pressures to the three ecological goals explained before as following:

- IS automating processes driven by mimetic pressure leads to eco-efficiency.
- IS informating downwards (environmental awareness) driven by normative pressure contributes to eco-equity.
- IS informating upwards (in compliance to environmental regulations) driven by coercive pressure contributes to eco-equity.

- IS transforming businesses by a combination of all three pressures leads to eco-effectiveness.

As a follow-up research, Chen et al. (2009) empirically investigated how mimetic and coercive pressures affect organizational adaptation of Green IS and IT. Normative pressures were excluded as they were deemed to be confounding with or hard to distinct from the other pressures. The researchers did however distinguish two types of isomorphism resulting from each of the other pressures:

- Frequency-based imitation: adoption of prevalent practices.
- Outcome-based imitation: adoption of observed successful practices.
- Imposition-based coercion: adoption of by authorities mandated practices.
- Inducement-based coercion: adoption of by supply chain partners demanded practices.

Chen et al. held a survey amongst IS and senior managers and consultants from several industries and countries. The questionnaire aims to clarify which pressures motivate organizations to adopt Green IS and IT for three business models: pollution prevention, product stewardship and sustainable development. 75 Organizations responded to the survey. According to Chen et al. the answers provide strong support for their adoption model in general.

Analysis of the answers provides further specified conclusions. First, they show strong evidence for outcome-based imitation as instance of mimetic pressure across the three business models. In contrast there was a low support for frequency-based imitation. So it is clear that most organizations are waiting for success stories from early adopters before they voluntarily adopt Green IT & IS as well.

Concerning coercive pressures, the patterns are less consistent. For pollution prevention and sustainable development, imposition is a significant source for development of green practices. Organizations typically adjust their behaviour after regulations come into effect. For product stewardship, pressure from supply chain partners is significant. Since product stewardship entails reducing the environmental impact of products along their full life cycle, and thus including the supply chain, this result could be expected.

Where Chen et al. (2008) focus on external drivers, other academics also take internal drivers into account. Mann et al. (2009) give the following list as drivers for Green IT:

- Regulation
    - Government regulations.
    - Industry-wide standards.
- Demand
- Leadership
- Cost

Thus, besides coercive (regulation) and normative (demand) pressures, Mann et al. pose that enthusiasm on management level to adopt Green IT also plays a role. They even expect that cost is the most important driver, but do not substantiate this claim with empirical data.

Molla (2008) identifies three drivers of Green IT (in which he includes Green IS): economical, regulatory and ethical. Where regulations relate to coercive pressure and ethics to normative pressure, Molla purely points to cost savings as economic driver. Furthermore he states that technological and organizational context influence the intention to adopt Green IT. The first concerns the currently installed IT base and the second business properties like size, sector and corporate citizenship. Finally, Molla considers the perceived readiness for Green IT a factor. Green thinking needs to gain ground within the organisation, gain momentum within the value network and become a topic in institutional forces. According to Molla's Green IT Adoption Model all these variables predict the intention to and ultimately adoption of Green IT.

Molla tested his model empirically as well (Molla, Pittayachawan, & Corbitt, 2009). A similar questionnaire as Chen's (2009) resulted in 143 responses. 83% of the participants are CIOs or IT managers, about two third from Australia and a quarter from the US. Their organizations vary in size, industry and IT base. The answers to the survey reveal that the main drivers for Green IT are internal ones. 80% mention IT cost reduction and 77% emphasize environmental consideration. Concerning external drivers normative pressures are mostly recognized; for 71% social acceptance is a main reason to pursue green IT and almost half mention pressure from clients. Also about half of the respondents sense coercive pressures, while only few provide reasons relating to mimetic pressures.

The survey also included questions on the actual adoption of Green IT. It became clear that organizations are still at an early stage of adoption. Actually, environmentally friendly disposal of IT products was most widely practiced, while this can be seen as one of the most simple means of Green IT. Furthermore most organization take some measures to reduce energy usage of IT equipment. Green IS is hardly in place, however. Although 77% is concerned about the organization's environmental footprint, only 7% is using a footprint monitoring IS.

More recently, Kuo and Dick (2010) reviewed the literature for potential influencing factors. Their model incorporates all pressures and other factors. It categorizes the external and internal pressures according to the three motivational factors explained by Bansal and Roth (2000). Furthermore, organizational factors and technological constraints influence the extent of Green IT (including Green IS) in organizations.

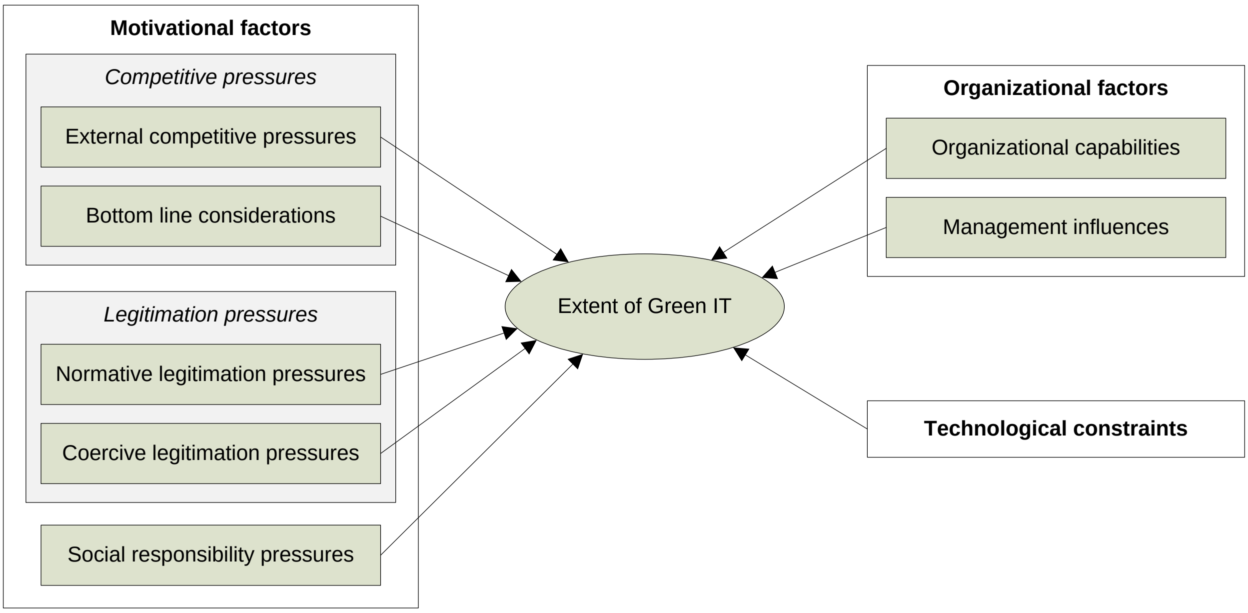

Figure 6: Model of factors influencing the extent of green IT in organizations (Kuo & Dick, 2010).

Kuo and Dick conducted a questionnaire which received 38 responses. Most participants hold positions in IT management in US or Australia based firms with more than 500 employees. Analysis of the answers shows that management influence is the strongest factor. Bottom line considerations and normative legitimation pressures are also found to be significant factors. The results provide no support for any of the other factors.

Comparing the surveys, the results from Kuo and Dick are in line with results from Molla. Both reveal that cost and normative pressures are important motivations. These are exactly drivers Chen did not ask for, which makes the first survey hard to compare with the latter two. The specific cases Chen asked about may support their framework, it is not certain whether for example imposition is an import motivation in general. Kuo and Dick also investigated organizational factors and even concluded that management influence is the strongest factor. This may be true when examining the extent of Green IT present in an organization. However, it does not clarify the management's motivations for adopting Green IT. Molla's survey is by far the most extensive one. However, a remark can be made here as well. The respondents simply had to agree or not on proposed reasons for Green IT adoption. This resulted in high percentages for several motivations, making it ambiguous what the single most important driver is.

Reviewing the survey methodologies the small sample sizes can be considered as a limitation. Especially little value can be attached to the survey by Kuo and Dick, which had only 38 valid responses. The geographical distribution of the participants is rather limited as well. Chen's participants were spread across the earth, but the other surveys had a large share of respondents from the US and Australia. More European views would be a welcome addition. According to the survey results, for example coercive pressures hardly play a role. But in the EU environmental legislation is further implemented than in other continents. A survey among European organizations may thus show different results on this topic. Finally, it must be noted that all three questionnaires have been conducted between 2008 and April 2009. With the advancing technological possibilities, legislation and societal views concerning environmental topics, a new survey may shift the outcomes as well.

Overall, the theoretical examinations of Green IT drivers have provided insight in why organizations would "go green". Especially the model by Kuo and Dick is a valuable contribution to the literature, incorporating all factors found in various theories. The questionnaires are less rigorous of nature. They are all used to support self-proposed frameworks, which may have resulted in part of the questions leading to desired answers. On the side of the participants, self-selection bias and social desirable answers may have increased the positive responses on certain motivations. Nevertheless the surveys provide a good impression of what factors influence Green IT adoption in practice.

Our conclusion is that most likely a small amount of organizations will form a group of early adopters of Green IS motivated by social responsibility. Yet, the factor of bottom line considerations is so evident in the survey results that even for them a viable business case will be a necessity. The majority of organizations will wait until successful and profitable implementations become observable or until normative and/or coercive pressures have risen until levels that leave reluctance of implementation no option. Obviously management support is important for initiating green practices, like it is for any change of direction within an organization. Technological constraints appear to play a minor role, probably because Green IT/IS implementations are not considered to have a major impact on the current IT infrastructure.

3.4 Benefits of Green IS

After the previous sections discussed the theoretical foundation for the adoption of Green IT/IS and already showed some examples of it, this section deals with concrete practical solutions to reduce carbon emissions with the deployment of Green IS.

In their Smart 2020 report (Webb, 2008), the Climate Group quantifies the reduction opportunities Green IT/IS offers. It accounts the Information and Communication Technology (ICT) sector for 0.83 Gt CO_2e, or 2%, of the total carbon emissions worldwide over 2007. These emissions are the sum of emissions during the production and use phase of ICT equipment. For 2020, the Climate Group expects ICT emissions to rise to 1.43 Gt CO_2e. However, it also estimates that ICT solutions may yield carbon emission reductions of up to 7.8 Gt CO_2e, almost five times ICT's own footprint. These figures support the claim that greening ICT equipment reduces the problem, but that the real potential lies in Green IS solutions improving the sustainability of businesses as a whole.

The reports discusses five fields of application in which ICT can enable abatements: dematerialization and smart motor systems, logistics, buildings and grids. Our research fits into the field of smart logistics, which comprises ICT solutions that improve the efficiency of logistic operations. Furthermore the report categorizes the solutions into five main functions. These are listed below, with examples of their application in smart logistics.

- Standardise: provide standardised information, e.g. repositories with fuel emission factors.
- Monitor: incorporate monitoring systems in operations, e.g. emissions caused by fuel consumption or inventory tracking.
- Account: provide platform to account carbon emission, e.g. calculating auditable CCFs.
- Rethink: offer innovative opportunities to change operations, e.g. route optimization, modal shift and driver behaviour.
- Transform: apply integrated approaches to automate and change behaviour, e.g. chain wide emission tracking, cooperation to improve capacity utilization.

The report claims that smart logistics offers a total potential carbon emission reduction of 1.52 Gt CO_2e by 2020, almost 20% of all potential ICT enabled abatements. With an expected carbon price of €20 per ton CO_2e this is worth 280 billion Euros. All in all several ICT applications can enable valuable reductions in the logistics sector.

3.5 Carbon Management Software

One example of Green IS are Carbon Management Software (CMS) packages, also called carbon accounting software. Although such an IS does not directly enable the reduction of carbon emissions, it does quantify them, providing a basis for reduction strategies. Regarding the Smart 2020 categories (Webb, 2008) its function is in the first place to monitor and (if supported) account. Furthermore, it should give insight in reduction opportunities, thus to rethink current business practices and perhaps even transform business ultimately.

These functions can also be related to the ecological goals and the framework of IS and ecological sustainability (Chen, Boudreau, & Watson, 2008). When emission monitoring automation triggers a fuel consumption or power usage decrease, this directly relates to using less non-renewable resources and thus eco-efficiency. Furthermore, reporting the carbon footprint to partners, regulatory institutions or society, improves ecological issue salience and consequently consciousness. According to Chen et al., this contributes to the development of eco-equity. Finally, if organizations use the insight a CMS provides to rethink and transform practices that cause ecological degradation, they achieve eco-effectiveness.

To examine whether transport companies have an incentive to implement CMS, we return to the Green IT/IS adoption theory. The following list shows all factors from the model by Kuo and Dick (2010), estimates their relevancy in the transport field and discusses their specific triggers and impacts for logistics service providers.

- External competitive. This could be a moderate driver. When competing transport companies adopt CMS and gain market share or increase efficiency, other transporters may imitate them.
- Bottom line considerations. This could be a major driver. Reducing emissions means reducing fuel usage and thus costs. Of course fuel reduction initiatives can be undertaken without monitoring carbon emissions. But implementing a monitoring system makes the reductions measurable, which will ultimately be more beneficial than ad hoc initiatives.
- Normative legitimation. This could be a moderate driver. Carbon emissions through fuel combustion is visible for everyone on a daily basis. Societal awareness and pressure to reduce emissions will grow. Social groups have no direct power, but may indirectly influence management and can thus be an additional driver.
- Coercive legitimation. This could be a major driver. It may take time before legislation forces road transport companies to monitor their emissions. Customers of transporters, however, may be either covered by legislation or voluntarily reporting emissions and consequently demand carbon reporting from their contractors.
- Social responsibility. This could be a minor driver. Some companies may adopt CMS for altruistic reasons, but most ones will regard this as a nice bonus and implement CMS out of self interest firstly.
- Organizational capabilities. Expected a moderate factor. To start monitoring, transport companies must have insight in the characteristics of their network, trucking fleet, cargo and additional activities. It may require some effort to collect this information, but should not be a major challenge.
- Management influence. Expected a major factor. Important for a successful adoption of green thinking and implementation of related IS. However, top support is crucial in any organizational initiative.
- Technological constraints. Expected a moderate factor. For detailed monitoring, a well established IT base needs to be present. For example without board computers no detailed data on transports can be collected. Most large transport companies will have the required infrastructure, though.

Reviewing the list, all motivational factors can be considered as drivers for implementing CMS. Especially cost incentives and legislation are major drivers, complemented with growing normative pressures. Altogether there is a solid base for the adoption of carbon monitoring at LSPs, particularly at larger firms that are organized well and have a decent IT infrastructure.

3.6 CMS market overview

This paragraph presents an overview of currently available CMS packages. The goal of this survey is to examine the sophistication level of CMS and to investigate whether any available package is suited to the transport industry and thus useful for a transport company. A few research companies have recently investigated the CMS market. Most notably is Verdantix' report (Verdantix, 2009). It has positioned 22 CMS vendors in a quadrant (Figure 7), distinguishing between leaders, challengers, specialists and entrepreneurs.

In another report, out of 60 investigated packages, Groom Energy Solutions (2010) lists eight leading vendors. These are (alphabetically): Enablon, Enviance, Hara, IHS, Johson Controls, PE International, ProcessMAP and SAP. With the note that ESS has been acquired by IHS, this means that all vendors regarded as leader by Verdantix, are also considered leaders by Groom Energy Solutions.

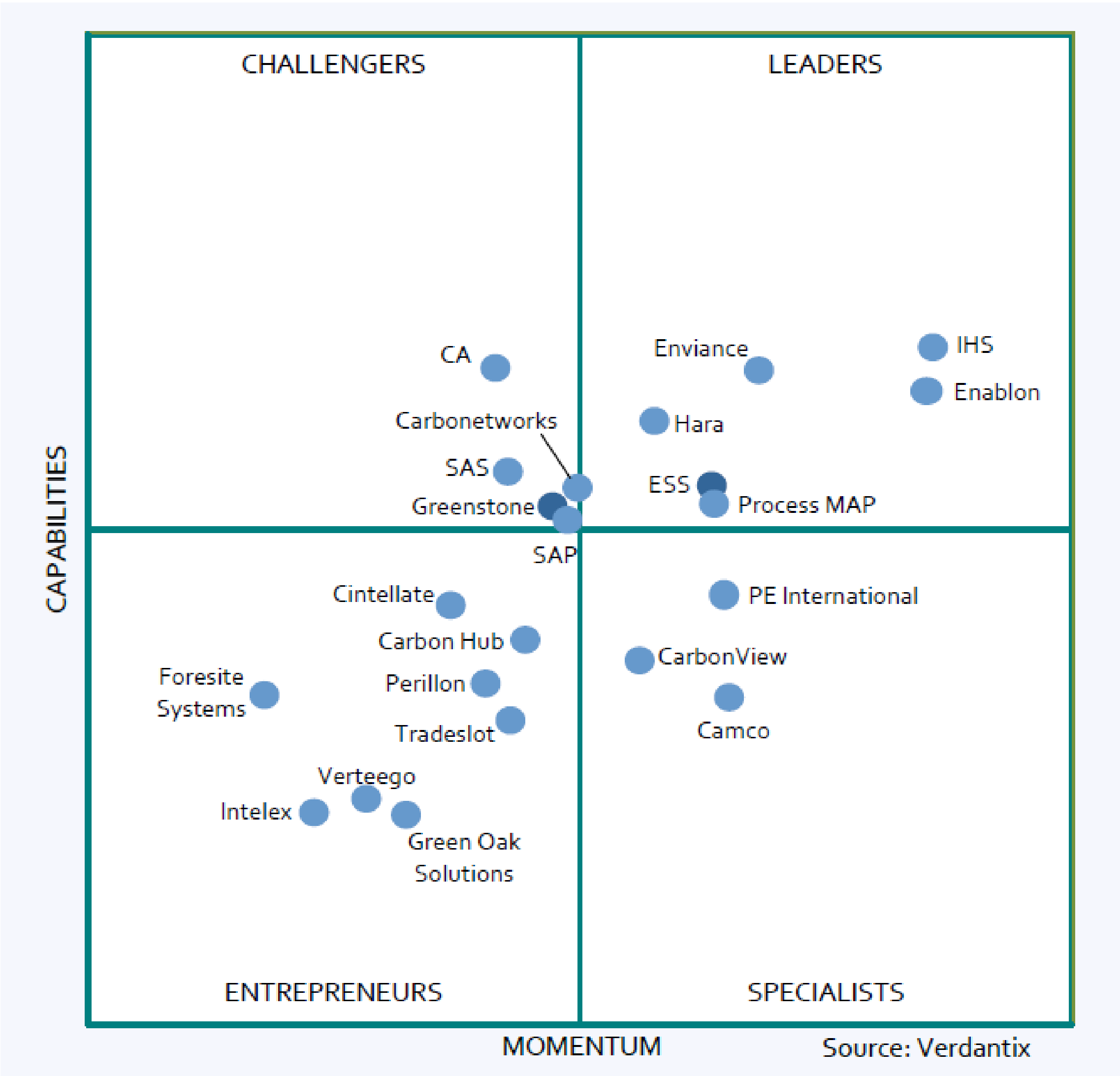

Figure 7: Green Quadrant of CMS vendors (Verdantix, 2009).

For our own overview we selected all vendors that were listed as leader in one of the reports for a review and comparison of their CMS characteristics. The remaining "specialists" (Camco and CarbonView) have been selected as well. Finally, after studying the websites of the challengers and a quick scan of the entrepeneurs' web sites, Greenstone was added to the survey, because of the extensive information about its CMS available online. An Internet search on solutions targeting LSPs yielded no valuable additions to the survey. Only some simple tools calculating carbon emissions of a single trip were found. Appendix A contains descriptions of all packages included in the survey.

The CMS packages have been compared on several criteria. The first two cover all carbon footprint aspects discussed in the previous chapter to compare the solutions on their approach and footprint contents. The other criteria have been established after a first iteration of CMS vendor website visits. A review of the product presentations resulted in a list of functionalities offered and technological aspects of the solutions. Next the items were categorized to establish the criteria. In a second iteration all vendor web sites and documentation about the solutions found elsewhere have been studied in depth to compare the solutions on all criteria. We consider going through such an iteration a solid approach to arrive at a clear overview of the current state of the art in carbon management software. Concerning the functionality the comparison criteria are:

- Approach: does the vendor calculate footprints according to a certain protocol and emission factors, or are various ones supported? Is the IS restricted to GHG emissions, or can it also manage other polluting emissions? Does the package only provide functionality on GHG topics, or are other environmental management functions included, or at least available in external modules?
- Footprint calculation: can the CMS calculate both CCFs and PCFs, and are more specified footprints available?
- Monitoring: how are the footprints presented, and are they calculated and presented real-time?
- Reporting: what kind of reports can be produced? Does the CMS allow for auditing of the process?
- Acting: besides monitoring and reporting, it is valuable to act upon the footprint data. How is the data being analysed and what tools are available to the user to support reduction initiatives. How thoroughly are these actions planned and does the CMS keep track of the progress?
- Accounting: does the CMS offer functionality for accounting of energy and carbon offsets and allowances trading?

Concerning the implementation, the CMS packages have been compared on:

- User management: can user roles or workflows be specified?
- Data entry: how can emission data be collected and entered into the IS?
- Integration: is the CMS able to communicate with other IS and is integration with supply chain partners possible?
- Deployment: is the IS deployed locally, web-based or provided as a SaaS solution?

The tables on the following pages show an overview of the functionalities and implementations of all selected packages. The goal of these tables is to acquire a general view. We have not strived for 100% completeness and therefore a blank cell does not necessarily mean the corresponding functionality is not supported. It may just as well mean we were simply unable to find information on the topic. ProcessMap is described in Appendix A, but has been excluded from the table because it provides little information on its IS.

	Camco	CarbonView	Enablon	Enviance	Greenstone	Hara	IHS/ESS	Johnson	PE Int	SAP CI
Approach										
Protocol	GHG	++	++	++	++	++	++	GHG	++	GHG
Emission factors	IPCC		++	++	++	++			++	++
Scope of emissions	GHG	GHG	GHG+	GHG	GHG	GHG	GHG+	GHG	GHG+	GHG
GHG vs Eco	Eco	GHG	in/ex	in/ex	in/ex	Eco	in/ex	GHG	Eco	Eco
Footprint calculation										
CCF	v	v	v	v	v	v	v	v	v	v
PCF		v				v	v		v	v
Process		v			v	v	v		v	v
Departments	v	v	v	v	v	v	v	v	v	v
Distance calculation					v					
Change management			v				v			
Monitoring										
Dashboards	v	v	v	v	v	v	v	v		v
Static / live	live	live	static	static	static	live	live	static	static	live
Alerts		v		v						
Calendar				v						
Reporting										
Office formats	v	v	v	v	v	v	v	v	v	v
Compliance formats	CRC	v	v	v	v	v	v		v	v
Auditing		v	v	v	v	v	v		v	v
Sharing	v				v	v		v		
Acting										
Data analysis	auto	man	man	man	man	auto	man	man	auto	man
Benchmarking in/external				int	int	ext	ext	int		int
Forecasting		v	v		v	v	v	v	v	
Scenarios			v		v	v	v		v	
Reduction planning		man			man	auto	man			man
Targets	v	v	v	v	v	v	v		v	v
Financial impact	v	v			v	v	v			v
Risks		v				v				v
Progress		v		v	v	v	v		v	v
Accounting										
Energy	v		v				v			
Offsets		v	v				v			v
Allowances		v	v	v			v			v

Table 4: Overview of CMS functionalities.

	Camco	CarbonView	Enablon	Enviance	Greenstone	Hara	IHS/ESS	Johnson	PE Int	SAP CI
User management										
User roles	v	v		v	v		v		v	v
User workflows		v		v						
Data entry										
Manual	v	v	v	v	v	v	v	v	v	v
File upload		v		v	v	v	v	v	v	v
Automatic	v	v	v	v	v	v	v		v	v
Mobile devices	v			v			v			
Integration										
IS in general	v	v	v	v	v	v	v		v	v
TMS		v			v					
Energy meters	v					v				
Supply chain		v				v			v	v
Deployment										
SaaS		v		v	v	v	v			v
Web-based	v		v				v	v	v	
Local			v				v		v	

Table 5: Overview of CMS implementations.

It appears that most CMS vendors support footprint calculation according to different protocols and using various emission factor sources. Since several companies have a background in environmental management systems, most offer more functionality than just emission management. Examples are utility and waste management, which are either included in the package or available via a separate module.

Considerable differences in the level of sophistication were found concerning footprint calculation, monitoring and acting. Most vendors stick to corporate footprints, resulting in static, for example monthly, information. Others support product footprints as well and are able to update the information more or less real-time. Looking at the decision support tools they vary from simple target setting and progress tracking to reduction plans with scenarios, financial impacts and benchmarks against other departments or companies. Finally, some packages include accounting functionality.

Comparing the implementation most vendors offer user management to some extent. Almost all CMS packages support digital data entry and integration with existing IS. A few vendors go further and allow for integration with supply chain partners, for example to let a contractor enter the emissions he is responsible for directly into the CMS. The most common deployment type is to offer subscriptions to the CMS on a SaaS basis. Other vendors sell their packages web-based, of which some offer local installation as well.

Some outstanding features worth mentioning here besides Appendix A are:

- Monitoring other polluting emissions, like NO_x or particle matter, as supported by Enablon, IHS and PE International
- IHS's and Enablon's change management features to adapt footprints after changes in protocols or emission factors
- Generating alerts when mandated reports under regulations are due, by CarbonView and Enviance
- Hara's benchmark database, which aggregates reduction plans and results from their clients
- Supporting data entry through mobile devices, like Cambo, Enviance and IHS do
- Integration with specific systems as Transport Management Systems (CarbonView, Greenstone) or energy meters (Camco, Hara)

Overall, the CMS packages of IHS/ESS, Hara and CarbonView can be regarded as the most sophisticated, with a wide range of functionalities and some outstanding features offered on a SaaS basis. However, it is also clear that all vendors target the average company, emphasizing corporate footprint reporting and aiming for energy saving plans. Only CarbonView and Greenstone mention integration with TMS, with the latter adding integrated distance calculation to this. Still, these are only some aspects relevant in transport business. The solutions reviewed do not qualify for transport companies desiring accurate footprints of their transport services.

3.7 Conclusion

With green business becoming an important corporate strategy, initiatives for green IT practices were undertaken to support this goal. While green IT helped to reduce the environmental business impact (eco-efficiency), green IS manifested itself as contribution to making whole businesses more sustainable (eco-effectiveness).

Section 3.3 reviews the literature on the drivers of Green IT/IS. Solid theoretical frameworks supported by modest questionnaires give a good impression of green drivers in practice. Our conclusion on this topic is that bottom line considerations are so evident in the survey results that before going green most organizations will wait for visible success of environmentally inspired early adopters or until normative or legal pressures force them.

Section 3.4 shows that logistics is a sector that can benefit from green ICT solutions and section 3.5 introduces Carbon Management Software as an example of such solutions. A CMS basically supports quantification of carbon emissions and gaining insight in reduction opportunities. Relating CMS implementation at logistics service providers to the theoretical adoption factors learned that there is a solid base for such a solution.

Finally a CMS market survey was conducted and discussed in 3.6. The survey shows that the solutions are quickly maturing, but that most vendors are focussed on providing corporate footprints for the average company. No CMS qualifies for thorough product footprinting of transport services. Therefore the conclusion is that a CMS specialized for transport companies is a valuable addition to the existing base. In the next chapter we develop a reference architecture for a Carbon Management IS for LSPs. The general characteristics of existing CMS solutions provide an answer to research question 2a) and are a valuable input for the architecture to avoid designing too narrowly scoped.

4 Transport Carbon Management IS Reference Architecture

While the previous chapter explored green information systems and carbon management software in general, this chapter presents a reference architecture of a CMS for the transport industry. The first section seeks a definition of what a reference architecture is. Section 4.2 describes the approach to develop the reference architecture: its content, the design principles and the modelling language. The first part of the content is the business domain. Section 4.3 provides insight in the transport industry and especially the transport process to learn which activities cause carbon emissions, and what constituents form a transport product carbon footprint. The transport IS domain is explored in section 4.4 to find out how the transport process can be supported and monitored by information systems and what data is available to calculate the emissions from. Finally section 4.5 presents our reference architecture. It first summarizes the key functionalities that can be expected from a Transport CMS, then discusses the business, application and technology layer, ending with some basic guidelines on how to instantiate the reference to a concrete architecture.

4.1 Definition of and criteria for a reference architecture

Before starting with the development of our reference architecture (RA), it is necessary to get a clear view of what it is. Several definitions of a reference architecture exist in literature and practice. The World Wide Web Consortium (W3C, 2004) gives the following definition:

A reference architecture is the generalized architecture of several end systems that share one or more common domains. The reference architecture defines the infrastructure common to the end systems and the interfaces of components that will be included in the end systems. The reference architecture is then instantiated to create a software architecture of a specific system. The definition of the reference architecture facilitates deriving and extending new software architectures for classes of systems. A reference architecture, therefore, plays a dual role with regard to specific target software architectures. First, it generalizes and extracts common functions and configurations. Second, it provides a base for instantiating target systems that use that common base more reliably and cost effectively.

Bass et al. (2003) first define a reference model as a division of functionality together with data flow between the pieces, and then arrive at the following definition:

A reference architecture is a reference model mapped onto software elements (that cooperatively implement the functionality defined in the reference model) and the data flows between them. Whereas a reference model divides the functionality, a reference architecture is the mapping of that functionality onto a system decomposition. The mapping may be, but by no means necessarily is, one to one. A software element may implement part of a function or several functions.

Greefhorst et al. (2009) have compared various definitions and concrete examples of RAs. Furthermore they held a workshop at a national architecture seminar to develop a common view. They propose the following definition:

A reference architecture is a generic architecture for a class of systems, based on best practices.

They point to the IEEE definition of architecture (IEEE, 2000) from which a reference architecture inherits several aspects:

The fundamental organization of a system, embodied in its components, their relationships to each other and the environment, and the principles governing its design and evolution.

So a reference architecture according to Greefhorst et al. is generic in the way that it is an abstraction from a concrete architecture. It describes components but these need to be instantiated or selected for a specific system. An RA does not prescribe any instants. However, it does provide principles and guidelines on how to translate the generic structure to a concrete architecture. The definition is valid for a class of systems and not specifically for one instant. It is thus reusable. Furthermore an RA does not only cover software systems, as opposed to the definitions from the W3C and Bass et al. Other systems like organizations are included as well. Finally, a reference architecture is based on best practices. Its principles need to be widely accepted and proven in practice.

Reviewing the definitions the reference architecture for transport carbon management IS should be:

- A generic architecture of the components of a system in the transport domain providing the functionality to manage carbon emissions.
- A map of its possible relationships to and interfaces with both the business and technological environment.
- Based on best practices and including guidelines on how to instantiate the reference to a concrete architecture.

4.2 Approach for developing our reference architecture

The previous section ended with a view on what our reference architecture should fundamentally look like. This section explains our approach to design the RA. First we describe the steps to develop the content of the RA. Then we discuss the design principles and finally we select the modelling language used to express and present the reference architecture.

4.2.1 RA content development

The first step is insight in the transport business domain. What does a transport look like, what activities do LSPs perform in order to transport a shipment from A to B? And what kind of emissions are caused by these activities? The following section digs into the transport process. The footprint protocols discussed in chapter 2 provide guidelines on what emission drivers to include in the footprint.

The second step is to gain insight in the transport IS domain. What systems support the transport activities and what systems can provide data for emission calculations? What interfaces are used to exchange this data? Section 4.4 provides an overview of transport information systems.

The third step is to build upon best practices. To our knowledge this is the first attempt to design an architecture for transport emission calculation using actual fuel consumption values. However, LSPs will not only have the desire to perform these calculations. Corporate footprints and general reduction strategies should be supported as well. As shown in chapter 3, several general CMS solutions are available on the market. The most common functionalities extracted from our market overview can be regarded as best practices. Such key functionalities should be supported in any CMS and thus are also included in the reference architecture.

The fourth and last step is to unite the business, IS and IT domains and to bridge the gaps between them. From the transport business domain and carbon footprint protocols key functional requirements can be derived. IS modules to provide the desired functionality have to be defined, as well as the infrastructure enabling them. Insight in the transport IS domain shows what systems the CMS can integrate with to acquire necessary data, minimize overlap of functionality and deliver relevant information. Altogether the combination of these aspects form the reference architecture.

4.2.2 RA design principles

Besides deciding upon what to include in the reference architecture, another issue is according to what principles it is designed. A quick survey on some reference architectures presented in the literature showed that academics often do not follow a standard modelling technique, but merely use basic block diagrams and own descriptions. However, in order to develop a sound RA it is preferred to comply to a standard modelling technique.

Several architecture frameworks have been developed over time. They are usually intended to support the structured design of an enterprise architecture (EA) or software system. We consider such standards useful to develop a reference architecture as well. Especially enterprise architecture is closely related, since it describes a broad structure of business entities and processes, their relationships to each other and the environment, and the IS and IT supporting them. Some well-known frameworks are the Zachman Framework (Zachman, 1987), Kruchten's 4+1 View Model of Software Architecture (Kruchten, 1995) and The Open Group Architecture Framework (TOGAF, 2009). The following paragraphs briefly describe each framework.

Zachman presented his framework in 1987, which is considered as the first attempt to accumulate all aspects of an IS architecture. It is a matrix with perspectives as rows and aspects as columns. For an enterprise architecture these can be translated as follows. The perspectives are contextual (scope), conceptual (enterprise/business), logical (information system), physical (technology), and as built (deployment). The aspects are what (data), how (function), where (network), who (people), when (time) and why (motivation). The cells show the outcomes for each question to each perspective, which form the elements of the overall architecture. The Zachman framework does not provide a methodology to develop the architecture (Zachman, 1987).

The 4+1 View Model also uses several viewpoints to represent a software architecture. These are the logical (functionality), process (software tasks), development (software management) and physical (mapping of software onto hardware) views. The fifth view then illustrates the architecture formed by the previous four by presenting scenarios or use cases. They can be used to test an instant of the architecture, to initiate an iterative architecture development (Kruchten, 1995).

TOGAF provides a framework for the design, implementation and evaluation of enterprise architectures. It distinguishes four architecture domains:

- Business: the organization and its key business processes.
- Applications: the individual application systems, their interactions and relationships to the business processes.
- Data: the structure of the organization's logical and physical data assets.
- Technical: the hardware, software and network infrastructure supporting the deployment of business, application and data services.

TOGAF's Architecture Development Method is an approach for the development of an EA. It consists of a multi-phased cycle to develop the inter-related Business, IS (comprising Data and Application) and IT Architectures, which together form the overall architecture (TOGAF, 2009).

Tang et al. (2004) present a comparison of six architecture frameworks, analyzing their goals, inputs and outputs. The three frameworks described previously are included. Their analysis shows that TOGAF is the most complete framework. It completely matches with almost all criteria. Zachman's framework does not result in a graphic overview of system components and the environment, which is considered a must for a reference architecture. The 4+1 view model is too much focused on software architecture development. A major drawback is that it neglects the environment of the system under development. Furthermore the latter two both lack a detailed description of the process to develop an architecture.

4.2.3 RA modelling language

The final methodological aspect to consider is what modelling language to use. A first alternative is the Unified Modelling Language (UML). This is a globally used language to create models of software systems. It defines several diagram types to visualize amongst others business processes, system structure, environment and interactions, databases and physical deployment. These diagrams cover all aspects of a reference architecture. However, they remain separate diagrams, which cannot be combined in one model.

A second alternative is ArchiMate (2009). This is an open and independent enterprise architecture modelling language. Its enterprise scope means that it describes the structure of an organization, its business processes, information systems and technical infrastructure as well as how these components operate and interact. ArchiMate cannot match the global fame and use of UML, but its advantage over UML is that all these aspects are naturally combined in a single diagram. Such a diagram consists of three connected layers: business, application and technology, integrating the aspects of information, behaviour and structure. An overview of these concepts can be seen in Figure 8 on the next page. The model is service-oriented; i.e. the higher layers use services provided by lower layers.

It is clear that ArchiMate matches well with TOGAF. ArchiMate is nowadays hosted by TOGAF and complements the framework. Both TOGAF's development method and ArchiMate distinguish the same enterprise layers. Altogether we consider ArchiMate the best option to model the reference architecture. More specific we use BiZZdesign Architect (2010) to draw the diagram. Now that the goal and approach for the RA are clear, the next section describes the transport business domain in detail.

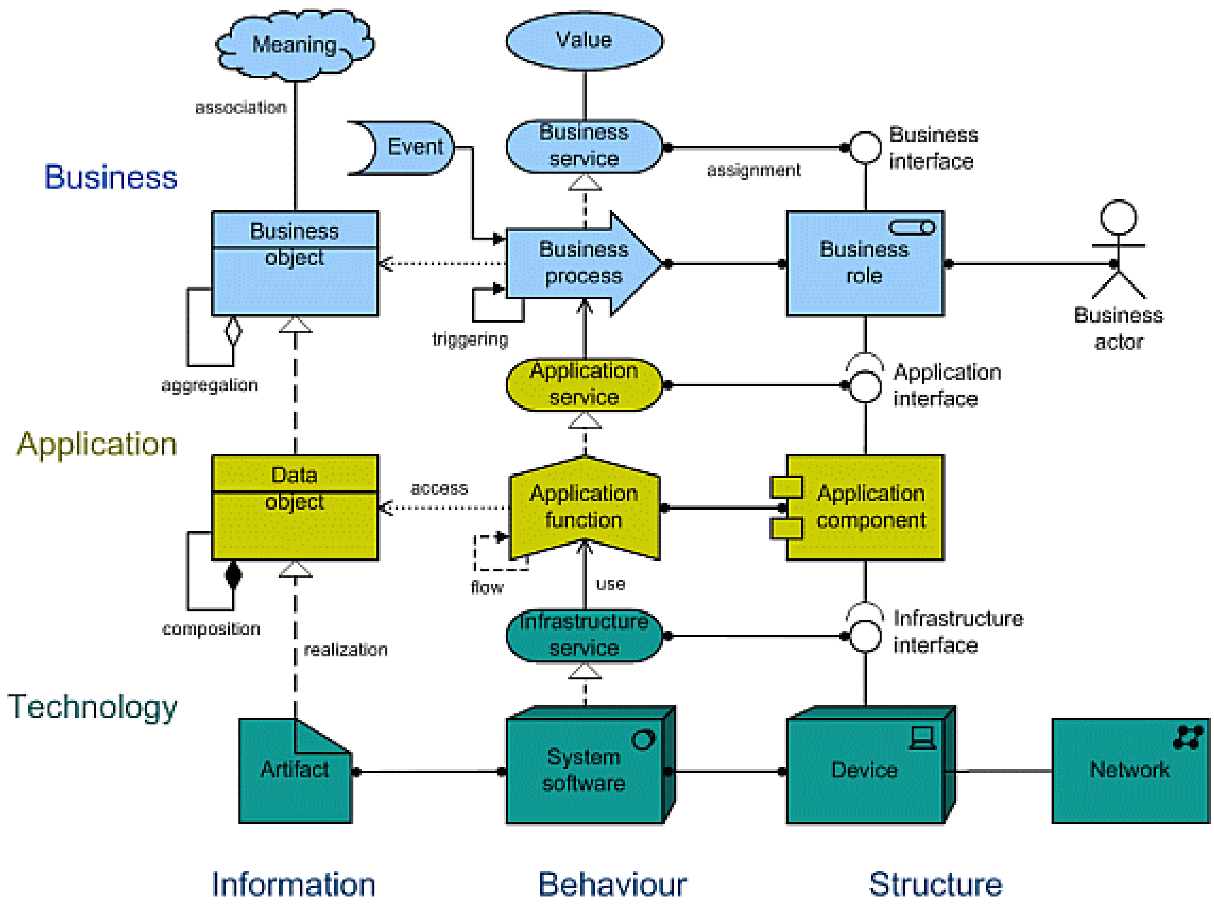

Figure 8: ArchiMate concepts (source: www.archimate.org).

4.3 Transport business domain

This section discusses the transport business. First we give a short introduction to what a transport is, which parties are involved and which terms are common in the transport domain. Nexus (2010) maintains an extensive glossary of logistics terms. Then we dig into the various order types and how a transport route can be constructed of several intermediate legs. These aspects show that a transport carbon footprint has to be constructed from various intermediate footprints as well. Section 4.3.3 is devoted to special equipment that may be utilized during road transport, contributing additional emission sources. Next (section 4.3.4) another dimension of transport is discussed: transport over different modalities. These domain insights have been gathered through discussions with CAPE consultants, the Master thesis of Van der Veeken (2009), who completed an earlier Master assignment at CAPE Groep, and the Handbook of Logistics by Rushton et al. (2006). After this general information section 4.3.5 provides a step by step analysis of a transport process, describing typical transport activities and their related carbon emissions. This way all the ingredients of a transport product footprint are covered.

4.3.1 Outline of a transport process

A transport is the movement of goods from one location to another. Transported goods are freight, also called cargo. A shipment is a concrete amount of freight. The party that performs the transport is the carrier. The carrier is often a transportation company, or logistics service provider in general. Its clients are shippers. The shipper orders the transport of a shipment and pays for it. The shipper may or may not be the consigner and/or the consignee of the shipment. The carrier collects the shipment at a pick-up location of the consigner and delivers it at a drop location of the consignee.

For executing the transport, the carrier uses equipment and staff. In case of road transport, a truck driver drives a vehicle. This if often a combination of a driving unit, also called pulling unit, with a freight unit, also called pulled unit. The most common example is a truck with a trailer. In the following sections these are often used exemplary for the used equipment. However, other configurations are also possible, f.e. containers on a chassis, an extra dolly, road tankers or vans. As part of the process, handling of the freight is often required. Handling includes loading and unloading of freight. This may also take place at a transhipment facility of the carrier, when it transports the shipment in more than one stage. In this case warehousing and value added services may be carried out.

A carrier may outsource (part of) the transport to a subcontracted carrier, also called charter. A third party logistics (3PL) provider is a business offering a variety of services, including warehousing and all kinds of freight handling. The following sections describe the transport process in more detail from the viewpoint of an order. Except as otherwise noted the carrier is assumed to use own equipment.

4.3.2 Order types

Basically two types of orders can be distinguished: Full Truckload (FTL) and Less than Truckload (LTL). In case the order comprises a substantial amount of freight or the shipper desires exclusivity, this is regarded as an FTL. Usually a truck picks up the freight at the consigner and drives directly to the consignee to deliver the shipment. Obviously there are limitations to the hours of service for the truck driver, which delays the transport. However, no freight handling is required during transport, since the shipment is not routed via transhipment facilities. This fastens the transport and reduces the risk of damage or loss.

A special case of FTL is when the trailer (or container) is transported as a whole, sometimes called Trailer Trucking. A truck picks up the trailer at the consigner and delivers it to the consignee. In this case the driver only has to (un-)couple the trailer as opposed to (un-)load the freight.

Another case where an order is FTL by nature is bulk freight. The volume determines the number of bulk holds necessary and the transport is usually billed to the volume or weight. Special freight units are necessary for bulk transport, like a silo trailer behind a truck or a tanker for sea transport. Bulk transport also requires special handling like cleaning of the freight unit and pumping of freight in and out of a hold.

But often orders are of less freight than the capacity of a trailer. Medium shipments that can be combined with a few other ones are regarded as Less than Truckloads. To increase efficiency LSPs consolidate these shipments into FTLs. For the shipper the advantage is that the transport is cheaper than ordering an FTL transport. Carriers usually calculate LTLs to the space they occupy. Current units are the number of pallets or loading meters. A loading meter is a running meter of the full width (240 cm) of a trailer. Pallets are often used for stackable shipments, while loading meters compensate for lost volume for unstackable goods. When the shipper bills an LTL to its weight, the standard conversion factor is 1850 kgs per loading meter.

A drawback of LTL is that the transport takes more time, due to the fact that the route is broken down in intermediate legs between pick-up location, transshipment facilities and drop location. Three types of transshipment facilities can be distinguished:

- Home depot: the depot from where a transport starts. From here shipments are collected from consigners in the vicinity, grouped and forwarded.
- Hub: intermediate transshipment facility where shipments are regrouped and forwarded to common destination areas.
- Away depot: the final transshipment facility a shipment passes. Here shipments for consignees in the vicinity are grouped and delivered in a short run.

It must be noted that any transshipment facility could be each of these types, depending on the viewpoint of a specific order.

First a truck picks up shipments at one or more consigners at a pick-up run. When an empty freight unit needs to be transported to the location of the goods this is sometimes called positioning. The truck may return to the home depot where the shipments are unloaded and sorted. Shipments to be delivered in the same area are collected and loaded in a trailer. A truck transports this trailer over a long haul to another depot. Here the shipments may be sorted and grouped again to achieve maximum efficiency in the following legs. This process may be repeated over several hubs. Finally shipments for consignees located closely to each other are delivered in a short route. The various routing alternatives are presented in a diagram below.

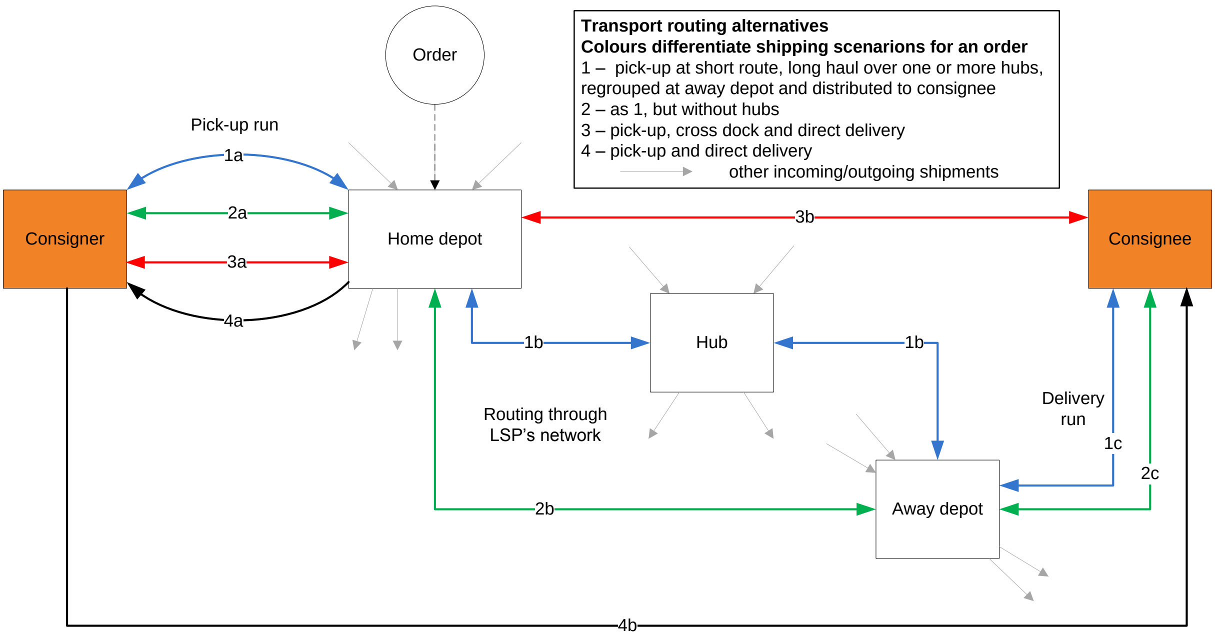

Figure 9: Transport routing alternatives of a shipment.

The model presents the four main routing alternatives for a shipment belonging to an order administrated at a home depot. In general the smaller the shipments, the more hubs it is routed through. Often different vehicles are employed for various legs. The begin and end arrows indicate that the vehicle may make a round trip while the shipment travels one way. In scenario 4 the truck will probably drive to the closest depot or hub after deliverance at the consignee. As described before a truck may travel to and from several consigners and consignees in one round trip, but the scope of this model is the routing of a single shipment. It is clear that LTLs require a lot of freight handling and that calculating the emissions for a shipment is more complex than simply monitoring the fuel consumption of a single trip.

Finally small orders consisting of just one or a few items weighing no more than a few hundred kilograms are considered parcels, with the corresponding transport regarded as parcel carrying or dense distribution. Parcels are usually billed to their weight. Routes may cover even more hubs and dozens of parcels are combined in a truck or van. The transfers and loading and unloading take more time than the driving itself.

In practice these distinctions are not as strict as they are presented here. Carriers striving for maximum equipment utilization will not hesitate to combine a few LTLs with some parcels when it turns out to be the best alternative. Furthermore they may deploy their equipment in various ways on a single route. For example a truck may first carry an FTL, deliver it at the consignee and on the way back pick up some LTLs.

4.3.3 Special equipment

The type of equipment used to fulfil a transport also depends on the freight characteristics. An important factor is whether or not the freight needs to be refrigerated during the transport. Three conditions can be distinguished: ambient, chilled and frozen. Refrigerated trailers, also called reefers, are used for conditioned transport of large shipments. The freight is usually cooled with a vapour compression system. Small amounts of refrigerants may leak from such systems. HFC-134a, a widely used refrigerant, has a very high global warming potential, contributing to the overall emissions. In most large vehicles an auxiliary diesel unit powers the compressor. The reefer has its own engine and a separate diesel tank (Tassou, De-Lille, & Ge, 2009). In The Netherlands it is allowed to use so called red diesel for refrigeration units. The excise duties for red diesel are lower than for normal diesel. There is no difference in the substances except for red dye added to visibly distinguish the diesel types. In the majority of vans and in some fixed truck combinations however, a direct belt from the vehicle engine drives the compressor. So in this situation no separate diesel tank is used. In either case the vehicle consumes additional diesel resulting in extra CO_2 emissions.

Figure 10: Truck-mounted forklift.

Depending on the cargo type and the facilities at the drop location, additional equipment may be required on the truck. Examples are truck-mounted forklifts (also called moffett or kooiaap after the leading brand, see figure) and loader cranes for loading and unloading of the freight. Forklifts can be powered by a combustion engine consuming diesel or LPG, or electrically with a battery. Obtaining reliable consumption figures for a single usage may be difficult, therefore an average consumption could be allocated as overhead. Loader cranes are often powered hydraulically, indirectly consuming diesel from the main tank. Finally, some equipment is attached to a truck via a power take-off (PTO). This is a mechanical or hydraulic system to drive external machines drawing energy from the vehicle's engine. They are thus consuming additional diesel as well. Examples are a winch on a tow truck, the bed of a dump truck and the compacter of a garbage truck.

4.3.4 Modal shift

While the previous paragraphs focus on road transport, the situation changes when various modalities are used to transport goods. For various reasons air, water or rail transport may be preferred over road transport. Possible reasons are to bridge long distances, to transport large volumes of freight or fast delivery by air transport. Water and rail transport are generally cheaper because they can ship larger volumes per trip and therefore they also cause less carbon emissions per ton of transported freight. Air transport both is more expensive and causes more emissions, due to the high fuel consumption.

The two forms of transport over more modalities are multimodal and intermodal transport. Multimodal means only the freight changes modality. It is for example unloaded from a truck at an airport and loaded into an airplane. Intermodal means the freight unit changes modality without handling the freight itself. For example when a truck crosses a sea on a ferry or when a container is taken from a truck chassis and put on a freight train wagon. In the latter case so called vertical handling at a terminal is required and often operated by a crane. When a truck has delivered freight to a terminal and returns empty to a location of the LSP, this trip is called empty repositioning.

The diagram below shows another model of transport routing alternatives. Here the focus is on the various movements of driving and freight units, including modal shift. Again the assumption is that incoming orders trigger transport movements starting at a home depot. In practice, a truck driver

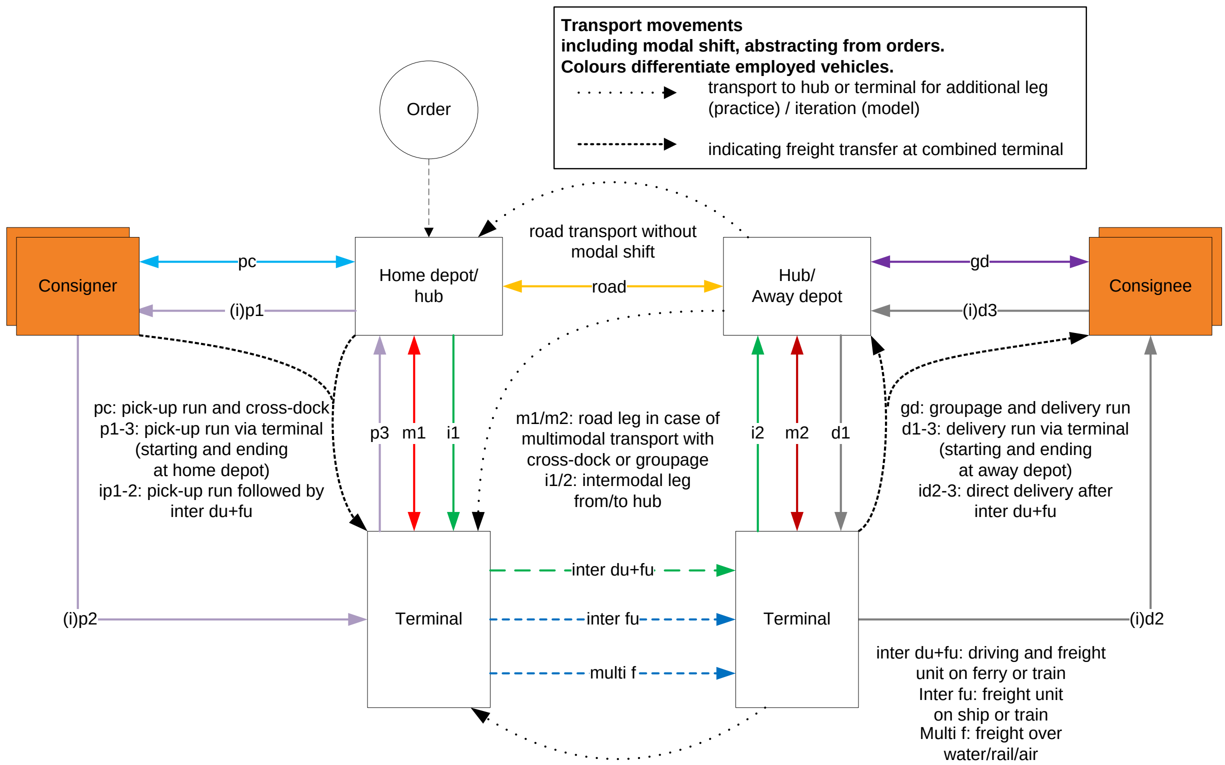

Figure 11: Transport movements including modal shift.

might depart from his own home, when he had a truck parked there overnight. The home depot in the model could be regarded as home of the truck driver for this situation. The same applies with the away depot in the comparable case that a truck drivers goes home after a delivery.

Trucks transporting several LTLs may visit multiple pick-up and/or drop locations in one round trip. However the model abstracts from this practice, depicting the locations as groups of consigners or consignees. Like in the previous model, legs with a begin and end arrow indicate that a truck empty (re)positions itself after dropping or before picking up a load. A terminal is a location where a modal shift takes place, e.g. a container terminal in a port, a rail terminal or an airport. In some situations a depot or hub may be a terminal as well, for example when an LSP operates a depot at an airport or has a hub connected to the rail network. Likewise the consigner or consignee may have a combined warehouse/terminal. However, in this model hubs and terminals are separate entities. Dashed arrows represent a combined situation, indicating freight transfers and handling between modalities. The rare occasions where the first pick-up run or final delivery run includes transport over another modality has been left out of this model for clarity reasons.

When a transport includes legs over multiple modalities, calculating emissions becomes even more complex than road transport over multiple hubs. Since in most cases the LSP will not operate the train, ship or plane itself, it has to gather information on energy consumption from the charter.

So to arrive at a transport carbon footprint it is on the one hand necessary to divide footprints from a single leg to the shipments transported in that leg and on the other hand to aggregate footprints from multiple legs. Furthermore emissions from other sources, like standalone special equipment or activities supporting the actual transport, have to be added. The next section discusses the full lifecycle of a transport including related carbon emissions.

4.3.5 Transport process

In an earlier Master assignment carried out at CAPE Groep, Van der Veeken (2009) extensively models the general process commonly in place at transport companies in relation to board computer requirements engineering. He based the reference process on literature, board computer documentation and interviews with CAPE consultants and transport company employees. One of the sources was a transportation reference process and model developed by Capgemini (2007).

We use these reference processes as a basis, see Figure 12 for the high level business process model. Execution support and finishing have been left out of the description, since the focus of these steps was the board computer communication (during the executing the driver is supported by employees at the home base) and logging off (registering final trip date) to finish an execution. Obviously our focus is on carbon emissions caused by the activities performed as part of the process. The process descriptions in the following sections therefore mention to what extent emissions occur. We relate to the PAS 2050 protocol (BSI, 2008) for product carbon footprints which defines what emissions should be included in the footprint. Appendix B contains excerpts of the protocol that are particularly relevant for transport services. The adaption and focus of the process steps are based on literature, conversations with CAPE consultants and a visit to Jan de Rijk Logistics.

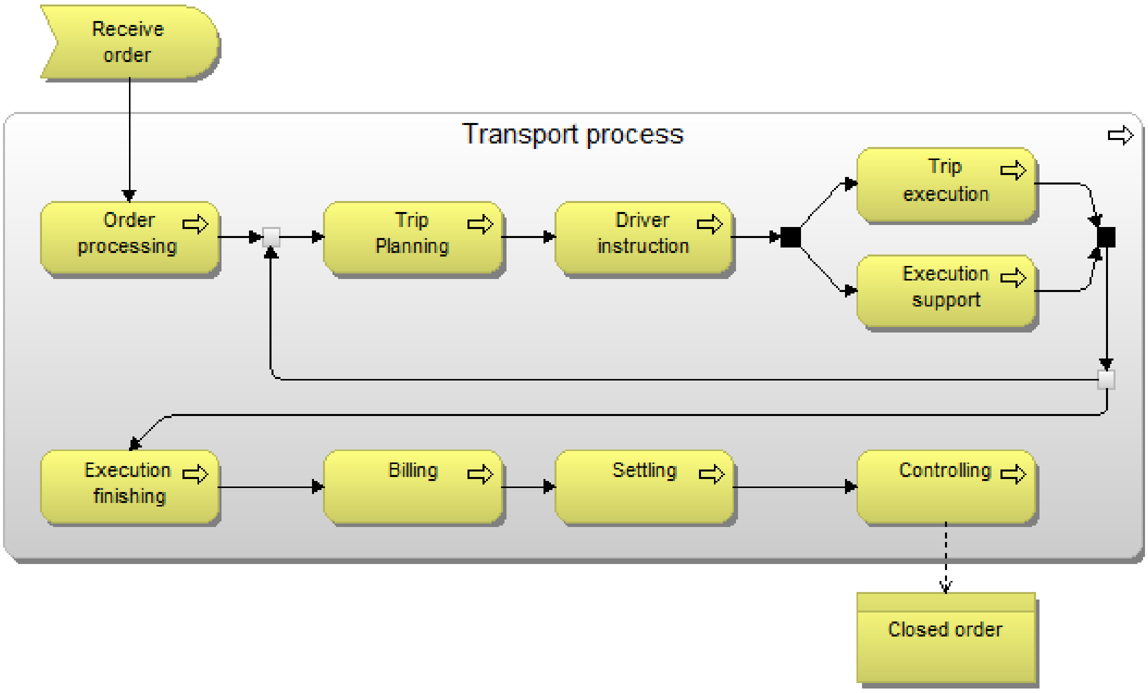

Figure 12: High-level transport business process.

4.3.6 Order processing

The transport process is triggered by the receipt of an order. A customer may pass an order via telephone, e-mail or a data link. An employee at the LSP's office registers the order, possibly after negotiating with the customer. As defined by the PAS 2050 protocol, the order receipt is the first step in the life cycle of a transport service. The employee uses electric devices. The electricity used causes carbon emissions (indirectly, the actual emissions take place at the power plant). Measuring the exact amount of electricity used for an order is very cumbersome. Therefore a better option is to regard these emissions as overhead and allocate them to a particular transport order using a method like activity based costing. Already at this stage, the shipper may desire a forecast of the emission caused by his order. The carrier could provide an estimation based on freight characteristics, distance to travel and expected equipment deployed for the trip. Such an estimation could also be useful to consider a modal shift for part of the transport.

4.3.7 Transport planning

Planning a transport (trip in Van der Veeken's model) contains several sub-activities. The first is Load Planning. To maximize equipment utilization LTL shipments are consolidated to FTLs. The carrier makes a schedule of pick-ups and deliveries in the same area that can be combined within time constraints set by the shippers. Load planning may also involve selecting the right transport modality: by truck, by train, by air or by water.

After the load, the fulfilment has to be planned. The carrier decides how the load will be moved. The first decision to take is whether to use own equipment or to subcontract another carrier. Carriers may have regular partners for certain areas, otherwise tendering and carrier selection may be part of this process. When the LSP uses own equipment the planner has to allocate resources to the transport. This means assigning the specific equipment, driving and pulled unit, and a driver for the trip. This could be a new trip starting from the home depot, but an order may also be added to a transport already in execution. The decision is constrained by the location and hours of service of a driver and the location and capacity of the equipment.

Load design is the process to define the optimal way to store the freight within a trailer or other transport medium. Criteria for the load design are the sequence of drop and pick locations on a route, to minimize loading and unloading, and the freight characteristics, such as stackability, to maximize the load factor.

The last step of the transport planning is to plan the actual trip. The optimal route is planned based on geographical maps and/or predefined routes and legs. Thus, as opposed to load planning that defines the locations to be visited, now the exact route is planned. Factors to take into account are for example distances, road types and expected loading times.

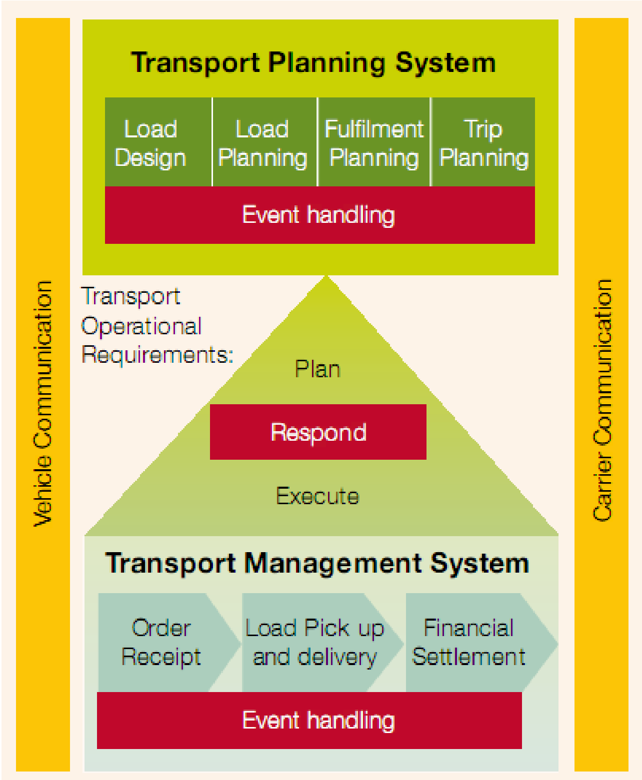

Figure 13: Transport reference process by Capgemini (2007).

Like the order processing, the transport planning is performed at the office with the support of various IT. The electricity used may be allocated as overhead to a transport order.

4.3.8 Driver instruction

Based upon the fulfilment plan, the driver (or carrier) needs to be informed. An employee collects all the trip details and sends the instructions to the driver. The information includes the vehicle to use, locations to visit, timeslots, shipment details, additional activities to carry out, and any other relevant remarks. When a carrier is subcontracted, the plan should be confirmed and details about the deployed vehicle may be provided at this point. Again, some energy is used at the office, which can be allocated as overhead. When the truck driver is at home he needs to travel to the home depot of the LSP. However, PAS 2050 excludes GHG emissions associated with commuting of employees from the system boundary of a product lifecycle.

4.3.9 Trip execution

After the transport has been planned and the driver is instructed (assuming the LSP deploys own equipment), he can start his trip. The first activity for a truck driver after entering the truck is to log on at the board computer and identify himself. Usually the truck driver registers the mileage and if relevant information on the vehicle status. To define the exact start of a trip to be allocated to a transport, there are several scenarios:

- Starting a new trip from the home base of the LSP
- Starting a new trip from the home of the truck driver

    - Firstly driving to the home base
    - Directly driving to the pick-up location
- Starting a new trip from a location "on the road"
- Adding a trip to another trip currently in execution

Calculating PCF emissions should only start when the truck is deployed for an order, so in all scenarios except the one where a truck driver drives from home to work. However, such trips should be included in a CCF an LSP may want to calculate. The same holds for another scenario. Occasionally a truck driver may be instructed to drive to a certain area in anticipation of incoming orders from consigners in that region. This part of the trip cannot be allocated to a shipment. Allocation starts when a truck driver starts a trip directed to a pick-up location (the "on the road" scenario).

If the freight needs to be refrigerated the driver has to start the refrigeration unit at some stage. The reefer has to be at the desired temperature before the freight is loaded, but starting it early wastes energy. Depending on the expected load time, the driver will start the refrigeration before leaving, during his trip to the pick-up location or at the pick-up location. From this moment the refrigeration unit consumes diesel from its own or from the pulling unit's diesel tank.

Usually the truck needs to be driven empty from the home base to the pick-up location(s) first. However, it may also depart loaded in case some transports are combined in one trip. Assuming the first case, the driver starts the navigation and is presented the route to follow. When he is ready to leave, the driver starts the engine. At this moment the fuel consumption starts, which is the main carbon emission cause. Positioning is considered part of a transport service and is therefore included in the footprint calculation. While driving, the consumption rate depends on the speed, road characteristics, load weight, etc. During the trip, the truck may face delays, for example due to traffic jams. After a while the driver will stop driving and stop the engine at a certain destination. At each of these moments, the fuel consumed and preferably the distance travelled in the finished part of the trip has to be calculated to allocate it to the shipments. Fuel consumption can be determined via a combination of sensor data on fuel levels from the motor management system and board computer data on refuelling activities entered by the truck driver. More about these systems can be found in section 4.4 that discusses the transport IS domain.

When the driver has just began his trip, the first possibility is that he has arrived at the pick-up location of the consigner. Here the shipment is collected and loaded into the trailer. The driver registers the loading and shipment details into the board computer, either manually or with a scanner. For the loading either own equipment or a forklift from the consigner is used. In case of trailer trucking, the driver couples the trailer to his truck without additional loading. The coupling itself and the shipment details are still registered, though. After loading or coupling, the truck continues its trip and drives to the next destination.

The second possibility is that the truck arrives at a transfer point of the LSP. As explained before, LTL shipments are usually transported over several hubs. From the transfer point to the next stop, the shipment may very well be transported with another truck. Also the driver may change truck or stop working, in which case he logs off and if relevant stop the refrigeration unit. At the transfer point the shipments are unloaded, checked and registered. Some transfer types can be distinguished. In case of cross docking the shipments are regrouped and then moved to another dock to be loaded in another trailer. The goods only stay in the cross dock facility for a short time. In case of a hub or depot the goods could be stored in a warehouse for some time. The LSP may add value to the shipment by e.g. packaging the product or even assembling parts. Sometimes the freight needs to be cleaned or refrigerated at the warehouse. And of course the LSP deploys forklifts, reach trucks, cranes and other equipment for unloading, moving, storing, collecting and loading the freight. Especially at a warehouse a substantial amount of energy may be consumed. For example electricity for lighting, gas for heating and fuel for forklifts could be allocated to a shipment.

A third possibility is that the driver makes an intermediate stop. He may need to rest, when his hours or service exceed his limit. When the truck crosses border, the driver has to deal with customs. In some cases the truck may require urgent maintenance. These events should be registered and taken into account, because they could influence carbon emissions or how they are accounted. While resting, the engine can normally be stopped, but the refrigeration unit has to remain operating. Activities in foreign countries might require different footprint methodology. Detouring to reach a garage should not be allocated to a shipment, etc.

In case of intermodal transport, the driver parks his truck on a ferry or train, possibly after having waited until boarding time. For this part of the trip, it is the ferry or train that consumes energy and thus causes emissions. The amounts are probably not reported by the charter. Therefore it is important to register the start and end locations so that emissions can be calculated distance-based.

Another reason for an intermediate stop is when the truck's fuel tank is empty. Refuelling itself does not cause emissions (apart from wasted fuel), but it is important to register the refuelling. The amount tanked, the mileage, fuel level before and after refuelling, the fuel station and its location, driver and truck are all data that can be used to calculate footprints and related performances. For example efficiency of a truck or driver.

The fourth possibility is that the driver arrives at the drop location. Again, if relevant, he stops the refrigeration unit. If necessary he unloads the freight with his own equipment, e.g. a moffett. In this situation the unloading is part of the transport service. Thus the emissions related to the unloading have to be included in the footprint calculation. However, according to PAS 2050 a service ends at the point of delivery. Therefore when the consignee uses its equipment to unload the shipment, related emissions do not have to be incorporated.

After unloading the driver continues his route when other LTLs are still in transport, or he returns to the home base. The PAS 2050 protocol states that emissions caused during empty return trips (or intermediate legs) have to be included in transport emissions. Therefore this last part of the trip has to be accounted as well. Finally, after returning to the home base, he logs off the board computer.

When the LSP subcontracts a charter, the amount of information that can be gathered is often smaller. When the charter is a regular partner for road transport and is using board computers, this data could be gathered like when own equipment is used. Often however, the best data transmitted is kilometres travelled and sometimes just map kilometres between pick and drop locations are available. Fuel-based calculations are always preferred. The alternative is distance-based: calculating the weight or number of pallets or containers transported over the distance travelled or if necessary map-based estimated to have been travelled. For transport over other modalities the emissions are always calculated distance-based in ton km or container km units. This also means that for a shipment transported partly using charters of any modality, the ultimate PCF is likely to be a sum of both fuel- and distance-based emission calculations. Charters add another complexity to carbon footprinting as well. For a corporate footprint, scope 3 emissions, of which subcontracted activities are an example, do not have to be included, so an LSP should always be able to differentiate on these parts of the transport's footprint.

4.3.10 Execution support

The trip execution is monitored and supported by employees at the LSP's office. If an exception occurs an employee takes action. For example when a shipment is late or a vehicle is off the road the employee contacts the driver and shipper and possibly re-plans the trip. Other supporting activities are controlling the driver's hours of service, guarding security, calling and text messaging and damage registration.

4.3.11 Billing and settling

After the transportation has been executed financial settlement with the shipper (customer) is required. If a load has been sub-contracted, there is also financial settlement with this carrier. An office employee consolidates relevant data like the time the transport took, the distance travelled, expenses made by the driver and proofs of delivery or other activities.

He also determines the fuel consumption. For this the refuelling data entered in the board computer may be matched against fuel bills from the fuel supplier. Neither motor management data nor truck drivers are always reliable. Slopes or malfunctioning probes may blur measurements and a truck driver may wrongly enter refuelling amounts or even put some fuel in a jerry can for private use. For trucks without BC fuel bills are the only source. In this case the employee allocates the fuel consumed between two refuelling occasions to the kilometres driven in the same period.

From all this data an invoice is created and sent to the shipper. The invoice is also the obvious choice to present the carbon emission for the shipment to shipper, if desired. Therefore at this stage the actual emissions of all activities associated with the shipment have to be aggregated to arrive at a product carbon footprint for the shipment. Furthermore the LSP's own accountancy is updated.

While the transport has to be paid by the shipper, the LSP has to pay its driver. In the settlement phase, the hours of service of a driver and his expenses en route are acquired. The accounts payable is updated so that the driver ultimately receives his salary. Both billing and settling are typical office activities, and like before emissions could be allocated to transports using ABC.

4.3.12 Controlling

Controlling is not really part of carrying out a specific transport, but reviews the process. It calculates and accounts KPIs like profitability, efficiency and quality of the transport. Such measures typically include hours, speed, fuel usage, engine idle time, etc. Based on these, the performance of a truck or driver can be evaluated. In our case the carbon emission is an obvious addition as KPI. Based on aggregated data, reduction opportunities can be defined. Finally, controlling could include identifying anomalies to track abuse, like unexpected amounts of fuel tanked.

Appendix C shows an activity diagram modelling the complete transport process from the viewpoint of an order. The focus is on activities causing emissions. Therefore the office activities are only included on a high level, while the trip execution is modelled in detail. Still some simplifications have been made, like the return truck activity after unloading at the recipient. Elsewhere assumptions have been made, for example that (if necessary) the refrigeration unit has been started at some moment before arriving and loading at the sender. Finally some described activities have been excluded, like additional activities at a hub. The model gives insight in the activities that need to be monitored in order to calculate footprints of the complete transport life cycle, plus possible sequences and iterations of the activities.

4.4 Transport IS domain

Now that the transport business domain has been described, the next step is to gain insight in the transport IS domain. The following sections give an overview of information systems typically present at transport companies supporting the various activities. The overview is based on information gathered from CAPE consultants, Van der Veeken's thesis (2009), which especially describes board computers in depth, and a large survey held by Transport en Logistiek Nederland (TLN, 2008).

450 members of this association responded to its survey on the use of ICT by LSPs. Full results of TLN's latest survey in 2010 have not been published. However, TLN comments on the results in a magazine article (D'Andolfi & Doppert, 2010). It reveals that ICT implementation rates have stagnated in the last two years, probably due to the economic crisis. Therefore we assume the 2008 figures still give a good indication of the current situation. We expect a CMS to be most relevant for larger LSPs for whom emission monitoring is complex and who benefit the most from reduction strategies. Therefore we refer to survey answers from respondents with more than fifty driving units. TLN's results show that the presence of IS grows with the fleet. Smaller transport companies have little IS in place, and are therefore unlikely to implement a CMS either.

4.4.1 Order Entry System

Via an Order Entry System (OES), shippers can order transports from carriers via Internet. 40% of LSPs with more than 50 pulling units are using automated order entry and the same amount intends to implement it. The advantage is that no human errors can be made during order registration and that all relevant information is acquired using a clear protocol for the order entry. Typical data that a carbon management IS could retrieve from the order entry IS are freight characteristics, like volume and desired condition, and time restrictions for the pick-up and delivery. Information a CMS could provide to an OES is a carbon emission forecast.

4.4.2 Transport Management System

A Transport Management System (TMS) supports several critical processes of an LSP and is therefore widely used. Over 90% of large carriers have implemented a TMS. It forms the administrative basis for the organization. A TMS typically stores relations with shippers and subcontractors, quotes, order and tariff arrangements. A first main functionality of a TMS is to file orders. After registering these (whether integrated with an OES or entered manually by an employee) it usually provides an initial load planning, and sometimes more enhanced transport planning. In most solutions however, a planner has to finalize the planning, or it is supported by an APS (see below). When the planner decides to subcontract another party, a TMS often covers automated carrier selection.

After approval by a planner the TMS creates the transport job and dispatches the job to the scheduled driver. For supporting the trip execution a TMS can usually communicate with board computers. It sends jobs to drivers and receives progress information, tracing events such as arrival, loading, unloading. Since all transport data is stored in the TMS another main functionality is to support the billing and settlements of transports. Furthermore a TMS usually provides management information measuring and reporting key performance indicators. For the CMS a TMS can provide route details, like locations to visit, and which shipments are combined in the truck. The emissions of a certain shipment should be delivered to the TMS, so it can be stored and presented on the invoice.

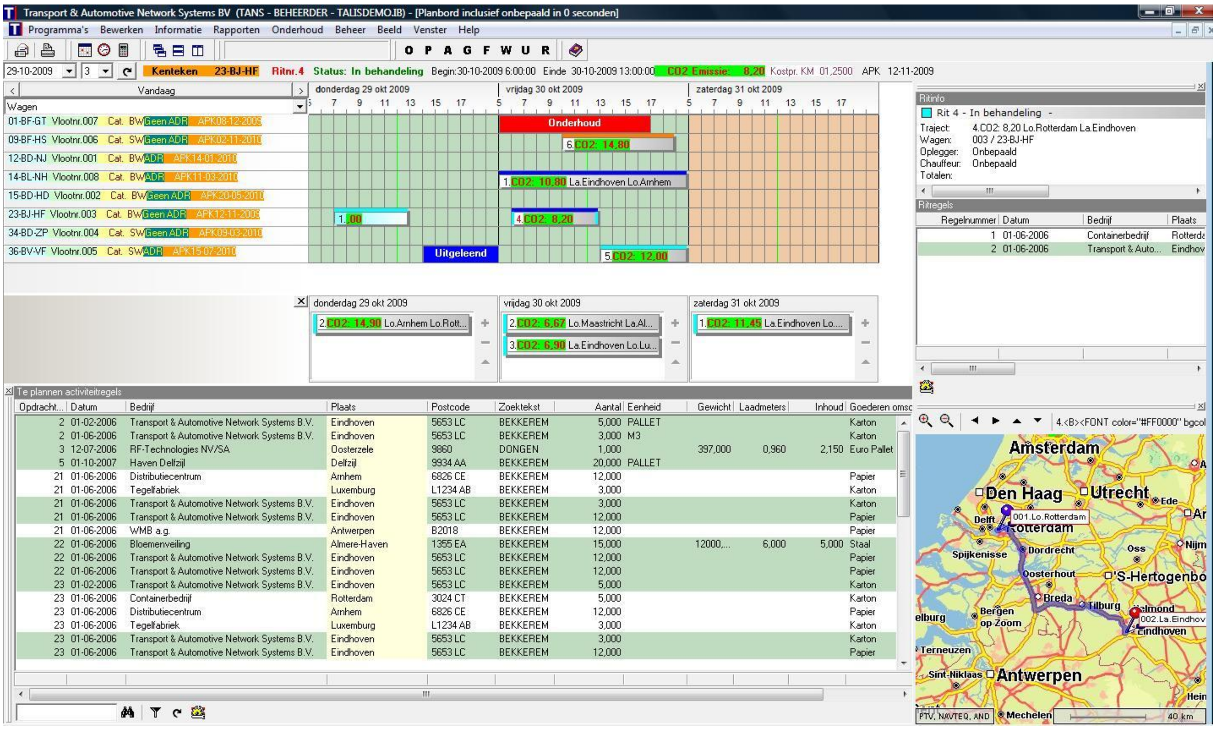

Figure 14: Screenshot of transport planning in a TMS. Source: TANS (2010).

4.4.3 Advanced Planning System

For large transport companies, with high amounts of orders, a large fleet and many constraints to cope with, the transport planning is often too complex for a TMS or a human planner. An Advanced Planning System supports all the facets of transport planning, from load and fulfilment planning to load design and finally trip planning. An APS monitors the transport real-time and is able to update the planning if necessary. In all cases, an employee still checks the proposed planning and adjusts it if necessary. Thus the final schedule is always defined by a human. About 60% of the large LSPs (over fifty driving units) has implemented an APS. The system is usually integrated with the TMS, but some solutions directly send schedules to board computers. Therefore a CMS may receive data directly from an APS as well.

4.4.4 Board computer

In the past, the planner communicated the transport planning to the truck driver by phone. The driver reported on the progress by phone as well. Files like proof of delivery and driver expenses were delivered on paper after returning at the office. Board computers (BCs) enable a more effective and efficient exchange of information. They have become very popular devices in the past decade. 95% of the large transport companies and over 50% of medium ones are using board computers. Vendors offer BCs both built-in in the truck or as mobile device. A board computer typically offers three main functionalities:

- Two-way communication between truck (driver) and office (IS/employee)
- Manual and automatic data registration
- Localization and navigation

So first board computers improve communication, supporting digital data exchange between truck and office. The driver receives the trip planning directly on the BC, instead of being contacted by phone having to take notes. Combined with a TMS or APS an employee can simply check the proposed trip planning, fine-tune it if necessary and then forward it to the BC. The BC thus requires less administrative efforts and reduces the chance of errors. The truck (driver) can send all kind of information to the office as well, as explained later.

Depending on the device’s age various communication protocols are supported. A GSM module allows for communication via SMS text messages or speech, in case a discussion or further clarification or details are desired. SMS is increasingly being replaced by more sophisticated data communication standards such as GPRS or UMTS. Data packets can be sent and received, typically in XML format. Since data exchange is cheaper than making calls, cost reduction is an advantage of board computers as well. When its trucks often visit remote areas, an LSP may opt for support of communication via satellite, albeit more expensive than land-based communication.

The second main functionality is data registration. The truck driver manually enters data on the progress of the trip execution. He typically selects an activity that he is about to start or that has just been finished, like arrival, waiting, unloading, refuelling, departure, etc. Following a question path he consequently enters details about the activity, like number of pallets unloaded, amount of diesel fuelled, etc. This data is real-time sent to the home base of the LSP, where the transport can be monitored. Based on the status updates, planning and estimated times of arrival may be adjusted. Sometimes the shipper can follow the progress too, when information systems of shipper and carrier are integrated or when the carrier offers a web-based portal to track shipments. Furthermore starting and finishing jobs by the truck driver allows for registration of the hours of service by the BC. Finally, some advanced board computers support proof of delivery by digitally signing on the screen. All this information is used for billing and settling as well, again reducing the administrative efforts.

Besides manual entries, the board computer also records all kind of data automatically. For example the mileage of the truck. A recent development is implementing an interface with the motor management system or CANbus (Controlled Area Network bus, a standard for communication between microcontrollers and devices within a vehicle without host computer). This system monitors whether the engine is running, including the speed, revs, acceleration and braking, i.e. the driving behaviour. Furthermore it monitors the fuel level with a sensor in the fuel tank. Thus fuel consumption is recorded and checked at the office, for example to educate drivers concerning their driving behaviour or to check anomalies at refuelling occasions and to notice fuel theft. Finally the CANbus can track fuel consumption by the power takeoff, if present.

Figure 15: Board computer with CANbus interface displaying driving behaviour. Source: TTM (2010).

For calculating carbon emissions of transports, the combination of board computer and CANbus is most relevant. At each activity entered in the BC, like unloading, the current fuel level is recorded by the CANbus and communicated to the CMS. This way the fuel consumption for each part of a trip can be calculated and allocated to the shipments involved. TLN did not ask shippers about the sophistication of their board computers, but according to TTM (2010) most board computers nowadays offer an interface to the motor management system via a CANbus interface.

The third main functionality is localization and navigation. Via GPS (Global Positioning System) the exact location of the truck is always known. The position is continuously sent to the home base, supporting tracking and tracing as well as planning. Often BCs contain navigation software, eliminating the need for a separate navigation device. The navigation depends on GPS. Sometimes information on traffic situations is sent to the BC, making the navigation more intelligent. Another feature that may be included is geofencing. A geographic area is marked and an alert is created when the truck enters or leaves this area. This warns a customer when a shipment is about to arrive, warns the truck driver that he should start the refrigeration unit, of warns the carrier when a truck enters an area it should not enter.

4.4.5 Cooling unit sensor

In case of refrigerated transport, a sensor system could be implemented in the cooling unit. It sometimes communicates with the board computer, but may also send its data directly to (an IS at) the home base via a wireless connection like GPRS. Unfortunately these systems often only probe the temperature and sometimes humidity in the pulled unit. More advanced sensor systems also monitor the status of the refrigerator unit (on/off) or even the fuel consumption by the separate tank of the reefer. The latter is the ideal situation for carbon footprinting, since it allows for fuel-based calculations. In most cases however, usage can only be estimated. Order data includes whether the shipment needs to be cooled. Refrigeration status could be derived from whether the sensed temperature is rising or dropping. However, this still does not ascertain the status since the outside temperature may be changing as well. An alternative would be to include the activity of starting and stopping the refrigeration in the question path of the B. TLN did not ask for the presence of sensors for refrigerated trailers. LSPs regularly transporting conditioned goods are likely to have the sensors to guard the quality. Jan de Rijk for example uses a basic sensor system to monitor the temperature.

4.4.6 Fleet Management System

An FMS stores data on the status of the carrier’s vehicles, both driving and pulled units. First it contains all the basic and factory data of trucks, such as the license plate, construction year, engine type, fuel type and average fuel consumption as reported by the manufacturer. Second it maintains historical data on the mileage of trucks, actual fuel consumption, and maintenance performed on the vehicle. Third it provides functionality for tracking and tracing of vehicles on the road using GPS, either linked to the board computer or to a simpler GPS device in the truck. This is useful to respond to events in the field, like additional incoming shipment orders and to guard security. About half of the large LSPs have implemented an FMS including tracking and tracing. About half of the driving units is actually equipped with a track and trace device.

4.4.7 Warehouse Management System

A WMS controls the movement and storage of goods in a warehouse. It directs the putaway, replenishment and picking of these goods. Furthermore it tracks the receiving and shipping of items. For emission monitoring a WMS acts as a source of information in two fields. First it helps to keep track of shipments that are transported over several hubs. Furthermore it provides stocking information. Since it stores data about which items occupy what space for how long, this information can be used to allocate energy consumed in the warehouse to the shipments. Almost half of the larger LSPs use a WMS.

4.4.8 Accounting Information System

An AIS is a general accounting system, storing all corporate expenses and revenues. This generally includes utility data, which means that this IS can provide data on the consumption of electricity, gas and water at premises of the LSP. Ideally smart energy meters track consumption continuously, but usually the consumption is registered on a regular basis, for example monthly. This data can be directly used for the calculation of corporate carbon footprints. For transport PCFs, it could be allocated via an ABC method, e.g. electricity used at the office per order, or at the warehouse per day per square meter occupied. Furthermore the AIS may provide data on waste amounts (possibly indirectly via waste costs). These cannot be related directly to a transport service, but should be taken into account for a CCF. Accounting systems are commonplace at LSPs, over 90% of the large as well as medium transport companies are using an AIS.

4.4.9 Human Resource Management System

An HRM system maintains data about employees and the organization as a whole. In the field of carbon management, this information is useful for two applications. The first is to break down corporate footprints to departments. The second is to track the performance of individual truck drivers over time. HRM systems are not too common in even large transport companies however, about 60% have implemented one.

4.4.10 Overview of Transport IS domain

Figure 16 contains a context diagram of a Transport CMS. The latter is presented in the middle as a black box. It shows all information systems that may be present in de environment of the CMS and summarizes what data it may exchange with these IS. The model abstracts from how this data exchange takes place.

Not discussed before is the fuel supplier delivering fuel bills. In case a BC is not present, fuel consumption may be derived from these bills, although this will result in estimations of consumption per shipment. The LSP could also use the bills to check consumption reported by the board computer or CANbus. In case anomalies are detected, an employee could manually correct fuel data.

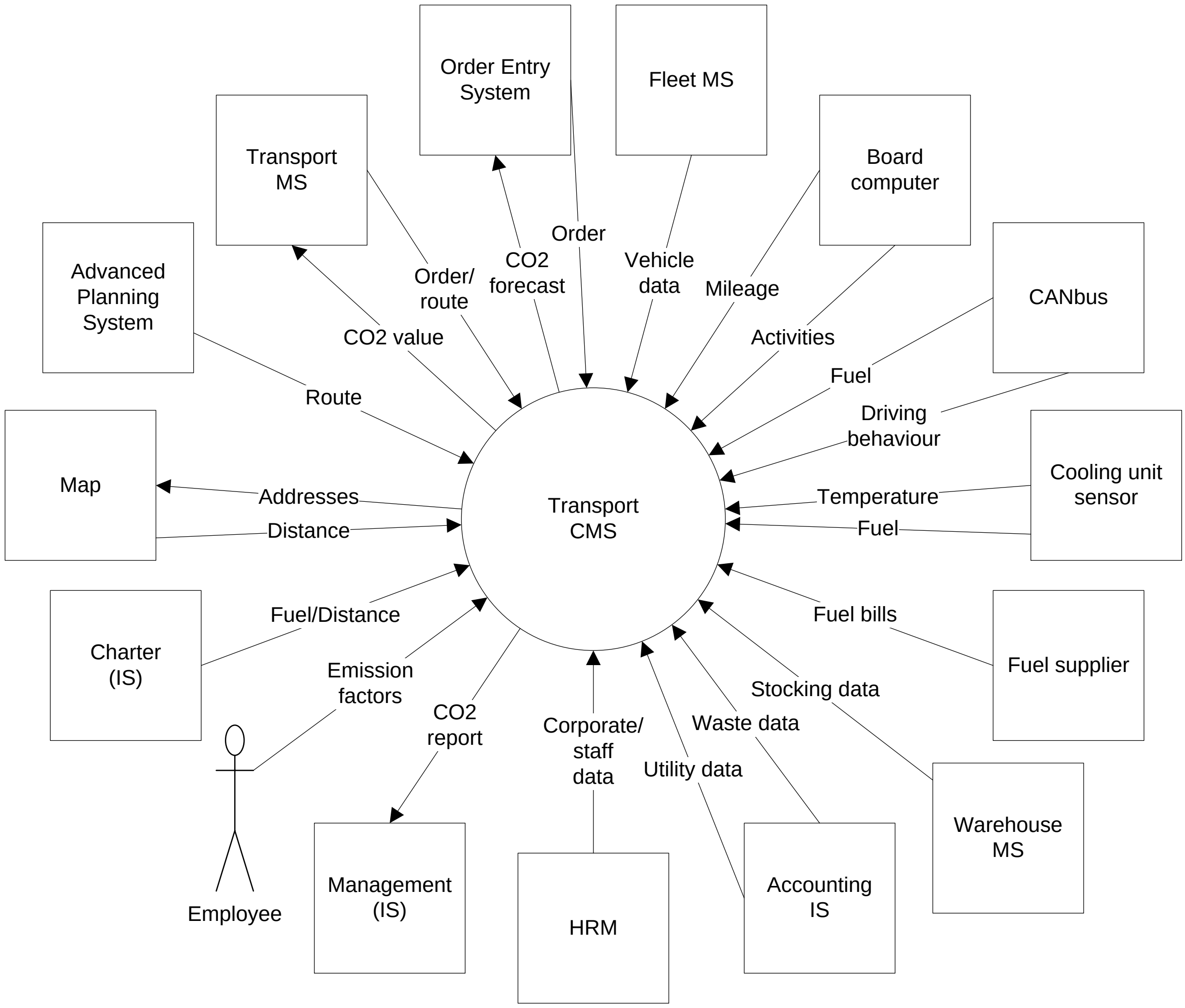

Figure 16: Context diagram of a Transport CMS.

When (part of) a transport is subcontracted, data on distance travelled or even fuel consumed has to be delivered by the charter. It may do so by integrating its BC or TMS, providing it from an invoice or by personal contact. The CMS has to distinguish between trips executed by own equipment and by charters to differentiate on the various scopes of a CCF. Furthermore a mapping system may be consulted to learn the distance between two locations. This could be useful to calculate an indication of the emissions resulting from an order. Finally it is assumed that emission factors are entered or updated by an employee, and that footprint reports in general may be composed and delivered to the management of an LSP via some information system.

4.5 Reference architecture for transport carbon management IS

After the previous sections have provided insight in the transport business and IS domains, the next step is to unite these domains to examine how transport carbon footprints can be calculated. For a transport service a carbon footprint is considered useful at two occasions during the transport process. First a planned value as an emission forecast when the order is begin processed. Second an actual value as a transport PCF after the transport has been executed. The following paragraphs summarize the key functionalities necessary to arrive at these footprints and link the functionality to IS in the environment that can provide required data or functionality. Furthermore we determine the best practices from the CMS market overview of section 3.6 and extract some key functionalities not typical to, but useful for, the transport sector. Finally we present our reference architecture for transport carbon management IS, divided in a business, application and technology layer.

4.5.1 Transport PCF key functionalities

The first key functionality is to provide a forecast of the emissions caused by a transport order. A carrier can use such a forecast to differentiate from competitors or, internally, to review routing alternatives including modal shift. A generic approach to determine an emission forecast is to build it from the following data:

- Order data, including freight characteristics, locations and times. To be received from an Order Entry System.
- Vehicle data, including probable equipment to be deployed and its historic fuel consumption average. To be collected from a Fleet Management System.
- The route to be travelled, including various scenarios for hubs and modal shifts. This could be collected from a TMS, a map system, or an own database with various routes between known locations.

The mentioned IS serve as a reference. As discussed in the Transport IS domain section, both OES and FMS are not commonplace in transport companies. The required data may thus also be collected from a TMS, which is the likely alternative to maintain order and fleet data. The planned value can be calculated as a weighted average for several vehicle and routing alternatives. Norms could be determined from historic data for vehicles, routes and actual emission values calculated for past transports. The combination of cargo, vehicle and distance leads to an expected amount of fuel consumption. Finally the emission factor(s) corresponding to the sources expected to be used need to be collected. Since many requests for emission factors are to be expected, it appears to be the best option to include such a database in the CMS. The forecast is then calculated by multiplying the expected fuel consumption with the corresponding emission factor.

The second key functionality is to provide transport PCFs. As opposed to a forecast, a transport PCF is based on actual values and thus calculates the actual emissions after a transport. Such a PCF may be desired by the shipper, or is useful for the carrier to gain insight in reduction opportunities. The challenge here is to harvest all necessary data and both break down and sum up these data to a single PCF. As explained in section 4.3 on the transport business domain a wide range of activities has to be taken into account and section 4.4 on the IS domain showed that data comes from several IS, some even real-time.

A generic approach to calculate a transport PCF is to build it from the following data:

- Order data, including freight characteristics. To be received from an Order Entry System.
- Vehicle data, including the actual driving and freight units deployed for the transport. To be received from a TMS.
- Activity data, while executing the trip. As discussed before, the CMS receives data from a board computer including distance travelled and fuel consumption, (un)load activities, etc. Data on warehouse activities may be added to this and the CMS could include some overhead from office activities.

For a dedicated single truck road transport, a PCF can be calculated from this data as explained before; by multiplying the amount of energy used with the corresponding emission factor. However, the exploration of the transport business domain showed that often shipments are combined and transported over multiple legs by various vehicles, sometimes by charters and/or using other modalities. Therefore a CMS in this field should also have the functionality to:

- Store intermediate activities and emissions of single legs.
- Allocate activities/emissions to shipments combined in the leg.
- Receive data on subcontracted legs from charters, generally via the LSP's own TMS.
- Aggregate intermediates from several legs and calculate total shipment footprint.

4.5.2 Best practice key functionalities

The third key functionality is to maintain emission factors. The forecast and PCF calculations rely on accurate and up-to-date emission factors, which are often requested by the CMS. As became in clear in chapter 2 these factors are still regularly renewed due to improved measurements and changing policies. The survey on existing Carbon Management Software in chapter 3 showed that most solutions support a variety of footprint protocols and emission factors. As LSPs often operate internationally and sometimes combinations of fuel-based and distance-based calculations are required (in case of charters) maintaining a thorough emission factor database is strongly desired.

The fourth key functionality is to provide Corporate Carbon Footprints, in standard reporting formats. Besides being able to provide PCFs to shippers, a carrier will also desire to gain insight in its own total footprint. In the future this even may be required by authorities. Furthermore the survey showed that CCF is the most basic CMS functionality supported by all solutions. To arrive at a CCF, the CMS needs to collect relevant data from Accounting IS, like energy used in a certain period. For more specialized CCFs the CMS may connect to a HRM system for department-level footprints or aggregate PCFs from transports in a certain period.

The fifth key functionality is to support reduction strategies. After gaining insight in its emissions, an LSP probably wants to reduce them. Offering assistance in this process is a must, as the survey revealed. The existing solutions all have their own approach on taking action. Manual or automated data analysis, simple targets or including benchmarks and scenarios, and different ways of tracking progress. But altogether reduction support is a clear best practice. Existing solutions usually take CCFs as a starting point and define targets for future periods, e.g. by defining anomalies for a certain energy source or department. In the transport sector PCFs can serve as starting point as well. Suggestion modal shifts for similar transports in the future or analyzing driving behaviour from CANbus data are examples of this.

The five key functionalities for a transport CMS form the basis for our proposed reference architecture, which is modelled in ArchiMate. The functionality is part of the application layer, however we discuss the architecture top down, starting with the business layer in the following section. Part of this layer is the actual business process. As mentioned earlier, this process has been adopted from Van der Veeken's (2009) reference process. He also modelled how various IS support the execution of the transport process steps, providing a valuable reference for our research. The architecture presented in the next sections strictly focuses on how IS support carbon footprinting, support of other business processes is out of its scope. Layer by layer the elements in the architecture are discussed. The nature of the relations between them are put in *italic*.

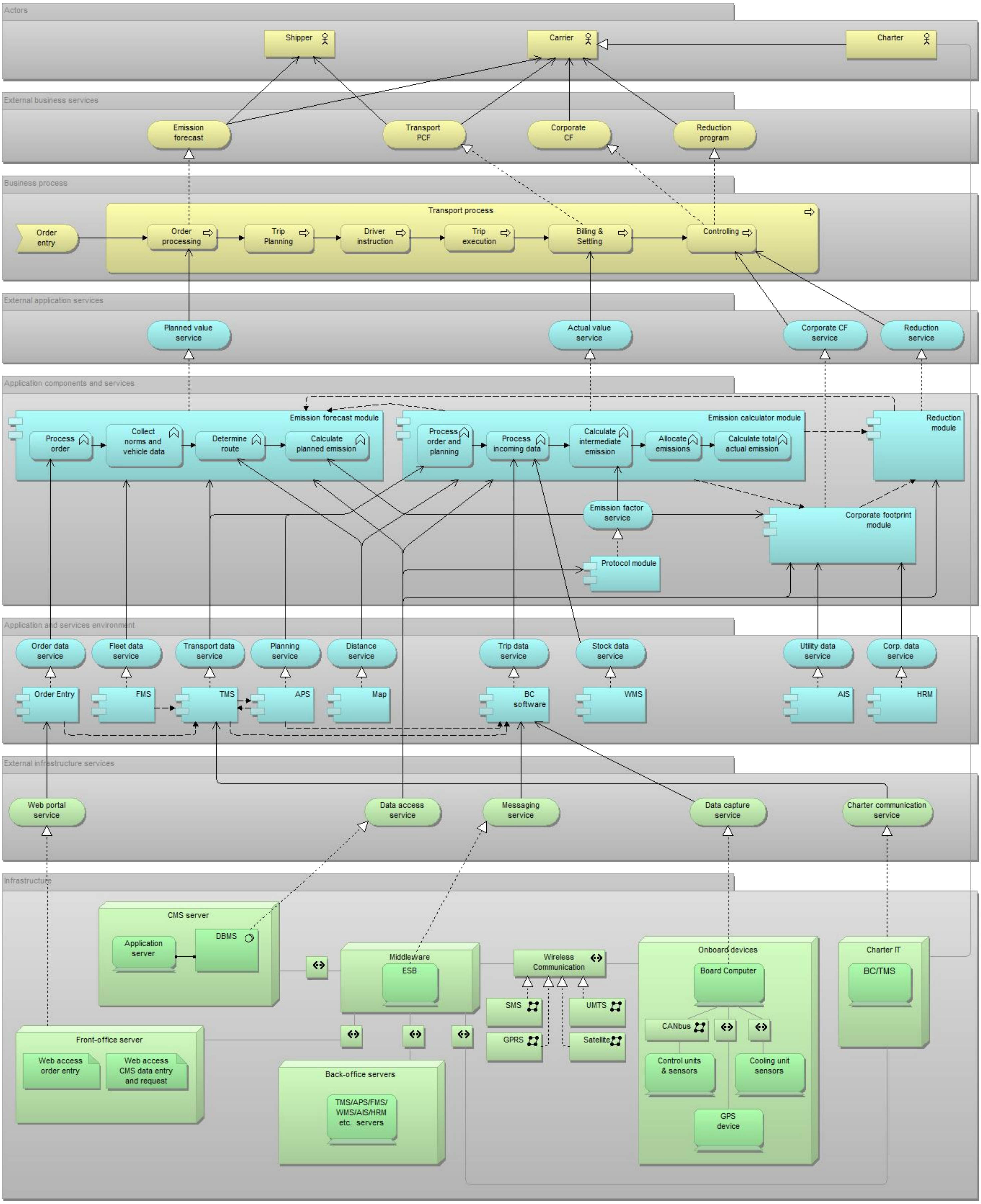

Figure 17: Reference Architecture for a Transport Carbon Management IS. See Figure 8 in section 4.2.3 for a legend.

4.5.3 Business layer

The upper layer of the architecture shows the most relevant actors for the transport CMS. These are:

- The shipper, who has an interest in forecasts and footprints of transports it has ordered.
- The carrier, who executes the transports and has an interest in various footprints as well as reduction opportunities.
- A charter, who, in this model, is a *specialization* of a carrier. The charter might be interested in footprints of its services, and most of all is responsible for providing data on transports it has been subcontracted for.

Obviously more actors perform a role in the transport process. Most notably are the truck drivers who are responsible for executing transports and who provide activity data via the board computer. However, they do not use the services provided by the CMS and are therefore not included. Various other employees of an LSP, who use the CMS both to enter data (e.g. emission factors) and request information (e.g. CCF reports) are abstracted in the carrier actor.

The external business services layer presents the elemental services the actors *use* from the CMS. As discussed before these are emission forecast, transport PCF, Corporate CF and reduction plan.

The third business level layer contains the business process as it actually takes place in a transport company. An order entry *triggers* the transport process. This process begins with order processing, which on its turn *triggers* the following steps from planning to controlling, as handled in the business domain section. The order processing *realizes* the emission forecast service. Similarly, billing and settling can be regarded as the process step where the transport PCF service is realized. One may think of the trip execution process as the one realizing the service. However, in multi-leg multi-vehicle transports, sometimes other trips have to be finished, before the final allocation to the corresponding shipment can be calculated. Furthermore emissions from other sources may be added and finally the emission may be presented on the bill. Controlling, the final business process, is regarded as realizing the CCF and reduction services.

4.5.4 Application layer

This layer represents the CMS application components, its IS environment and the services it delivers. The visible and upper part of the application layer constitutes of external application services. These are *used* by the business process and similar to the external business services. In this layer they are represented as system outputs, though. The planned value service delivers the calculated emission value that is *used* by the order processing. Likewise the CMS offers an actual value service, a CCF service and a reduction service.

The application components and services layer presents the modules that generally constitute a CMS. The five modules depicted each support one of the key functionalities described in the previous section. The internal functionality of the Emission forecast module and the Emission calculator module matches the approach in the aforementioned section. Since Corporate footprint modules cannot be seen as innovative, the internal functionality is not deliberated here. The reduction module is shown without internal processes as well. In this case the reason is that reduction initiatives may be very diverse, as explained in the section on key functionalities. This would make the reference architecture complex and less generic, while it is intended to allow instances of the architecture to implement the reference according to an organization’s own wishes.

Four of the modules *realize* one of the external application services. The protocol module however, *realizes* an internal application services, namely the emission factor service. This service is *used* by all footprint modules to collect emission factors. From the emission calculator module, data may *flow* to other modules. Examples are to set norms for forecasts, to aggregate PCFs in a CCF and differentiate on trips executed by charters that are categorized in scope 3 of a CCF, or to serve as input for reduction plans. Other internal flow examples are long term corporate footprint data as input for reduction programs and alternative routes proposed by the reduction module to the forecast module.

The application and services environment layer shows all relevant IS in the environment of the CMS. The environment is modelled as combinations of an IS *realizing* a single, general service. These services are all *used* by some of the application components. A few relevant data *flows* in the IS environment are included. The Order Entry System sends the order to a TMS, which arranges the transport. The TMS will first collect vehicle data from an FMS and second delegate the planning to an APS, if these are present as distinct IS. Otherwise it plans the trip by itself. Depending on the situation, one of these systems sends the order and trip data to the board computer.

The best option to integrate a CMS with these information systems is as follows. The Order data service is used in the first step of the forecast module. This module will typically update its norms by occasionally collecting fleet data from an FMS and renewing the transport network from the TMS. In special cases when a drop or pickup location has not been defined before, the module may instantly connect to a mapping system to receive the distance to be travelled.

For the emission calculator module however, there is no need to integrate with Order Entry. It receives all initial order and trip data from the TMS or APS, after the transport has been completely planned. While the trip is being executed, it receives activity and shipment status updates from the board computer. To allocate emissions to combined shipments, the calculator may consult a map server, since the demanded transport distances could be used as ratio of distribution.

As stated before, some of the services in the environment layer are directly used by the transport business process as well. However these relations have been excluded from this transport CMS reference architecture, because they are not important for the CMS and would confuse the diagram.

4.5.5 Technology layer

The third layer, also called infrastructure layer, represents the infrastructure of the CMS and its environment. It shows the hardware, software and network deployment of the services that are supported by the infrastructure. Once again, these services are shown in a external infrastructure services layer. These services have little meaning on their own, as they are not discussed before. Therefore the following paragraphs dig into them together with the actual infrastructure, which forms the bottom layer of the reference architecture.

The first node in the infrastructure layer is the CMS server running the applications performing calculations, generating reports, etc. and including a database management system *assigned* to (i.e. deployed on) the application server. The DBMS *realizes* a data access service (of course including create, read, write and update) that is used by the CMS application components.

In the environment of the CMS server both front-office and back-office servers are present, as well as on-board devices. All connected to each other via middleware, using communication paths that *associate* the nodes to each other. We opt for this design as current practice is, as also shown by the CMS market survey, to provide web-based service oriented architectures. Most communication paths have not been specified, they are typically wired networks.

A front-office server *realizes* a web portal service, which is *used* by the order entry system. The order entry web access, depicted as artefact, is the start of any transport process. Furthermore CMS users access the CMS information system via the front-office server when they want to enter data or request information. The reference architecture abstracts from where the nodes are located. As long as both carriers and shippers can access the CMS, it can be both deployed web-based at the carrier or the CMS supplier, or even as Software-as-a-Service (SaaS) solution at the CMS supplier or at an external hosting provider. The latter is an important requirement, as both the survey in section 3.6 showed that SaaS is the most common deployment type for carbon management software, and the logistics industry is starting to adopt SaaS solutions as well (Jorritsma, 2010).

The other information systems shown in the application and services environment layer are aggregated in the Back office servers node. How exactly these IS are deployed is out of the scope of this reference architecture.

Onboard devices are very important to enable fuel-based carbon footprint calculations, as explained in earlier sections. The main device is the Board Computer, which *realizes* a data capture service, *used* by the BC software. Besides data entered by the truck driver, it also connects to other onboard devices. Via the CANbus network, it received data from several units and sensors that form the motor management system, most import fuel levels. Furthermore the BC typically contains a GPS device, which delivers the exact location of the BC (and thus driving unit). Finally it may be connected to sensors in the freight unit in case it is cooled, although these may also directly communicate with the TMS using wireless communication.

Three main types of wireless communication between onboard devices and middleware infrastructure can be distinguished:

- SMS messages exchanged between truck driver and office employees over a GSM network.
- GPRS or UMTS data packets exchanged over a mobile network.
- Communication via satellite, for remote areas.

How these networks are structured, is not relevant for the architecture. Most important for the CMS is the data exchange over GPRS or UMTS, typically standardized by the BC software and formatted in XML.

The middleware node represents a hub and spoke solution to allow communication between all other infrastructure nodes. The Enterprise Service Bus is an example of such an implementation. This enables communication between applications without requiring from each of these applications to know the communication details of peer applications. The middleware *realizes* a messaging service. This service is in practice *used* by several applications, in the model this relationship is depicted only with the BC software as an important example.

Note that the CMS server is depicted individually as it is the centre of the application. From other viewpoints, it may be just as well be one of the front- or back-office servers. In fact, although the architecture may show various servers as different nodes, in practice these may be virtual nodes deployed on a single server node. In general, the reference architecture does not prescribe how to deploy the servers, excludes telematics issues like network characteristics (e.g. routers) and does not take qualitative requirements into account, like security issues (e.g. firewalls).

Finally at the bottom right a generic node representing the infrastructure of a charter is shown. Via a charter communication service, the charter is expected to communicate with the carrier's TMS on a logical level. The charter actor at the upper business layer is *associated* with the charter IT node. At the infrastructure level data is exchanged over the internet to the middleware.

4.5.6 Guidelines

The next page presents the reference architecture in an ArchiMate diagram. To develop a concrete architecture based on this reference architecture, we propose to follow the same steps performed in this study to arrive at the reference. However the instance is obviously focussed on the specific wishes and circumstances of the concerned organization. The proposed steps are:

Define the business needs. Four general business services have been defined in the reference architecture. Are all four desired, or does the organization four example have no interest in emission forecasts?

Analyze the LSP's business process. Does the actual transport process fit into the generic process depicted in the reference architecture? Is warehousing an important activity of the LSP? Does it offer refrigerated transports?

Analyze the LSP's IS domain. For accurate fuel-based carbon footprint calculations, the presence of board computers connected to motor management systems is crucial. The reference architecture includes all IS that are possibly present and relevant. The actual presence of IS like Order Entry, Fleet MS and APS determines what data can be gathered from what systems.

Analyze the LSP's infrastructure. Are the IS that need to exchange data fully integrated? Is hardware available to install the CSM on? What communication protocol is used for data exchange between onboard devices and IT at the home base?

Altogether the analysis of the organization's business and IT provides insight in the possibility for carbon footprint in the current situation. An architecture for the particular situation, including the business processes provided, present IS and infrastructure landscape, can be drawn as starting point for the design of a CMS. If the current IS and IT landscape is insufficient to support fuel-based transport PCF calculations, the LSP should either:

- Upscale the current IS and/or infrastructure according to the reference architecture.
- Downscale the business desires, e.g. opt for distance-based calculations.

Assuming the first option, the LSP needs to elect the requirements for the implementation of the necessary infrastructure, like board computers or middleware. For CSM itself, the LSP (together with the intended solution provider) has to decide upon the deployment as a local web-based or remote SaaS implementation.

4.6 Conclusion

The goal of this chapter was to develop a reference architecture for a carbon management IS for the transport industry, solving the second main research question. The reference architecture can be found in section 4.5. A review of various RA definitions resulted in three general characteristics presented at the end of section 4.1. The presented RA matches these characteristics.

First it is a generic architecture, that includes all relevant components in the transport IS field, but abstracts from implementation details. The CMS application is composed of various modules. These modules each provide one of the key functionalities that could be identified to manage carbon emissions.

Secondly, the RA is a map relating the application layer to both the business and technological environment. The application components are linked to the general transport business process. The transport business domain is discussed in depth in section 4.3, answering research question 1b) on transport activities and what data serves as input for carbon footprints. Studying the logistics industry learned that the practice of combining multiple shipments in freight units routing shipments through multi-hub, and possibly multimodal, transport networks, with several corresponding loading and supporting activities, makes calculating carbon emissions a complex task.

The application components are also integrated with applications in the transport environment (i.e. common IS present at LSPs), as explored in section 4.4, providing the answer to research question 2b). With board computers and transport management systems present in 90% of the larger (over fifty driving units) transport companies, from the IS perspective the aim of automatic footprint calculation appears a realistic goal. Furthermore the application layer is supported by a technology layer, which shows a generic deployment of infrastructure nodes and how these nodes can be connected to each other.

Thirdly, parts of the functionality in the application layer, and the loosely coupled organization of the infrastructure in the technology layer, allowing for web-based or SaaS implementation, are based on best practices from the CMS market review in section 3.6. Finally some basic guidelines on how to instantiate the reference to a concrete architecture accompany the RA. Altogether the diagram and accompanying documentation answer research question 2c). To validate the reference architecture we develop a prototype. The requirements for such an instance are elected in the next chapter.

5 Requirements for a fuel-based transport CMS

This chapter specifies the requirements for a transport CMS as instance of the reference architecture presented in the previous chapter. First the approach for the requirement specification is explained in section 5.1. The specification starts with the mission statement (5.2). Sections 5.3 and further are kept confidential. In the confidential version these sections list the actual requirements for the Carbon Emission Protocol and Factor module, followed by the requirements of the Product Carbon Footprint Calculator module. Then the already implemented Indicator module and the Corporate Footprint module are briefly described, followed by the requirements for the Carbon Reduction module and some quality requirements valid for any instance.

5.1 Approach

From the research viewpoint, the goal of designing an instance of a transport CMS is to verify the reference architecture presented in the previous chapter. No particular LSP is the intended owner of the system. Therefore organizational aspects are left out of the scope of the requirements and design. For implementation at a specific organization aspects such as what departments have what power and responsibilities, and to what extent jobs will change after the introduction of the IS, possibly leading to resistance among employees, should be investigated as well.

However, we focus on the structure and behaviour of the system, not the organization. This chapter provides requirements for a general instance of the reference architecture, covering the key functionalities described in section 4.5.1 and according to the five modules distinguished in the application components layer in the reference architecture.

First we introduce the system in the Mission section (5.2). According to Wieringa (2003) a mission statement is a good introduction to any system design. It is a high-level description of the purpose and scope of the system. It defines the system goal, states what the system is responsible for and what not, shortly presents its composition and explores the system environment. The mission statement serves as an excellent link between the reference architecture, which it more or less summarizes, and the instance specified in the succeeding sections.

We do scope the requirements to certain modules, however. A forecast module has already been developed by CAPE Groep in the past, named Carbon Product Indicator. Going through a requirements and design process for an existing application is of no use, therefore the functionality of this module is only described. Furthermore Corporate Carbon Footprint applications are commonplace, which makes it scientifically not challenging to design such a module. The niche of the intended system is the fuel-based calculation of transport footprints and subsequent reduction opportunities. Thus the focus of the requirements and design lies in these modules.

The Footprint Protocol and Emission Factor module is an exception to the other modules. It does not provide a particular functionality towards the end users, but is essential for supporting the other modules. It also needs to contain some transport specific functionality. Therefore we start with the requirements for this module. Then we specify the requirements for the Product Carbon Footprint Calculator module and finally we present them for the Reduction Module.

Hickey and Davis (2004) present a unified model of a requirements elicitation process, based on a literature survey. The model does not state users/customers as the sole input for requirements, but stresses knowledge of problem, solution and project domain as valuable input for requirement elicitation. The problem domain includes problem characteristics, the application domain and existing systems. Exploring these inputs for the elicitation process has already been conducted and described in previous chapters. Insight in carbon footprinting, the transport business process and transport IS environment have been integrated in the reference architecture in the previous chapter. The solution domain includes the type of solution and the development approach. This domain is quite straightforward: it is an in-house development of a software application. The project domain contains characteristics of methodology, users and developers. These organizational aspects are not taken into account, as explained in the first paragraphs of this section.

The other source for requirements elicitation consists of the users, customers and stakeholders involved. Lauesen (2002) discusses several techniques for requirements elicitation with users. Examples are interviews or workshops with intended users, observation of their daily work, questionnaires and prototyping. However, as explained before, in our case there is no specific customer for the system. This makes such techniques not useful for requirements elicitation. Therefore we choose to base the requirements on the domain knowledge gained as part of developing the reference architecture in the previous chapter. These requirements cover the general situation present at intended users of the system. For any particular organization some adaptations to the requirements are unavoidable, but the specification is useful as a starting point for any implementation.

Lauesen (2002) also discusses several styles to structure and present requirements. Three types of requirements can be distinguished. Functional requirement specify what functionality is provided by the system. Data requirements specify what data is stored and exchanged by the system. Quality (also called non-functional) requirements specify how well the system performs the functionality. One can formulate requirements at different levels:

- Goal: what business goal should the system help to achieve (the business problem)?
- Domain: what business process or task should the system support (the business solution)?
- Product: what function should the system provide (the software problem)?
- Design: how should the system implement the function (the software solution)?

Each of the levels has its weaknesses. The business-levels are often too vague for software developers. The design-level trap is to skip questioning what and immediately start with designing how. Product-level might fall in between, creating a gap between what the business desires and how the developer interpreters the requirements. Concerning the structure of the requirements specification, Lauesen (2002) handles several techniques, ranging from the traditional feature requirements to event lists, screens and various user/task-based formats.

Since most functions of the CMS are automated and not performed by users and given the general character of the intended CMS we structure the functional requirements as feature requirements. These are concise textual descriptions of requirements, which we structure around the facets of carbon footprinting in the transport industry and possible scenarios of transport processes discussed in section 4.3. Following these business processes the background of a requirement on a domain-level precedes the actual feature requirement on the product-level.

The approach to link the software level with the business level counters the possible objection to stand-alone feature requirements, that it is hard to judge whether they allow for achievement of the business goals. It also makes the requirements easier to understand for both business users and system developers. Furthermore, an advantage of feature requirements is that after implementation it is easy to check whether each requirement is covered by the product.

Occasionally the design-level is reached when we consider further specification necessary. We consider the inclusion of design aspects in the requirements in such cases not problematic given the goal of the application (generic and as validation of the reference, for which the problem domain has already been investigated in depth) and the fact that an iterative requirements election process is not targeted. The requirements are validated in a session with CAPE senior consultants with domain knowledge. Since end users are absent, no sessions with them are necessary.

As communication with various IS and storing data takes place during the business processes, data requirements are not presented in a separate section, but included in the functional requirements. A data model is often included in the requirements. We consider this as a design aspect, though, and present it in the next chapter. Quality requirements, of which usability, efficiency, reliability and maintainability are examples, are often typical for a particular organization. Therefore less attention is paid to these aspects, narrowing to some requirements relevant to the functionality in general. These are discussed in the final section of this chapter.

Finally, another aspect of requirements structuring is prioritization. Our specification distinguishes two priorities. The following chapter presents a prototype of a Product Carbon Footprint Calculator. The prototype serves as proof of concept of the CMS and intends to demonstrate its core functions in a straightforward manner. We consider the requirements listed in plain text as must haves for the prototype to demonstrate the key desired functionalities. Requirements put in *italic* are not to be covered by our prototype. Such requirements can be regarded as wanted functionalities of future extensions of the prototype, or are eventually required for a CMS completely covering the reference architecture.

5.2 Mission

This section provides a first glance at the system to be developed. It gives the system a name, specifies the system goal and refines this goal into main responsibilities. Further it depicts the system composition and environment, the latter including the IS landscape and an overview of the stakeholders and actors relevant for the IS. Finally it states some exclusions, i.e. responsibilities or functionalities the system does not have. While researching these aspects is generally a good starting point for electing the requirements, in this case they mostly have already been covered in the previous chapter. Therefore the following paragraphs highlight each of the topics without really digging into them, referring to the previous chapter for further background information.

5.2.1 Name

The intended name of the complete carbon management system for logistics service providers as coined by CAPE Groep is Carbon Reduction Suite (CRS).

5.2.2 System goal

The goal of the CRS is to support LSPs in monitoring and reducing their carbon emissions. It covers both transport specific aspects of carbon management, namely forecasting and calculating product footprints of transports, and general aspects, namely calculating corporate footprints and supporting the organization in reducing its emissions.

5.2.3 Responsibilities

Five main functionalities of a transport CMS have been defined and explained in section 4.5.1. These are essentially the responsibilities of the CRS. The following list repeats them:

1. Provide a forecast of carbon emissions caused by a transport order.
2. Provide transport Product Carbon Footprints. The peculiar feature is to calculate PCFs fuel-based by obtaining fuel usage of vehicles from board computer data.
3. Maintain emission factors.
4. Provide Corporate Carbon Footprints, in standard reporting formats.
5. Support reduction strategies.

5.2.4 Composition and system environment

The application components layer in the reference architecture, described in section 4.5.4, distinguishes five modules. These can be translated to each of the system responsibilities and together constitute the CRS:

- Product Carbon Footprint Indicator module
- Product Carbon Footprint Calculator module
- Carbon Emission Protocol and Factor module
- Corporate Carbon Footprint module
- Carbon Reduction module

Section 4.4 extensively describes the common information system landscape at large logistics service providers. Figure 16 shows a context diagram including all systems possibly present. Together they form the system environment for the CRS as a whole.

For the prototype instance, the assumption is that the most elementary systems, namely a Transport MS (or APS) for trip and order data, and Board Computers with CANbus network in vehicles, are present. Less common systems, namely Order Entry System, a Fleet MS, cooling unit sensors, warehouse MS, and Map system also fall under the scope of a full. Functionalities they serve as source for, are covered by the requirements wanted for later extensions or CMS implementing the complete reference architecture, as described in the Approach section.

Figure 18 on the next page displays the architecture of the intended prototype instance covered by the requirements. It contains selected parts of the reference architecture, according to the scoping described before. The business layer is omitted from this architecture, and the only service provided is the actual value of transport carbon emissions. Systems and functionalities not relevant for the product calculator are left out of the architecture as well. Components and services that would normally be relevant for the module, but are left out of the scope of the prototype, are displayed in greyscale. We consider these aspects (specified in *italic* requirements) not necessary to validate the high-level service to be provided by the PCF module; a fuel-based actual value using data from TMS and BC.

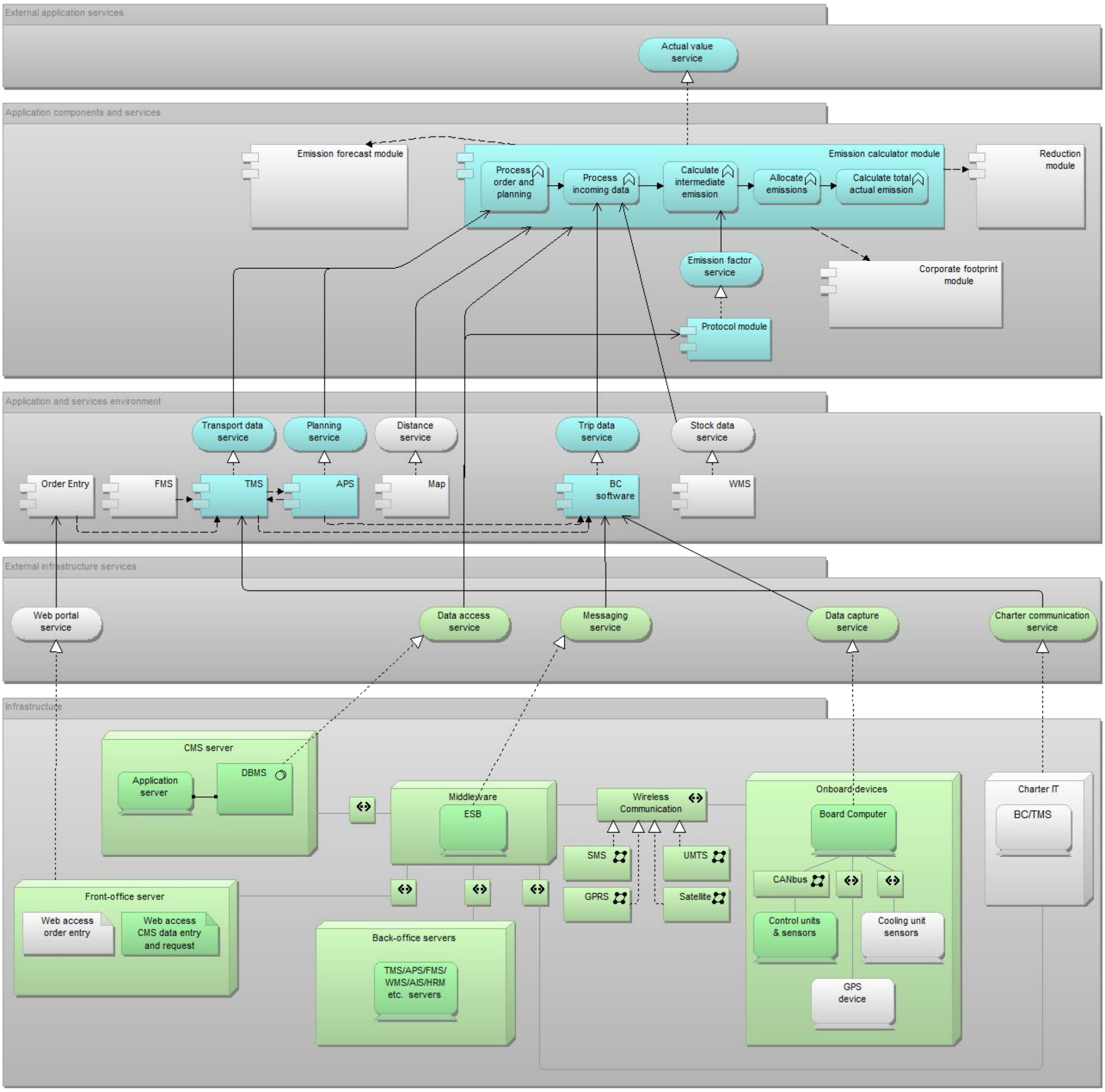

Figure 18: Architecture of the application and infrastructure layers of the intended prototype instance of a transport CMS.

5.2.5 Stakeholders/actors

The stakeholders are presented in the upper layer of the reference architecture and described in section 4.5.3. The three organizations involved in the carbon management IS are:

- Shippers, who have an interest in forecasts and footprints of transports ordered.
- The carrier, who executes the transports and has an interest in various footprints as well as reduction opportunities. The carrier is the system owner.
- Charters, who might be interested in footprints of their services, and most of all are responsible for providing data on transports they have been subcontracted for.

Other actors that can be distinguished as individuals are:

- Planners of the LSP. Carbon emissions associated with various routing options may be added as a parameter in the transport planning.
- Truck drivers, who provide activity data via the board computer while executing transports. It may be necessary to adjust or increase the information provision. Furthermore consequences of reduction programs may affect their way of working.
- An employee responsible for keeping the footprint protocol and emission factors current.
- Employees or managers requesting and monitoring footprints or reduction programs from the CMS.
- IT employees maintaining the CMS and its infrastructure.

For any particular instance these actors and the organizational consequences should be taken into account when specifying the requirements. As explained before, we focus on the functionality, starting with the first module in the next section.

5.2.6 Exclusions

As explained in the Approach section, the Product Carbon Footprint Indicator is excluded from the requirements specification since this module has already been implemented by CAPE Groep. The Corporate Carbon Footprint module is also excluded from this particular instance of the CRS because it has no scientific value.

The CRS only monitors carbon emissions, other polluting emissions are excluded.

The CRS is not responsible for validating the reliability of fuel consumption amounts as reported by the motor management system (CANbus). A carrier may opt to check these amounts against refuelling data entered on the board computer by the truck driver and against fuel bills provided by the fuel supplier. In case the application performing these checks triggers a change of fuel consumption allocated to an order, this impacts the allocated carbon emissions proportionally. This requirement specification assumes reliable real-time figures from the CANbus. When an organization chooses to use another source, the specification needs to be updated to fuel consumption input from a fuel application (or TMS) and the real-time character of the calculations is lost.

5.3 Requirements for the Carbon Reduction Suite

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Sections 5.3 and further provide the requirements for the modules forming the Carbon Reduction Suite. Especially for the Product Carbon Footprint Calculator module, an extensive set of requirements, partly on design-level, has been specified. For competitive reasons for CAPE Groep, the remainder of this chapter is kept confidential.

6 Transport CMS Prototype

This chapter presents a prototype for the Product Carbon Footprint Calculator module of the Carbon Reduction Suite (CRS). The goal of implementing the prototype is to verify whether an IS can be built according to the reference architecture and to validate whether such an IS is able to provide correct fuel-based carbon footprints of transport services. The further structure of this chapter is that we first explain the scope of the prototype in section 6.1 and our development approach in 6.2. Sections 6.3 until 6.5 discuss the design of the prototype; successively the domain model, interfaces with Transport Management System and Board Computer, and the carbon footprint calculation functionality. A test case for the prototype is performed and examined in section 6.6, after which we reflect on the verification of the calculated values. Finally, in section 6.8, we discuss what it takes to go from prototype to actual product.

6.1 Scope

The application components and services layer of the reference architecture presented in chapter 4 is composed of five main modules. The requirements for an instance of the reference elicited in the previous chapter leave the Product Carbon Footprint Indicator and Corporate Carbon Footprint modules outside since they respectively already exist or are not considered interesting from a scientific perspective.

The requirements emphasize the Product Carbon Footprint Calculator module. It contains functionality most relevant to the logistics industry and interacts with several information systems present in the logistics domain. But most of all, its fuel-based approach to footprint calculation is a niche and its intended functionality complex. Therefore we choose to scope the prototype to this module together with a limited implementation of the less complex Carbon Emission Protocol and Factor module to support the PCF calculations. Hereby the goal is to comply with the requirements elicited for these modules in sections 5.3 and 5.4. Including a Carbon Reduction module, with its wide variety of functionalities and types of reduction opportunities, is not considered feasible within this final Master project.

6.2 Approach

We use the Mendix Business Modeler (Mendix, 2011) to develop the prototype. Mendix aims to serve as an agile, model-driven platform to develop applications that are easy to integrate in the existing business and IT environment. Mendix is the most practical tool to develop our prototype, since it is used by CAPE Groep as standard software development environment. The Product Carbon Footprint Indicator module has also been developed by CAPE Groep using Mendix. Therefore no alternative software development tools have been considered. Three key document types available in Mendix are shortly described in the list below. For detailed information, including legends for the domain models and microflows depicted in the following sections, we refer to the reference guide (Mendix, 2011):

- Domain model: a data model representing the information stored in the application in an abstract way. It consist of entities with attributes and associations, the latter drawing relationships between entities.
- Forms: the user interface to the end user. By browsing through tables users can search for desired information and by entering data in special forms (data views) or clicking buttons users can manipulate data.

- Microflows: describe the logic of the application, specifying behaviour of activities that manipulate objects, perform calculations, interact with clients or remote web services, etc.

According to the infrastructure layer of the reference architecture and the recent trend of outsourcing this layer as much as possible, e.g. Software-as-a-Service solutions, we design the prototype as a loosely coupled application that exchanges data over the web in standard XML format. Such integration is fully supported in Mendix.

6.3 Prototype design - domain model

The following sections present the domain models for the Carbon Emission Protocol and Factor module and the Product Carbon Footprint Calculator module.

6.3.1 Protocols

This module intends to support calculation and reporting of various kinds of footprints. Since our prototype is focussed on product footprints of transports, we implement a very limited version of this module. The domain model (see Figure 19) is actually partly exemplary.

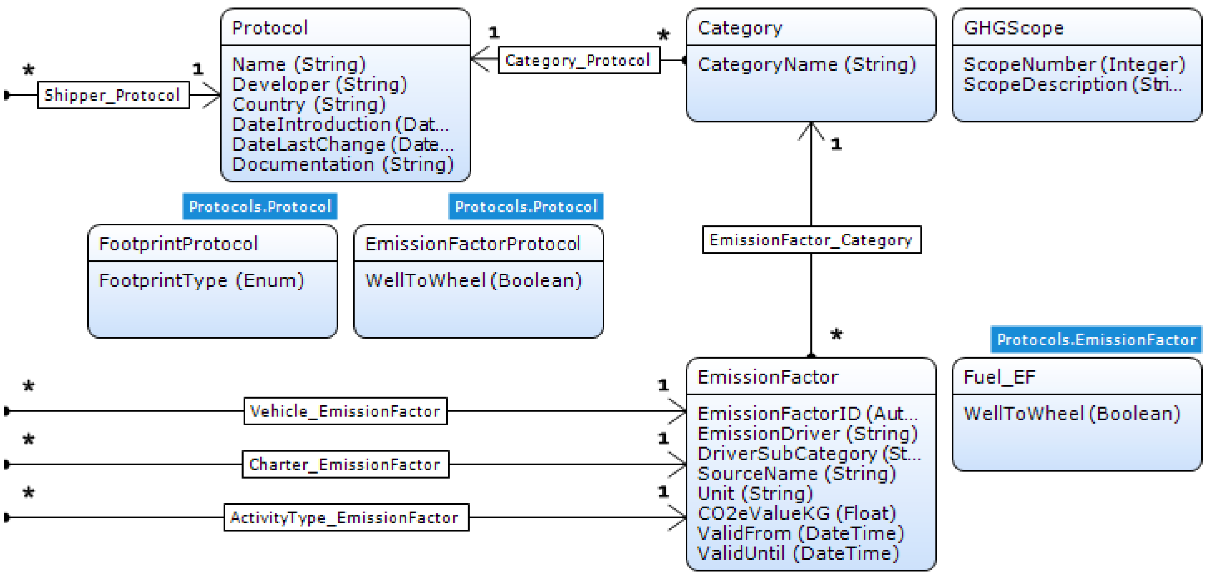

Figure 19: Domain model of the Carbon Emission Protocol and Factor module of the prototype.

In the Protocol entity various protocols can be documented and shippers can be associated to a certain protocol, according to which they desire the emissions to be calculated (e.g. well-to-wheel versus tank-to-wheel fuel factors) or presented.

Most important in this module is the Emission Factor database. This table forms the basis for all emission calculations performed in other modules. CO_2e values corresponding to certain emission drivers related to vehicles, charters or activities are often requested by other modules. Fuel emission factors could be maintained in specialized entities to allow for more detailed distinction.

Another functionality not functional in the prototype but desirable as future extension is to categorize emissions for footprint presentation and analysis as well as distinguishing between the three scopes of the GHG protocol trips and activities fall under. The application could mark subcontracted trips as scope three emissions, for example. Altogether, despite the minimal functionality, the structure of the domain model meets most requirements specified in section 5.3.

6.3.2 Product calculator

The domain model of the prototype for the Product Carbon Footprint Calculator is depicted in Figure 20. The following paragraphs describe the entities modelled.

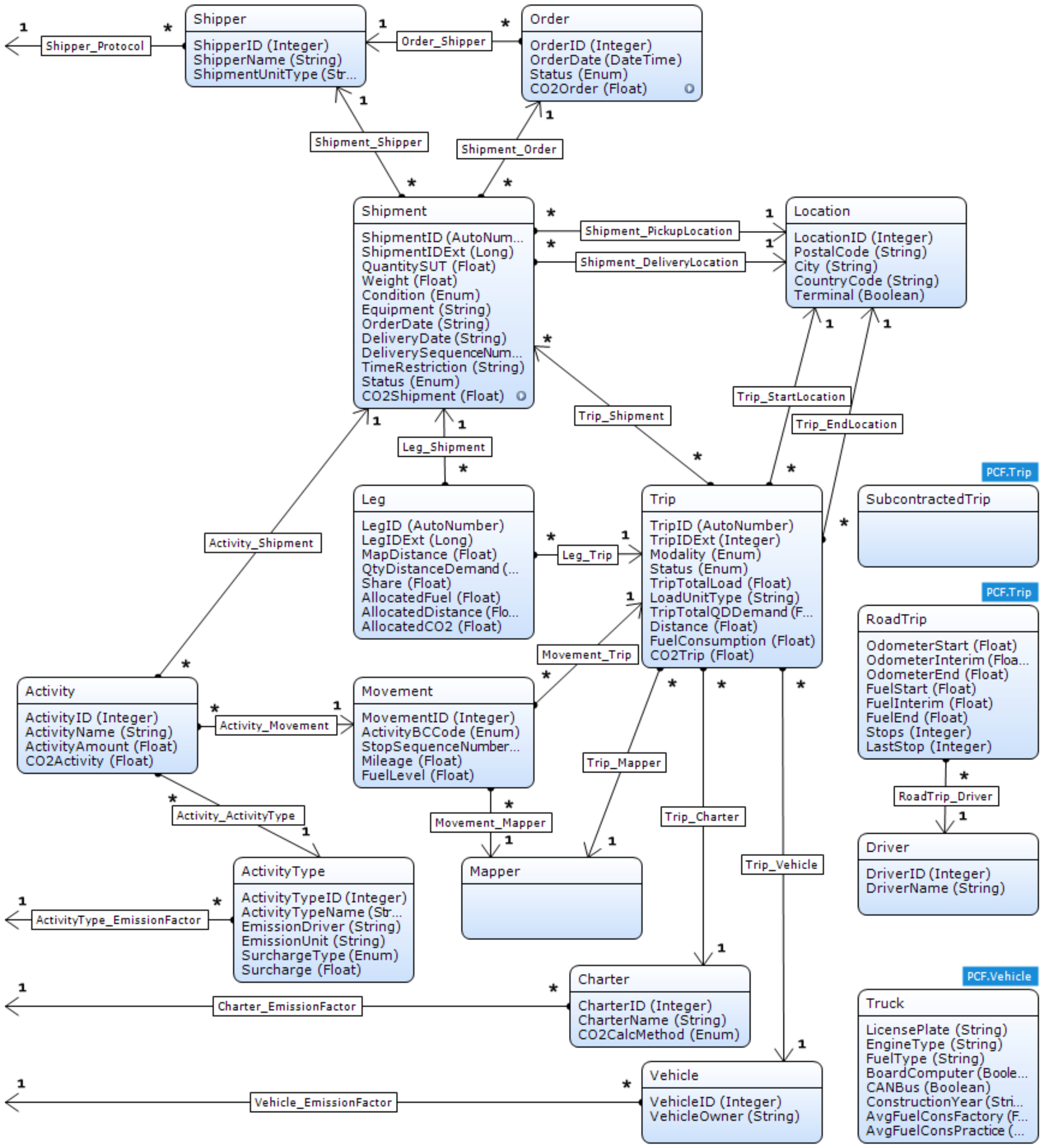

Figure 20: Domain model of the Product Carbon Footprint Calculator module of the prototype.

6.3.2.1 Shipper

Contains information on the shipper. For our prototype the shipper's name and its preferred protocol (exemplary association) are adequate and in accordance to the requirement specified in section 5.4.1 on shipper details. The ShipmentUnitType is the unit in which the shipments are accounted, e.g. loading metre or m3. This is an artificial rather than a realistic situation, as a shipper may order transports of goods of different nature over time.

6.3.2.2 Order

Contains order details and the ultimately calculated carbon emission caused by all activities carried out for an order, in case it is composed of multiple shipments.

6.3.2.3 Shipment

Contains shipment details and the carbon emission caused by this shipment, which is calculated after all Trips in which the shipment has been involved have been finished. For incoming shipments the prototype assumes the quantity is provided in the shipper's default shipment unit type and by the shipment's weight. Furthermore its required temperature condition, equipment during transport (truck-mountable forklift, loader crane, etc.) and transport dates are stored and finally the transport status is tracked in this object. This covers the requirement on order and shipment details given in section 5.4.2. While one or more shipments are in practice usually part of a transport order, for practical reasons the prototype also links them directly to the shipper. Like trip and leg objects discussed later, shipments are assigned an automatically generated number as ID besides the external ID adopted from other IS. This is mainly done to easily sort on the creation moment of what can be considered the most important objects of the application, and at the same time preserves their uniqueness.

6.3.2.4 Location

Contains some basic geographic attributes considered sufficient for the prototype. Possible extensions are more address details and lat long coordinates as well as specializations for e.g. terminals and hubs. Each shipment has a pickup and a delivery location. Each trip has a start and end location.

6.3.2.5 Trip

Contains information on concrete trips executed by the carrier, which may transport several shipments at the same time. Notable are the modality (road, rail, etc.) and the total load in some unit, that are part of incoming trip plannings. The total quantity distance demand is used for allocating combined shipments (explained in the Leg paragraph). The distance and fuel consumption are to be retrieved after the trip has been finished, after which the carbon emission caused by the trip is calculated.

6.3.2.6 Trip specializations

Two kinds of trips are distinguished in the prototype. Subcontracted trips are carried out by charters and are in this version by default multimodal (thus rail, water or air transport). No attributes are stored for subcontracted trips. A Road trip is in this version by default carried out by the carrier itself. This object keeps track of the progress of the trip maintaining data on odometer and fuel level amounts and the stops that are made during the trip to fulfil the transport jobs.

Reviewing the requirements on route details of section 5.4.3, the conclusion is that the prototype design partially fulfils them. The most important elements are included, but for example maintaining data about hubs on the route, intermodal trips and linking trips to the GHG protocol scopes are not.

6.3.2.7 Leg

Contains information on abstract legs from the viewpoint of a certain shipment that are executed by the carrier as part of a trip for (a.o.) the aforementioned shipment. In UML class diagrams this could have been modelled as an association class, since the entity contains information on the relationship between each trip-shipment combination.

The map distance is the distance that the shipper actually desires to have its shipment transported along. Without routing constraints and other transport jobs to fulfil this might be the distance the transporting vehicle actually travels. But most important it serves as base for allocating combined shipments. The quantity distance demand (map distance multiplied by the shipment's quantity) is the key figure to base the shipments' shares on. When the distance, fuel and corresponding carbon emission of a trip are known, the amounts allocated to each shipment involved in the trip are stored in the leg object.

6.3.2.8 Movement

Contains information gathered during various stages of a trip, which is a sequence of several movements. A movement is the part between two nodes of a trip. The application expects data to be sent from a board computer about the movement that has just been finished at each node the vehicle stops. Transmitted mileage and fuel levels are stored in the corresponding road trip object. The board computer codes are used to update trip, shipment and order status and to trigger carbon emission calculations when the trip has been finished. More details on performed activities (e.g. resting or fuelling) and possible extensions to the prototype such as including actual locations to movements could be valuable sources for discovering reduction opportunities. Such functionality is not included in this prototype, however.

6.3.2.9 Activity

To cover the complete lifecycle of a transport service, instead of only monitoring emissions caused by fuel combustion during trips, other activities causing emissions are to be included in the product footprint. Activity objects are intended to cover these emissions. An activity can be linked to a movement or to a shipment and contains some basic information and the calculated carbon emission associated with the activity, using data on the activity type.

6.3.2.10 ActivityType

This entity is used to predefine types of activities. The carrier needs to define the way different kinds of activities are accounted in the carbon footprint. For activities of which the exact amount of the emission driver source consumed is impossible to determine, surcharges can be defined. Using long term utility data, a carrier could for example account a fixed surcharge on electricity used for processing an order. Variable surcharges are supported as well, e.g. taking the quantity of the shipment into account. To calculate the actual carbon emission for a certain activity, this entity is linked to an emission factor in the Emission Protocol and Factor module. This design meets the requirements on other activities of section 5.4.8.

6.3.2.11 Mapper

This is an artificial entity used in Mendix to wrap XML to domain mappings in. These mappings are used for incoming trip plannings from a TMS and updates on movements from board computers (discussed later). The Mapper objects enable further manipulation of incoming data and associated objects.

6.3.2.12 Driver

For each road trip the truck driver is stored in an object of this entity. The prototype allows for storage of a driver ID (comparable to an employee number) and his name, meeting requirement R74 specified for reporting functionality. The carrier could use this link to analyze the driving behaviour of its employees. Our prototype does not provide such functionality, however.

6.3.2.13 Charter

Contains some basic information about charters that execute trips subcontracted to them. Important is the calculation method provided by the charter, i.e. either distance or fuel-based. Thus a charter is linked to an emission factor as well. In practice charters mostly provide distance travelled without fuel consumed.

6.3.2.14 Vehicle

Contains data on the vehicle deployed for a trip. Based on the type of vehicle an emission factor is associated to the vehicle. In this prototype only one type of vehicle is covered.

6.3.2.15 Truck

A specialization of a vehicle. Contains data that could be helpful for analyzing emissions of multiple trips to discover reduction opportunities. Such functionality is not implemented in this prototype, though. The engine and fuel type as well as the presence of board computer and CANbus determine the emission factor that needs to be used for calculating carbon emissions for trips the truck is deployed for. The requirements concerning vehicle data of section 5.4.4 are met concerning driving units, but freight units are not distinguished in the prototype design.

For practical reasons most associations in the domain model have been drawn between the parent entities. Semantically drawing the relations e.g. directly between RoadTrip and Truck, or between SubcontractedTrip and Charter would be more correct. Relating the parents does not influence the functionality however. The benefit of relating the parents is that multiple tier associated objects (for example the truck deployed for a leg) are in this way easier to retrieve or include in forms.

6.4 Prototype design - interfaces

Looking back at the architecture drawn for the prototype in Figure 18 in section 5.1 the calculator module interfaces with various applications in the environment. For our prototype we do not distinguish between a TMS and APS as source of transport and order details. We assume a TMS sends complete trip plannings including order details to the CMS. An interface with a map system could be realized to obtain demanded map distances, but such an interface has not been realized in the prototype. No application was directly available to integrate the prototype with and as this functionality was not considered critical (provided determined otherwise) for both the calculations itself and the validation of the architecture no effort was put in finding a solution for this. Map distance are assumed to be delivered by the TMS in the here discussed prototype. A TMS may be able to obtain the distances from a map system or to determine them itself using data of the carrier's transport network. The fourth interface drawn in the architecture is that with board computers to retrieve real-time updates on trips executed. This interface is functional in the prototype.

The next sections discuss how the prototype implements the two interfaces with the TMS and board computer respectively. Processing incoming data using these interfaces are also the first two core activities performed in the calculator module. "Process order and planning" handles incoming trip plannings and "process incoming data" handles incoming messages from board computers. These two main functionalities of the module are discussed directly after the corresponding interfaces have been presented.

6.4.1 Import TMS data

First we define an XSD which contains the elements a trip planning XML file should contain and the way the elements are structured in the XML file. A small sample of the XSD file is given below. It starts at the complex element Trip. A trip plan may contain an unbounded number of trips, but contains at least one. A sequence of trip attributes is defined, of which a few are given. The modality has restricted options. Nested in the trip the complex element Shipment contains shipment details. A trip may contain an unbounded number of trips, but might be empty as well. Note that some occurrence constraints are omitted to let the concerning element fit on a single line.

```
<xsd:element name="Trip" minOccurs="1" maxOccurs="unbounded">
  <xsd:complexType>
    <xsd:sequence>
      <xsd:element name="TripID" type="xsd:long" minOccurs="1"/>
      <xsd:element name="Modality" minOccurs="1" maxOccurs="1">
          <xsd:simpleType>
              <xsd:restriction base="xsd:string">
                  <xsd:enumeration value="Road"/>
                  <xsd:enumeration value="Rail"/>
                  <xsd:enumeration value="Inlandwater"/>
                  <xsd:enumeration value="Seawater"/>
                  <xsd:enumeration value="Air"/>
              </xsd:restriction>
          </xsd:simpleType>
      </xsd:element>
      <xsd:element name="Stops" type="xsd:integer" minOccurs="0"/>
      <xsd:element name="Shipment" minOccurs="0" maxOccurs="unbounded">
          <xsd:complexType>
              <xsd:sequence>
                   <xsd:element name="ShipmentID" type="xsd:string"/>
<!-- end of fragment -->
```

Appendix E provides an overview of data that can be exchanged between the home base of transport companies (e.g. by a TMS) and trucks using a CarrierWeb board computer. Forward tables contain trip and job info sent to board computers. The same data, if necessary formatted differently, can obviously be transmitted to a CMS. The tables make clear that it is a realistic target to obtain the trip planning data required to calculate carbon emission based on actual values of fuel consumption during trips by linking planning data on trips, shipments involved in trips and vehicles deployed for trips, to activity data returned by board computers (discussed later) during these trips.

After importing an XSD file, Mendix offers the possibility to graphically map the elements to domain objects and attributes. The complete trip mapping is shown in Figure 21. One can see that a trip has zero to many shipments, and that a shipment always has one leg for its trip. For the purpose of our prototype and the test case of section 6.6 only delivery locations are relevant, but the mapping is obviously extensible for more locations. For the location as well as the shipper the built-in search is used with their IDs as parameter to check if the object already exists. If not a new object is created. Such a simple check is sufficient for these entities, since the prototype does not contain further functionality manipulating them.

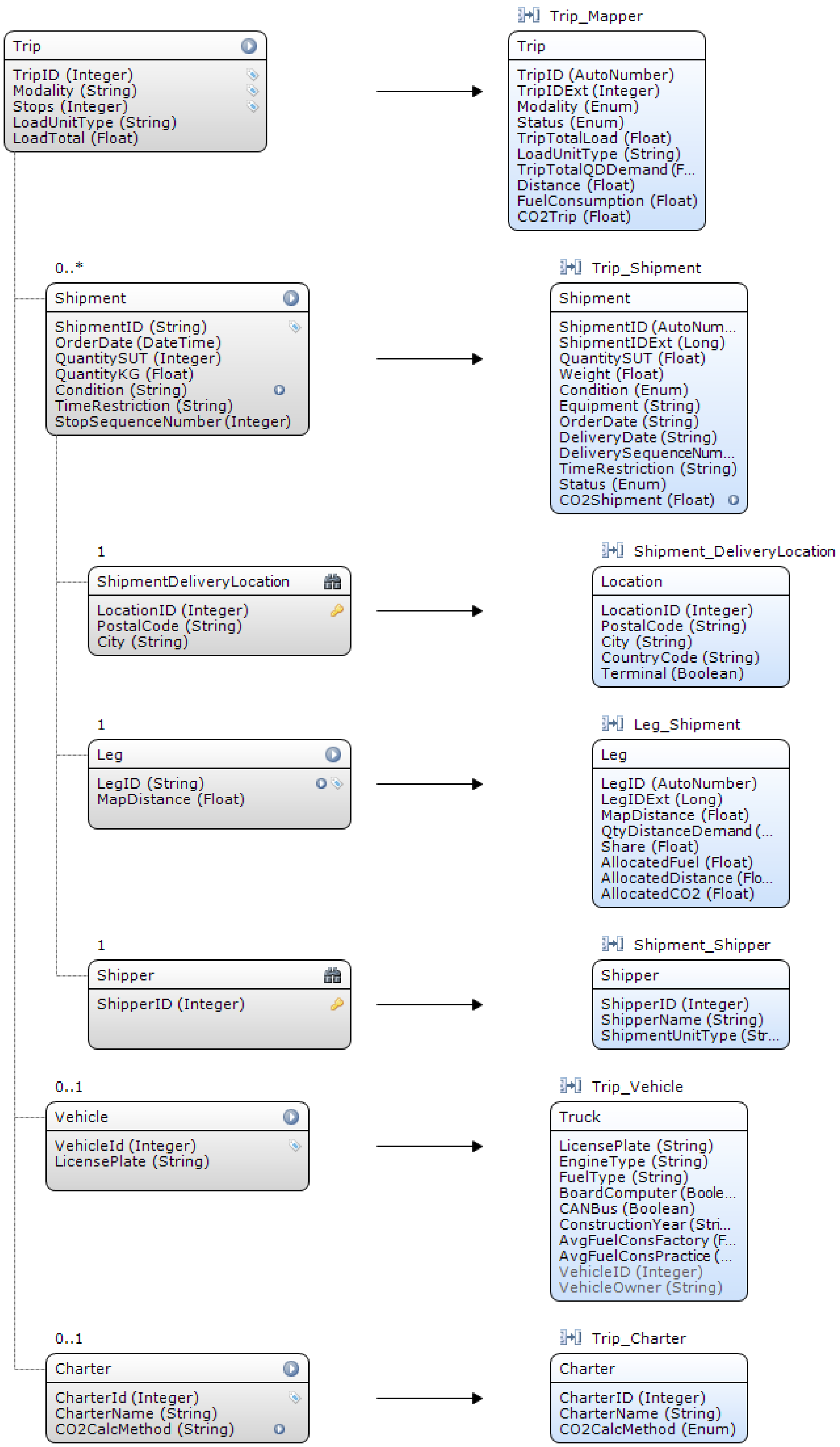

Figure 21: XML to domain mapping of a complete trip planning.

Instead of simply searching for and creating new objects, the mapping allows for specifying a microflow to obtain an object. Figure 22 shows such a microflow, in this example executed to obtain a Trip object to map the XML elements to. The first activity calls another microflow that converts the Modality, which is a string as XML element, to the corresponding enumeration format defined in Mendix. Next it checks whether the imported Trip already exists in the database by checking the Trip table for the external trip id passed to the microflow as input parameter. If so it returns the existing trip to the mapping. If not it checks the modality. In case it concerns road transport, a new RoadTrip is created as specialization of a Trip. Otherwise the microflow creates a SubcontractedTrip. In both cases it sets the external trip id and concerning modality as attributes and returns the trip, with the specialization inherited, to the mapping.

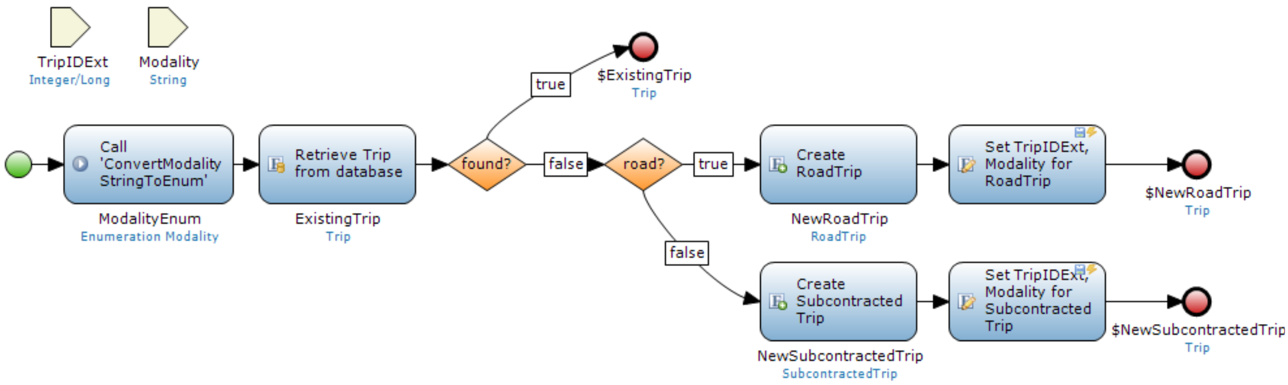

Figure 22: Microflow to obtain trip object to map XML element to.

The other microflows that are called from the mappings perform similar database checks, enumeration conversions and set some more associations than to the parent only. Altogether complete trip plannings can be mapped to domain objects automatically. With the Wrapper object discussed before, additional functionality is called after the mapping is complete. Here we set the trip and involved shipment status to “planned” and call microflows that calculate all trip properties that can be calculated in advance. These are first the total load of the trip (if not retrieved from TMS, by summing the quantities of the trip’s shipments), second the quantity distance demand of each leg of the trip, third, summing the latter, the total quantity distance demand of the trip and fourth the shares of each leg within a trip. After the trip planning has been completed, the CMS will wait for incoming updates on the trip execution progress.

6.4.2 Import Board Computer data

The import of board computer data that provides trip progress information, and eventually the fuel consumed as final input for the carbon emission calculation, is implemented in a similar way to importing trip plannings. Using an XSD file the schema is defined and with an XML to domain mapping in Mendix the data is actually imported in the database. The expected incoming data for a movement consists of:

- movement ID; a unique number to identify each movement.
- trip ID; the trip the concerning movement is part of.
- activity board computer code; referring to the activity performed. At this stage we distinguish between Start trip, End trip, Load and Unload, which is adequate for our functionality.

- stop sequence number; optionally the number of the last stop since starting the trip.
- mileage; the all-time distance travelled recorded from the odometer.
- fuel level; the amount of fuel currently in the fuel tank (obtained through the CANbus).

Board computers communicate a wide variety of data, see Appendix E for what data on activities can be transmitted by a CarrierWeb board computer. The transmission of activity data is triggered manually by the truck driver when he selects an activity performed on the board computer screen. The Canbus performance data can be transmitted automatically simultaneously. As stated above, for our application only little information is relevant. Like the TMS import data in the previous section, the tables in the appendix show that is a realistic assumption this information can actually be obtained from board computer data.

Figure 23 shows the microflow modelled to process incoming board computer data and update the trip accordingly. First it checks whether at least the mileage is included, otherwise the incoming message is considered useless. This check is rather exemplary, but future versions could handle various kinds of messages. Second the microflow retrieves the associated trip and verifies if it is a road trip. Third it reads the board computer activity code type. Depending on the activity reported, various follow-up actions are undertaken. In case a trip has just been started, the start levels for the odometer and fuel (attributes of a road trip) are stored and the trip and shipment status is set to "In progress". At load or unload activities the application stores interim odometer and fuel levels. When the board computer transmits that the trip has been finished this is the trigger to start calculating the associated carbon emissions. First the end levels for odometer and fuel are set. The difference between the start and end levels determines the distance travelled and fuel consumption for the

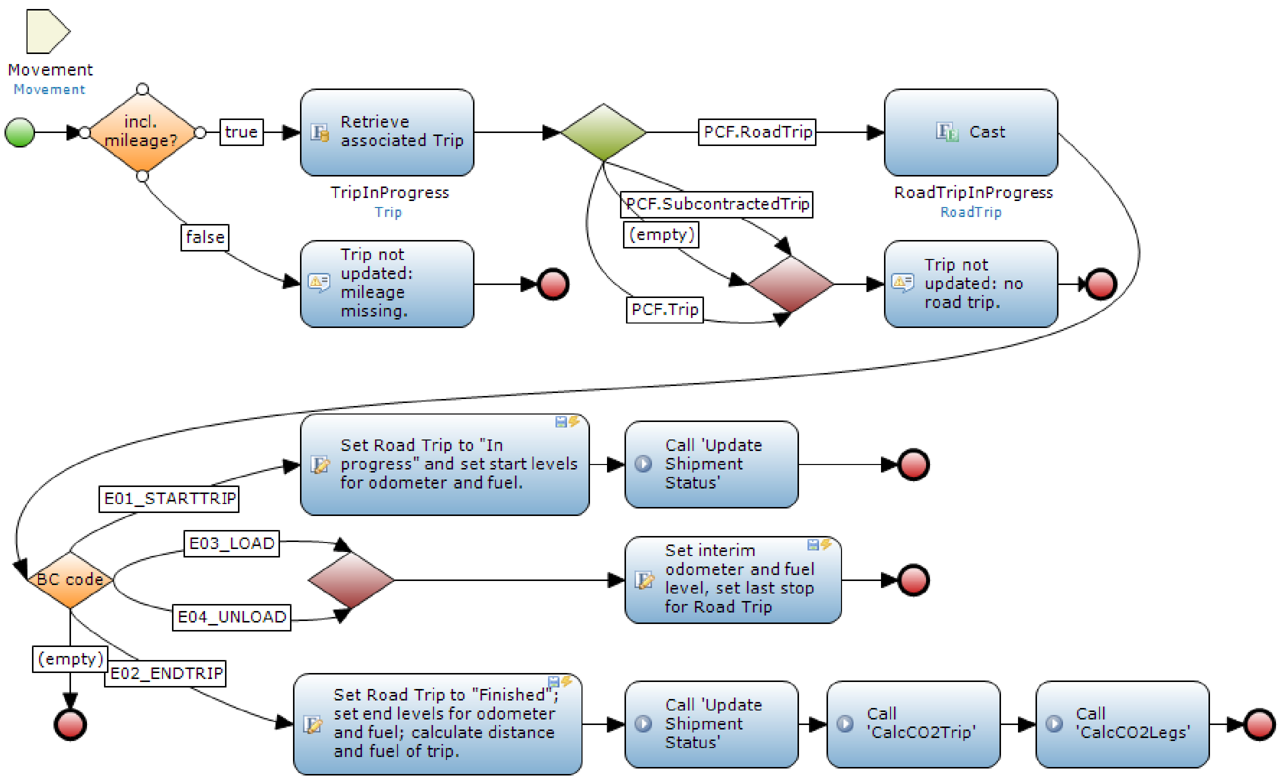

Figure 23: Microflow to update trip after incoming board computer XML data mapped to a movement object.

trip. The microflow also sets the trip and shipment status to “Finished”. Finally it calls other microflows that are responsible for the footprint calculation. These microflows are discussed in the next section.

6.5 Prototype design - carbon footprint functionality

The functionality of the prototype to calculate footprints as discussed in the following sections is first to calculate the emission of a complete trip and second (6.5.2) to allocate emissions to combined shipments and to aggregate various emissions of a certain shipment to a final value.

6.5.1 Calculate trip emission

The third core function of the calculator module as defined in the reference architecture is to calculate intermediate emissions. It leaves open to the implementation on what level the intermediates are determined. One could think of calculating emissions for each movement. This results in a valuable source for reduction opportunities, e.g. to detect anomalies and trace them down to activities performed, such as fuel consumption while resting. We consider a complete trip as the intermediate calculation. The goal of this prototype is to validate that the carbon emissions of a transport can be calculated fuel-based using board computer and CANbus data. Taking the emissions of a trip as basis satisfies this goal.

Figure 24 shows the microflow that calculates the carbon emission of a trip. With the concerning trip as input, it first determines the trip type, either road or subcontracted. Otherwise the microflow terminates. In practice error messages such as modelled in the previous microflow would be desirable when unexpected terminations occur. As our prototype operates in a controlled environment and to keep the diagrams clear, we leave them out here. The microflow splits depending on the trip type.

As explained at the domain model, the prototype assumes that a road trip is executed by a truck of the carrier which contains both board computer and CANbus. In the truck table the actual presence of these devices is stored, however. The microflow could therefore easily be extended with a check on the presence after retrieving the truck, and if necessary fall back to distance-based calculation in a sub flow. This microflow also looks up the emission factor that fits with the truck’s properties. But by assigning BC and CANbus to each truck, the retrieved emission factor is always fuel-based in litres of the truck engine’s fuel type. By multiplying the emission factor with the fuel consumption previously stored as road trip attribute, the microflow calculates the carbon emission of the trip.

The lower activity flow handles subcontracted trips. Similar to road trips the model here assumes that charters always provide distance travelled only and account the cargo in ton kilograms. Again the microflow looks up the emission factor at the associated charter object, but it always receives an EF with unit ton*km in our prototype. The microflow then calculates the carbon emission of the trip as multiplication of the emission factor and distance and load. Note that the load in this situation is not the total load on board, but the total that the charter is subcontracted for to transport.

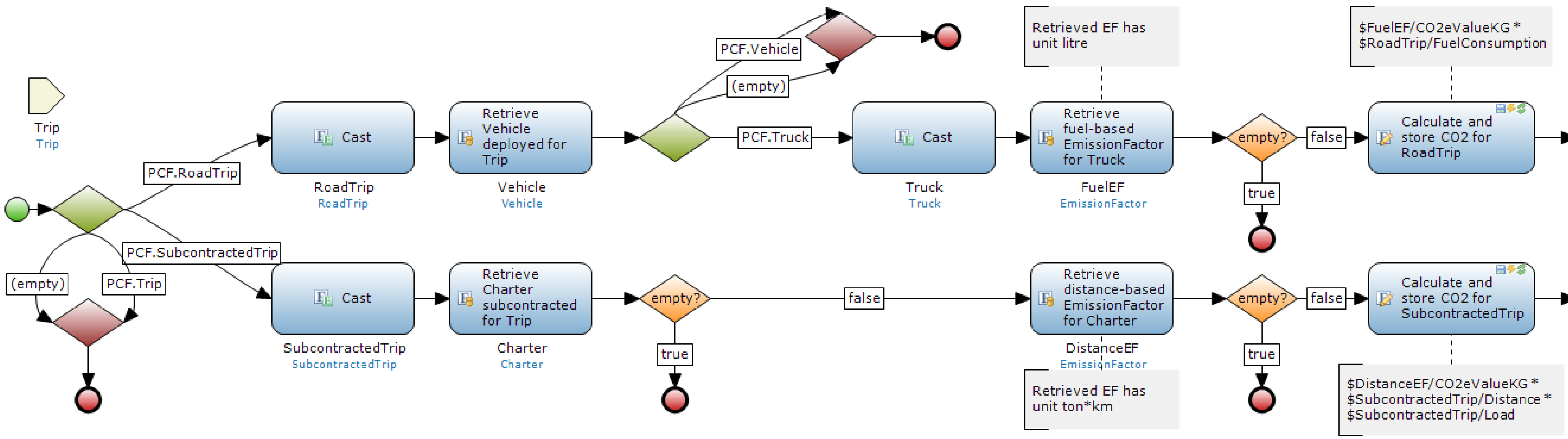

Figure 24: Microflow to calculate the carbon emission caused by a trip.

Including a basic type of multimodal subcontracted trips is a first extension to road trips executed by the carrier itself. The diagram of Figure 11 showing movements for all kinds of modalities shows that the real world is far more complex. By defining more trip types the model could be extended with extra flows for these various kinds of trips. Looking back at the requirements specification for footprint calculation of trips (section 5.4.5) the different deployment statuses are not taken into account in our design and only the most elementary board computer reports are handled. However, the important functionality of linking shipments to a trip and tracking distance travelled and fuel consumption during trips is part of the prototype.

6.5.2 Allocation and aggregation of emissions

In the reference architecture the fourth core function of the emission calculator module is to allocate emissions to the shipments combined in the trip. The allocation takes place in the leg object that is associated to each shipment-trip combination. After the carbon emission caused by a trip has been calculated, it is rather straightforward to execute the allocation. Most work for this mechanism has already been carried out after importing the trip planning, namely to calculate the quantity distance demands of all shipments combined and consequently the share of each shipment. Figure 25 shows the microflow that is responsible for the allocation. It receives a trip as input and then performs a database query to receive all legs associated with the trip. Next, while iterating over the list, it calculates the allocated amounts of distance travelled, fuel consumption (both with the purpose to provide extra information) and most important the carbon emission.

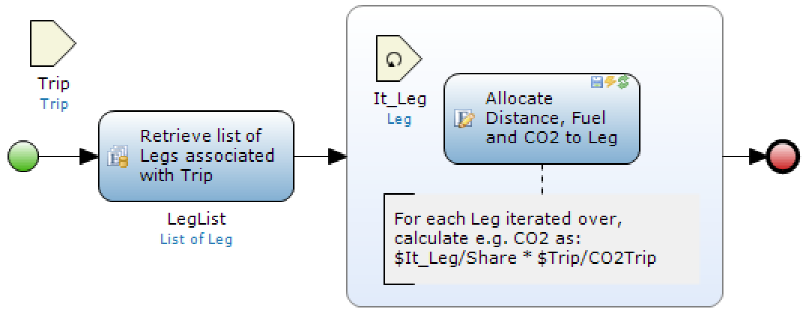

Figure 25: Microflow to allocate carbon emissions of a trip to the associated legs.

Finally the fifth core function declared for the emission calculator module is to calculate the total actual emission for a transport service. This means accumulating the emissions allocated to all legs over which the shipment has been transported from pickup location to delivery location. Furthermore emissions caused by other activities assigned to the shipment, e.g. surcharges for fuel consumption by forklifts in warehouses or by refrigeration units, have to be added to the transport product carbon footprint, see Figure 26.

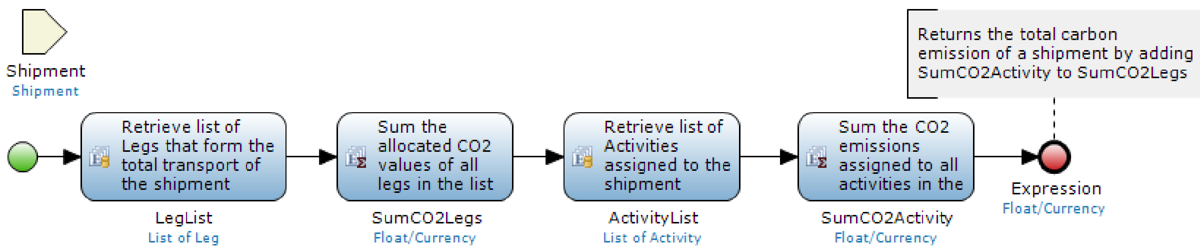

Figure 26: Microflow to calculate the total carbon emission of a shipment caused by the transport service.

In the prototype the sum is automatically calculated as a user looks up a shipment. This means it is a virtual attribute with the microflow calculating the total emission as source. In future versions of the PCF calculator module it may be desirable to store the emissions in separate objects. This would enable advanced analysis functionality. For the prototype the ultimate goal is to calculate the carbon emission value, which is satisfied by this solution. Furthermore the prototype completely meets the requirements specified in section 5.4.6 on allocation and aggregation of emissions.

6.6 Prototype test case

After explaining the functionality of the prototype we now demonstrate it with a simple test case. Section 5.4.6 on requirements for footprint allocation provides an example of a multi-stop LTL road trip including allocated fuel consumption for each shipment. The graph is repeated below.

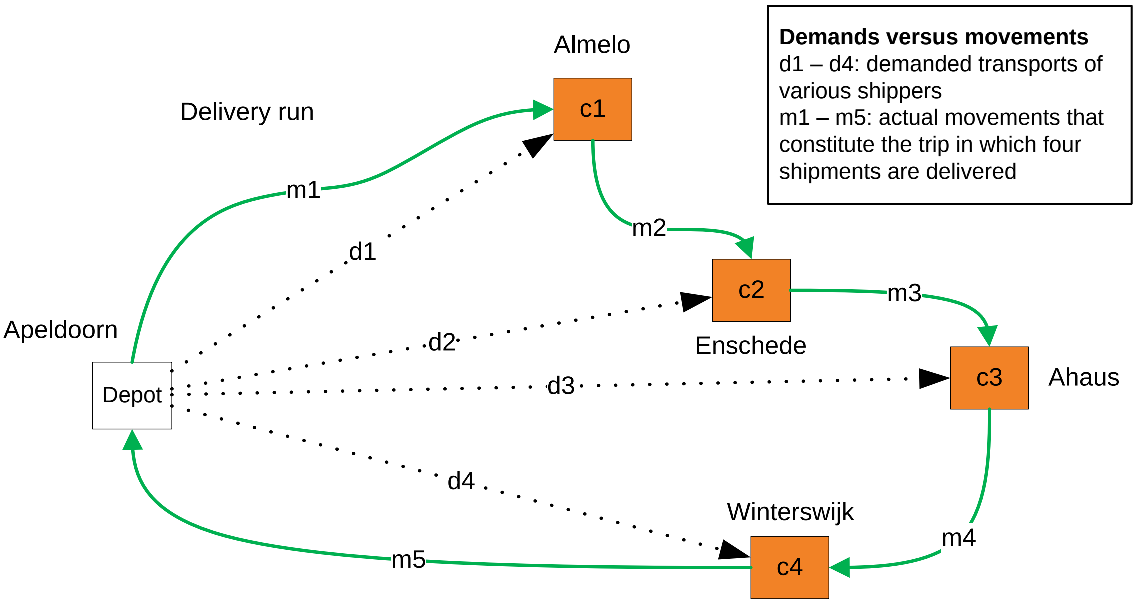

Figure 27: Demanded transports versus actual movements of a trip used to test the prototype.

We simulate a trip with four stops to deliver shipments as depicted in Figure 27 with the prototype. The goal of the test case is to validate the prototype outcomes against the figures calculated using Microsoft Excel for the requirements specification, repeated below in Table 6.

move-ment	distance travelled (km)	fuel cons. (l)	order	qty (lm)	map (km)	lmd (lm km)	share lmd	accounted fuel (l)
m1	62	17	d1	4	57	228	22%	13,5
m2	25	6	d2	1	69	69	7%	4,1
m3	26	7	d3	5	98	490	48%	29,0
m4	29	8	d4	3	76	228	22%	13,5
m5	80	22						
total	**222**	**60**		**13**	**300**	**1015**	**100%**	**60**

Table 6: Footprint calculation of combined shipments to be validated with prototype.

The following XML code lines show part of the TripPlanning.xml that we first import in the prototype. The three last shipments have been omitted from the XML copy.

```
<?xml version="1.0" encoding="ISO-8859-1"?>
<TripPlanning xmlns="http://www.capegroep.nl/co2service"
      xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
      xsi:schemaLocation="http://www.capegroep.nl/co2service
TripPlanning.xsd">
<TripList>
<Trip>
  <TripID>23051</TripID>
  <Modality>Road</Modality>
  <Stops>4</Stops>
   <Shipment>
    <ShipmentID>44662</ShipmentID>
    <OrderDate>21-03-2011</OrderDate>
    <QuantitySUT>4</QuantitySUT>
    <Condition>Ambient</Condition>
    <TimeRestriction>11:30</TimeRestriction>
    <StopSequenceNumber>1</StopSequenceNumber>
    <ShipmentDeliveryLocation>
      <LocationID>1122</LocationID>
      <PostalCode>7605QW</PostalCode>
      <City>Almelo</City>
    </ShipmentDeliveryLocation>
     <Leg>
       <LegID>230511</LegID>
       <MapDistance>57</MapDistance>
     </Leg>
     <Shipper>
       <ShipperID>121</ShipperID>
     </Shipper>
  </Shipment>
<!--break: actual file contains more shipment elements-->
   <LoadTotal>13</LoadTotal>
   <Vehicle>
    <VehicleID>78</VehicleID>
    <LicensePlate>BZ-ZZ-22</LicensePlate>
   </Vehicle>
</Trip>
</TripList>
</TripPlanning>
```


After importing the XML file, the XML to Domain mapping shown in Figure 21 stores the planning as objects in the application's database. Figure 28 shows the result of the import and accompanying microflow actions automatically carried out after the mapping. The upper table displays imported trip number 23051 containing a list of the four shipments defined. These shipments are listed in the middle table. It provides freight and order information (without showing all location details). Finally the lower table lists the legs created for each shipment-trip combination. Here a microflow calculates the quantity distance demand (QDD) for each leg, in this case in loading metre demand (LMD) since it used as unit to account the freight. Furthermore the trip attributes load (although this was imported as well) and load distance demand (LDD) are sums of the loads of the shipments and of the QDDs of the legs respectively. Finally the QDD of each leg is divided by the LDD to arrive at the leg's share. The figures of the QDD match with the LMDs calculated in Table 6 and the same holds for the shares.

Trips

Search | New | Edit | Delete — 1 to 1 of 1

Trip ID	Shipments	Status	Modality	Truck	Charter	Load	Unit	LoadDistDmnd	Distance	Fuel (l)	CO2 trip
23051	44662;44663;44699;44714	Planned	Road	BZ-ZZ-22		13.00	LM	1015.00	0.00	0.00	0.00

Shipments

Search | New | Edit | Delete — 1 to 4 of 4

Shipment ID	Shipper	Quantity	Unit	Weight kg	Temp	Equipment	Order date	Delivery date	Time	Stop #	Area	Status	CO2 kg
44662	Kamp Electro	4.00	LM	0.00	Ambient		09-03-2011		11:30	1	7605QW	Planned	0.00
44663	Kamp Electro	1.00	LM	0.00	Ambient		09-03-2011		12:00	2	7533ER	Planned	0.00
44699	Grum GMBH	5.00	LM	0.00	Ambient		09-03-2011			3	48683	Planned	0.00
44714	Vries BV	3.00	LM	0.00	Ambient		09-03-2011		17:00	4	7101TY	Planned	0.00

Legs

Search | New | Edit | Delete — 1 to 4 of 4

Leg ID	Shipment	Trip	Qty	Unit	Kg	Map distance	Qty Dist Dmnd	Share	Truck	Charter	Allocated fuel	Distance	CO2
230511	44662	23051	4.00	LM	0.00	57.00	228.00	0.22	BZ-ZZ-22		0.00	0.00	0.00
230512	44663	23051	1.00	LM	0.00	69.00	69.00	0.07	BZ-ZZ-22		0.00	0.00	0.00
230513	44699	23051	5.00	LM	0.00	98.00	490.00	0.48	BZ-ZZ-22		0.00	0.00	0.00
230514	44714	23051	3.00	LM	0.00	76.00	228.00	0.22	BZ-ZZ-22		0.00	0.00	0.00

Figure 28: Combined screenshots of tables with the Trip, the Shipments and Legs after import of the trip planning.

After the trip planning has been received, it is a matter of waiting for incoming messages from the board computer of the deployed truck (or updated trip planning data from the TMS). The XML fragment below shows some elements that could be derived from a BC activity message.

```
<MovementID>723612</MovementID>
<TripID>23051</TripID>
<ActivityID>9070</ActivityID>
<StopSequenceNr></StopSequenceNr>
<TachoOdometer>675839</TachoOdometer>
<FuelLevel>664</FuelLevel>
```

In this case the activity ID matches to our defined “Start Trip” activity, using the CarrierWeb’s cwActivityIdCodes in the final table of Appendix E as example. This explains why the stop sequence number is empty. This specific activity ID only triggers updates of the shipment and trip status to “In Progress” and copies the levels of the odometer and fuel to the start values of the road trip. The follow-up messages at each location are simulated with the distance travelled and fuel consumption amount of each movement copied from the first columns of the example table. An example of the next activity message, with an activity ID meaning “Unloading”:

```
<MovementID>723698</MovementID>
<TripID>23051</TripID>
<ActivityID>40</ActivityID>
<StopSequenceNr>1</StopSequenceNr>
<TachoOdometer>675901</TachoOdometer>
<FuelLevel>647</FuelLevel>
```

Figure 29 shows the tables after all movements have been completed and the trip has thus been finished. The first table gives an overview of all movements and how the mileage and fuel level developed during the trip. The road trip table shows the same trip as the previous picture, but now its specialization containing all the odometer and fuel details. Based on the fuel consumption the carbon emission for the trip is calculated and stored. In the shipments table, where the prototype does not change the delivery date or time, the carbon emission for each shipment is now provided after the trip has been finished. The source for these values are the associated leg objects. Based on the shares, the allocated distance, fuel consumption and carbon emissions have been determined.

Movements

Search New Edit Delete 1 to 6 of 6

Movement ID	Trip ID	Activity ID	Stop #	Mileage	Fuel level
723612	23051	Start trip	0	675839.00	664.00
723698	23051	Unload	1	675901.00	647.00
723748	23051	Unload	2	675926.00	641.00
723795	23051	Unload	3	675952.00	634.00
723888	23051	Unload	4	675981.00	626.00
723967	23051	End trip	5	676061.00	604.00

Road Trips

Search New Edit Delete 1 to 1 of 1

Trip ID	Truck	Odo start	Interim	Odo end	Distance	Fuel start	Interim	Fuel end	Consumption	Status	Stops	Last	Load	Total LMD	CO2
23051	BZ-ZZ-22	675839.00	142.00	676061.00	222.00	664.00	38.00	604.00	60.00	Finished	4	4	13.00	1015.00	188.40

Shipments

Search New Edit Delete 1 to 4 of 4

Shipment ID	Shipper	Quantity	Unit	Weight kg	Temp	Equipment	Order date	Delivery date	Time	Stop #	Area	Status	CO2 kg
44662	Kamp Electro	4.00	LM	0.00	Ambient		09-03-2011		11:30	1	7605QW	Finished	42.32
44663	Kamp Electro	1.00	LM	0.00	Ambient		09-03-2011		12:00	2	7533ER	Finished	12.81
44699	Grum GMBH	5.00	LM	0.00	Ambient		09-03-2011			3	48683	Finished	90.95
44714	Vries BV	3.00	LM	0.00	Ambient		09-03-2011		17:00	4	7101TY	Finished	42.32

Legs

Search New Edit Delete 1 to 4 of 4

Leg ID	Shipment	Trip	Qty	Unit	Kg	Map distance	Qty Dist Dmnd	Share	Truck	Charter	Allocated fuel	Distance	CO2
230511	44662	23051	4.00	LM	0.00	57.00	228.00	0.22	BZ-ZZ-22		13.48	49.87	42.32
230512	44663	23051	1.00	LM	0.00	69.00	69.00	0.07	BZ-ZZ-22		4.08	15.09	12.81
230513	44699	23051	5.00	LM	0.00	98.00	490.00	0.48	BZ-ZZ-22		28.97	107.17	90.95
230514	44714	23051	3.00	LM	0.00	76.00	228.00	0.22	BZ-ZZ-22		13.48	49.87	42.32

Figure 29: Combined screenshots of tables with Movements, Road trip, Shipments and Legs after the trip has finished.

6.7 Verification of results

When we compare the allocated fuel values, the conclusion is that the prototype has arrived at the same values as calculated before in Microsoft Excel (Table 6). This shows that our concept of defining legs for each shipment within a trip, and the corresponding allocation mechanism, works correctly in the prototype.

When we consider verification of results in general, the emission values reported by the PCF Calculator depend on three parameters (assuming performing correct arithmetic operations):

- Shipment details, fuel consumption, and details of complementing activities received from TMS, board computer, other information systems
- The allocation algorithm used for combined shipments
- The emission factor selected by the application

Correctness of the first parameter, shipment details and fuel consumption, is not the responsibility of the PCF Calculator. Depending on the sophistication of motor management systems, the reported fuel consumption amounts may be unreliable. However, verifying these amounts is considered the responsibility of the organization using the application and excluded from the system responsibilities.

Correctness of the allocation algorithm has been demonstrated by the test case. With regard to external users of a CMS, it is important to be transparent about the allocation method used. When presented a breakdown of a final emission value, including the load share of its shipment, a shipper should be able to recalculate the values.

Correctness of the emission factor used to convert the fuel consumption into carbon emissions can be verified easily. If the fuel consumption is known, a user can simply look up the publicly available emission factor (see Appendix D) and recalculate the emission value.

All in all, given a certain amount of fuel, the CMS produces a verifiable corresponding carbon emission value. Although this test case is very limited concerning the transport example of just one round trip, it does prove that the prototype works. Four of its intended core functions, namely to process trip plannings and incoming board computer data, calculate intermediate (trip) carbon emissions and allocate these to the combined shipments have been performed correctly. Only aggregation of multiple legs or activities has not been tested in this case. Still the overall conclusion of this test case is that the prototype of the Product Carbon Footprint Calculator module both verifies that an application can be implemented according to (selected parts of) the reference architecture and validates that such an application can correctly calculate transport carbon emissions fuel-based using board computer data.

6.8 From prototype to actual product

The previous sections presented our prototype for a Product Carbon Footprint Calculator module for transport services. This section discusses whether the prototype forms a sound basis for the development of an actual product. First, it relates the functionality currently supported to what is ultimately desired in practice. Second, it discusses possibly required adjustments to current configuration of IS/IT in practice. Third, it considers the scalability of the application, regarding the gap between a small prototype and full operation in practice. Finally, it indicates whether there is a viable business case for a carbon management system in the logistics industry.

6.8.1 Functionality

One goal of the prototype was to validate whether it is able to provide correct fuel-based carbon footprints of transport services. The functionality implemented is sufficient to achieve this goal for basic examples of shipments and trips. It contains the core functions to receive transport planning and board computer data, calculate trip emissions, allocate emissions to combined shipments and aggregate emissions of multiple legs. However, the prototype implementation has several limitations. Concerning input of TMS data it assumes equal load unit types (e.g. all shipments in loading metre) and availability of map distances. The design includes location objects, but functionality using these (e.g. requesting or even calculating map distances between two locations) has not been implemented.

The prototype also assumes BC and CANbus presence in all vehicles, while in practice older ones may lack these devices. Only little data from board computers is currently used. The prototype only collects mileage and fuel data at the start and end of a trip and at (un)load activities. More data on drivers, driving behaviour, activities between trip segments such as fuelling or resting, locations, etc. could be stored in practice. Of the many possible transport varieties the prototype only distinguishes between road transport executed by the carrier and multimodal transport executed by a charter. In practice more varieties occur and should be supported. Finally, these limitations only regard footprint calculations, while the reference architecture for a complete CMS also contains reduction functionality. Altogether significant extensions to the prototype are required before it will be able to cope with all complexities of transport services and satisfy all desires from practice.

6.8.2 Deployment

On the other side, an organization that implements a CMS according to our architecture probably has to adjust its IT/IS to the presence of the CMS as well. While discussing the interfaces of the prototype we related the input generated for the test case to messages exchanged between home base and vehicles in practice using CarrierWeb board computers. Its External Access Interface application supports keeping track of these messages, of which Appendix F shows message contents relevant for carbon management.

CarrierWeb and Dasko Group, an LSP specialized in temperature-controlled transport operating over 100 vehicles, were kind to provide access to their EAI giving insight in the messages exchanged. Unfortunately, it was not feasible to use this data for our test case. First the configuration of Dasko's board computers, i.e. the question path drivers follow and thus the data transmitted to the home base, is rather limited. The messages often lack information on shipments and CANbus data is not related to transport jobs. Second the amount of incoming messages is so great that it would cost too much effort to filter data required for our simple test case.

Both aspects show that an LSP may need to reconfigure its board computers and instruct drivers about adjusted question paths before they can properly start with carbon management. Furthermore middleware has to be configured to pass only messages required for carbon management to the CMS.

6.8.3 Scalability

The test case shows that the prototype is able to calculate the emissions for a single transport service. However, large transport companies operate a fleet of hundreds of vehicles executing many trips each day. The example of Dasko in the previous section makes clear that this results in a huge amount of incoming board computer data. This raises the question whether calculating emissions real-time for all those transport jobs is feasible in practice.

In fact the EAI application itself proves that it is possible to handle board computer messages on a large scale. The messages of all board computers are initially received at CarrierWeb's data centre. The EAI synchronizes a local database of a particular LSP with messages from its trucks received at the data centre every minute. Thus the EAI makes BC messages available to internal systems almost real-time. It is the responsibility of the LSP's middleware to quickly forward the relevant messages to the CMS.

The next question is what is required from the CMS to handle large amounts of incoming messages and to perform subsequent calculations. Experiences of CAPE Groep during past projects with BC communication have learned that implementing such applications is feasible. A first example is a track and trace portal developed for Jan de Rijk Logistics. Through an enterprise service bus, both transport planning data from the TMS and real-time messages from board computers are received by the portal, like the intended interfacing of the CMS. One of the functionalities of the track and trace portal is that it calculates estimated times of arrival (ETA) based on activities reported from trucks. When an updated ETA deviates more from the demanded ETA than a predetermined threshold, the application generates warning messages.

A second example is an application developed for Mammoet Road Cargo. It matches activities reported by board computers with projects received from an ERP system and updates the project status according to the nature of the BC message. For example the hours of service of the truck driver as reported by the BC is stored as hours worked for a project. The hardware deployed for both applications is modest, each is running on a single server with quite ordinary specifications. Furthermore, a property of the Mendix application is that it supports load distribution over multiple machines. Thus in case the carrier's fleet becomes very large, or calculations become more complex, the application remains scalable regarding hardware configuration. Based on these experiences we conclude that scalability is not a major issue when the prototype is extended to an actual product.

6.8.4 Business case

Finally, LSPs interested in carbon management will ask themselves whether there is a business case for implementing a CMS. This depends on the motivation for starting with carbon management and what benefits are regarded as a result of it. Section 3.3 learned that normative pressure is a possible reason to adopt green IS such as a CMS. In logistics such a pressure may come from a shipper demanding the carrier to report the carbon emission caused by its order. When the carrier cannot provide this service, it may ultimately lose the customer and consequently revenues. Costs for implementing a CMS may be lower than the possible lost revenues in such a case.

Another possible motivation comes from coercive pressures. As the motivation for our research (section 1.1) explained, the EU may include the road transport industry in the European Trading System for emission rights in the near future. If so, large LSPs have little choice but to adopt carbon management and the only question remaining is how sophisticated they desire a CMS to be.

The latter question points to the extension of the Product Carbon Footprint Calculator module with a Carbon Reduction Module. This module is intended to give insight in carbon reduction opportunities. If an LSP is indeed able to reduce emissions, the profits are twofold. First it requires less emission rights (if the LSP falls under such legislation) and second it indirectly saves costs on fuel, as in transport carbon reduction can be translated to fuel usage reduction. One may argue whether decreased fuel usage is really a merit of the CMS, or in other words, whether a CMS is really required to decrease fuel consumption instead of other initiatives. We argue that when a CMS is the incentive for such reductions, it can at least partially be regarded as foundation for it.

Experiences with driving style projects in the Netherlands ("Blik op brandstof" and "Het nieuwe rijden") have learnt that driving behaviour training for truck drivers yields savings of 2 to 3 percent on average up to 7%. When combined with monitoring fuel consumption on management level 10% is even possible (Logistiek.nl, 2008; TLN, 2009). The latter is a typical functionality of the CMS.

The following paragraph shows an estimation of carbon reduction benefits. In the example we consider a transport company with a fleet of 100 vehicles, each travelling 150,000 kilometres per year, averaging a consumption of 1 litre diesel per 3.5 kilometre. The total consumption per year is thus 4,286,000 litres of diesel for 15,000,000 kilometres. With an emission factor of 3.140 kg CO_2e per litre of diesel, the LSP is responsible for 13,458.04 tonnes of CO_2e emission.

Table 7 shows the benefits for saving fuel consumption and carbon emissions ranging from 1% savings to 7%. Regarding fuel consumption, the table lists benefits for diesel prices of €1.10 respectively €1.35 per litre. Regarding emission rights, it distinguishes between 15 and 20 euro per ton CO_2e. In the scenario of 3 percent reduction, with conservative diesel and emission right prices, the transport company from the example saves 141,438 euro on fuel and another 6056.12 on emission rights on a yearly basis.

Fuel	savings (%)	fuel consump. (litre)	savings (litre)	savings (€)	
				price of diesel (€/litre)	
Base case		4286000		1.10	1.35
Scenario 1	-1%	4243140	42860	47146	57861
Scenario 2	-3%	4157420	128580	141438	173583
Scenario 3	-5%	4071700	214300	235730	289305
Scenario 4	-7%	3985980	300020	330022	405027
Carbon	**savings (%)**	**emission (ton CO2e)**	**savings (ton CO2e)**	**savings (€)**	
				price of emission right (€/ton CO2e)	
Base case		13458.04		15	20
Scenario 1	-1%	13323.46	134.58	2018.71	2691.61
Scenario 2	-3%	13054.30	403.74	6056.12	8074.82
Scenario 3	-5%	12785.14	672.90	10093.53	13458.04
Scenario 4	-7%	12515.98	942.06	14130.94	18841.26

Table 7: Monetary benefits of fuel and carbon reduction.

Obviously costs are involved as well for starting with carbon management. However, these may vary a lot depending on company characteristics, current IT/ IS base, modules desired, deployment (local versus SaaS), etc. We do not attempt to quantify these costs for various scenarios. However, from the yearly savings calculated for the example company, it becomes clear that for large transport companies, a reasonable return on investment is achievable, even when the CMS only contributes to minor reductions in fuel consumption or carbon emissions.

6.9 Conclusion

This chapter presented a prototype of a transport CMS, developed with the Mendix Business Modeler. The goal of implementing this prototype was twofold. First our aim was to verify whether an IS could be designed and implemented as instance of our reference architecture presented in chapter 4. In accordance with the definition and guidelines of the reference architecture, an architecture for the prototype covering parts of the reference had already been composed in chapter 5, where we specified the requirements for a transport CMS in general and more specifically for the prototype presented in this chapter. Thus the prototype is scoped to the Product Carbon Footprint Calculator module assisted by a minimal version of the Carbon Emission Protocol and Factor module.

While considering verification of the RA, the prototype first realizes the external application service it is intended for; providing actual values of carbon emissions of a transport service. Second it contains the five core functions the architecture’s application component is composed of, using the emission factor service of the Protocol module. Third it is integrated with the two critical information systems in the application environment; TMS providing order and transport data and board computer software transmitting real-time trip data. Further integration with e.g. a WMS has not been achieved, but could be realized in future versions. Altogether the design provides an answer to research question 3a on how to apply the reference architecture to develop a CMS.

The second goal of the prototype was to validate whether such an instance of the reference architecture is able to provide correct fuel-based carbon footprints of transport services. After carrying out a test case and reflecting on the reliability of the calculated values, our conclusion is that the prototype indeed fulfils its intended purpose, by correctly and automatically calculating emissions of a transport.

A limitation of the test case is its artificial character, simulating incoming TMS and BC data rather than by integration with systems actually used in practice by transport companies. Reviewing the specification of a common board computer learned that retrieving the required data is feasible, though. Yet research question 3b about how to obtain data from board computers and motor management systems is unfortunately only answered theoretically.

Furthermore the single trip simulated does not guarantee correct behaviour for the many varieties of transport routes and modalities. The design does distinguish between road trips and subcontracted multimodal trips though, supporting distance-based calculations for the latter. This distinction can be extended with more varieties. Another important achievement is the ability to allocate emissions to combined shipments in accordance with the fair quantity distance demand algorithm specified in section 5.4.6 of the requirements. Supporting additional activities assigned to shipments also ensures the complete lifecycle of a transport service can be included in the product carbon footprint, complying to the main requirements of section 5.4.8 and the PAS 2050 protocol. Aggregating multiple legs and emissions is a quite straightforward last step as shown in Figure 26. Altogether we conclude that the prototype implementation presents a practical solution to research question 1c on how to calculate a carbon footprint for LSPs.

The last research question to answer is 3c about whether the realised implementation provide its users insight in their carbon emissions and opportunities to reduce it. The prototype clearly provides insight in carbon emissions. However we must also conclude that the ultimate goal of carbon management, to reduce emissions, is not supported by the prototype. Chapter 5.7 does specify requirements of some reduction functionalities, but it turned out that implementation of these features was not feasible within this project. The product calculator may serve as basis for such extended functionality, however. Actual emission values collected over a longer term will contribute to the services provided by emission forecast or reduction modules, since the application relates emissions to trips, vehicles, drivers, locations, shippers and more. It thus is a source for statistical analysis of emissions, which serves as starting point for any carbon reduction initiative.

The final section discussed the step from prototype to actual product. Like described in the previous paragraphs, with regard to functionality, the prototype is just a beginning of the development of a satisfying end product. On the other hand, we are confident that the application is scalable to work under much heavier loads than in our test case. Last not but least, the exemplary business case in section 6.8.4 showed that a CMS is expected to yield significant benefits when LSPs realize reduction of fuel consumption and carbon emissions.

7 Final remarks

This chapter draws the conclusion of this thesis. We reflect on the main research question defined in the first chapter, discuss the contributions to science and practice, and give recommendations for future directions in research and practice.

7.1 Conclusions

The main research question of this thesis is:

What reference architecture can best provide a basis for the design of an information system that allows logistics service providers to gain insight in their carbon emission and how to reduce it, by integration of relevant systems and fuel-based calculation of the emissions during transport services?

To structure our research, we divided the main research questions into three questions each covering a specific field of research; respectively carbon footprint, architecture and design. The following paragraphs reflect on each research question before we draw our final conclusion in relation to the main research question.

RQ1. What forms a carbon footprint on both product and corporate level for logistics service providers?

In order to answer this question, our approach was to study the carbon footprint and transport field from a business perspective. We started with an exploration of the carbon footprint literature and practice. The first conclusion of this research is that carbon footprinting is an immature practice. Both in science and practice no single definition of the concept has been widely accepted. Based on literature we conclude that for product level footprints a full life cycle approach is preferred.

For logistics service providers this means that the carbon footprint of a transport service is composed of more emissions than just those associated with fuel combustion during trips. Loading and unloading, warehousing, and office activities are examples of other sources of emissions part of a transport service. As these services may stretch over multiple legs, some possibly multimodal, while consolidating multiple shipments in one freight unit, calculating carbon emissions is a complex task.

The immaturity of carbon footprinting is also expressed in the numerous standards and protocols developed for composing footprints. Little synthesis between them is visible, while consolidation would greatly improve the reliability, transparency and comparability of carbon footprints of different organizations and products. Now the wide variety of protocols developed and emission factors published may rather obstruct than encourage companies in adopting carbon reduction strategies. Furthermore it may obscure citizens from published footprints, since footprints say little when choosing another source for the emission factors would result in different values for the carbon emission.

We conclude that PAS 2050 is the best product level protocol to comply with, because of its global support, life cycle approach and transport specific instructions. The GHG protocol is the de facto standard for corporate level footprints. Stimular's Milieubarometer emission factors are considered the best alternative for the logistics industry, as it provides all factors relevant for the logistics industry including numerous fuel-based emission factors.

RQ2. What reference architecture can best provide a basis for the design of a carbon management information system for logistics service providers?

In order to answer this question, our approach was to study the carbon footprint and transport field from an information technology perspective. Together with the business domain and footprint practice, this study formed the input to develop the reference architecture.

The carbon footprint information technology side is still in its infancy as well. Companies are tending to wait with introducing green IS in their organization for visible success of environmentally inspired early adopters or until normative or legal pressures force them. Otherwise bottom line considerations are the only reason to adopt Green IS.

For the logistics industry, both normative or legal pressures, and bottom line considerations may trigger the adoption of green IS. As one of the few sectors where carbon emissions have risen over the last decade, it is under pressure to break this trend. Furthermore reducing emissions can only be achieved by reducing fuel combustion, which can be translated to saving money if carbon reduction initiatives cost less.

A carbon management information system is such an initiative. However, our market survey among CMS vendors reveals that no CMS qualifies for thorough product footprinting of transport services. Most applications are aimed at corporate footprinting for the average company. To determine emissions associate with transport, current practice is to use distance-based emission factors, using long-term averages of fuel consumption per kilometre. This may satisfy companies for which transport is not the core business. For LSPs, more accurate footprinting is desirable, however.

To close this gap we have developed a reference architecture for a carbon management IS for the transport industry. Five key functionalities for such a CMS are:

1. Provide a forecast of carbon emissions caused by a transport order.
2. Provide transport Product Carbon Footprints. The peculiar feature is to calculate PCFs fuel-based by obtaining fuel usage of vehicles from board computer data.
3. Maintain emission factors.
4. Provide Corporate Carbon Footprints, in standard reporting formats.
5. Support reduction strategies.

The reference architecture is presented in Figure 17 in section 4.5.4 of this report. It maps the application layer containing modules each responsible for one of the key functionalities to both the business and technological environment. With board computers and Transport Management Systems present in 90% of the larger (over fifty driving units) transport companies, from the IS perspective the aim of automatic footprint calculation appears a realistic goal. The transport business domain is full of complex transport planning and execution activities, making especially PCFs complex. To calculate a transport PCF the following five core functions need to be implemented:

1. Process order and planning.
2. Process incoming data.
3. Calculate intermediate emission.
4. Allocate emissions.
5. Calculate total actual emission.

Thus the central PCF Calculator module has been modelled in detail, and together with other carbon management modules realizing services used during various stages of the transport business process. Furthermore the modules are integrated with an extensive IS landscape commonly present at large transport companies, and supported by infrastructure enabling web-based provision of carbon management services. Altogether our conclusion is that the reference architecture provides an excellent basis to design a CMS for transport companies.

RQ3. How to design an information system that allows logistics service providers to gain insight in their carbon emission and how to reduce it?

To verify whether an IS can be designed according to the reference architecture and to validate whether such an IS is able to provide correct fuel-based carbon footprints of transport services we designed and implemented a prototype and performed a test case with it.

We limited the prototype to the Product Carbon Footprint module. It contains the five core functions listed above to provide actual values of carbon emissions of transport services. To allocate emissions to combined shipments, an allocation algorithm based on the quantity distance demand has been developed. The prototype is also able to integrate with TMS and board computers, exchanging data using web services techniques. Altogether we conclude that its design is in accordance with the reference architecture, which has thus been verified.

A test case consisting of a simulation of a roundtrip with multiple shipments has been carried out. The only input to the prototype for this trip were an XML file with a trip planning and a sequence of XML messages with incoming board computer data, both containing information feasible to obtain from TMS and BC in practice. The prototype correctly calculates carbon emissions of simulated trips fuel-based (provided the truck BC is connected to a CANbus network) including allocation to combined shipments. Therefore we conclude the design has been validated as well. Finally we conclude that the prototype can be extended to an actual product. Its functionality needs additional development, but the CMS is scalable to practice and yields significant benefits when it provides the opportunity to reduce emissions or fuel consumption.

Looking back at the main research question our final conclusion is that our reference architecture provides an excellent basis for designing an information system that allows logistics service providers to gain insight in their carbon emission. Integration with relevant information systems has been demonstrated regarding Transport Management Systems and board computers, which enables fuel-based calculation of the emissions during transport services. The reference architecture also suggests how to include carbon reduction functionality in the application. It appeared not feasible to include such functionality in the prototype within this Master assignment. However, collecting PCF values over time maintaining links to all involved emission drivers, does offer a basis for statistical analysis as starting point for carbon reduction programs.

7.2 Contributions

The contribution to science lies in the reference architecture for fuel-based PCF calculations of transport services. The current state of the art in carbon footprint information systems is focussed on general corporate footprints. Calculating transport emissions is typically performed with distance-based methods. This approach takes long-term averages of fuel consumption per kilometre to estimate fuel consumption of a trip and subsequently the corresponding emissions.

Distance-based calculation has adverse effects. First the reported emission is not accurate. Fuel consumption may actually vary over time, because of differences in road characteristics, traffic situations, driving behaviour, load factor, etc. Second without accurate insight in carbon emissions, it is difficult for LSPs to start with carbon reduction initiatives.

Our approach is to calculate transport emissions fuel-based. We have developed a reference architecture integrating the business and information technology domains of typical logistics service providers. More specifically, integrating Transport Management System and board computers with a Carbon Management System allows for real-time monitoring of fuel consumption during trips and consequently for calculating detailed and accurate carbon footprints of transport services. This approach has not been used before and no literature seems to have been published on fuel-based carbon management.

The contribution to practice lies in the prototype that is fully functional for calculating carbon emissions of road trips and with some extension for each kind of trip that could be defined. By implementing a CMS companies can gain insight in their carbon emissions, which may be a starting point for reduction strategies. This may ultimately make a small contribution to reducing global warming.

7.3 Recommendations

This research has resulted in a reference architecture supplemented with a prototype. The focus on product carbon footprints and limitations to the prototype mean some fields for future research can be identified:

Empirical validation: the prototype showed that theoretically the desired trip data can be obtained from TMS and board computers, but the real world may be more complex than anticipated. Therefore a follow-up research to test the prototype in a real environment at one or more transport companies, would stronger validate whether our system works in practice and is scalable to large fleets.

Carbon reduction opportunities: ideas for logistics specific reduction opportunities mentioned in this thesis are simulating alternative transport routes over multimodal networks or simulating various delivery constraints of transport orders. The effects of such initiatives need to be investigated before they can be properly implemented in a CMS. Furthermore completely new initiatives in other transport areas could be determined.

Data analysis: over time many PCFs are calculated. The ultimate goal of gathering this data is to find reduction opportunities. Futures research is necessary to find efficient and effective ways to search this data and to determine which data is useful to base reduction programs on.

Comparison of fuel-based and distance-based outcomes: when a large set of fuel-based emission values have been collected, an interesting study would be to recalculate these values distance-based. Comparison of both data would provide insight to how accurate the common distance-based emission factors are.

Emission factors: a key element in calculating carbon emissions are the emission factors. Our exploration of the carbon footprint field made clear that often various emission factors have emerged for one emission source. This makes carbon footprints ambiguous. Further research in this field is necessary to define the most accurate emission factors.

Besides further research, our study of current practice and work on the prototype leads to the following recommendations to practice:

Carbon footprint consolidation: the numerous protocols currently known make carbon footprints ambiguous. Therefore it is recommended to consolidate protocols and emission factor databases. The recent announcement by Stimular, Prorail and Connekt, three Dutch organizations providing carbon management tools and standards, that these organizations align their emission factors as of February 2011 is a welcome initiative towards such consolidation. However, many other footprint organizations have emerged and further consolidation remains necessary.

Carbon reduction module: after the possibilities to implement reduction programs in the CMS have been studied more thoroughly, an obvious recommendation is to develop a carbon reduction module. By developing such functionality the ultimate goal of carbon management, to reduce emissions, may be achievable.

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List of abbreviations

ABC	Activity Based Costing
AIS	Accounting Information System
APS	Advanced Planning System
BC	Board Computer
CANbus	Controller Area Network bus
CCF	Corporate Carbon Footprint
CMS	Carbon Management System
CO_2e	Carbon dioxide equivalent
EAI	External Access Interface
ETS	European Trading System
FMS	Fleet Management System
FTL	Full Truckload
GHG	Greenhouse gas
GWP	Global Warming Potential
HRM	Human Resources Management
IPCC	International Panel on Climate Change
IS	Information System
ISO	International Organization for Standardization
IT	Information Technology
LCA	Life Cycle Analysis
Lm	Loading metre
LSP	Logistics Service Provider
LTL	Less than Truckload
OES	Order Entry System
PAS 2050	Publicly Available Specification 2050
PCF	Product Carbon Footprint
PTO	Power Take-Off
RA	Reference Architecture
SaaS	Software-as-a-Service
Tkm	Ton km
TMS	Transport Management System
UML	Unified Modelling Language
WMS	Warehouse Management System
XML	Extensible Markup Language
XSD	XML Schema Definition

Appendix A Overview of Carbon Management Software vendors

Camco

The UK-based company Camco offers strategic, technical and financial services in the fields of sustainability and energy. Consultants help to identify and implement on-site solutions. Camco also develops and maintains carbon offsetting and clean energy projects and trades carbon credits. In 2009 it introduced a web-based Carbon Desktop application. Data can be collected manually or automatically by connecting to automated meter reading systems or building management systems. The tool can analyse these data and set reduction targets. Furthermore it can report in compliance with the British CRC mandatory reporting standard. The real-time interface with energy meters is a strong feature, but also a weakness, as the software appears to be biased towards energy consumption, lacking attention for other emission sources.

CarbonView

CarbonView's CMS package consists of three integrated modules. The Footprinter composes static product and corporate footprints in compliance with various protocols including the GHG protocol and PAS 2050. Data entry goes manually or through file uploads or system interfaces. Footprints are presented on dashboards, that allow for detailed analysis and identification of reduction opportunities. User roles can be defined to vary access rights. Furthermore the module can report the footprints in reports formatted in accordance with various reporting initiatives.

The Visibility module is meant for dynamic or live footprinting. By integration of CarbonView with existing IS, like ERP ,TMS, or systems at partners in the supply chain, emissions can be reported on demand and (almost) in real-time. This enables process-based emission reporting throughout the supply chain. Alerts are generated when emissions exceed user-defined thresholds.

The Optimiser module is an accounting tool. Users can manage carbon offsets and allowances. Costs of reduction programs can be compared with their benefits, environmentally as well as financially. The software combines emission data with user-defined budgets, capacities and constraints to define optimal reduction opportunities in the fields of sourcing, manufacturing and distribution, including analysis of contingencies and risks.

Enablon

The French company Enablon provides software solutions in the fields of CR, EHS, Risk and Governance. One of its products is the Enablon GHG MS, including the following modules:

- Emissions Sources Modelling: inventories emission sources and collects data from present IS both automatically through interfaces and by manual entry.
- Emissions Calculation Formulas Library: contains definitions of emission types and factors, footprint protocols and equations.
- Offset & Credit Management: deals with abatements and emission rights.
- Emission Forecasting: calculates future emissions based on production and activity estimates.
- Scenario Analysis: shows consequences of user-defined scenarios.
- GHG Emissions Accounting and Reporting: calculates footprints, recalculates after changed emissions factors, provides management and compliance reports.
- Permit Management: keeps track of permits, regulations and assessment requirements.

Reviewing the functionalities, it appears that Enablon is strong in reporting emissions for various protocols and regulations. However, it offers little for internal reduction strategies, rather focusing on offsetting and emission trading. Enablon offers its software either as web-based application services or installed locally at the customer.

Enviance

Enviance is a provider of Environmental ERP software. One of the included modules supports GHG & Carbon accounting. It features:

- A centralized database maintaining GHG data
- A multi-protocol emission calculator
- Standardized reporting in accordance with various regulations
- Benchmarking against reduction goals
- Functionalities for keeping track of regulatory obligations and emission allowances

Enviance uses a cloud computing infrastructure and delivers its solutions through a Software-as-a-Service model. However, using Enviance's SDK, clients can locally develop a message handler to integrate their existing IS with that of Enviance. The module meets the basic requirements for carbon management, but does not seem to distinguish itself from competitors with certain features.

Greenstone

Greenstone is a carbon management consultancy and software provider. Its Acco$_2$unt suite is a web-based solution. Greenstone maintains a central database with standards and emission factors as well as a distance calculator. Each instance has a local database. It contains client data on the organizational structure, processes and associated emissions, energy, travel and transport as well as analysis data storing actual emissions and reports. The key functionalities are:

- User management. To define user roles and manage access and security issues.
- Data management. To define the client data and emission data entry methods. Options are manually, spreadsheet upload or integration. Acco$_2$unt allows for connections to AIS, ERP and other IS through various interfaces like XML, SOAP, Biztalk, message queue or using APIs. Furthermore the tool supports data analysis and benchmarking.
- Decision support. To analyze emissions and energy consumption. The user can explore reduction scenarios including return on investments, set targets and monitor progress.
- Management information. To generate reports in various formats meeting requirements from different mandatory and voluntary reporting initiatives. Gives insight in emissions via own dashboards or through integration with other MIS.

Greenstone has a wide range of integration possibilities. Concerning functionality, it has no more than basis carbon management to offer.

Hara

This recent start-up (2008) is a specialized software company offering a single Software-as-a-Service solution: an Environmental and Energy Management IS. It consists of four modules, also available separately:

- Discover: collects data to gain insight in energy consumption, emissions and environmental impact. Supports both CCF and PCF calculations in accordance with multiple standards.
- Plan: a decision support tool that defines reduction programs with clear targets including time frame and financial consequences.
- Act: tracks the execution and results of reduction programs, and provides audit trails.
- Innovate: organization wide sharing of best practices aiming at continuous improvements.

Hara aggregates historic data from clients in a central database in order to produce realistic reduction programs. The product's reduction features are its biggest strength. It also provides an integration framework to automatically collect data from present information systems.

IHS/ESS

Founded in 1959, IHS is a provider of business information systems in the fields of Energy, Product Lifecycle, Security and Environment. In 2009 IHS acquired ESS, which was also regarded as leader in Verdantix' quadrant. One of its products is the Greenhouse Gas (GHG) and Energy Management Solution. Key components are:

- Emissions Inventories. A footprint calculator including the three GHG scopes and other protocols as well as all GHGs and other pollutants. Collected via manual entry or interfaces with present IS. Results from source to corporate level in formatted reports or xml.
- Compliance & Verification. To assure compliance with relevant regulations, e.g. EU ETS or US EPA.
- Reporting. Office tool to create reports for internal and external audiences.
- Cap and Trade Management. Tracks emission rights and abatement/offsetting projects.
- Energy Management. Tracks energy usage and reduction programs.
- Strategic Planning. Decision-support tool that aggregates external data to provide emission benchmarks, emission price forecasts.

Customers can either purchase the software (hosted in-house or by IHS), or opt for a monthly subscription via SaaS delivery. Altogether, the combined solutions of IHS and ESS appear to offer a comprehensive carbon management package.

Johnson Controls

Core businesses of Johnson Controls are building efficiency and power solutions. Its web-based Energy and Emissions Management System consists of five modules:

- Utility: captures information from utility bills
- Greenhouse Gas: calculates a corporate carbon footprint in accordance with the GHG Protocol using data from other modules
- Energy projects: reports information about energy efficiency projects
- Facility equipment: maintains data of energy consuming equipment
- Environmental: manages information about waste

It is clear that Johnson Controls does not diverge far from its main competences. With these tools, it can only provide a CCF with global values derived from energy and fuel bills and waste data.

PE International

The German company PE International provides consultancy and software solutions in the field of sustainability. It offers to distinct products for corporate and product carbon footprints. SoFi is a CCF tool. It calculates CCFs in accordance with a.o. ISO 14064 and the GHG protocol using emission factors from various sources. In a client-server model all data is collected in a central database through manual entry or interfaces to systems like ERP, CRM and SCADA. The server may be installed locally or at a partner hosting company. The tool can identify reduction opportunities and allows for goal setting and performance tracking.

GaBi is a stand-alone PCF tool. It calculates PCFs in accordance with ISO 14044 and PAS 2050. The calculator combines specific product data and emissions caused directly by the producer with secondary data about emission in other stages of the life cycle collected by GaBi. The tool includes a simple business process modeller. The user can graphically model the flow of activities and quantified resources for the production or use of goods in Sankey diagrams. Using the emission factor database GaBi presents the ecological impact of the product, including GHG emissions. Additional modules allow for reporting in various formats. The software shows process steps with high impacts and contains a scenario analysis tool. However, GaBi lacks the visualization of clear reduction opportunities and planning of reduction programs.

ProcessMap

ProcessMap is a provider of Environmental, Health and Safety (EHS) information systems. Amongst others, it offers a GHG Inventory/Enterprise Carbon Accounting Module. With this module customers can measure and forecast emissions of organizations and units. Furthermore it provides auditable reports and mitigation options. More specific functionalities could not be found. Customers can choose between local installation and a SaaS model.

SAP Carbon Impact

The software multinational acquired CMS vendor Clear Standards in 2009 and offers its web-based Carbon Impact solution since. Functionalities are divided in:

- Assess. Consolidation of emission data from spreadsheets or systems within the organization or in the supply chain into one database. Integrated survey forms allow for data entry by suppliers. Calculation of footprints for products, activities or organizations. The CCF complies with the GHG protocol and ISO 14064.
- Analyze. Emission trends and rankings are visualized on dashboard screens. These are role-based, with relevant information and options for different departments (a.o. finance and marketing). With manual queries detailed information can be collected. Effects of reduction or offset initiatives can be modelled, both environmentally and financially.
- Act. To set goals, track and communicate progress. Supports reporting in accordance with various regulations. Keeps track of emission offsets and allowances purchases.

Strengths of SAP's Carbon Impact are management reporting and its supply chain approach.

Appendix B PAS 2050 – relevant definitions for a transport service

This appendix contains excerpts from the PAS 2050 specification (BSI, 2008). Relevant definitions of PAS 2050 are cited in the following paragraphs, numbered as in the specification. Part of these citations are emphasized to highlight the most important phrases for transport PCFs. We comment on each definition by explaining its consequence for calculation a PCF for a transport service.

6.2 Partial GHG emission information for business-to-business assessment

The system boundary for the assessment of GHG emissions for an input that is made available or used in a business-to-business manner shall include all emissions that have **occurred up to, and including, the point where the input arrives at a new organization** (including all upstream emissions). Downstream emissions shall be excluded from the system boundary GHG emissions assessments carried out for business-to-business assessments.

Note The purpose of partial GHG emission assessment is to facilitate the provision of consistent GHG emission information within the supply chain for products, and to simplify the implementation of this PAS. This cradle-to-gate perspective of the supply chain allows incremental addition of GHG emissions at different stages of the supply until the product is provided to the consumer (where the assessment of GHG emissions includes the emissions arising from the entire life cycle).

Consequence: A transport service ends when the shipment is delivered to the consignee (and the truck has finished its trip, see paragraph 8.4 below). When the consignee uses own equipment to unload the freight, these emissions shall be excluded from the carrier's PCF.

6.3 Material contribution and threshold

Calculations carried out in accordance with this PAS shall include all emissions within the system boundary that have the potential to make a material contribution to the life cycle GHG emissions of the product.

3.33 material contribution

contribution from any one source of GHG emissions of **more than 1%** of the anticipated life cycle GHG emissions associated with a product.

Consequence: For transport services the fuel consumption during a transport may be the dominating emission source, to such an extent that overhead from e.g. office electricity usage in general contributes less than 1% to the total emissions. In such a case the office operations do not have to be included in the PCF. For internal reporting, it may still be useful to allocated these emissions as overhead, though.

6.4.3 Capital goods

The GHG emissions arising **from the production of capital goods** used in the life cycle of the product shall be **excluded** from the assessment of the GHG emissions of the life cycle of the product.

Consequence: no emissions from the production of trucks, freight units, or parts of these (e.g. tyres) need to be allocated to transport services.

6.4.5 Operation of premises

The GHG emissions arising from the **operation of premises**, including emissions from factories, **warehouses, central supply centres, offices**, retail outlets, etc., shall be **included** in the assessment of the GHG emissions of the life cycle of the product.

*Note **Operation includes the lighting, heating, cooling**, ventilation, humidity control and other environmental controls over the premises. An appropriate approach for the division of emissions arising from the operation of, for example, warehouses, would be to use the residence time and volume of space occupied by the product as a basis for the division.*

Consequence: the mentioned emissions shall be allocated to transport services.

6.4.6 Transport
The GHG emissions arising from road, air, water, rail or other transport methods that form part of the life cycle of the product shall be included in the assessment of the GHG emissions of the life cycle of the product.
Note 1 Emissions associated with environmental control requirements during transport (e.g. refrigerated transport) are included in 6.4.7.
Note 2 ***GHG emissions from transport include the emissions associated with transporting fuels*** *(e.g. emissions arising from the operation of pipelines, transmission networks and other fuel transport activities).*
Note 3 GHG emissions from transport include the emissions arising from transport associated with individual processes, such as the movement of inputs, products and co-products within a factory (e.g. by conveyor belt or other localized transport methods).

Consequence: well-to-wheel emission factors shall be used to calculating emissions arising from fuel consumption. Transport movements at hubs shall be included in the PCF.

6.4.7 Storage
The GHG emissions arising from storage shall be included in the assessment of the life cycle GHG emissions of the product, including:
a) **storage** of inputs, including raw materials, **at any point** in the product life cycle;
b) **environmental controls** (e.g. cooling, heating, humidity control and other controls) related to a product at any point in the product life cycle (see 6.4.5 for the operation, including environmental control, of factories in which products may be stored);

Consequence: emissions associated with a) temporary storage of freight at hubs and b) environmental control of freight during transport and storage shall be included in the PCF.

6.5 System boundary exclusions
The system boundary of the product life cycle shall **exclude** the GHG emissions associated with:
a) human energy inputs to processes and/or preprocessing (e.g. if fruit is picked by hand rather than by machinery);
b) transport of consumers to and from the point of retail purchase;
c) **transport of employees to and from their normal place of work**; and
d) animals providing transport services.

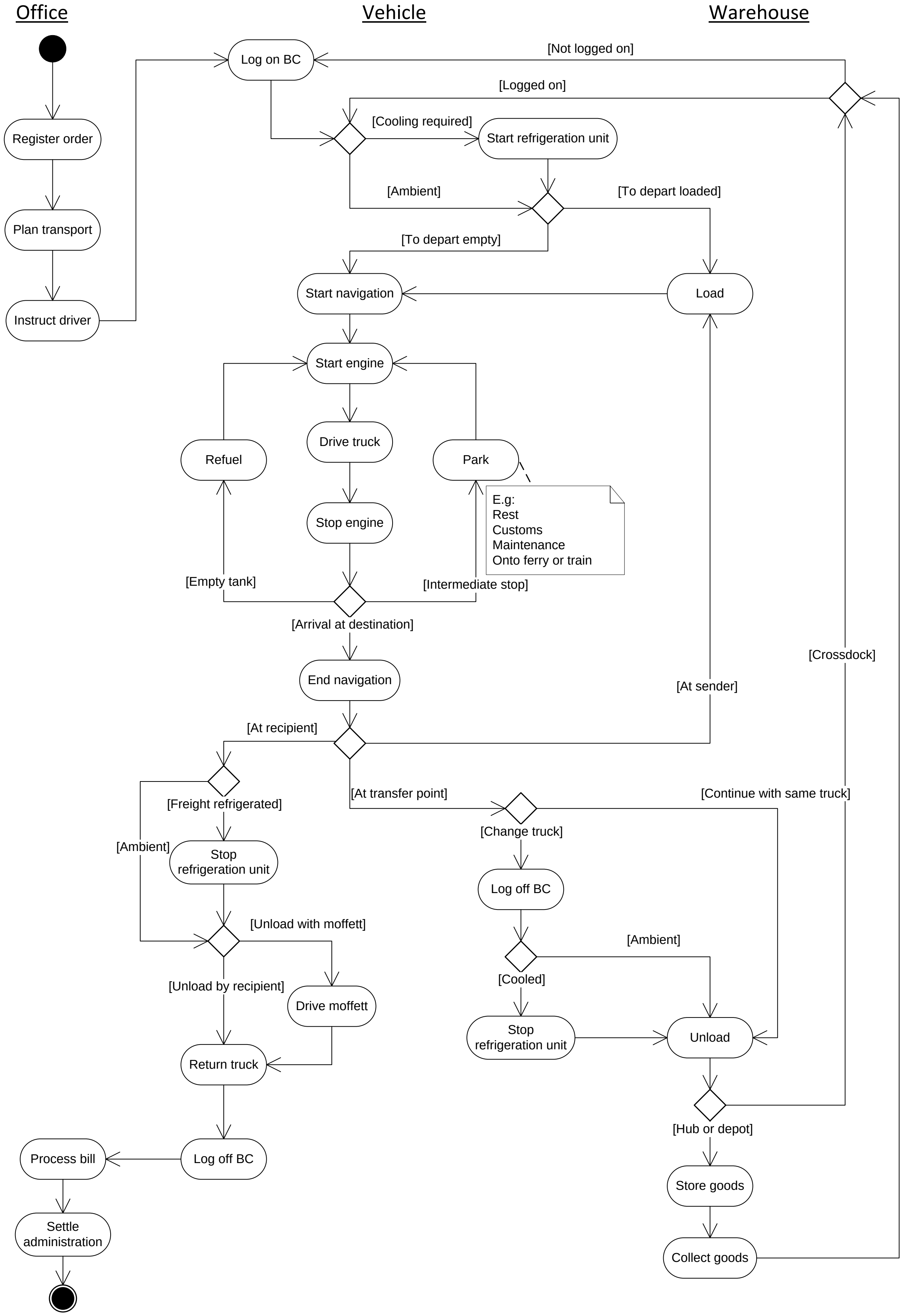
Consequence: commuting of employees shall be excluded from transport PCFs, even when a truck driver travels to or from home with a truck also deployed for transport jobs.

8.4 Emissions from transport
Where more than one product is being transported by a transport system (e.g. a truck, ship, aircraft, train), the emissions arising from the transport system shall be **divided** amongst the products on the basis of:
a) where **mass** is the limiting factor for the transport system: the relative mass of the different products being transported; or
b) where **volume** is the limiting factor for the transport system: the relative volume of the different products being transported.

Transport emissions shall include the emissions associated with the **return journey** of a vehicle where the vehicle does not transport products on its return, or for that proportion of the return journey where the vehicle does not transport products.

Consequence: for FTL shipments volume is mostly the limiting factor, making number of pallets or loading meter a suitable allocation principle. Furthermore empty return trips/repositioning shall be proportionally included in a PCF.

Appendix C Activity diagram of a transport process



Appendix D Milieubarometer emission factors

The following tables list the emission factors of the Dutch Milieubarometer (Stimular, 2011).

CO2 factoren in de Milieubarometer

Stichting Stimular (24-02-2011)

Onderstaande CO2 factoren zijn vastgesteld in overleg met Prorail en Connekt.
Stimular , Prorail en Connekt hanteren vanaf februari 2011 dezelfde CO2 factoren.

Factoren met een ! ervoor zijn nog in onderzoek	Eenheid	2010 CO2-equivalent	2011 CO2-equivalent
Elektriciteit			
Ingekochte elektriciteit	1 kWh	0,490 kg CO2	0,470 kg CO2
Waarvan groene stroom	1 kWh	-0,490 kg CO2	-0,460 kg CO2
Waarvan groene stroom uit biomassa	1 kWh		-0,152 kg CO2
Waarvan groene stroom uit wind	1 kWh		-0,458 kg CO2
Waarvan groene stroom uit water	1 kWh		-0,464 kg CO2
Waarvan groene stroom uit zon	1 kWh		-0,390 kg CO2
Brandstoffen			
Aardgas voor verwarming	1 m3	1,83 kg CO2	1,83 kg CO2
Aardgas voor productie	1 m3	1,83 kg CO2	1,83 kg CO2
Aardgas voor WKK	1 m3	1,83 kg CO2	1,83 kg CO2
Warmte (geleverd door derden)	1 GJ	16,8 kg CO2	18,5 kg CO2
Huisbrandolie	1 liter	3,19 kg CO2	3,19 kg CO2
Diesel voor verwarming	1 liter	3,14 kg CO2	3,13 kg CO2
Propaan	1 liter	1,53 kg CO2	1,53 kg CO2
Houtmot	1 m3	44 kg CO2	44 kg CO2
Water & afvalwater			
Drinkwater	1 m3	0,30 kg CO2	0,30 kg CO2
Afvalwater	1 VE		40 kg CO2
Emissies			
Oplosmiddelen	1 kg	8 kg CO2	8 kg CO2
Koudemiddel - R22 (=HCFK)	1 kg	1.810 kg CO2	1.810 kg CO2
Koudemiddel - R404a	1 kg	3.922 kg CO2	3.922 kg CO2
Koudemiddel - R507	1 kg	3.985 kg CO2	3.985 kg CO2
Koudemiddel - R407c	1 kg	1.774 kg CO2	1.774 kg CO2
Koudemiddel - R410a	1 kg	2.088 kg CO2	2.088 kg CO2
Koudemiddel - R134a	1 kg	1.430 kg CO2	1.430 kg CO2
Mobiele werktuigen			
Benzine	1 liter	2,78 kg CO2	2,78 kg CO2
Diesel	1 liter	3,19 kg CO2	3,14 kg CO2
Rode diesel	1 liter	3,19 kg CO2	3,14 kg CO2
LPG	1 liter	1,80 kg CO2	1,86 kg CO2
Woon-werkverkeer			
Openbaar vervoer	1 km	0,044 kg CO2	0,065 kg CO2
Scooter en bromfiets	1 km	0,069 kg CO2	0,069 kg CO2
Motor	1 km	0,159 kg CO2	0,159 kg CO2
! Personenwagen	1 km	0,206 kg CO2	0,235 kg CO2
! Bestelwagen	1 km	0,202 kg CO2	0,235 kg CO2
Vliegtuig Europa	1 personen km		0,285 kg CO2
Bezoekersverkeer			
Openbaar vervoer	1 km		0,0650 kg CO2
Bromfiets en scooter	1 km		0,0690 kg CO2
Motorfiets	1 km		0,159 kg CO2
! Auto	1 km		0,235 kg CO2
Kantoorpapier			
Standaard (houtvrij) papier	1 kg	1,19 kg CO2	1,21 kg CO2
Gerecycled papier	1 kg	1,12 kg CO2	1,46 kg CO2
Papier met milieukeurmerk	1 kg	0,88 kg CO2	2 kg CO2

CO2 factoren in de Milieubarometer

Stichting Stimular (24-02-2011)

Onderstaande CO2 factoren zijn vastgesteld in overleg met Prorail en Connekt.
Stimular , Prorail en Connekt hanteren vanaf februari 2011 dezelfde CO2 factoren.

Factoren met een ! ervoor zijn nog in onderzoek		2010	2011
	Eenheid	**CO2-equivalent**	**CO2-equivalent**
Zakelijk verkeer			
Openbaar vervoer	1 km	0,044 kg CO2	0,065 kg CO2
Scooter en bromfiets in km	1 km	0,069 kg CO2	0,069 kg CO2
Scooter en bromfiets (in liters) mengsmering	1 liter	2,77 kg CO2	2,78 kg CO2
Motor in km	1 km	0,16 kg CO2	0,16 kg CO2
Motor (in liters) benzine	1 liter	2,78 kg CO2	2,78 kg CO2
! Personenwagen in km	1 km	0,21 kg CO2	0,24 kg CO2
Personenwagen (in liters) benzine	1 liter	2,78 kg CO2	2,78 kg CO2
Personenwagen (in liters) bio-ethanol	1 liter	0,71 kg CO2	1,60 kg CO2
Personenwagen (in liters) diesel	1 liter	3,19 kg CO2	3,14 kg CO2
Personenwagen (in liters) bio-diesel	1 liter	1,74 kg CO2	0,35 kg CO2
Personenwagen (in liters) LPG	1 liter	1,80 kg CO2	1,86 kg CO2
Personenwagen (in kg) aardgas	1 liter	2,54 kg CO2	2,63 kg CO2
! Deelwagen in km	1 km	0,21 kg CO2	0,24 kg CO2
! Bestelwagen in km	1 km	0,20 kg CO2	0,24 kg CO2
Bestelwagen (in liters) benzine	1 liter	2,77 kg CO2	2,78 kg CO2
Bestelwagen (in liters) bio-ethanol	1 liter	0,71 kg CO2	1,60 kg CO2
Bestelwagen (in liters) diesel	1 liter	3,18 kg CO2	3,14 kg CO2
Bestelwagen (in liters) bio-diesel	1 liter	1,74 kg CO2	0,35 kg CO2
Bestelwagen (in liters) LPG	1 liter	1,83 kg CO2	1,86 kg CO2
Vliegtuig Europa	1 personen km	0,42 kg CO2	0,29 kg CO2
Vliegtuig mondiaal	1 personen km	0,24 kg CO2	0,22 kg CO2
Helikopter (in liters) kerosine	1 liter	4,67 kg CO2	4,63 kg CO2
Goederenvervoer			
! Bestelwagen in km	1 km	0,20 kg CO2	0,27 kg CO2
Bestelwagen (in liters) benzine	1 liter	2,77 kg CO2	2,78 kg CO2
Bestelwagen (in liters) bio-ethanol	1 liter	0,71 kg CO2	1,6 kg CO2
Bestelwagen (in liters) diesel	1 liter	3,18 kg CO2	3,14 kg CO2
Bestelwagen (in liters) bio-diesel	1 liter	1,74 kg CO2	0,35 kg CO2
Bestelwagen (in liters) LPG	1 liter	1,83 kg CO2	1,86 kg CO2
Kleine vrachtwagen in km	1 km	0,50 kg CO2	0,50 kg CO2
Middelgrote vrachtwagen in km	1 km	0,77 kg CO2	0,77 kg CO2
Grote vrachtwagen in km	1 km	1,01 kg CO2	1,01 kg CO2
Vrachtwagen (in liters) diesel	1 liter	3,14 kg CO2	3,14 kg CO2
Vrachtwagen Euro I (in liters) diesel	1 liter	3,22 kg CO2	3,14 kg CO2
Vrachtwagen Euro II (in liters) diesel	1 liter	3,22 kg CO2	3,14 kg CO2
Vrachtwagen Euro III (in liters) diesel	1 liter	3,22 kg CO2	3,14 kg CO2
Vrachtwagen Euro IV (in liters) diesel	1 liter	3,22 kg CO2	3,14 kg CO2
Vrachtwagen Euro V (in liters) diesel	1 liter	3,22 kg CO2	3,14 kg CO2
Vrachtwagen Euro VI (in liters) diesel	1 liter	3,22 kg CO2	3,14 kg CO2
Vrachtwagen (in liters) bio-diesel	1 liter	1,74 kg CO2	0,35 kg CO2
Vrachtwagen (in liters) LPG/CNG	1 liter	1,85 kg CO2	1,86 kg CO2
Uitbesteed wegtransport (per ton km)	1 ton km	0,15 kg CO2	0,16 kg CO2
Uitbesteed wegtransport (per container km)	1 container km	0,98 kg CO2	0,98 kg CO2
Uitbesteed wegtransport (per palletplaats km)	1 palletplaats km	0,055 kg CO2	0,055 kg CO2
Uitbesteed wegtransport (per pakket)	1 pakket	0,38 kg CO2	0,38 kg CO2
Snel- / koerierdienst met bestelwagen	1 vracht km	0,40 kg CO2	0,40 kg CO2
Snel- / koerierdienst met vrachtwagen	1 vracht km	1,54 kg CO2	1,54 kg CO2
Binnenvaart (bulk)	1 ton km	0,026 kg CO2	0,060 kg CO2
Binnenvaart (containers)	1 container km	0,49 kg CO2	0,58 kg CO2
Zeevaart (bulk)	1 ton km	0,011 kg CO2	0,028 kg CO2
Goederentrein (containers)	1 container km	0,398 kg CO2	0,22 kg CO2
Goederentrein (bulk)	1 ton km	0,026 kg CO2	0,027 kg CO2
Vliegtuig	1 ton km	1,04 kg CO2	1,04 kg CO2

The following tables contain the previous release of the Milieubarometer emission factors.

Bron	Eenheid	kg CO2e 2009	kg CO2e 2010
Elektriciteit			
Ingekochte elektriciteit	1 kWh	0,550	0,490
Waarvan groene stroom	1 kWh	-0,550	-0,490
Waarvan teruggeleverd	1 kWh	-0,550	-0,490
Brandstoffen			
Aardgas voor verwarming	1 m3	1,800	1,825
Aardgas voor productie	1 m3	1,800	1,825
Aardgas voor WKK	1 m3	1,800	1,825
Waarvan groen gas	1 m3	-1,800	-1,825
Warmte (geleverd door derden)	1 GJ	5,026	16,800
Huisbrandolie	1 liter	3,190	3,185
Diesel voor verwarming	1 liter	3,190	3,135
Propaan	1 liter	1,530	1,530
Houtmot	1 m3	44,000	44,000
Water & afvalwater			
Drinkwater	1 m3	0,000	0,298
Afvalwater	1 VE	0,000	39,860
Emissies			
Oplosmiddelen	1 kg	0,000	8,000
Koudemiddel - R22 (=HCFK)	1 kg	0,000	1810,000
Koudemiddel - R404a	1 kg	0,000	3922,000
Koudemiddel - R507	1 kg	0,000	3985,000
Koudemiddel - R407c	1 kg	0,000	1774,000
Koudemiddel - R410a	1 kg	0,000	2088,000
Koudemiddel - R134a	1 kg	0,000	1430,000
Mobiele werktuigen			
Benzine	1 liter	2,220	2,780
Diesel	1 liter	2,680	3,190
Rode diesel	1 liter	2,680	3,190
LPG	1 liter	1,650	1,796
Woon-werkverkeer			
Openbaar vervoer	1 km	0,041	0,044
Scooter en bromfiets	1 km	0,059	0,069
Motor	1 km	0,136	0,159
Personenwagen	1 km	0,188	0,206
Bestelwagen	1 km	0,169	0,202
Zakelijk verkeer			
Openbaar vervoer	1 km	0,041	0,044
Scooter en bromfiets in km	1 km	0,059	0,069
Scooter en bromfiets (in liters)	1 liter	2,370	2,770
Motor in km	1 km	0,136	0,159
Motor (in liters) benzine	1 liter	2,380	2,780
Personenwagen in km	1 km	0,188	0,206
Personenwagen (in liters) benzine	1 liter	2,374	2,780
Personenwagen (in liters) bio-ethanol	1 liter	0,000	0,706
Personenwagen (in liters) diesel	1 liter	2,680	3,190

Personenwagen (in liters) bio-diesel	1 liter	0,000	1,740
Personenwagen (in liters) LPG	1 liter	1,597	1,800
Deelwagen in km	1 km	0,188	0,206
Bestelwagen in km	1 km	0,169	0,202
Bestelwagen (in liters) benzine	1 liter	2,634	2,770
Bestelwagen (in liters) bio-ethanol	1 liter	0,000	0,706
Bestelwagen (in liters) diesel	1 liter	2,668	3,180
Bestelwagen (in liters) bio-diesel	1 liter	0,000	1,740
Bestelwagen (in liters) LPG	1 liter	1,632	1,830
Vliegtuig Europa	1 pers. km	0,223	0,419
Vliegtuig mondiaal	1 personen km	0,204	0,244
Helikopter (in liters) kerosine	1 liter	3,880	4,670
Goederenvervoer			
Bestelwagen in km	1 km	0,169	0,202
Bestelwagen (in liters) benzine	1 liter	2,634	2,770
Bestelwagen (in liters) bio-ethanol	1 liter	0,000	0,706
Bestelwagen (in liters) diesel	1 liter	2,668	3,180
Bestelwagen (in liters) bio-diesel	1 liter	0,000	1,740
Bestelwagen (in liters) LPG	1 liter	1,632	1,830
Kleine vrachtwagen in km	1 km	0,420	0,502
Middelgrote vrachtwagen in km	1 km	0,643	0,768
Grote vrachtwagen in km	1 km	0,824	1,010
Vrachtwagen (in liters) diesel	1 liter	2,630	3,140
Vrachtwagen Euro I (in liters) diesel	1 liter	2,715	3,220
Vrachtwagen Euro II (in liters) diesel	1 liter	2,715	3,220
Vrachtwagen Euro III (in liters) diesel	1 liter	2,715	3,220
Vrachtwagen Euro IV (in liters) diesel	1 liter	2,715	3,220
Vrachtwagen Euro V (in liters) diesel	1 liter	2,715	3,220
Vrachtwagen Euro VI (in liters) diesel	1 liter	0,000	3,220
Vrachtwagen (in liters) bio-diesel	1 liter	0,000	1,740
Vrachtwagen (in liters) LPG/CNG	1 liter	1,650	1,850
Uitbesteed wegtransport (per ton km)	1 ton km	0,130	0,155
Uitbesteed wegtransport (per container km)	1 container km	0,824	0,984
Uitbesteed wegtransport (per palletplaats km)	1 palletplaats km	0,046	0,055
Uitbesteed wegtransport (per pakket)	1 pakket	0,322	0,384
Snel- / koerierdienst met bestelwagen	1 vracht km	0,338	0,404
Snel- / koerierdienst met vrachtwagen	1 vracht km	1,286	1,536
Binnenvaart (bulk)	1 ton km	0,022	0,026
Binnenvaart (containers)	1 container km	0,409	0,489
Zeevaart (bulk)	1 ton km	0,009	0,011
Zeevaart (container)	1 container km	0,148	0,171
Goederentrein (containers)	1 container km	0,346	0,398
Trein (tonkm)	1 ton km	0,000	0,026
Vliegtuig	1 ton km	0,871	1,040
Kantoorpapier			
Standaard (houtvrij) papier	1 kg	0,000	1,186
Gerecycled papier	1 kg	0,000	1,116
Papier met milieukeurmerk	1 kg	0,000	0,883

Appendix E CarrierWeb board computer messages

This appendix contains a selection of tables copied from the CarrierWeb External Access Interface application manual. These tables specify what data can be exchanged between the home base of transport companies and trucks using a CarrierWeb board computer. Forward tables contain trip and job info sent to board computers. Return tables contain activities performed as part of executing jobs and CANbus measurements sent back to the home base. Several other types of information can be exchanged, e.g. navigation, telemetry, hours of service and free form messages, but these are not relevant for carbon management. The tables make clear that it is a realistic target to calculate carbon emission based on actual values of fuel consumption during trips, linked to shipments involved in trips, but also enabling linking emissions to various other data such as drivers and their driving behaviour, vehicles, shippers, visited locations, etcetera.

cwForwardTrips

Name	Type	Details	Required
ID	auto_increment(10)		NO
TripID	int(10)	Unique for each trip Forward trip number	YES
ModificationFlag	Tinyint	1 = add, 2 = edit, 3 = delete	YES
TripReference	char(20)	Customer specific	NO
EquipmentType	char(3)	Customer specific	NO
DispatchTime	Datetime	Date and time when instruction should be sent to the vehicle	YES
CWTruckID	int(10)	CW specific	NO
TruckNumber	char(10)	Customer specific assigned vehicle name.	NO
CWDriver0ID	int(10)	CarrierWeb unique id	NO
Driver0Number	char(10)	Customer specific	NO
Driver0Name	char(36)	Driver name	NO
CWDriver1ID	int(10)	CarrierWeb unique id	NO
Driver1Number	char(10)	Customer specific	NO
Driver1Name	char(36)	Driver name	NO
CWTrailerID	int(10)	CarrierWeb unique id CW specific	NO
TrailerNumber	char(10)	Customer specific assigned trailer name.	NO
CWContainer0ID	int(10)	CarrierWeb unique id CW specific	NO
Container0Number	char(10)	Customer specific	NO
CWContainer1ID	int(10)	CarrierWeb unique id CW specific	NO
Container1Number	char(10)	Customer specific	NO
AllowReorder	Tinyint	0 = no, 1 = yes	NO
ReplaceMDT	Tinyint	Unused, set to zero	NO
EfCustomerID	int(10)	CarrierWeb unique id	NO
AssignmentStart	Datetime	Date & time	NO
AssignmentEnd	Datetime	Date & time	NO
RouteGeofenceID	char(10)	Customer specific	NO

cwForwardJobs

Name	Type	Details	Required
ID	auto_increment(10)		NO
TripID	int(10)	Unique ID per trip Forward trip number	YES
JobID	int(10)	Unique job ID per job per trip	YES
ModificationFlag	tinyint	1 = add, 2 = edit, 3 = delete	YES
JobReference	char(20)	Customer specific	NO
JobType	int(10)	1 = Load, 2 = Unload, 3 = Pickup, 4 = Drop	YES
JobTypeCode	char(3)	Customer specific	NO
ConsignorID	int(10)	Customer specific	NO
ConsignorName	char(25)	Customer specific	NO
EarliestTime	datetime	Earliest request arrival time	NO
LatestTime	datetime	Latest requested arrival time	NO
SortTime	datetime	Time defining the ordering of the Jobs within a Trip	NO
AddressID	int(10)	Customer specific	NO
Name	char(50)	Name of a Job address	NO
Street0	char(96)	Street name of Job address	NO
Street1	char(96)	Street name of Job address	NO
HouseNumber	char(5)	House number of Job address	NO
Zipcode	char(8)	Zipcode of Job address	NO
City	char(25)	City name of Job address	NO
County	char(30)	County name	NO
Latitude	int(10)	Latitude in decimal degrees	NO
Longitude	int(10)	Longitude in decimal degrees	NO
Country	varchar(4)	Country of Job address. ISO code, or extended state code see appendix B	NO
ContactPerson	char(25)	Name of Job address contact person	NO
PhoneNumber	char(15)	Phone number contact	NO
MobilePhone	char(15)	Mobile phone number of Job address contact person	NO
FaxNumber	char(15)	Fax number of Job address contact person	NO
GeofenceRadius	int(10)	Radius of Job geofence in km.	NO
EMailGeofence	Tinyint	0=No geofence, 1 = E-mail geofence event to list of contact email addresses	NO

cwForwardJobInfo

Name	Type	Details	Required
ID	auto_increment(10)		NO
ModificationFlag	Tinyint	1 = add, 2 = edit, 3 = delete	YES
TripID	int(10)	Customer specific (unique) trip number	YES
JobID	int(10)	Unique job ID per job per trip	YES
Label	char(30)	For instance: weight, number	YES
Value	char(30)	For instance: 100 kg, etc.	YES
SortOrder	Int(10)	Used to sort labels in the list	NO

cwReturnActivities

Name	Type	Details
ID	bigint	
ExportID	bigint	
NextActivityID	bigint	ID of the next activity
CWVehicleID	int(10)	CW specific
VehicleNumber	char(10)	Customer specific
VehicleType	tinyint	1 = truck, 2 = trailer
StartTime	datetime	The time the activity start was recorded.
StartTimeZone	int(10)	
EndTime	datetime	The time the activity end was recorded. This value is not changed even if the duration is corrected. To find the corrected end time you must use the CorrectedDuration or activity correction logs.
EndTimeZone	int(10)	
ActivityId	int(10)	Labels activity, see cwActivityId Codes table
SubActivityId	int(10)	This is not used, and will always be zero
MinTime	int(10)	The minimum time an activity can take.
MaxTime	int(10)	The maximum time an activity can take.
CWDriver0ID	int(10)	CarrierWeb unique id
Driver0Number	char(10)	Customer specific
Driver0Name	char(36)	Driver name
CWDriver1ID	int(10)	CarrierWeb unique id
Driver1Number	char(10)	Customer specific
Driver1Name	char(36)	Driver name
CWVehicleTripID	bigint	Carrierweb internal vehicle trip number
TripNumber	char(15)	When using the simple trip module this is the trip number entered by the driver, when using the consignment module it is the trip number selected by the customer and sent along with the trip via the EAI. Customer trip number
HOSTripNumber	char(15)	This is the unique internal trip number in the carrierweb system. It is sometimes refered to as a vehicle trip number or the HOS trip number. Customer trip number
TripID	int(10)	The ID of the Trip from the consignment module. Forward trip number
JobID	int(10)	The ID of the Job from the consignment module.
HomeBase	int(10)	Value 0 means outside home base, value 1 means inside home base (but not defined in customer home base list, e.g. used for off duty activities), value 2 means at driver's private address and values greater than 2 contain customer defined home bases.
StartLatitude	int(10)	Location of the vehicle when the activity ended Latitude in decimal degrees
StartLongitude	int(10)	Location of the vehicle when the activity ended Longitude in decimal degrees
StartCountry	varchar(4)	Start Country
StartLocation	varchar(30)	Start Location

StartZipCode	varchar(8)	Start Zip Code
StartProximityDistance	int(10)	The proximity of the vehicle to the nearest city
StartProximityDirection	int(10)	The direction the city is in relation to the vehicle
StartGPSOdometer	int(10)	In km*10, 0 to 999999
StartTachoOdometer	int(10)	The reading from the tachopulse in km*10,0
StartFuel	int(10)	Integer to determine the fuel used.
StartFuelLevel	int(10)	Integer to determine the fuel level.
StartLandmarkId	bigint	ID of the Landmark where the activity started
EndLatitude	int(10)	Location of the vehicle when the activity ended Latitude in decimal degrees
EndLongitude	int(10)	Location of the vehicle when the activity ended Longitude in decimal degrees
EndCountry	varchar(4)	End Country
EndLocation	varchar(30)	End Location
EndZipCode	varchar(8)	End Zip Code
EndProximityDistance	int(10)	The proximity of the vehicle to the nearest city
EndProximityDirection	int(10)	The direction the city is in relation to the vehicle
EndGPSOdometer	int(10)	In km*10, 0 to 999999
EndTachoOdometer	int(10)	The reading from the tachopulse in km*10,0
EndFuel	int(10)	Integer to determine the fuel used.
EndFuelLevel	int(10)	End fuel level.
EndLandmarkId	bigint	ID of the Landmark where the activity ended
CorrectedDuration	int(10)	Corrected duration in seconds WARNING this field is ONLY valid when the activities export module is configures so that you need to close the day. If you do not have the system configured to require you to close each day on the website you MUST ignore this field (corrections will be available in cwReturnActivityCorrectionLogs)
Trailer	varchar(15)	The trailer identifier entered by the driver at the start of a trip.
CWTrailerID	int(10)	The Carrierweb ID for the trailer connected to the vehicle. This will only be filled when trailer matching is available. CW specific
CreationType	int(10)	If the record was received from the HOS module running on the device the CreationType is 1 if the record was generated server side at a fixed time (e.g. midnight) then the CreationType is 3. If you are not interested in these records you can ignore the records with types other than 1.
LoggingCategory	int(10)	The category this HOS state falls into. 0=undefined, 1=off duty, 2=sleeper birth, 3=on duty-driving, 4=on duty-not driving
TripCustomer	char(20)	The customer selected for the current vehicle trip. This is only filled in when the driver enters this info as part of a start trip.

cwReturnCanbusPerformance

Name	Type	Details
ID	bigint	
ExportID	bigint	
CWVehicleID	int(10)	CW specific
VehicleNumber	char(10)	Customer specific
VehicleType	tinyint	1 = truck, 2 = trailer
CWDriverID	int(10)	CarrierWeb unique id
DriverNumber	char(10)	Customer specific
DriverName	char(36)	Driver name
Day	int(10)	The date as an integer (YYYYMMDD)
DayDateTime	datetime	
Odometer	int(10)	The distance as measured by the truck's built in sensors
Fuel	int(10)	The fuel level as measured by the truck's built in sensors
HighRPM	int(10)	High RPM time (>1700 RPM); minutes
HighTorque	int(10)	High torque time(>90% of maximum torque); minutes
CruiseControl	int(10)	Cruise control time; minutes
Accelerations	int(10)	Acceleration time (acc. > 0.8 m/s^2); minutes
OverSpeed	int(10)	Overspeed time (speed > 89 km/h); minutes
BrakeApplications	int(10)	Number of brake applications
HardBrakeApplications	int(10)	Number of harsh brake applications (dec. > 1.5 m/s^2)
EngineRollout	int(10)	Coasting distance; km*10.000
EngineRunningTime	int(10)	Engine running time; minutes
IdleTime	int(10)	Engine idle time; minutes
IdleFuel	int(10)	Engine idle fuel usage; liters
PTOTime	int(10)	PTO time; minutes
PTOFuel	int(10)	PTO/high idle fuel usage; liters

cwActivityIdCodes

Code	Description	Code	Description
1	Driving	9000	Unspecified
5	Break	9010	Preparing to depart
10	Resting	9020	Traffic jam
20	Waiting	9050	Driver 1 login
30	Loading	9051	Driver 1 logout
40	Unloading	9060	Driver 2 login
50	Fueling	9061	Driver 2 logout
55	Washing	9070	Start trip
60	Ferry	9071	End trip
65	Train	9072	Auto-logout
70	Border crossing	9100	Off duty
80	Garage	9999	Other
90	Pickup/drop trailer		
100	Pickup/drop container		