

**Monitoring and increasing carbon efficiency
in road freight transport by today's improved
computerized routing and scheduling
and vehicle telematics**

Dissertation

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Für Ika, Iris und Philip

Abstract

This dissertation proposes a method for automatic assessment of a trucking company's transport efficiency, without manual reporting routines. It focuses primarily on reducing freight transport-related carbon emissions. The goal is to define an instrument which shows the development of key performance indicators such as utilization (weight and volume), route efficiency, fuel use and carbon efficiency. The method could be used to monitor the reactions of trucking companies to external changes in order to find out which legislative measures are most relevant to carbon emissions and which operational efficiency measures are most effective. The monitoring method was developed while surveying the technology sector of computerized routing and scheduling systems and vehicle telematics. The dissertation asks whether the introduction of such systems will enhance transport efficiency in trucking companies with corresponding decreases in carbon emissions, and secondly whether it is possible to obtain further reductions in emissions by improving computerized routing and scheduling systems and vehicle telematics. Quantitative and qualitative methods produced positive answers to both questions.

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2 Introduction

European road transport makes high demands on energy in the form of petrol and diesel fuels. At the start of the new century, road transportation of passengers and goods was responsible for the emission of numerous harmful exhaust gases, including the greenhouse gas carbon dioxide (CO₂). Europe as a whole has managed to stabilize or even reduce the transport-related emissions of certain harmful substances, but carbon dioxide is not among them. In the last two decades, there has been a particular increase in carbon emissions from road transportation of goods. This rise in emissions cancels out the significant advances made elsewhere, e.g. in the industrial and energy sectors. In terms of environmental politics, this can lead to significant failures. In addition to climate problems, further increases in road transport will continue to generate a range of socio-economic and environmental problems, such as accidents, congestion, air pollution, land use demand, noise and the degradation of ecosystems. In Germany, these factors as a whole are leading to an unsustainable mobility situation. This diagnosis was made as early as 1994 by the Enquête Commission of the Federal Parliament on the Protection of the Earth's Atmosphere (Enquête Kommission, 1994), underscored by the Federal Environmental Agency (Umweltbundesamt, 2002), and confirmed again by the German Advisory Council on the Environment in 2005 (Sachverständigenrat für Umweltfragen, 2005).

One generally agreed approach to meeting the carbon mitigation demands set forth in the Kyoto Protocol is to increase energy efficiency in different fields of activity. In transportation, the goal is to enhance transport performance for the same energy consumption. Different strategies to counter the negative consequences of road freight transport are either on trial or being implemented. Up to today, the introduction of new vehicle designs has been the most successful strategy on the transport sector. However, the improvement in efficiency has not yet brought any noticeable reductions in greenhouse gas emissions for the EU transport sector (European Environment

Agency, 2006; European Commission, 2006; European Environment Agency, 2007; European Commission, 2008). The high growth rates in road freight transport in Europe more than cancel out the efficiency increases in new vehicles, with further growth highly probably for the future. The Prognos Institute predicted a further increase in road freight transport in the next ten years (Prognos, 2001). This prognosis is underscored in the OECD sustainable transport report (Organisation of Economic Cooperation and Development, 2002) and the PRIMES scenario developed for the European Commission Directorate-General for Energy and Transport (Capros et al., 2008). As a result, there is constant pressure on this sector of the economy as well as the political process, with a demand for a new approach to be taken in other areas in addition to vehicle design.

Given these general socio-economic conditions, this dissertation proposes a method for monitoring the effectiveness of efficiency measures in the transport sector. It does so on the operational level for efficiency measures introduced in individual trucking companies. Carbon emissions or better energy use is therefore put into a wider picture by defining transport efficiency through appropriate key performance indicators. By providing an adequate, automated monitoring method, the idea is to initiate improvements in transport efficiency particularly in carbon emissions, following the old management adage: you can't manage what you can't measure. The sector of special interest featured in the development of this measuring method is computerized routing and scheduling and vehicle telematics.

The following central questions are examined:

- How can transport efficiency be measured in an individual trucking company?
- Can the introduction of computerized routing and scheduling and vehicle telematics in a trucking company reduce its carbon emissions?
- Is it possible to further reduce the carbon emissions of a trucking company by improving computerized routing and scheduling and vehicle telematics systems?

To discuss these questions, three individual studies have been conducted which make up the core of this dissertation. They are headlined by the chapter titles:

- CO₂ efficiency in road freight transportation: Status quo, measures and potential.
- Improving computerized routing and scheduling and vehicle telematics: A qualitative survey.
- The concept of transport efficiency – Monitoring and improving transport processes.

2.1 The European transport sector

In 2005 the EU-27 states emitted 5,464.8 million tonnes of CO₂ equivalents. This overall figure represents a substantial downward trend, as in 1990 the emissions of the same states added up to 5,790.0 million tonnes of CO₂ equivalents. The shares of the greenhouse gas emissions by sector in 2005 were as follows (figures for 1990 in brackets): energy industries 28.9 % (29.4 %), industry 20.1 % (22.4 %), transport 23.4 % (16.6 %), households 9.0 % (9.2 %), services, etc. 5.3 % (5.5 %) and others (solvent use, fugitive, waste and agriculture) 13.3 % (16.9 %) (European Environment Agency, 2007). The drastic increase of emissions in the transport sector thwarts the downward trend in the other sectors. The PRIMES scenario developed for the

European Commission Directorate-General for Energy and Transport forecasts that the increasing share of transport in emissions and total energy consumption will persist (Capros et al., 2008).

Looking at the EU-27's energy consumption instead of emissions, the transport sector even accounted for 31 % of total end-energy consumption in 2005, up from 26 % in 1990 (Capros et al., 2008). Two major trends in transport are responsible for this development: increasing activity in aviation (particularly strong between 1990 and 2000) and road freight transport (particularly strong between 2000 and 2005).

Accordingly, aviation consumed 13.8 % of total end-energy for transportation in 2005, up from 10.4 % in 1990. The PRIMES scenario forecasts that aviation will account for 18.6 % in the total sector's energy consumption in 2030 (Capros et al., 2008). The strong upward trend in road freight transport reflects the considerable increase in commodity trading following the EU enlargement and the market integration, as well as globalization. The most affected areas are port hinterlands, transit corridors and urban conurbation areas. The carbon situation of port hinterlands was surveyed on example of the Hamburg port in detail by Krusch (2003). The study analyses the carbon reduction potential of container transports by trucks on the operational level as well as chances and barriers of carbon reducing measures. The author finds no evidence not to transfer the result to other port hinterlands.

Private cars are the dominant means of transport on the roads, accounting for 55.9 % of total energy used in road transport in 2005. This share was 60.6 % in 1990 and remained fairly stable during the decade 1990 to 2000. There was very fast growth in transport by trucks from 2000 to 2005 as a result of increasing freight transport in the enlarged EU. Energy used by trucks therefore accounted for 39.4 % of total energy used in road transport in 2005, up from 34.5 % in 1990. Energy consumption by buses accounted for 1.5 % of total energy in road transport in 2005 and motorcycles accounted for 3.3 %. Energy use by trucks is forecast to account for 45.5 % of total

energy consumed in road transport by 2030. Consequently, the share of private cars in energy consumed in road transport will decrease to 50.4 % in 2030 (Capros et al., 2008).

For the years 1995 to 2006, freight transport (tkm) grew at a rate of 2.8 % p.a. and passenger transport (pkm) at a rate of 1.7 %, while GDP (at 1995 prices and exchange rates) grew by 2.4 % for the EU-27 countries (European Commission, 2008). Those figures show a slight decoupling of passenger transport from GDP growth, while freight transport grew faster than GDP. For 2006 to 2010, freight transport growth for the EU-27 is expected to slow down to the same magnitude as GDP growth (Capros et al., 2008). The latest figures for Germany and the EU-27 do not confirm this forecast, with the inner-German transport performance increasing by 7.3 % from 2005 to 2006 and by 8.0 % from 2006 to 2007 (Statistisches Bundesamt, 2007 and 2008) and the EU-27 transport performance increasing by 4 % from 2006 to 2007 (Pasi, 2008 and 2009).

In 2006 the freight transport performance for the four land transport modes road, rail, inland waterways and pipelines in the EU-27 added up to 2,595 billion tkm. Road transport accounted for 72.7 % of this total, rail transport for 16.7 %, inland waterways for 5.3 % and oil pipelines for the remaining 5.2 % (European Commission, 2008). From 1995 to 2006, road transport grew by 3.5 % p.a., rail transport by 1.1 %, inland waterways by 1.2 % and pipelines by 1.5 % (European Commission, 2008). Those figures also imply a change in the modal split of road vs. rail to the disadvantage of rail in freight transport.

The PRIMES scenario expects rail transport to recover, as manifested by a significant increase in rail activity; this is more pronounced for passenger transport. This is considered to be a consequence of infrastructure development, low relative cost of transportation and increasing congestion in road transport. The statistics show that these trends already took place in the period 2000 to 2005, showing a reversal of

previous trends of declining rail activity (Capros et al., 2008). However, the forecast shows still declining market shares for both passenger and freight transportation by rail, with the activities of other modes, such as road and aviation, increasing much faster than rail.

Coming back to road freight transport, but on a national level, the following section gives an overview per country of the changes in road freight transport (national and international transport; only haulage of heavy goods vehicles (usually >3.5 tonnes load capacity)). In the time period 1995 to 2005, there were strong increases (>50 %) of transport performance (tkm) in Bulgaria, Estonia, Ireland, Spain, Latvia, Luxembourg, Hungary, Poland, Romania and Slovenia; these are mostly new member states and/or rapidly growing economies. There were medium increases (25 % to 50 %) in the Czech Republic, Germany, Greece, the Netherlands, Austria, Portugal, Slovakia and Finland (European Commission, 2008).

The developments in German freight transport since 1991 indicate that increases in truck efficiency are below the level required to compensate for the annual rise in transport performance. In exact numbers, enhanced vehicle design reduced the specific carbon emissions per tonne-kilometre of the German truck fleet in 2005 to 77 % of the 1991 value (Umweltbundesamt, 2006a). On the other hand, the total transport performance (in tkm) increased in Germany from 1991 to 2005 by a total of 64.6 % (Umweltbundesamt, 2007). This led to an increase in carbon emissions by 38.2 % in the observed time period, up to the level of 48.7 million tonnes CO₂ in 2005 (Umweltbundesamt, 2006b). It is worth noting the strong upward trend in emissions from light trucks (<3.5 t) between 1995 and 2005 in Germany.

2.2 Outline of the surveys

The first study is based on two quantitative surveys with different methods in 2003. For the first part, information was gathered on fuel consumption, distance, payload

and loading space utilization by keeping manual records for 2-3 day trips. The results showed a wide range of emission efficiency and therefore potential for improvement. The downside of this particular method consists of its limited potential for showing more than a snap-shot of current trip performance; nor was it truly representative, given the limited number of trucks involved, together with an inadequate branch mix. The results therefore do not permit the aspired definition of a national 2003 transport efficiency baseline. The major result of this survey consisted in the introduction of the indicator mass-kilometre, which includes the empty weight of a truck in the indicator tonne-kilometre. It was thus possible to eliminate one weak point in the allocation of transport emissions.

The second part of the first study is based on yearly transport performance and fuel consumption data on the operational level. This information was gathered for the year preceding and the year following the introduction of a computerized routing and scheduling (CRS) system with/without vehicle telematics in order to measure corresponding effectiveness. The results show positive effects on the efficiency of the participating trucking companies. It has to be mentioned that in some cases the underlying measuring methods differed in some parameters for the preceding and following period. Again the results were not representative, with the survey graded on the level of case studies. One problem is the absence of a reliable validation of the method used, even though data selection gave highest priority to excluding those trucking companies where other substantial parameters had changed in addition to introducing this kind of system.

Learning from these weaknesses, the second study continues to elaborate the area of CRS and vehicle telematics by taking a qualitative approach. Therefore a survey carried out in 2005 asked transport and IT experts how and to what extent today's CRS and vehicle telematics systems can be improved. The answers were filtered on the basis of carbon mitigation targets. From this point of view, a greater degree of

integration between the various IT and telematics systems, such as creating interfaces between CRS and on-board monitoring systems, would appear to play a central role in further research and development. The approach taken in the study proved quite appropriate in answering this kind of question. However, the future practical acceptance of such carbon-relevant measures remained unclear. The interviewed experts backed the initial decision to investigate CRS and vehicle telematics measures, and confirmed the trends found in the first study on the basis of their practical experience.

The third study builds on the methodological conclusions of the first two studies by stating that it is laborious, costly and time-consuming to obtain data through manual trip records and yearly performance data on an operational level. Sometimes the data are unreliable; some data simply do not exist. In the end the results are often unrepresentative because of an insufficient study design or inadequate response. On the other hand, qualitative approaches offer a good instrument for explaining quantitative findings. To answer the question as to how to monitor transport efficiency, study three proposes a method for automatic assessment without time-consuming manual reporting procedures. The method is based on vehicle telematics, CRS and a new system introduced into these procedures for remote measurement of how a truck's loading space is utilized. One criticism of the theoretical discussion is that the results need to be validated by simulation results or an empirical appraisal of the problem. Finally it would appear to be difficult to assess the efficiency increase yielded by introducing this kind of monitoring system on its own.

The next chapter starts with the studies described above. It is followed by a final section which tries to filter out the central results and conclusions derived from the three studies.

3 CO₂ efficiency in road freight transportation: Status quo, measures and potential¹

Abstract

Road freight transport continues to grow in Germany and generates 6 % of the country's CO₂ emissions. In logistics, many decisions influence the energy efficiency of trucks, but causalities are not well understood. Little work has been done on quantifying the potential for further CO₂ reduction and the effect of specific activities, such as introducing computer assisted scheduling systems to trucking firms. A survey was survey out and linked fuel consumption to transport performance parameters in 50 German haulage companies during 2003. Emission efficiency ranged from 0.8 tonne-km to 26 tonne-km for 1 kg CO₂ emissions. The results show potential for improvements given a low level of vehicle usage and load factor levels, scarce use of lightweight vehicle design, poorly selected vehicles and a high proportion of empty runs. IT-based scheduling systems with telematic application for data communication, positioning and navigation show positive effects on efficiency. Fuel use and transport performance was measured before and after the introduction of these systems.

3.1 Introduction

As a result of various influencing factors such as European Union (EU) enlargement, European continental freight transport demand grew faster than the economy, and in the period 1991-2001 road freight traffic in Germany increased by 40 %. In the year 2001 this traffic was responsible for about 29 % of transport-related CO₂ emissions or

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about 6 % of total CO₂ emissions in Germany. In contrast to the long-term growing trend in demand for energy and transportation observed in industrialised countries (Schipper and Fulton, 2003), largely resulting from GDP growth (Lakshmanan and Xiaoli, 1997), total road traffic-related CO₂ emissions have been slowly falling in Germany since 2000 (Umweltbundesamt, 2003) (Figure 3.1).

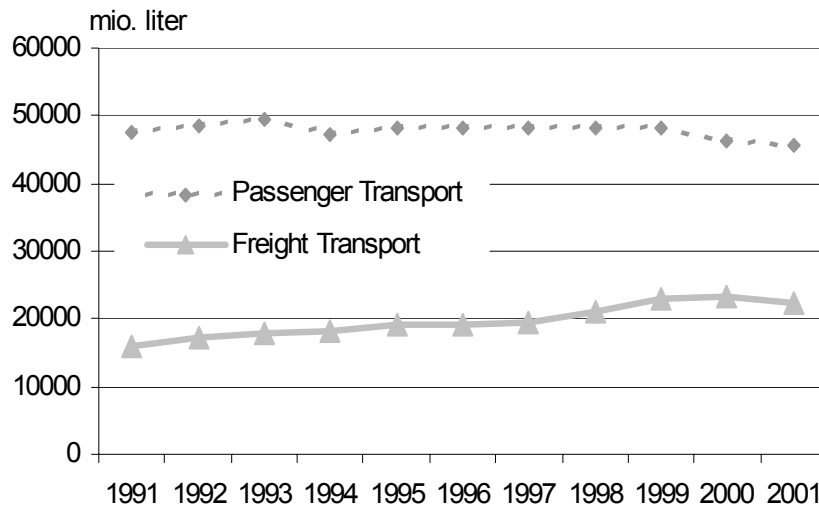


Figure 3.1: Trend of fuel consumption in German road freight and passenger traffic (resulting correspondingly in CO₂ emissions) from 1991 to 2001.

Nevertheless, if no additional measures are implemented (Umweltbundesamt, 2002), road transport emissions are expected to increase until 2030, while those from the rail sector remain stable. At an international level, road freight transport performance, measured in metric tonne-kilometre, is also expected to grow in the EU and the US, and this suggests the need for improved efficiency in energy use and for the implementation of at least three types of policy levers: technological, operational and modal (Vanek and Morlok, 2000). Changes in the efficiency of logistics structures and transportation processes might have the potential of mitigating total traffic emissions and their adverse impacts, while maintaining economic growth. It is anticipated that many logistics measures such as more back-loading or shared user distribution could produce significant economic and environmental benefits (McKinnon, 2003).

To better understand and to measure the potential available for further efficiency improvements within the road freight sector, it is useful to quantify the main parameters responsible for freight transport business efficiency in a field survey, identifying the factor influencing successful implementation of efficiency measures and estimating the effects for one type of instrument: the IT scheduling systems.

Although this approach could have a large influence on policy measures aiming at reducing overall freight energy use, or could lead to modifications at the level of entire intermodal transportation chains, the purpose here is more geared to the internal decision-making processes in trucking firms.

3.2 Status quo of CO₂ efficiency in road freight traffic

The CO₂ emissions from road freight traffic and the other performance parameters were determined at the beginning of 2003 under normal daily business conditions in representative German haulage companies. The measurements process followed the principles and recommendations for the standardisation of greenhouse gas reporting in companies by the Intergovernmental Panel on Climate Change (1996). Established statistical methods, such as the standardised use of key performance indicators in Britain (McKinnon et al., 2003) or company statistics in Germany (Deutsches Institut für Wirtschaftsforschung, 2002), were not used because these are too broad with too much focus on specific economic or financial indices that are not directly relevant to fuel efficiency. The analysis is based on a representative survey using interviews and a driver questionnaire. No extrapolations, emission factors or test situations were used, to avoid system errors.

3.2.1 Typology of efficiency measures

Initially operational efficiency measures were identified, with a focus on fuel savings, based mainly on statements from 200 interviews of randomly selected operators and

experts, and on British and German examples (Department of Environment, Transport and Regions, 2002). These measures can be classified at different levels:

- Logistic efficiency, with the aim of increasing the load factor, choosing the optimum vehicle category or optimising the entire transportation chain from origins to final delivery.
- Vehicle efficiency, with improvements in fuel consumption efficiency through vehicle design and technology, such as motor oils, low resistance tires, etc.
- Driver efficiency, with training or assistance from on-board units used for measuring components of driving behaviour that influence fuel use.
- Route efficiency: information on itinerary, road conditions or traffic can help to optimise routing (Haughton, 2002). These measures are related to disposition efficiency.

In telephone interviews with 53 randomly selected companies, individuals were asked for a short description of achievements relating to nine main measures (Table 3.1).

Table 3.1: Implementation of efficiency measures in 52 German road freight companies, 2003

Measure type	Percent of firms
Technical improvements	53.8
Driver training	51.9
Informal co-operation	40.4
Scheduling with IT	23.1
On-board-systems	17.3
Others	15.4
Shift to rail/ship	15.4
Scheduling with IT and telematics	9.6
Stacking area optimisation software	5.8
Formal co-operation	3.8

More than half of the companies have implemented at least one economic technology (synthetic oils, low rolling resistance tires and/or wind spoiler) and trained their personnel in fuel-saving driving behaviour at least once in the last 5 years. 26.6 %

answered that they did not apply any efficiency measures. Less than 20 % of the companies confirmed the use of technologies expected to have a high potential effect on fuel efficiency, such as on-board units for registering vehicle fuel consumption, IT-based scheduling systems and telematics applications. The politically relevant shift to rail or ship is found in 15 % of the companies, but to a small extent, and is not expected to rise, as stated in interviews. Only a few firms equipped their entire fleets with on-board units providing information on fuel consumption and transport performance. Monitoring and evaluation of energy efficiency performance remains highly unlikely for most of the decision makers. One cannot, therefore, rely on digital records for a representative survey and we have had to create our own driver questionnaire, despite some doubts about practicability.

3.2.2 Representativeness, sample and main unit

To evaluate the baseline, the average efficiency level in Germany in 2003, questionnaire based on manual records for 2-3 day trips were used. Drivers were asked to answer a questionnaire between two refuelling stops. They had to fill the tanks up to exactly the same level at the beginning and end of the period. Information on fuel consumption was given for a long distance (up to 4000 km), leading to an average value for each dataset. Between each stop, information was recorded on distance (km) and payload in metric tonne (t), allowing for exact measurement of transport performance in tonne-kilometre, including empty runs. In terms of volume, we asked the drivers to estimate volume utilisation in percent of total volume capacity, with the help of five classes (empty, 0-30 %, 30-60 %, 60-90 %, full). We did not ask for the number of pallets or the average pallet height, because this information is not available for container transports, and generally more difficult to obtain. General information was also requested on the vehicle type (empty load t2), company type (retail, construction, container, etc.), numbers of trucks operating, and level of efficiency measures implemented. The type of goods transported remains unknown; drivers and trucking companies often do not have this information.

The questionnaire was sent to a national sample of companies, identified by random choice in actual handbooks for trucking businesses. Statistical information on number, size and spatial distribution of trucking firms was incomplete and inconsistent.

Altogether 153 usable questionnaires were analysed from 336 questionnaires sent to 50 companies from approx. 200 companies who had originally been approached about the survey (56.25 % return rate, 45.5 % usable rate). To address possible non-response biases, national statistics on trucks, tonne-kilometre and company structures (Kraftfahrt-Bundesamt und Bundesamt für Güterverkehr, 2004) were compared with the data of the respondents. Similar average fuel consumption is seen of about 33 l per 100 km (11.7 miles per gallon or 3.3 km/l) for trucks over 12 tonnes in the statistics and in our sample.

To substantiate the results, comparisons were made with the digital records (over 22,000 datasets) of three companies with vehicles equipped with on-board units, and obtained very similar mean results for heavy truck load factors, fuel consumption (33.4 l/100 km), transport and energy efficiency. It was not possible to verify the data for trucks below 40 tonnes (n = 44) because very few digital recording systems were in use for this vehicle category in 2003.

To provide further support from another perspective, comparisons were made with data provided by the manufacturers. In the sample the average fuel consumption of 33.1 l/100 km for heavy trucks was 10-20 % better than the values stated by the manufacturers. This could mean that those in the sample are slightly more efficient than average.

Logistics service providers dominate the branch distribution in the sample (57 %), while retail (15 %), container transports (12 %), construction industry (3 %) or others (13 %) are under-represented. In the sample, medium (11-50 trucks) and large-sized

companies (more than 50 trucks in use) represent 72.2 % of the total; more than the German average of 12.9 %.

3.2.3 Results for CO₂ efficiency and the influencing factors

To calculate the emission efficiency, an indicator metric, tonne-kilometre (tkm) per emitted kg CO₂ was used (McKinnon, 1999). For the sample, the mean CO₂ efficiency (E) is 10.4 tkm/kg CO₂. Emission efficiency shows a large variation of between 0.8 and 26 tkm for 1 kg CO₂ emissions (Table 3.2).

Table 3.2: Main parameter values for total sample, trucks >40t and <40t, 2003

Parameter	Sample	Trucks >40t	Trucks <40t
	n = 153	n = 109	n = 44
<i>Vehicle use efficiency</i>			
Efficiency of vehicle use in tkm/mkm	0.36	0.40	0.28
Mean weight load factor in %	44.2	44.7	43.0
Mean volume load factor in %	59.3	63.6	48.2
Mean empty runs in % of distance	17.4	16.3	20.3
Vehicle mean age in years	3.1	2.5	4.4
<i>CO₂ efficiency</i>			
Mean CO ₂ efficiency in tkm/kg CO ₂	10.4	12.5	5.5
Mean fuel use in l/100 km	31.6	33.1	24.9
Highest CO ₂ efficiency in tkm/kg CO ₂	26.0	26.0	18.3
Lowest CO ₂ efficiency in tkm/kg CO ₂	0.8	1.3	0.8

The question then arises as to what are the most important factors influencing CO₂ efficiency. Table 3.3 offers a correlation analysis. The survey confirms the influence of vehicle load weight factor and vehicle class on CO₂ efficiency (Kolb and Walker, 1995). The lowest load factor is shown by the container transportation business, with 48 % proportion of truck kilometres run empty, compared to the sample average of 17 %. This mean result is relatively low, compared with the findings of McKinnon (1999) when looking at UK surveys, with a mean value of 29 % empty running in 1993, and 19 % in 2002 in the food supply chain (McKinnon et al., 2003).

Table 3.3: Correlation analysis of selected variables of the sample, 2003

Correlation of CO ₂ efficiency (in tkm/kg CO ₂) with	
Efficiency of vehicle usage (in tkm/mkm)	$r^2 = 0.96$
Vehicle load class (in t)	$r^2 = 0.70$
Vehicle empty weight (in t)	$r^2 = 0.61$
Degree of utilisation by volume (in %)	$r^2 = 0.42$
Fuel consumption (in l/km)	$r^2 = 0.42$
Load factor (in % of maximum load capacity)	$r^2 = 0.41$
Correlation of efficiency of vehicle usage (tkm/mkm) with	
Fuel consumption (l/100 km)	$r^2 = 0.39$

A second possible influencing factor is the operating sector of the company. In our sample, the economic sector (construction, parcel delivery, container, wholesale, etc.) has no influence on CO₂ efficiency, with efficient and inefficient transports taking place to a similar degree in every sector.

Company size and fleet structure (vehicle weight classes) have a marginal influence on the CO₂ efficiency of truck transports. The average CO₂ efficiency is slightly lower for small companies than for medium and large-sized companies. Small firms owned more small vehicles in our sample, and the efficiency differences are largely explained through the different fleet structures. The hypothesis is considered that large firms could be more efficient than small ones, because decisions to dispatch large quantities of orders and schedule several drivers can be taken in the context of a large number of available trucks, and with fewer restrictions on time and space. Within the sample, it was not possible to verify, nor to definitely negate this hypothesis.

The drivers were asked to estimate a volume utilisation ratio for each loading. To calculate the average volume used, a mean factor was used: empty = 0; 0-30 % = 0.15; 30-60 % = 0.45; 60-90 % = 0.75; over 90 % = 100 (full). We calculated the mean volume capacity used for each trip (as we did for tkm, litre use or other values), and then obtained the mean volume utilisation factor for the total dataset of each truck. A weak interrelation can be observed between volume utilisation and CO₂ efficiency (Figure 3.2).

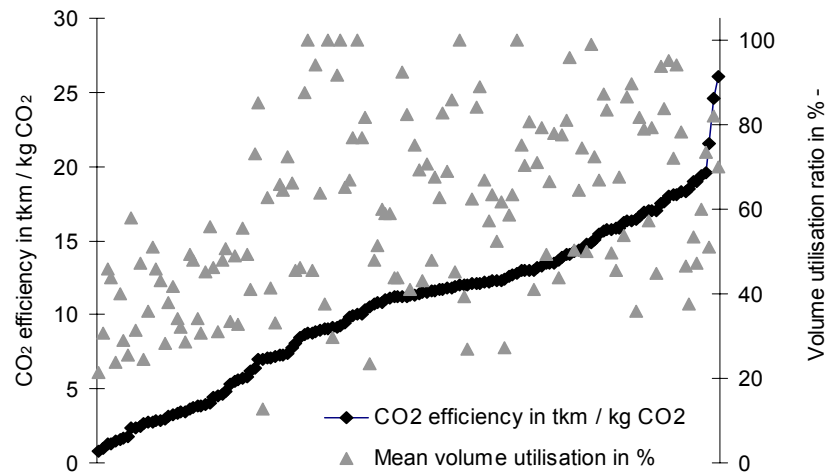


Figure 3.2: Volume utilisation and CO₂ efficiency in the sample, 2003.

In the sample a volume utilisation above 80 % always corresponds to a tkm/kg CO₂ value above 5. The lowest values for volume utilisation, as expected, were found in small vehicles for distribution transport. The average volume utilisation ratio of all vehicles is only 60.7 %, pointing to potential for better utilisation. However, given the subjective nature of the drivers' estimates, the level of confidence in the results is "medium" in this area.

The new indicator mass-kilometres (mkm) and the new ratio tkm/mkm were established with the objective of measuring the efficiency of vehicle use (Evu) more correctly. This was not well understood, because the main indicator for freight demand "tonne-kilometres" (tkm) neither includes the vehicle empty weight nor the vehicle-kilometres travelled empty. To calculate mkm (mass-kilometres), the weight of the empty vehicle (t₂) is added to the load of the freight (payload t₁), resulting in the total weight (m) of a vehicle.

$$E_{vu} = \text{tkm} / [(t_2 + t_1) \times \text{km}]$$

The value of the ratio E_{vu} indicates how much more physical transport capacity was actually carried out in addition to the tkm-value, including the vehicle empty weight

and the vehicle-kilometres travelled empty. The indicator tkm/mkm represents the "efficiency of vehicle usage".

These results show that we can measure CO₂ efficiency (E) in road freight transport with the unit tkm/kg CO₂ emitted. It is a factor directly influenced by the efficiency of vehicle usage E_{vu} , choice of vehicle class (vc), driver behaviour (d) and route (r) parameters.

$$E = E_{vu} \times vc \times d \times r$$

In the sample, heavy trucks shows a high correlation ($r^2 = 0.96$) for E and E_{vu} . This leads to the consequence that under all the partial efficiencies in road freight transport, the most important one for CO₂ reduction is the efficiency of vehicle usage, measured in tkm/mkm.

Other external factors proven to be relevant for overall efficiency of logistic processes and truck fuel use, e.g. service quality, time of vehicle use, average speed, snowy weather, and traffic congestion (Samuelsson and Tilanus, 2002). Certain planning, or economic instruments, can enhance or reduce the efficiency of road freight traffic, e.g. longer red lights in central areas and fuel taxation (Calthrop and Proost, 2003). Supply chain decisions, constraints or the financial framework of the business often inhibit efficiency improvements such as a higher return rate (McKinnon, 2002). However, as many managers have said in the interviews, most of these factors cannot be influenced by decisions on the managerial level of trucking firms. Managers say that most of the factors can be regarded as general conditions that are valid for everybody and neutral in terms of concurrence. This led to the tentative conclusion that, in terms of the efficiency of the entire transportation chain, there are only a few points that can be influenced by the managers of trucking companies. One of these points is the choice of the vehicle type, another is the implementation of an IT scheduling system.

3.2.4 Potential analysis

To evaluate the potential for further efficiency improvements, the survey results were converted into a frequency distribution graph for the classes of Evu (Figure 3.3). This shows that the main transport performance and the largest amount of emissions occur around an average of 0.36 tkm/mkm.

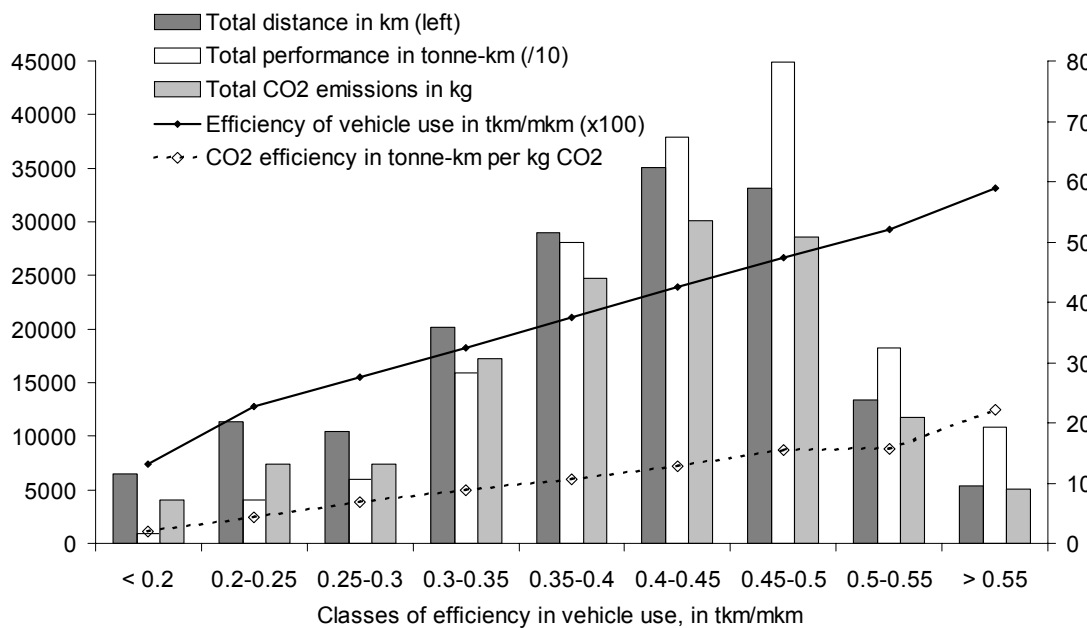


Figure 3.3: Potential analysis: transport performance, emission amount (left scale), and efficiency of vehicle use and CO₂ efficiency (right scale).

The best company showed an average of 0.56 for Evu and had implemented a good but not exceptional level of efficiency measures. One simple hypothetical exercise consists of establishing the theoretical optimum of Evu which is available in the short term for a trucking company; this can be illustrated with the example of investing in a lightweight vehicle fleet. The best available German truck on the market in 2003 has 11 t empty weight and 40 t maximum vehicle weight (our sample average is 14 t empty weight). Assuming full load for each trip, this truck would reach a value of $E_{vu} = 0.725$ tkm/mkm. Assuming this for each type of load (food, container, construction, wood, etc.), it could be possible to design such a lightweight vehicle and

reach a mean value of 11 t empty weight in Germany for all kinds of 40t trucks. With an average load factor of about 70 % for heavy trucks in spring 2003 (Kraftfahrt-Bundesamt und Bundesamt für Güterverkehr, 2004), this would result in a mean value of around 0.5 tkm/mkm. Assuming that all the companies below 0.5 tkm/mkm could buy this truck, and would reach an average of 0.5 for their Evu values, this would result in an overall reduction of 20 % in CO₂ emissions of the road freight transportation branch.

Other kinds of mainly self-financing efficiency measures could also be implemented (McKinnon, 2003), resulting in further effects. In that case, traffic would be significantly reduced while transport performance in tonne-kilometre would be the same. The market value of the corresponding reduced amount of diesel fuel would be about €5 billion per year only for Germany. This potential may also exist in other countries, perhaps at a lower level, and the appropriate technologies and applications could be easily exported.

Fleet managers were asked to their forecast on future potential efficiency gains. Additional measures were mentioned such as "adjusting the choice of vehicle class to the load". Many managerial decision-making processes were also identified, such as subcontracting, co-operation and others. Even if they are relevant for the optimisation of physical transport, it is impossible to quantify their effects in a nationwide representative manner. According to some managers, there would appear to be another aspect of decision-making on a company level which influences fuel efficiency. Some firms could optimise their customer-supplier relations in time and space with regard to location and fleet structure, resulting in a very high utilisation rate for each vehicle. Perhaps the most important overall view expressed, however, was that the notion of optimising potential is pure theory. Individually, each manager saw no potential, and no possibility of overcoming existing constraints.

This all leads to somewhat contradictory positions: a higher target for performance efficiency (like $E_{vu} = 0.5$) represents a feasible step, already successfully implemented in many firms. Higher efficiency gains are very likely to occur. The sceptical attitude of the managers leads to the idea that higher market transparency, better assessed cost-benefits for each measure and better monitoring of the companies' performance indicators could create the conditions for an accelerated diffusion of existing technologies.

3.3 Efficiency increase by IT-based scheduling and the use of telematics

What kind of technology could be said to be promising? With information and telecommunication technologies, it seems to be potentially less difficult to coordinate a large quantity of trucks and a growing number of orders. The expected improvement in load factor brought us first to the idea that this kind of technology could lead to a substantial overall effect on efficiency in the trucking industry of an entire country. Further expected effects are the reduced energy needs while the road congestion problem does not increase or even could decrease. No effects are expected on economic growth or increasing freight transport demand. In this study, it was necessary to validate these assumptions in a separate small survey and analysis.

Only few firms implemented IT-based scheduling or telematics in Germany (Figure 3.2). There would appear to be a greater diffusion of telematics in the UK (McClelland and McKinnon, 2003). Market estimates (Umweltbundesamt, 2000) brought us to the hypothesis that in future, this type of technology could be a fast-growing sector. The empirical approach consists in quantifying the CO₂ emissions of German truck transport companies under normal working conditions before and after system implementation in the years 2000-2003, a step inspired by the work of Pagano et al. (2001) in the bus transportation sector. So far, little work has been done on potential fuel efficiency and transport performance gains from these systems, compared

to other efficiency strategies for trucking such as improved aerodynamics, tyres with reduced rolling resistance, weight savings or reduced engine idling (Ang-Olson and Schoeer, 2002). Pagano et al. state that despite some significant changes, bus transport operators have not seen the dramatic efficiency gains they had hoped for by implementing the new scheduling systems. For the US, Hubbard (2003) provided evidence that advanced on-board computers and electronic vehicle management systems increased the freight vehicle utilisation ratio by 13 % in the years 1994 and 1997, leading to major economic gains. Golob and Regan (2002) analyse operator use of these tools and point out the usefulness of traffic information, but did not quantify the effects on energy or transport efficiency. Effect on mileage has been estimated at up to 20 % in UK case studies (McKinnon, 1999).

We use a mixture of quantitative, systematic and qualitative empirical socio-economic research methods. We made 79 calls in spring 2003 to randomly chosen trucking company managers, and about 90 % of them were relying on disposition systems. We selected these road hauliers and were aiming to identify those without any major changes in size of fleet, customer structure, type of goods, or other measures influencing annual fuel use, except IT scheduling systems or telematics. Structured questionnaires were sent to these firms to collect yearly performance and fuel consumption data. In accordance with Pagano et al. (2001), the company situation was described (number of trucks, truck weight) and we asked about the same efficiency parameters as in the main survey, in the year before and the year after the system was introduced. The situation before introduction can be described as background or baseline against which improvements can be measured. Seven usable questionnaires from 22 respondents were given in-depth analysis (32 % return rate, 9 % usable rate). This low return rate is likely because managers could not expect any immediate financial advantage from the analyses, the marketing of the survey was very limited because of the time constraints, and only very few data were correctly collected before the introduction of digital systems. Data on the year before were often missing in the

answers. This technical limitation is also the reason why data could not be obtained on tonne-kilometre.

The main parameters are presented together with the other survey samples in Table 3.4, and compared with the last statistical data available for Germany in 2001.

Table 3.4: Disposition survey: Key indicators and verification of the 7 firms analysed in the sample of 22 firms

	Disposition survey 2003			Container survey 2003	Baseline survey 2003	Road transport statistics Germany
	Sample values for 22 firms	7 firms with scheduling system	7 firms to sample in %			
Total load (t)	5,145,734	2,437,262	47.36		6700	2,870,300,000
Total distance (km)	201,152,706	74,857,140	37.21	44,600,000	177,124	76,000,000,000
Total fuel use (l)	67,797,900	25,731,574	37.95	14,200,000	55,989	20,000,000,000
Mean fuel use (l/100 km)	33.70	34.07		31.80	31.61	26.32
Number of trucks	1,681	790	47	383		2,782,000

Sources: Baumgartner and Léonardi, 2004; Deutsches Institut für Wirtschaftsforschung, 2002; Umweltbundesamt, 2002.

In the samples, fuel consumption varies from 31.6 to 34 l/100 km. In Germany the average consumption rate is lower, with 26 l/100 km, but this is explained with the large number of lightweight vehicles. If we look at the total distance, the 7 firms of the sample represent a market share of 0.5 %. In conclusion, we observe no major distortion between the sample and other data obtained. The dataset is likely to be representative for the average performance of most of the long-distance trucking companies in Germany.

3.3.1 Balance of the climate and traffic relevant efficiency effects

One year after investing in a new system, the performance rates show an average increase in total payload weight by more than 14 % and an increase in mileage by

about 3 % (Figure 3.4). The mean fuel consumption remained stable, CO₂ emissions rose by 2.5 % and truck mileage increased at 2.2 % a year. Compared to the overall changes in Germany from 2000 to 2001, these are relatively large.

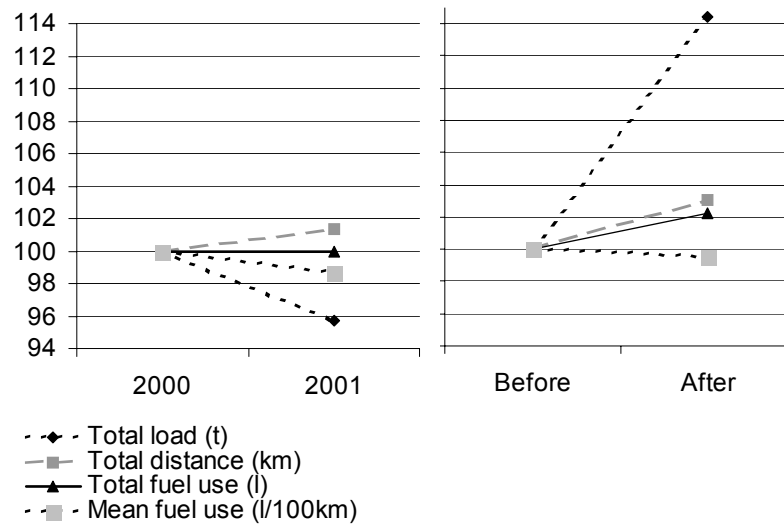


Figure 3.4: Effects of IT-based scheduling on t, km and fuel use in the sample (right), compared with the German means for 2000 and 2001 (left).

What are the processes responsible for these changes in energy and performance efficiency? There were two important changes in the sample companies. One firm operates with more trucks, and the share of long-distance traffic grew by about 10 % corresponding to the overall situation in Germany. Between 2000 and early 2003, the number of heavy trucks grew together with the average trip length. In one of the companies, other influencing factors were informal partnerships and changed driver behaviour. To the extent that a number of additional external and internal conditions (harsh winter, changing routes, etc.) always influence the performance of a company, it may not be that the CO₂ efficiency gain was due exclusively to new IT scheduling or telematic systems. However, the managers asked were not able to identify any other change that could have resulted in such an increase in payload while mileage was growing at a far slower rate.

Another logistics effect is that better-utilised trucks are heavier and use more fuel per kilometre, but, in theory, less distance has to be driven for the same payload. Both effects were observed, and they could therefore consequently reduce the overall yearly fuel consumption. But additional new trucks were running and the average distance travelled was growing. In the end we observe an overall increase in total mileage. This was strong enough to compensate for reductions in fuel consumption per truck, leading to a slight overall increase in consumption and therefore to a small increase in emissions. This unexpected result complies with theoretical considerations: the growth of the transportation sector overcompensates for gains in efficiency. Unfortunately, as a primary effect of the introduction of IT scheduling system or telematic, our survey indicates an improvement in efficiency but no reduction in total CO₂ emissions.

3.3.2 Benefits of scheduling systems and telematic applications

To validate the data collected, 21 interviews were conducted with decision makers in logistic firms and asked for an estimation of past effects and a qualitative evaluation of further application potential. To further substantiate the survey, managers from 12 software companies were interviewed about market potential, return on investment, design and functionality of software and an estimation of efficiency effects in terms of costs, personnel and fuel consumption. Operators and users were asked, on the phone or at fairs, about advantages and problems related to new IT-based scheduling systems, resulting in an initial characterisation of functional effects on business and physical transport.

Most users and potential buyers see the highly diverse range of products as a barrier to investment. Beneficial effects of IT include:

- Increased transparency of the operational activities.
- Services as a management-oriented information system.
- Increase in the vehicle load factor.
- Decrease in the average transport distance.
- Identification of unprofitable customers and orders.
- Planning and rescheduling of transport operations during the day.

With the implementation of a new scheduling system, the company often needs a transition time of about 6 months. The main changes take place on the level of operational decision-making, mainly in the responsibility of the expeditor, in direct contact with the drivers. It is not clear which kind of decision supported by the system has the highest effect on efficiency. Is it the decision related to time, routing/distance or load capacity? It was not possible to isolate these factors in the survey, nor to obtain satisfactory answers from the company leaders, managers or employees.

For operators and fleet managers, some secondary effects of the systems were not obvious. If the load factor increases, it produces a substantial indirect benefit through the value of the additional goods transported, therefore reducing the variable costs per order and improving the financial situation. This connection was not featured in any answers, because the accounting systems and the scheduling systems work separately.

When telematic elements have been added to the scheduling system, the perceived benefits were mainly the further increase in vehicle utilisation and further decrease in the average transport distance thanks to accurate position information, the recognition of time-critical transports and the minimisation of detours by helping the drivers. Helpful information includes the availability of monthly data on fuel consumption, kilometre, vehicle hours, and driver behaviour (McClelland and McKinnon, 2003). In many interviews, the managers state that it is possible to improve the quality of scheduling systems and telematics at the level of decision making for schedulers and

customers, especially with regard to routing and time components, confirming Slater's (2002).

IT-based scheduling systems and telematic applications can boost the productivity of employees. After the implementation of a new system, we observed an increase of more than 25 % in the number of trucks per scheduler. On average, €1020 to €1235 was invested per truck for a new system. Depending on the company size and the number of trucks to be scheduled, the features fluctuate between relatively simple and complex, and the investment for a new system varies between €500 and €2300 per truck. IT-based scheduling systems can be amortised through savings in salaries for accounting and scheduling employees and through lower fuel costs. In one company, one scheduler was dismissed. In the sample, IT-based scheduling systems have a rate of return of 75-100 % per year. This result confirms the findings by McKinnon (2003).

The additional investment in a telematic system represents €2050 to €2350 per truck and can vary from €1200 to €3500 per truck. The return on investment for companies from these systems comes from further savings in fuel consumption and reduced costs for employees. In the sample, telematic applications have a rate of return of 40-75 %. This technology can be considered as a self-financing measure.

3.4 Conclusion

A survey of trucking in Germany in spring 2003, found the mean CO₂ efficiency (E) is 10.4 tkm/kg CO₂. Emission efficiency shows a large variation between 0.8 and 26 tkm for 1 kg CO₂ emissions, between the most efficient and the most inefficient transport. A high potential for future technological and organisational improvements is therefore identified. If any enhancement of the CO₂ efficiency is observed in road freight traffic, it can be partly explained by an increased efficiency of vehicle usage, which can be measured by the newly introduced indicator tkm/mkm. The indicator is calculated analogue to the indicator tonne-kilometre, but also includes the mass of the empty

vehicle and therefore does not neglect the vehicle kilometres travelled empty, because the relevance of this is verified by an increase in the indicator tkm/mkm results strongly correlated in increased CO₂ efficiency of transport.

To a large extend, the measures aimed at improving transport efficiency have been poorly implemented. This is explained partly by poor public information regarding such things as cost-revenue ratios, but by also the limited recognition of energy and performance inefficiency inside the logistics companies themselves. Based on the survey, it is possible to estimate the effect of IT-based scheduling and telematics on performance and energy efficiency. The CO₂ efficiency of the companies surveyed increases after the implementation of an IT-based scheduling system or a telematic application for data communication, positioning and navigation. Onboard units are a key technology to monitor the success of other efficiency measures, because they can register and tie fuel consumption with other vehicle parameters (distance driven, payload, etc.).²

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4 Improving computerized routing and scheduling and vehicle telematics: A qualitative survey³

Abstract

Previous work has shown that computerized routing and scheduling and vehicle telematics can play an important role in reducing fuel consumption and CO₂ emissions of trucking companies. Here we use expert surveys to look at how these systems could be improved to positively impact on the CO₂ efficiency and the utilization of trucks. The broad range of options was filtered on the basis of CO₂ emissions mitigation targets as part of the decoupling of transport growth from energy use.

4.1 Introduction

European road freight transport uses considerable amounts of energy and is responsible for numerous environmentally damaging emissions, including the greenhouse gas, carbon dioxide (CO₂). One approach to meet the CO₂ mitigation demands in the Kyoto Protocol is to increase energy efficiency in different fields of activity. In transportation, the goal is to enhance transport performance for the same amount of energy consumed. As a result different strategies to counter the negative consequences of road freight transport are either on trial or being implemented. To-date, the introduction of new vehicle designs has been the most successful strategy. However, this strategy has not yet brought any noticeable reductions in greenhouse gas emissions in the EU transport sector as the high growth rates in road transportation more than cancel out any efficiency increases in new vehicles

³ This chapter was previously released as: Baumgartner, M., Léonardi, J., Krusch, O., 2008. Improving computerized routing and scheduling and vehicle telematics: A qualitative survey. Transportation Research Part D: Transport and Environment, Volume 13, Issue 6, 377-382.

(European Commission, 2006; European Environment Agency, 2006), with further growth highly probably for the future.

Computerized routing and scheduling (CRS) and vehicle telematics are often discussed as a promising area for improving transport performance. On the basis of data from the US Census Bureau, Hubbard (2003) concludes, that a load factor improvement across the whole US transport industry of as much as 3 % between 1992 and 1997 was brought about by the use of on-board computers for positioning and data communication together with trip recorders. An increased load factor corresponds directly to a decrease in kilometres driven for the same amount of goods transported. This leads to a reduced fuel use and lower CO₂ emissions. To this same end, the UK Government has introduced a programme to concentrate efforts on marketing telematic equipment in road freight transport. British trucking companies surveyed by McClelland and McKinnon (2004) used the new equipment mainly for checking position and running times of the vehicles, the first factor is known to improve the load factor of a trucking company. For German trucking companies, distinct CO₂ reductions were found in the 12-month period following the introduction of CRS and telematics systems for positioning and data communication (Léonardi and Baumgartner, 2004).

A qualitative survey is conducted that addresses target groups on both the demand and the supply sides of the market. The initial hypothesis is that today's CRS and vehicle telematics systems can be improved by a combination and the better use of existing technology and by specific technical developments to positively impact on the CO₂ efficiency and the utilization of trucking companies. The prime aim of the study is to identify the areas suspected of having the greatest potential for saving CO₂.

4.2 Technologies

Here, efficiency is interpreted to mean achieving the aim of “transport performance” with a simultaneous reduction in environmentally negative effects. To be more precise, energy efficiency and CO₂ efficiency relate to the reduction of energy consumption and emissions per unit of freight transport performance (measured in tkm or per ton). The levers for improving efficiency are the internal company logistics and organization decisions as well as the introduction of technical systems, that were investigated by Ang-Olson and Schroeder (2002).

Scheduling is defined as “the ensemble of co-ordinated practices of time and route planning for orders, vehicles, and personnel”. In daily business procedures, the scheduler has the task of sorting incoming orders and passing them on to the appropriate delivery agents. This system also has to manage the material flows and stock inventories for reliable and punctual delivery at minimum cost. In the process, less-than-truckload jobs, which are compatible in terms of time frame and delivery area, are bundled together to form a trip. Return trips need to be taken into account early. Difficulties arise for example from time windows and side constraints for pick-up and deliveries. Each improvement in the logistics process leads to improvements in load factor and to potentially ecologically positive results.

CRS does not differ from manual scheduling with regard to the targets involved but does differ in the use of computers and computer software. CRS systems form part of the transport software that manages the job process from receiving orders through to billing. There are two different classes of CRS systems; forwarding-orientated systems, and trip optimization systems for distribution or the special needs of shippers.

There are two sub-classes of forwarding-oriented systems; classic systems, and systems with semi-automated route optimization procedures that try to help the scheduler by making route and bundle suggestions. The key variables used in that

process are pick-up and delivery locations and time frames to suggest optimum routes in terms of distance, load factor and time. By contrast, trip optimization systems are used for a large number of delivery points in classic distribution or general cargo transport. An example of this is the delivery of drinks or foodstuffs to various end users or small shops. Often, vehicles from outside the software user's fleet are guided by those systems as well. A second characteristic of trip optimization systems is the diversity of side constraints they can deal with.

In the area of vehicle telematics the focus is on fleet management systems that can be divided into two functional subunits: telematics systems for positioning and data communication to support CRS and on-board monitoring systems. The survey deals on a peripheral level with on-board navigation systems and traffic information systems. Legislative and fiscal instruments such as road pricing systems, parking control systems and the introduction of the digital tachograph are not considered.¹

The basic element of most vehicle telematics systems is the positioning function. In fleet management systems this is incorporated in a tracking and tracing process with the position of the vehicle recorded at set intervals. The route taken by the driver can be recorded exactly on the basis of the position history. The position is determined using either GPS signals or via the GSM network. Another common characteristic of fleet management systems is an on-board computer. This mobile computer processes, buffers and transmits all occurring data.

Telematics systems for positioning and data communication provide as working environment mobile end devices for the driver. These can vary from mobile communication devices to entire computer work stations. According to the sophistication of the system, order information, digital delivery notes, status information (e.g. loaded/unloaded), photos, barcode scans and electronic delivery confirmation may be transmitted between the central office and the vehicle, together

with position information. Normal phone calls are standard, too. The principal function of these systems is to improve scheduling and order processing, in other words the logistics process. According to Hubbard (2003), such systems improve productivity by enhancing decision quality, with particular reference to the allocation of resources in the scheduling process. To emphasize, a telematics system for positioning and data communication is highly incomplete without connection to a sound CRS system.

By contrast, on-board monitoring systems are not used for direct communication between the driver and the central office, although certain data recorded in the vehicle electronic systems can be uploaded by data transfer. They serve solely to record vehicle and trip-specific data by making use of the CAN (Controller Area Network) bus. These data can then be evaluated by the fleet manager for example in order to influence driving behaviour. Besides driving behaviour parameters, modern on-board monitoring systems offer a lot more valuable information. The list includes general tour data, technical vehicle inspection information and trip evaluation parameters (Table 4.1).

Table 4.1: The main parameters measured by on-board monitoring systems

General data	Driving behaviour	Trip difficulties	Technical vehicle inspection	Additional information
<ul style="list-style-type: none"> - Date, time - Position (GPS) - Vehicle, driver, trailer - Status (driving/rest) - Change of tachograph - Distance driven - Fuel consumption (running and stationary) - Speed 	<ul style="list-style-type: none"> - Braking behaviour - Gear changing behaviour - Driving pedal movements - Constancy of speed 	<ul style="list-style-type: none"> - Gross vehicle weight rating - Number of stops - Average gradient 	<ul style="list-style-type: none"> - Brake wear - Refrigerant level - Oil level - Disturbances reporting - Maintenance scheduling - Tyre pressure 	<ul style="list-style-type: none"> - Loading space temperature profile

On-board navigation is defined as computer-supported navigation with the aid of satellite positioning information (GPS) and digital road maps. With this information, the system knows its position and can guide the driver to his destination.

Traffic information systems could in future support on-board navigation, as they provide up-to-date traffic information to the driver or to the central office. Many years of experience which transport conditions can be expected on which route at a particular time, the so-called load curves, could be incorporated into the system. Golob and Regan (2005) asked 700 Californian trucking companies which information was of the greatest interest for their drivers. Those companies indicated that the most important information was the location of road accidents and lane closures, the weather, the predicted driving time for alternative routes, and waiting times at terminals or ports.

4.3 The survey

The survey is not intended for making quantitative statements. A qualitative method was therefore chosen for collecting information, by consulting with experts in the field. Ten trucking companies using CRS software were surveyed (Table 4.2), as well as ten leading software and hardware manufacturers, in spring 2005. The representatives from the trucking companies were managing directors, schedulers and fleet managers. In software companies, the interview partners came from the development departments and from management. All interview partners had to fulfil two criteria: a minimum of ten years experience in transportation and a senior position in their respective company.

The trucking companies were selected by random internet searches. Each company was allocated to a market player group according to the Bundesamt für Güterverkehr (2005) typology. Table 4.2 provides some details of the sample. A large proportion of the types of players active in the German forwarding market are

represented in this sample distribution. Two companies surveyed were from an industry using a trip optimization system; one a shipper managing an external fleet and the other managing its internal transport demand.

Table 4.2: Sample description of the transport companies

Company category	Transport sector	Own vehicles (#)	CRS system	Telematic system for positioning and data communication	On-board monitoring system
Small transport company	Forwarding	10	+	+	-
Niche service provider	Forwarding	34	+	+	-
Forwarding company	Forwarding	14	+	+	-
Forwarding company	Forwarding	28	+	+	-
Sector specialist	Forwarding	60	+	-	Test phase
Sector specialist	Forwarding	90	+	+	-
Sector specialist	Forwarding	95	+	+	Test phase
Sector specialist	Forwarding	150	+	+	60 vehicles
Industrial company	Distribution	22	+ (Trip opt.)	-	-
Shipper	Distribution	0	+ (Trip opt.)	-	-

The selection of technology manufacturers was arbitrary. Only well-known companies with established market shares were surveyed. Overall, the selection gives an outline of the current developments on this market in Germany. Table 4.3 categorizes the technologies provided by the manufacturers.

Table 4.3: Sample description of the technology providers

Technology	Companies (#; multiple entries possible)
Telematics system for positioning and data communication	6
Forwarding-orientated CRS system	4
On-board monitoring system	2
Trip optimization system	1
On-board navigation system	1
Traffic information system	1

4.4 Proposed technologies

The most frequent sought attribute was for a fully functional, problem-free, integrated logistic software architecture, in which all necessary sub-components from order input via transport execution to invoice output work together smoothly, regardless of their production origins. This might also include warehousing tools, office applications and SAP routines. Modular addition of individual components should be possible. Above all this indicates there is no need for manual transfer of data by the users or commands from one sub-system to another. There is a positive response to the fact that the main transportation software packages with CRS modules function well with the prominent telematics systems for positioning and data communication. Nevertheless, this demand for better integration is strong in all companies using components from various manufacturers. In this context, the users reported a slight dependency on manufacturers. After deciding to invest in a particular system, end-users are dependent for a longer period of time on the service quality and further developments of the respective technology supplier, largely in terms of new interfaces to other products.

Frequent complaints were made about the instability of the telematics hardware. One managing director of a company with around 100 commercial vehicles reported that “the system normally is not working in 5 vehicles”. It should be mentioned that a truck cab is one of the most difficult environments for operating an IT system. Nonetheless, the users often felt that the high costs of the equipment were not justified in terms of reliability.

CRS systems with telematics for positioning and data communication are currently separated in technology terms from the on-board monitoring systems. On-board monitoring systems provide primarily a connection to the CAN bus, a device which centralizes all sensor data from the vehicle while it is running. In doing so they can collect the full range of digital information about vehicle condition and performance

available in modern trucks. One additional feature is the position information that is likewise provided by telematics systems for positioning and data communication. Manufacturers offering on-board monitoring systems thus also provide customers tracking and tracing functions. Recently these manufacturers extended their service by adding a data communication functionality. This combination of position information with data communication can be described as a tracking and tracing system with data communication. However, in 2005 no such system incorporates a sound CRS system although there is no technical reason why these systems need to be separated. In the survey, only one trucking company had a telematics system for positioning and data communication while at the same time around half of his fleet of trucks was equipped with on-board monitoring systems. Only two trucking companies had onboard monitoring test vehicles in operation.

Objections by end-users who operate on-board monitoring systems reveal that these systems often produce data over-kill raising questions about who is to evaluate it. In a similar vein some criticized the time-consuming, difficult process involved in interpretation of the data, requiring expert skills, together with the partly incorrect aggregation of the data by the systems.

The “comparison of planned and actually driven routes” approach deals with the systematic monitoring of the routes selected by the individual driver and comparing them with planned routes. The underlying issue is whether and to what extent the fuel consumption of a trucking company increases when drivers detour or traffic conditions necessitate route changes. One system provider claimed that he has already introduced this check as a standard function providing simple case analyses in a 3-h cycle. But in general, telematic systems for positioning and data communication do not offer systematic, statistical monitoring of this parameter. Even without comparison function, in 2005 there is no system offering a continuous monitoring function that is accurate down to a minute. Costs are the main reason – it is not financially feasible to

send a current position report every minute. However, location information can be saved every 30 s with the location track being sent back to the office every one to 3 h permitting precise individual route analysis.

The transport experts were asked about an on-board monitoring method for measuring the loading space utilization of a commercial road freight transport during the actual journey. To illustrate the significance of such a technology, in 2002 McKinnon and Ge (2004) carried out a 48-h survey of 53 fleets, comprising roughly 3500 vehicles, in the UK food supply chain. They found that on average, loaded trips utilized 69 % of the deck area and 76 % of the available height; corresponding to a mean loading space utilization of 52 % of all loaded trips. The advantage of such a measuring technology is that continuously available information on weight and loading space utilization can be used to monitor and evaluate the success of logistical measures introduced by trucking companies. Around half of the companies questioned showed an interest in the possibility for remote measurement of current loading space utilization. Some companies could not see how to implement such a system in their sector (e.g. car transports), whereas others have no need for it, time being in their opinion amore important factor than load efficiency.

Interviews with the trucking companies from the forwarding sector included a discussion of semi-automated route optimization. Some pointed out that such an option was not available to them. Others indicated the importance of this feature by explaining the process and the benefits. The procedure initially uses the optimization system to generate route and bundle suggestions. In the second step, these are either adopted or reworked by the schedulers: around 80 % to 90 % of the suggestions being adopted, the rest needing revision. This reduces the workload on the scheduler. Some companies did not favour such semi-automated route optimization procedures because they cannot model the complex reality of their transport processes accurately

enough. These companies rely on classic CRS without semi-automated route optimization.

More advanced CRS systems offer the opportunity to statistically analyze transport processes from an economic perspective. This kind of management information system gives companies the option of evaluating past consignment data using freely defined filters. The results consist of trip statistics on customer or partner basis, or data on order volumes for particular times or regions. One possible option is the targeted search for return trip volumes from particular regions. Those interviewed suggest improving these systems and developing more user-friendly interfaces, with a wider spread of this technology.

One development is the new generation of barcode scanners that can also be used as fully-functional telematic terminals for positioning and data communication. This equipment is mainly used for generating electronic signatures in combination with barcode scans at the shipment delivery point. Trucking companies using such scanners no longer need to print and scan delivery notes. Upgrade scanners add full telematic functionality without high additional equipment costs making it irrelevant whether a PDA, a scanner or an onboard computer is used as telematic end device.

On-board navigation is the subject of some dispute. Basically on-board navigation is of interest for short-haul distribution transport and for drivers operating on unknown routes. This indicates that navigation support is also needed at the very end of long-distance runs, in the so-called last mile. This is especially true for foreign language areas. Drivers who operate day-in day-out in the same delivery areas are probably quicker without navigation support, because they are better able to judge the traffic situation from their daily experience and local knowledge. Many trucking companies reject on-board navigation for these reasons. One fundamental weakness of such systems was always the lack of basic data or adequate mapping. At the time of the

survey no specific software was available to take account of the requirements of larger trucks by providing information on bridge and tunnel clearances, weight limits or other access limitations. This is probably one reason why some trucking companies have reported that these systems can be used effectively only in cars. At the beginning of June 2005, the European market leader for on-board navigation introduced a new product. This new version prepared solely for use in commercial vehicles tries to tackle these limitations with the aid of new mapping information. No information based on experience was available in the survey period.

One area of technology currently being researched is the integration of traffic information into the various planning tools and on-board navigation systems. Many years of traffic data are necessary to generate an accurate time variation curve on usual traffic situations for any specific route. These diagrams can provide information on what kind of traffic and travel time can be expected on a particular route at a particular time. On the other hand, instantaneous information on particular events is crucial for such a system to function well. Manufacturer research is investigating the potential for making these tools more accurate with faster reaction times. Such systems should be able to suggest the best possible route to the drivers at any given point in time, based on historical, statistical, and current information. This information could also be obtained by the scheduler.

4.5 The environmental effects

The technologies for improving CRS and telematics systems are generally assessed on the basis of their CO₂ relevance in terms of high, medium, or low importance – Table 4.4.

Table 4.4: Assessment of the CO₂ relevance of the proposed technologies

Technology	CO ₂ relevance
Combination of CRS and on-board monitoring	high
CRS using semi-automated route optimisation	high
Monitoring loading space utilisation of vehicles	high
Comparison of planned and actually driven routes	medium
New generation of bar code scanners	medium
Simplifying on-board monitoring data	medium
Statistical analysis of transport processes	medium
Higher level of integration of transportation software	low
Integrating traffic information into planning tools and on-board navigation	low
On-board navigation tailored for use in commercial vehicles	low
Stability improvements of the telematics hardware	low

One issue is the separation of CRS systems with telematics for positioning and data communication from the on-board monitoring systems. These are two analog systems with almost identical hardware but with different ways of affecting CO₂ emissions; one by logistics and one by driver performance. Trucking companies have tended to choose between these options for reasons on the basis of economic efficiency.

There is no simple answer as to whether semi-automated route optimization is superior to classic CRS without semi-automated route optimization, although it remains highly probable that the introduction of semi-automated systems would lead to significant improvements in efficiency, given the drastic reduction in the standard workload for schedulers would allow greater focusing on problem issues. On the other hand, route optimization, and sometimes, CRS, is not necessary in all contexts. However, semi-automated optimization is a relatively uncommon technology that brings leverage to bear on exactly the right point, which explains the high CO₂ relevance rating. As this technology already exists, the need is for further dissemination of such systems. The second issue is whether CRS systems with semi-automated route optimization can be upgraded by incorporating technology from more complex trip optimization systems.

Load factor information is a standard parameter in on-board monitoring systems. The additional incorporation of loading space utilization was considered in the survey of transport and IT experts. The advantage of the technology is that continuously available information about weight and loading space utilization can be used to judge precisely the success or failure of logistics measures in a trucking company by analyzing the parameters over time. Without knowledge of loading space utilization, any variation in load factor relates either to an increase in utilization, or to a change in cargo structure. This approach is therefore rated as being highly CO₂ relevant. In addition to utilization time series, it is then possible to assess utilization differences of vehicles with different cargo structures allowing benchmarking and cross-industry comparisons. No such loading space measurement technology is readily available.

While CO₂ emissions are almost linear correlated with kilometers driven because of the tie with fuel consumption, most of the fleet operators interviewed suspected a fraction of their drivers of recurrent detouring. The issue then becomes one of whether route changes were traffic related or driver detours. Separating the two effects requires driven trips to be monitored in near-real time intervals and their comparison with the planning data. Subsequently fleet managers can enquire into the reasons behind significant deviations from the planed routes, what is seen to be of medium CO₂ relevance.

As far as mobile end devices are concerned, market observations clearly show a trend towards multifunctional mobile equipment, such as the development of a new generation of barcode scanners. This has medium CO₂ relevance. Companies investing in multifunctional barcode scanners can generate additional benefits at low additional cost. To support CRS it is in the end irrelevant whether a PDA, scanner or on-board computer is used as telematic end device for positioning and data communication.

The experts interviewed suggest a simplification of on-board monitoring data is of medium relevance to CO₂ efficiency. Many users of on-board monitoring systems are overwhelmed by the amount of data generated. Further, the aggregated data prepared by the suppliers cannot be used for objective driver assessment or as a basis for incentive salary or bonus schemes because of the insufficiency of the algorithms.⁴

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5 The concept of transport efficiency – Monitoring and improving transport processes⁵

Abstract

This article proposes a method for automatic assessment of the transport efficiency of a trucking company, without time-consuming manual reporting procedures. The method is based on vehicle telematics, computerized routing and scheduling and a new system for remotely measuring the utilization of a truck's loading space. The analysis develops known methods for describing transport performance further by means of qualitative expert interviews. Questioned were trucking companies and manufacturers of the different technologies operating in Germany. The result of the analysis is a set of key performance indicators. All indicators included have to meet three demands: the existence of operationally substantial potential for improvement, the feasibility for measuring the factor automatically and the possibility of being influenced by the trucking company. The proposed concept includes key performance indicators in five dimensions. These are utilization, route efficiency, CO₂ efficiency, quality and time efficiency, all serving one goal: to improve the efficiency of transport processes on the operational level.

5.1 Introduction

This article proposes a method for automatic assessment of the transport efficiency of a trucking company, without time-consuming manual reporting procedures. The overall objective is to define an easily interpreted instrument for trucking companies to

⁵ This chapter was submitted in November 2008 to Computer-Aided Civil and Infrastructure Engineering as: Baumgartner, M., Léonardi, J., Krusch, O., 2008. The concept of transport efficiency – Monitoring and improving transport processes.

achieve an internal improvement of their transport processes. In times of rising CO₂ emissions, limited resources and shrinking profits, this objective leads to a win-win situation for the environment, society in general and private business. The proposed assessment method is based on vehicle telematics (on-board monitoring systems and telematic systems for positioning and data communication), computerized routing and scheduling systems and a new procedure introduced into these systems for remotely measuring the utilization of a truck's loading space. The result of the analysis consists of a set of key performance indicators (KPIs) which describe the transport efficiency of a trucking company. All KPIs included in the proposed concept have to meet three demands: the existence of operationally substantial potential for improvement, the feasibility for measuring the factor automatically and the possibility of being influenced by the trucking company.

The article therefore analyses three known methods for describing the efficiency of transports; these methods then undergo further development. The analysis and development is mainly based on two series of qualitative expert interviews conducted in Germany in early 2003 and early 2005. The surveyed target groups comprised representatives of arbitrarily selected leading soft- and hardware manufacturers (in the field of vehicle telematics and computerized routing and scheduling systems) as well as representatives of randomly selected trucking companies using such systems. Altogether 45 transport and IT experts were questioned.

The finally proposed concept includes key performance indicators in five dimensions. The dimensions are utilization, route efficiency, CO₂ efficiency, quality and time efficiency, all serving one goal: to improve the efficiency of transport processes on the operational level. In providing an adequate, automated monitoring method, the idea is to initiate improvements in transport efficiency, following the old management adage: you can't manage what you can't measure.

5.2 Technologies under review

5.2.1 Vehicle telematics

The world of vehicle telematics is very rich in different applications. The review by Giannopoulos (2004) gives a precise description and analysis of the various vehicle telematics technologies that are available. In our particular context, so-called fleet management systems are of interest. Fleet management systems can be divided into three functional sub-units:

- Tracking and tracing systems
- Telematic systems for positioning and data communication
- On-board monitoring systems

The basis of most vehicle telematics systems is the positioning function. Nowadays in almost all fleet management systems that function is incorporated in a process called tracking and tracing. Systems that incorporate only tracking and tracing functions are getting very rare. To track and trace a vehicle, the position of the vehicle is recorded at set intervals. On the basis of the position history it is then possible to record exactly the route taken by the driver. The position is determined either by using GPS signals or via the GSM network.

On-board computers are another common characteristic of fleet management systems. These mobile computers process, buffer and transmit all ensuing data. In Germany, communication between the central office and the on-board computer generally takes place using the data channels of mobile phone networks.

Telematic systems for positioning and data communication

As mentioned above, telematic systems for positioning and data communication are based on the tracking and tracing function and on-board computers. As a working environment, such systems provide the driver with mobile end devices. These can

vary from mobile communication devices to entire computer work stations. A corresponding portable device might be a PDA, a barcode scanner or a PC. Many systems also incorporate a printer and a camera or similar. According to the sophistication of the system, order information, digital delivery notes, status information (e.g. loading/unloading), photos, barcode scans and electronic delivery confirmation along with the position information may be transmitted between the central office and the vehicle. Normal phone calls are of course standard. The principal function of these systems is to improve scheduling and order processing in the logistics process. Under normal circumstances, they are used in combination with computerized routing and scheduling systems.

State-of-the-art on-board monitoring systems

In comparison, on-board monitoring systems are not used for direct communication between the driver and the central office although here too, certain data are uploaded by means of mobile data communication. For monitoring use first of all, the various telemetric vehicle data are recorded by on-board sensors. The data are then transferred via the so called CAN (controller area network) bus to an on-board computer, where they are processed and stored temporarily. Finally they are transferred in certain intervals or on demand to the head office via GSM or GPRS.

On-board monitoring systems serve per definition solely to record vehicle and trip-specific data. These data can then be evaluated by the fleet manager or the controller, for example to influence driving behavior or to plan maintenance slots. Some systems also use a display to give direct support to the driver in the form of current system figures e.g. fuel consumption. In addition to position information and driving behavior parameters (e.g. gear changing), modern on-board monitoring systems today provide a lot more valuable information. This includes: general data, technical vehicle information (e.g. brake wear and tear or cooling water level) and trip parameters (e.g. speed or gradient). The scope of work of the individual systems varies according to the

respective supplier. The most progressive equipment can record most of the parameters shown in Table 5.1. Nowadays it is increasingly common for the registration of vehicle and trip-related data to be only one element amongst several other applications, so that commercial systems are starting to mix different functions.

On-board monitoring systems are the technological key for measuring trip-related parameters. They automate recording routines and dispense with time-consuming and inaccurate manual notes. In our context, parameters such as fuel consumption, tour length, total vehicle weight and load factor are of major importance. According to the expert interviews (see below for detailed description) and our own results, the accuracy of the measured values is in most cases better than $\pm 1\%$ on a monthly basis using state-of-the-art technology, as applies to fuel consumption and tour length. The most inaccurate value to date is total vehicle weight which can be measured with an error of about $\pm 2\%$ on a monthly basis. Reliable measurement of that parameter and the load factor derived from it is relevant in the context of this article. Three systems on the German market measure total vehicle weight with the braking moment. A fourth system measures the axle load with the air pressure in the air suspension system. One problem in correctly stipulating the load factor consists in the fact that these systems do not provide any information about the actual empty weight of the specific vehicle configuration, although this should not be a problem in technical terms. Retrospective assessment as to whether tours took place with or without trailers or semi-trailers is difficult and inaccurate. It is therefore considered mandatory for future on-board monitoring systems to have a routine that identifies the respective truck configuration.

Table 5.1: Important parameters currently measured by on-board monitoring systems

General data	Driving behaviour	Trip difficulties	Technical vehicle inspection	Additional information
<ul style="list-style-type: none"> - Date, time - Position (GPS) - Vehicle, driver, trailer - Status (driving/rest) - Change of tachograph - Distance driven - Fuel consumption (running and stationary) - Speed 	<ul style="list-style-type: none"> - Braking behaviour - Gear changing behaviour - Driving pedal movements - Constancy of speed 	<ul style="list-style-type: none"> - Gross vehicle weight rating - Number of stops - Average gradient 	<ul style="list-style-type: none"> - Brake wear - Refrigerant level - Oil level - Disturbances reporting - Maintenance scheduling - Tyre pressure 	<ul style="list-style-type: none"> - Loading space temperature profile

5.2.2 Computerized routing and scheduling systems

The process of scheduling is defined here as the ensemble of co-ordinated practices of time and route planning for orders, vehicles, and personnel. In daily business procedures, the controller or scheduler has the task of sorting the incoming orders and passing them on to the appropriate delivery agents. This system also has to manage the material flows and stock inventories in order to achieve the reliable and punctual delivery of all orders at minimum cost. In the process, smaller jobs (less-than-truckload), which are compatible in terms of time frame and delivery area, are bundled together to form a trip. Return trips need to be taken into account early on. Difficulties of different complexities, depending on the size of the company, time of business, restrictions and so on, result for example from time windows and side constraints for collections and deliveries. Every optimization in the logistics process leads to improvements in load factor and thus to economically and ecologically positive results.

Computerized routing and scheduling applications do not differ at all from manual scheduling with regard to the targets described above. The only difference is that they

use computers and computer software. Computerized routing and scheduling systems calculate the optimum transport sequence with regard to time, distance, utilization, resources (vehicle and driver availability) and all sorts of restrictions or ancillary conditions (side constraints). Current literature on the vehicle routing problem and the traveling salesman problem shows how hard it is to find an appropriate solution. See for instance the classic review by Crainic and Laporte (1997). Any calculation method is limited by factors such as an ignorance of the side constraints on the part of customers, warehouses, vehicles or tours. The trucking companies need to take care of the daily changes in these side constraints if the system is to function correctly. On the customer side, such constraints include for example vehicle dimension restrictions and vehicle type specifications. For warehouses these can be the opening hours, for example. As far as the vehicle fleet is concerned, the side constraints include operating times and capacities.

Today many different software products with many different functions and characteristics are commercially available in this field. Some are written for forwarding-orientated trucking companies, some for distribution transports or for the needs of shippers. Some consist of elementary transformations of manual scheduling processes onto computerized workstations; some are highly complex applications with sophisticated optimization algorithms. Some optimize A to B routes using the variables resources, distance, load and time. Some optimize a large number of delivery points for classic distribution by the use of more than 100 variables and side constraints. On the other hand, many software applications don't even optimize at all, with the argumentation that no optimization algorithms can ever reproduce the complex reality. This means that computerized routing and scheduling systems are highly diverse and form different sub-groups. This also means that in the context of our discussion, only computerized routing and scheduling systems with optimization algorithms are of importance, and are referred to as such in the following.

5.3 Datasets used

The discussion and the proposed concept of this article is based on three datasets. In the first place, this is a study we call “base survey”, because it gives an initial overview of Germany’s CO₂ efficiency and utilization status. The base survey took place in early 2003. It covered 113 heavy-duty vehicle trips in the weight category 35 to 44 t. The recording period of the participating trucks was between 2 and 3 days, during which 7 sub-trips were carried out on average. The truck drivers were asked to protocol all details of their particular trip. All vehicles were refueled at the beginning and end of the trips to determine fuel consumption. At every loading or unloading stop, the cargo weight (according to the freight papers) and the covered distances were noted; furthermore the loading space utilization was estimated in 5 groups by the driver. In general the precision is seen to be good, apart from the space estimate, where an error of +/-15 % must be accepted.

Secondly, the study is based on two series of qualitative expert interviews conducted in Germany in early 2003 and early 2005. The surveyed target groups were on the demand side and the supply side of the market for vehicle telematics and computerized routing and scheduling systems. Altogether 45 transport and IT experts were questioned. The two groups consist firstly of the representatives of 29 randomly selected trucking companies using such systems, and secondly of the representatives of 16 arbitrarily selected leading soft- and hardware manufacturers in that field. Most of the interviews were carried out by phone. For the most part, the dialog partners were the managing directors and scheduling or fleet managers on the user side. On the software manufacturer side the interviews were conducted mostly with staff from the development departments and in some cases from marketing. The interviews are believed to be representative of all groups of the German transport and telematics market. The questions centered on the following topics: company or product description, market served, achieved improvements, further potential for operational

improvement, loading space utilization, measuring, range of KPIs, scope of operational decisions, fleet management systems, computerized routing and scheduling systems, economic situation and future prospects.

Finally, this discussion is based on “case study company C”. The so-called company C is a trucking company based in South Germany. It has about 90 company-owned heavy-duty trucks (40 t) operating throughout Europe but with a focus on German-based business. 10 of its trucks have a complete digital history of 4 years on-board monitoring data. The company operates in a broad spectrum: paper, steel and automotive logistics. Secondary it has a smaller section operating for the engineering industry and runs food tanker vehicles as well as transporters for the normal freight transport market.

5.4 Factors influencing transport

What factors affect the efficiency of a trucking company and (how) can these factors be measured? The analysis isolates factors influencing transport processes which are known from literature and practice, and checks them on the basis of three criteria:

- To what extent does the factor offer potential for operational improvement?
- Can the factor be measured automatically?
- Can the factor be affected by operational decisions?

After answering these questions, it is possible to generate a specific set of key performance indicators in order to define an easily interpreted instrument for trucking companies to achieve an internal improvement of their transport processes.

To be more specific, the method in discussion is a focused check of transport processes, and not an efficiency check of all logistics activities of a trucking company. In other words, important logistic factors such as site selection, intermodality or

supply chain management are not directly involved in the proposed method of valuation. However, strategic decisions have an indirect effect on the transport efficiency KPIs described below. In the same way, the proposed concept focuses on optimum execution of the physical transports and not on the resulting cost efficiency.

5.4.1 Methodical bases

The concept of TE is based on three known methods for describing the efficiency of transports, and it develops these further. These are the concept of overall vehicle effectiveness (OVE) by Simons et al. (2004) as well as the framework efficiency model for goods transportation with the idea of overall efficiency (OE) by Samuelsson and Tilanus (1997). The third set of KPIs was used empirically by McKinnon and Ge (2004) in the context of a synchronized vehicle audit (SVA).

OVE is a primarily time-based efficiency indicator, which in turn is based on the concept of overall equipment effectiveness (OEE) by Nakajima (1984). OEE aims to quantify the level of non-value adding activity that constitutes the big loss areas for manufacturing: equipment failure, set-up adjustment, idling and minor stoppages, reduced speed, defects in process and reduced yield. If each of these were reduced to zero, then the OEE rate would be 100 %. OEE is therefore basically a measure for the use of a machine (or the available resources) in a given time period. Simon et al. (2004) define OVE as a result of two value-adding activities (transportation and the activity of loading and unloading) and five non-value adding activities (waste) which represent a reduction in efficiency: driver breaks, excess load time, fill loss, speed loss and quality delays (Table 5.2).

In Samuelsson und Tilanus' (1997) framework, OE indicates the actual transportation output as a percentage of the theoretical maximum output. OE in a general freight context consists of the continuous product of the four dimensions time, distance, speed

and capacity. The four dimensions are divided by the authors into 18 sub-areas or KPIs (Table 5.2).

In the empirical transport study by McKinnon and Ge (2004), the scientists and trucking companies agreed on a set of five transport KPIs: vehicle loading, empty running, fuel efficiency, vehicle time utilization and deviations from schedule. The first three KPIs are essentially utilization measures, the fourth is a productivity index and the last assesses the effectiveness of a trucking company or delivery operation. On the basis of these transport KPIs, 53 fleets were compared with each other over a time period of 48 hours in a synchronized vehicle audit.

The use of KPIs to monitor the efficiency and effectiveness of logistics and transport has been further discussed by the Nevem Workgroup (1989), Caplice and Sheffi (1994, 1995), Ploos van Amstel and D'Hert (1996) and Donselaar and van Sharman (1998). Long lists of possible KPIs have been compiled to assess the performance of many different aspects of logistics operations. Inter-company benchmarking of logistic KPIs is also well established (Hanman, 1997; Randall, 2003). The mentioned authors base their concepts primarily on economic considerations, with the pure transport function taking a minor role. These concepts were therefore not used as a basis for this analysis.

5.4.2 Analysis of the factors influencing transport

With respect to the applicability and importance of the assessment concepts and their respective KPIs, three immediate consequences can be derived from the briefly introduced concepts (OVE, OE and SVA). First of all, some of these indicators represent social or economic factors which can hardly be affected by the companies. Secondly, some factors cannot be measured or only with enormous effort. And thirdly, some of the factors offer hardly any potential for improvement on an operational level. So the aim of the analysis is to put forth a new indicator set including only those factors which fulfill these conditions (without major information losses).

Table 5.2 introduces the dimensions and KPIs of the three concepts and compares them on the basis of the defined criteria. The derived concept TE is compared to these in Table 5.3. The assessment of all concepts is achieved by analysis and deduction according to the conclusions of the 45 expert interviews conducted in Germany. Every indicator was rated on a three-step assessment scale (+, +/-, -).

Regrettably it is impossible to recapitulate the definitions of all cited KPIs within this article as some of them are very elaborate. Please refer to the individual sources. Also it is impossible to argue the underlying reasons for the particular ratings of the KPIs derived from the 45 expert interviews as the analysis does not aim to discuss all specific indicators. The objective of this analysis is to highlight relevant factors according to the defined criteria. These factors should then be included in the new concept TE in an identical or modified format. Chapter 5 therefore discusses all included factors as well as many related (but rejected) factors in detail. What we found during the analysis is that many of the rejected factors are in some way present in the included factors.

Table 5.2: Analysis of the three concepts: overall vehicle effectiveness (OVE) by Simons et. al (2004), overall efficiency (OE) by Samuelsson and Tilanus (1997) and the synchronized vehicle audit (SVA) by McKinnon and Ge (2004) on the basis of three criteria

Concept	Dimension	Key Performance Indicator	Potential for operational improvement	Feasibility for automation	Influence possibility by trucking company
OVE	Availability	Driver breaks	+-	-	-
		Excess load time	+	+/-	+/-
	Performance	Fill loss	+	+/-	+
		Speed loss	-	-	-
	Quality	Quality delays	+	+/-	+
OE	Time	Business time efficiency	+	+/-	-
		Availability	-	+	-
		Utilization	+/-	+/-	+/-
		Driving factor	+	+	+/-
	Distance	Infrastructure factor	-	+	-
		Backhaul factor	+	+/-	+/-
		Routing factor	+	+/-	+/-
		Detour factor	+/-	+/-	-
		Actual trip execution efficiency factor	+	+/-	+
	Speed	Speed limit factor	-	-	-
		Congestion factor	+/-	-	-
	Capacity	Capacity factor	-	+	-
		Floor space occupancy factor	+	+/-	+/-
		Height utilization factor	+	+/-	+/-
		Pallet load factor	+/-	-	-
		Box load factor	-	-	-
		Net product factor	-	-	-
		Actual loading execution efficiency	+	+/-	+/-
SVA	Utilization	Vehicle loading	+	+/-	+/-
		Empty running	+	+	+/-
		Fuel efficiency (l/100 km)	+	+	+/-
	Productivity	Vehicle time utilization	+	+	+/-
	Effectiveness	Deviation from schedules	+	+/-	+/-
+ = great potential, easy to measure and implement +/- = medium potential, some difficulties in measuring and implementation - = very little potential, little or no possibility for measuring and implementation					

5.5 Discussion of the concept of transport efficiency

All three concepts proved very helpful as discussion basis and stimulus during the expert interviews. Table 5.3 assesses the derived factors included in the concept of TE according to the same criteria stated above. It can be seen as a brief summary of the

interview and discussion process. It is followed by a detailed discussion. In general, the positive selection includes only the most fundamental transport indicators in the new concept, in some cases using a compound approach. The analysis of the 45 expert interviews revealed that relevant factors had not been taken into account yet and that additional KPIs have to be included in the concept of TE.

Table 5.3: Analysis of the concept of transport efficiency (TE)

Concept	Dimension	Key Performance Indicator	Potential for operational improvement	Feasibility for automation	Influence possibility by trucking company
TE	Time efficiency	Driving time	+	+	+/-
		Loading time (additional: geo-reference)	+	+	+/-
	Route efficiency	Route efficiency and deviations from schedule	+	+/-	+/-
		Utilization	+	+	+
	CO ₂ efficiency	Vehicle design (with regard to lightweight construction and loading space optimization)	+	+	+/-
		Load factor	+	+	+/-
		Loading space utilization and deck-area utilization	+	+/-	+/-
	Quality	CO ₂ efficiency	+	+	+/-
		Quality loss	+	+/-	+

5.5.1 CO₂ efficiency and utilization

CO₂ efficiency

From the point of view of CO₂ mitigation, CO₂ efficiency is one of the most important KPIs describing transport processes. Here the CO₂ efficiency of a truck transport is expressed as metric tonne-kilometre per emitted kilogram of carbon dioxide (tkm/kg CO₂) (corresponding to metric tonne-kilometre per liter fuel used (tkm/l)). Unfortunately the calculation of tonne-kilometres needs accurate and constant monitoring by an on-board monitoring system, which explains why CO₂ efficiency is relatively seldom used. Moreover, a trailer identification system and a vehicle

database are necessary to calculate the vehicle tare weight. All other approaches to calculating transport performance in tonne-kilometres, such as monthly nationwide transport statistics, are based on appraisal values.

The CO₂ efficiency of a truck transport is affected by various factors. The factors influencing CO₂ efficiency can be divided into four groups: total vehicle weight (vehicle empty weight plus load weight); vehicle properties and condition (engine properties and condition, air resistance, tires and tire pressure, lubricants...); driver performance (fuel saving vs. non-fuel saving driving style); route characteristics (weather, street type, traffic situation, gradient...).

The most important of these influencing factors is total vehicle weight, which is closely related to the load factor. The indicator tkm/kg CO₂ shows all four factors in an individual number, which is what makes this KPI so helpful. Some of these factors can be affected by the company and by the driver; others can hardly be affected at all (such as route characteristics and incoming orders). At present, total vehicle weight can be measured, while the other three factors influencing the CO₂ efficiency can be assessed only in rudimentary terms. A clear downside of this KPI is that it is difficult to go into further detail with present monitoring technologies. In addition, the indicator CO₂ efficiency favors heavy-duty trucks. This leads to the need for the indicator to be considered separately for different vehicle weight classes.

The indicator fuel consumption per km (sometimes called fuel efficiency (l/100 km)) is easy to determine and therefore very often used in practice instead of CO₂ efficiency. However, fuel consumption per km contains no direct information about the transported load weight, so that this indicator is only a poor substitute for CO₂ efficiency. Adding load factor information to fuel consumption per km makes it a far better substitute, but knowledge of the load factor means that CO₂ efficiency itself can also be calculated.

Load factor

Load factor is the second important weight-based KPI. In contrast to CO₂ efficiency, it has no fuel consumption dimension. The case study of company C shows that it is possible to monitor this parameter today (Figure 5.1). In the SVA concept, vehicle loading and empty running are separated by counting only laden trips into the vehicle loading indicator. The indicator load factor as we understand it incorporates empty running. Any kilometer driven empty gives a load factor of zero for that particular distance. That means the very popular dimension empty running is not necessary except for special monitoring purposes.

The great disadvantage of the KPI load factor is that without knowledge of loading space utilization, any variation in load factor can relate basically to two factors: either an actual increase in utilization, or a change in cargo structure. This is the case, for example, if heavier goods are transported after the trucking company has acquired a new customer. The resulting interpretation problem is presented in Figure 5.1. Without further information, it is not possible to judge whether efficiency increased or the cargo structure changed in company C.

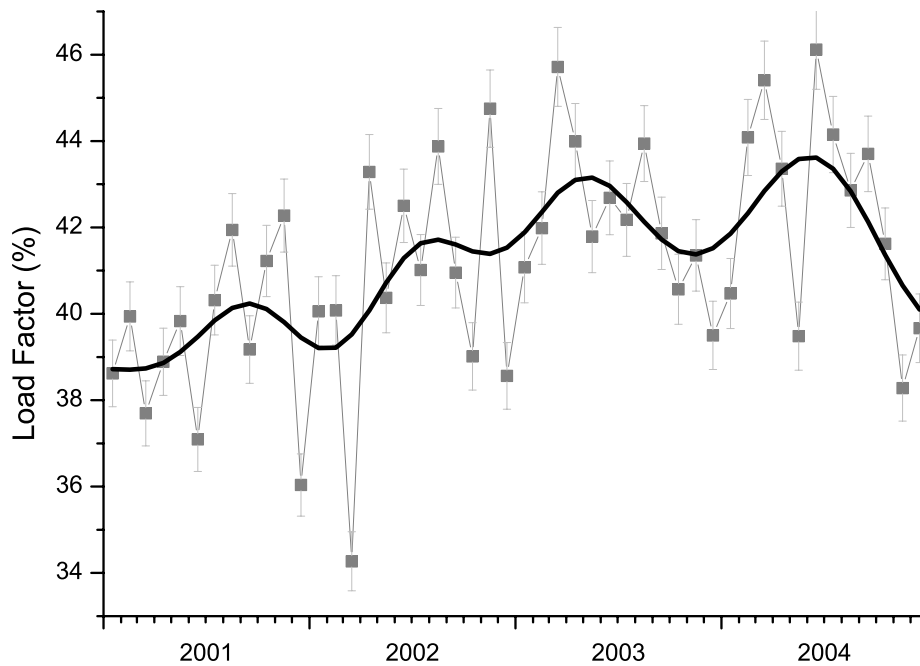


Figure 5.1: Case study company C: load factor of 10 trucks (5 point FFT smoothing) (n=477 truck months)

Loading space and deck-area utilization

Figure 5.2 compares the utilization in terms of weight and loading space of the 113 examined base-survey tours and shows that the majority of the transports were limited by their space capacity. Figure 5.2 also shows high potential for theoretical improvement, since many of these transports were carried out with low loads.

Admittedly, the survey is not 100 percent representative for the situation throughout Germany, but with exception of the building industry, it does show quite a good overall picture of heavy-duty truck transports in Germany. This basic result is confirmed by Ang-Olson and Schroeer (2002) who find that the majority of US long-haul trucks are volume-limited (cube-out). The authors base their analysis on the 1997 US Vehicle Inventory and Use Survey.

In a study conducted in the Netherlands and Sweden, Samuelsson and Tilanus (1997) asked a panel of industry experts to estimate the average utilization of trucks engaged

in less-than-truckload deliveries with reference to a series of space-related indices. This revealed that loading space utilization was typically very low at around 28 %. On average, however, just over 80 % of deck-area was occupied and 70 % of the available pallet spaces filled. It was therefore mainly in the vertical dimension that space was being wasted, with average load height reaching only 47 % of the maximum. To further illustrate the relevance of that area, in a 48 hour survey of 53 fleets comprising roughly 3500 vehicles in the UK food supply chain in 2002, McKinnon and Ge (2004) found that on loaded trips on average 69 % of the deck area and 76 % of the available height was utilized, corresponding to a mean loading space utilization of 52 %. It should be added that unloaded trips are not included in the above numbers.

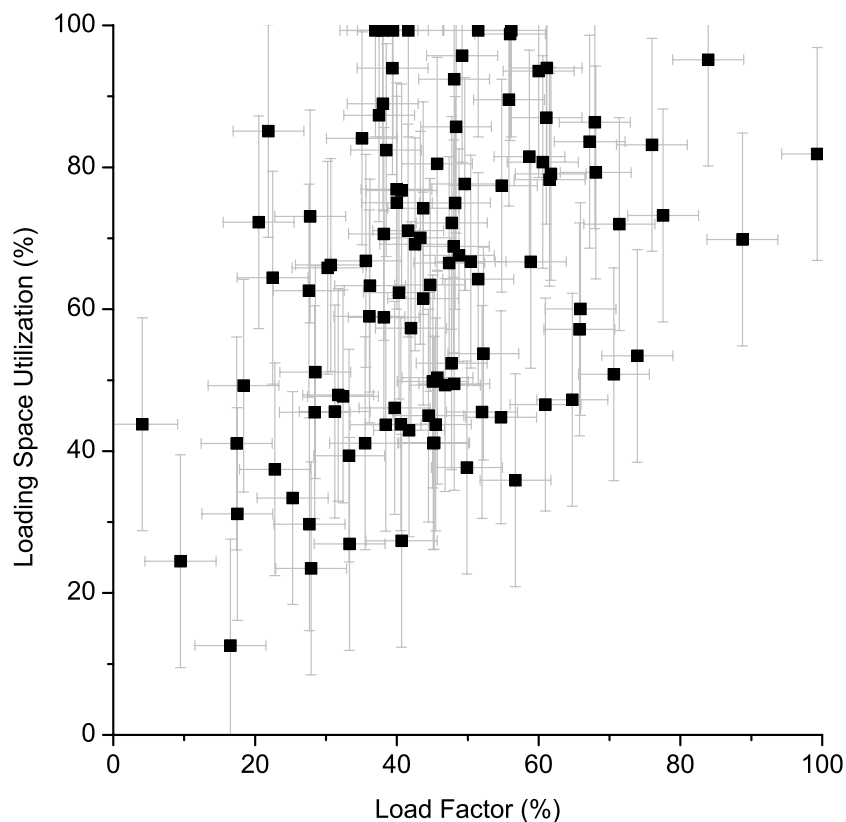


Figure 5.2: Base survey: Load factor vs. loading space utilization of 113 tours

To measure loading space utilization, McKinnon and Ge (2004) suggest forming the KPI pallet-kilometers per emitted kilogram of carbon dioxide, in which pallet-

kilometers are calculated in the same way as tonne-kilometres. This value shows how many pallet spaces are occupied inside a truck, multiplied by the driven kilometers. In his later work McKinnon (2006) refers to deck-area utilization.

McKinnon and Ge (2004) used an enquiry method where the data had to be measured manually or – if available – adopted from other software systems (e.g. computerized routing and scheduling systems). This created a great workload even for the short survey period of 48 hours with many difficulties in their study, as manual measuring is inaccurate and time consuming. In our context, adopting the data from other software systems would lead to two different data acquisition systems (a planning tool and a monitoring tool). In principle, our expert interview partners in the software industry felt that automated data acquisition using two different systems would be possible. In the end, however, there is no guarantee that the transport has actually taken place as planned. The approach relies on extensive in-house routines for continuous update and maintenance of the datasets, and on obtaining precise, complete initial values from the ordering customer. One frequent weak point is that generally not all necessary data are entered in the system; e.g. only one of the load characterizing quantities (such as weight, volume, loading meters or number of pallets) is transmitted to the trucking company when entering the order.

To conclude, an automated on-board measuring system is needed for monitoring loading space utilization and deck-area utilization in addition to load factor and distance driven.

Proposed method for measuring loading space utilization

Distance gauges (e.g. ultrasonic or laser) are fitted in the roof of a truck above every pallet space (or approximately every meter in two rows). These distance sensors measure the free height (distance between truck roof and load upper edge) at each pallet space. When the truck is being loaded, the load height at all individual pallet

spaces can be calculated by the total height of the truck. With this information, loading space utilization can be calculated by the total volume of the truck. Total height and space of the truck or trailer have to be determined and entered in the truck database beforehand. Conceivable solutions include sensors moving on rails or swiveling sensors. Imaging procedures could be an additional possible method, but the question of costs arises here; as with illumination, this solution entails problems with shading and picture interpretation. See patent Baumgartner (2005) for a detailed description and further execution examples. Generally, the procedure consists of selective distance measuring projected onto space information. The average precision of the methods is estimated at +/-5 percent; this can be ascertained in tests. Precision naturally increases with the number of installed sensors.

For instance, in the case of pallet transports knowing how much of the total space of the truck is filled is less important; the number of used pallet spaces is more important. Here the additional information of deck-area utilization makes perfect sense as McKinnon and Ge (2004) suggested. The number of transported pallets or the number of used pallet spaces is measured. For example, the information of 40 % total loading space utilization can be produced in several different ways. On the one hand, low pallets but all pallet spaces occupied, on the other hand high pallets and not all pallet spaces occupied. In one case it would be possible to continue loading, but not in the other. This is also true for many other transports using different types of boxes. Deck-area utilization therefore has to be recorded as an individual KPI.

Version with ultrasonic distance sensors

These are standard sensors which stand out due to low costs with adequate precision of approximately +/- 1 mm. The sensors encounter difficulties with parts loaded at an angle. If the parts are too slanted, the signal is not reflected back to the sensor anymore, so that it gives an infinite diagnosis (or the maximum height of the truck). If the load area of a truck is completely loaded, it is relatively improbable for there to be

“suddenly” no load in the middle of the truck. It can therefore be assumed that such measuring errors can be recognized and calculated using an algorithm. Another disadvantage of these sensors is the minimum measuring distance from 20 to 30 cm. This problem can be avoided by carrying out measurements at short intervals during loading. As the truck is loaded, the total height of the load increases slowly towards the maximum, and then sinks suddenly (wrongly) to zero. While unloading, the opposite effect should appear. This problem can therefore be recognized in a time series. It might be a good idea to define the minimum measuring distance of the sensors as the theoretical upper limit of the truck. Firstly, this reduces inaccuracies in measuring and secondly, every loading/unloading manipulation needs some room right at the top, which in practice is rarely used as a load hold.

Version with laser distance sensors

These are insensitive standard sensors which stand out due to high precision. But this precision has its price. Again the minimum measuring distance (see above) from 20 to 30 cm has to be named as a disadvantage.

In the end the information about load factor and loading space utilization can be used to judge the success or failure of many logistics measures of a trucking company. The variations of weight and space utilization are therefore analyzed over time. In addition to a utilization time series, differences in utilization can be assessed between vehicles with totally different cargo structures, both within a company and between companies. Performance comparisons within the same line of business, so-called benchmarking, should be of prime interest to trucking companies. Cross-industry comparisons are of major importance for science and policy advice as well.

Vehicle design (with regard to lightweight construction and loading space optimization)

In the utilization dimension another KPI has to be added to the discussion. This is the KPI we call vehicle design (with regard to lightweight construction and loading space optimization). Where weight is concerned, it deals with the carrying capacity vs. the vehicle tare weight, which determines the achievable payload and thereby load factor. Here the aspect of vehicle construction in the sense of lightweight construction is often neglected. The surveys by Ang-Olson and Schroerer (2002) and Léonardi and Baumgartner (2004) showed a substantial, easily achieved potential for increasing transport efficiency in that area. This factor can be incorporated in an assessment concept in the form of a trailer identification procedure and a vehicle database. There are naturally certain economic and technical limits. It would appear that with regard to reasonable costs and short payback periods, the ratio of carrying capacity to tare weight could be improved in the range of 10-20 percentage points. Ang-Olson and Schroerer (2002) assume that a typical combination heavy-duty truck could achieve an average weight reduction of 1360 kg. However, this factor can only be influenced once on purchasing a new vehicle or trailer. Here a world class standard has to be defined for every vehicle weight class and/or transport situation; actual vehicle characteristics then have to be compared to this standard. The same situation is true when it comes to loading space. In recent years, various loading space optimized vehicles have appeared on the trailer market, such as so-called XXL trucks or giga-liners.

5.5.2 Time efficiency

The time efficiency dimension describes the use of a scarce resource (like a vehicle or a driver) in a given time period. This dimension is interesting primarily in terms of operational costs. The time dimension of any transport can be subdivided into three main aspects: driving time; loading time; and other stops (resting time prescribed by law and other stops (due to traffic situation, business situation, maintenance...)).

According to the expert interviews, the time efficiency dimension is surveyed adequately by monitoring the KPIs driving time and loading time. Detailed definition of other vehicle stops would entail finding the cause for every stop minute. In the first place, this is unrealistic. Secondly, strategic decisions for reducing the stop times of a vehicle (such as night delivery, use of swap trailers, use of two drivers in long-distance traffic, adjustment of vehicle fleet to order amount, management of preventive and corrective maintenance,...) should not depend on the use of a monitoring system. And thirdly, such decisions would also result in an improved driving time itself.

The driving time is measured per day, week or month. By this definition it is measured neither as a percentage of the economically potentially utilizable time, nor as a percentage of the technically potentially utilizable time as suggested by Samuelsson and Tilanus (1997). The resulting monthly mean is therefore relatively small and varies in the case study of company C between 18 and 27 percent (Figure 5.3). The driving time can be measured digitally with an on-board monitoring system connected to the CAN bus, distinguishing between drive and stop. With this information any company can query the value and analyze how the driving time can be improved.

The driving time in the case study of company C is relatively stable as a monthly average for the four years surveyed and shows no significant long-term trend for the 10 heavy-duty trucks. Seasonal fluctuations can be recognized in the smoothed average. The monthly and seasonal fluctuations show efficiency potential. Taking account of the different bases, the results correspond to the study by McKinnon and Ge (2004). In this study restricted to UK foods distribution, 3128 surveyed vehicles from 28 fleets were on the road for 28 % of a 48 hour weekday period.

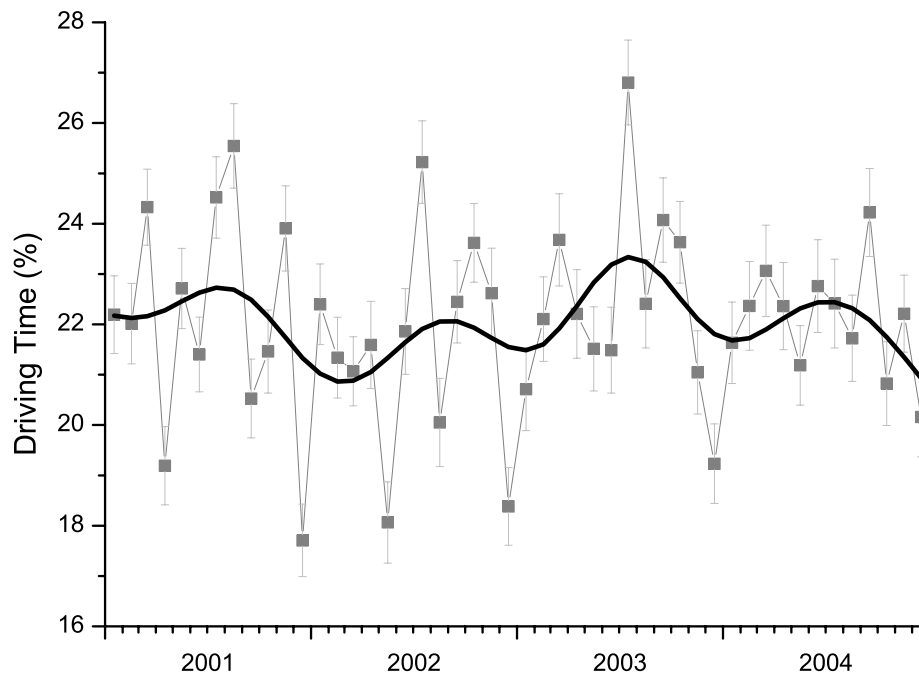


Figure 5.3: Case study company C: monthly driving time of 10 trucks (5 point FFT smoothing) (n=474 truck months)

With the assistance of the driver, the loading time can be measured with currently common telematic systems for positioning and data communication. And so the driver is equipped with a communications device capable of sending status reports. The driver reports his status at the beginning and end of any loading and unloading. Such systems based on GPRS services can also be used to transmit other status reports and free text. A sophisticated TE user could break down the loading time further into loading/unloading, awaiting loading/unloading and pre-loaded and awaiting departure.

The authors Simon et al. (2004) refer to the transport and loading activities (up to a certain extent) as the value-adding areas in any transport process, defining excess loading times as waste. They suggest the definition of a world class standard for loading and unloading activities to clearly distinguish between normal and excess loading times. We cannot agree with the definition a standardized reference time for

loading and unloading (e.g. per pallet), because all loading events are different. The particular transport manager must judge the specific situation (freight type, quantity, number of warehouse workers...). The assessment of the KPI loading time also turns out differently depending on the country. For example, in France, by law drivers are not allowed to load a vehicle, with the unions abiding by the law. This means the consignee has to maintain suitable human resources for these tasks. By contrast, in Germany it is frequently the drivers who do the main job of loading and unloading. Also the principle of first come, first served is frequently ignored. Trucks are unloaded following the consignee's priorities, e.g. trucks with brand articles are often unloaded first.

In a further step it seems to make sense to apply the KPI loading time to recurring loading/unloading sites, which means adding a geo reference based on GPS positioning to the time dimension. The trucking company could analyze the average manipulation time for every recurring loading site or customer. This could be extended to time of day or day of the week. The company could then draw its conclusions, such as different approaching times for a warehouse, adjusted and renegotiated freight rates or giving up a low-profit customer.

Other stops can have many causes. We reached the conclusion that it is almost impossible to distinguish unavoidable stops from unnecessary stops in a correct and automated way. At best, qualitative data and observations can monitor other stops. To set the context: stop times include not only extra unnecessary driver breaks, as is often argued. Other reasons for stop times are legal rest periods, no business, traffic jams, no business hours, maintenance... The results of the UK food distribution survey by McKinnon and Ge (2004) can be used to illustrate the proportions. The study shows that the average driver rest period within a 48 hour weekday period accounted for only 2 % of the time. This contrasts to 28 % of the time with the vehicles running on

the road, 28 % idle (i.e. empty and stationary), 35 % accumulated waiting times and 7 % for maintenance/repairs.

5.5.3 Route efficiency and deviations from schedule

In the concept of TE, there are two sub-dimensions to this KPI. Firstly it highlights the negative impact of delivery time restrictions on efficiency. Secondly it calculates the percentage of occurred deviations from schedule. The whole range of this dimension can only be monitored in trucking companies using advanced computerized routing and scheduling systems as well as telematic systems for positioning and data communication.

An advanced computerized routing and scheduling systems calculates an “ideal” or near to optimum transport sequence with regard to time, distance, utilization, resources and all sorts of side constraints. The quality of this indicator depends strongly on the calculation method. The difficulty consists in defining a genuine algorithm for comparing with reality. Factors limiting any calculation method consist of an ignorance of side constraints on the part of customers, warehouses, vehicles or tours. The calculation method also has to solve the following problem. Simons et al. (2004) questioned whether their OVE measure was pushing the trucking company to carry heavy loads further to increase the rating. For instance, “if a vehicle left Cardiff with a load of 20 tons, 15 tons of which was destined for a customer in Nottingham and the other 1 ton for a customer in Manchester, the most cost-effective route would be to drop the heaviest load first then deliver the lighter load. However, the OVE rate would be higher if the route was the other way round, as the heavier load would remain on the vehicle longer.”

In the concept of TE the scheduler will calculate the “ideal” route combination and vehicle choice for the next day using an advanced computerized routing and scheduling system. In contrast to normal procedure, the first calculation step will

neglect all time restrictions imposed by customers, e.g. narrow delivery time slots. This results in the “ideal” transport plan without delivery time restrictions. The second step is the same as the ordinary scheduling job: the normal transport plan is calculated by the software with delivery time restrictions and revised by the scheduler. This results in the normal transport schedule for the next day. The question for TE calculation is: what is the difference between the “ideal” transport plan without delivery time restrictions and the normal transport plan with delivery time restrictions? The idea is not to ban delivery time slots but to highlight the resulting inefficiencies. The second question is: were there any deviations from the normal transport schedule during effective transport execution?

The KPI route efficiency looks at differences between the following planning and execution steps:

- “Ideal” transport plan (without delivery time restrictions; computer generated)
- Normal transport schedule (with delivery time restrictions; computer generated but revised by scheduler)
- Effective transport execution

In experimental terms, the method could be extended to trucking companies not using computerized routing and scheduling systems. These trucking companies therefore need to record their transport orders and schedules over a period of time. This data can then be recalculated to compare their transport schedules with optimized versions. It would also be interesting to compare different optimization methods and algorithms, e.g. by different software developers.

The route efficiency dimension is the most difficult area of all suggested KPIs. It will result in development workload for software manufacturers, but the interviewed experts believe that it could show major deficits. Samuelsson and Tilanus (1997)

describe a trucking company which could theoretically save 18 % of its transport costs by eliminating time restrictions. In this case, time windows were imposed on 17 % of all shipments. The expert interviews conducted in this survey confirm that time restrictions or narrow time windows play a greater role in determining the choice of route and the utilization of a truck than efficiency considerations. On the other hand, our expert interviews indicate a substantial efficiency potential for the German economy. A need for further research and development is identified here.

5.5.4 Quality

Avoiding quality losses: quality loss refers to any delays resulting from internal quality failures. Simons et al. (2004) mention “driver disorientation, vehicle breakdown, incorrect delivery notes or reconciliation of a consignment due to damage in transit” as examples of quality losses. This area can be covered by status reports and should lead to in-house statistics of goods which are wrongly delivered, not delivered at the first attempt or damaged during transport.

5.5.5 Resources needed to measure transport efficiency

Table 5.4 highlights the different systems needed to measure all KPIs included in the analysis for assessing the TE of a trucking company and comments on their implementation status.

Table 5.4: Resources needed to measure transport efficiency (TE)

Dimension	KPI	Measuring system	Comment
Time efficiency	Driving time	On-board monitoring system	Existing
	Loading time (additional: geo-reference)	Telematic system for positioning and data communication	Existing
Route efficiency	Route efficiency and deviations from schedule	Modified computerized routing and scheduling system; Telematic system for positioning and data communication	Complex; Existing
Utilization	Vehicle design (with regard to lightweight construction and loading space optimization)	Enhanced on-board monitoring system (including trailer identification procedure)	Feasible
	Load factor	Enhanced on-board monitoring system (including trailer identification procedure)	Feasible
	Loading space utilization and deck-area utilization	Enhanced on-board monitoring system (including measuring system for loading space utilization)	Complex
CO ₂ efficiency	CO ₂ efficiency	Enhanced on-board monitoring system (including trailer identification procedure)	Feasible
Quality	Quality loss	Telematic system for positioning and data communication	Existing

The analysis shows that basically three systems are necessary to assess the TE of a trucking company: an enhanced on-board monitoring system (including a measuring system for loading space utilization and a trailer identification procedure), a common telematic system for positioning and data communication (to send status reports and to track and trace vehicles) and a modified computerized routing and scheduling system (to calculate deviations between “ideal”, scheduled and executed transports).

Most of the corresponding systems are commercially available today. These still need minor modifications on the one hand, such as the trailer identification procedure and combining the systems into one assessment concept. On the other hand, more research and development is required with regard to route efficiency and loading space utilization.

5.6 Conclusion

The main part of the study analyzes factors with an influence on transport, and comes up with a comprehensive assessment method covering all relevant transport-related activities of a trucking company. The concept proposed in this study is called transport efficiency. All influencing factors featured in the study are filtered by three criteria: potential for operational improvement, the feasibility for measuring the factor automatically and the possibility of the company influencing the factor. It includes KPIs in five dimensions. These are utilization, route efficiency, CO₂ efficiency, quality and time efficiency. Our expert interview partners believed that such an evaluation method will show major potential for operational improvement in the truck transport sector.

At today's level of technological development, most of the KPIs can be measured automatically with existing or partly enhanced systems as discussed in the study. The analysis shows that basically only three systems are necessary to assess the TE of a trucking company: an enhanced on-board monitoring system (including a measuring system for loading space utilization and a trailer identification procedure), a common telematic system for positioning and data communication to send status reports and modified computerized routing and scheduling system to calculate deviations between "ideal" and actually scheduled transport plans as well as finally executed transports. Most research and development is required mainly with regard to the dimensions of route efficiency and loading space utilization.

To give corresponding impetus, the study demonstrates how the loading space utilization and deck-area utilization of a driving truck could be measured in a reliable, exact and cost-effective way. The great advantage of this kind of monitoring technology would be in providing continuously available information about weight and space utilization for precise appraisal of the success or failure of logistics measures in a trucking company. For this purpose, the variation of load factor and loading space

utilization had to be analyzed over time. Without knowledge of loading space utilization, any variation in load factor relates basically to two factors: either an actual increase in utilization, or a change in cargo structure. This approach therefore has substantial potential for operational, economic and environmental improvement. In addition to utilization time series, it is possible to assess the utilization differences of vehicles with totally different cargo structures, both within a company and between companies. Performance comparisons within the same line of business, so-called benchmarking, should be of prime interest to trucking companies. Cross-industry comparisons are also important for science and policy advice. ⁶

⁶ I thank Jacques Léonardi, Oliver Krusch, Hartmut Graßl, Felix Fiseni, Ingo Möller, Stephan Bakan, Wolfgang Tröger, Bernd Ctortecka, the companies and their staff involved in this survey for their support, time and effort. The project was funded by the German Federal Ministry of Education and Research (FKZ 19G2064 and FKZ 19G4006) and the Max Planck Institute for Meteorology, Hamburg.

6 Conclusion

6.1 Central results

One basic goal of this dissertation is to define an evaluation method for monitoring the effectiveness of efficiency measures in the transport sector. It focuses primarily on reducing freight transport-related carbon emissions. Carbon emissions or fuel consumption is therefore put into a wider picture by defining transport efficiency through appropriate key performance indicators. In the development of this measuring method, special interest focuses particularly on computerized routing and scheduling (CRS) together with vehicle telematics.

The first study is based on two quantitative surveys with different methods. Part one tries to establish a baseline of national transport efficiency by manual trip records. Part two takes yearly performance data to analyse whether the introduction of CRS and vehicle telematics in trucking companies enhance transport efficiency and thus diminishes carbon emissions.

- The results of part one show a wide range of emission efficiency and therefore potential for improvement. The downside of this particular method consists of its limited potential for showing more than a snap-shot of current trip performance and the difficulty of obtaining representative results. The results therefore do not permit the aspired definition of a baseline for national transport efficiency.
- The case studies in part two lead to the conclusion that the introduction of CRS and vehicle telematics systems in trucking companies is very likely to decrease the carbon emissions of trucking companies.
- Both surveys showed how difficult it is to obtain representative results in the transport sector on an operational level in view of the large investments required in terms of research time and money.

- One contribution made by this study is to introduce the mass-kilometre indicator, which includes the empty weight of a truck in the tonne-kilometre indicator. It is thus possible to eliminate one weak point in the allocation of transport emissions.

As the previous work has shown that CRS and vehicle telematics can play an important role in reducing fuel consumption and carbon emissions of trucking companies, study two uses expert surveys to look at how to improve these systems in order to have a positive impact on carbon efficiency and the utilization of trucks. The broad range of options was filtered on the basis of carbon mitigation targets.

- Three key areas were found: combining CRS systems with on-board monitoring systems, developing a measuring system for loading space utilization, and achieving a broader dissemination of CRS systems using semi-automated route optimization methods.
- The qualitative approach taken in the study proved quite appropriate in answering this kind of question. However, the future practical acceptance of such carbon-relevant measures remained unclear.

The third study builds on the methodological conclusions of the first two studies to answer the question as to how to monitor transport efficiency. These conclusions reveal that it is laborious, costly and time-consuming to obtain data through manual trip records or yearly performance data. Secondly, it transpired that qualitative approaches offer a good instrument for explaining quantitative findings.

- Study three proposes a method for automatic assessment of the transport efficiency of a trucking company, without time-consuming manual reporting procedures. The method is based on vehicle telematics, CRS and a new system for remotely measuring the utilization of a truck's loading space. The proposed

concept includes key performance indicators such as utilization (weight and volume), route efficiency, carbon efficiency, quality and time efficiency.

- Monitoring of the indicators only requires a few modifications and new developments of the existing CRS and vehicle telematics systems.
- The method could be used to monitor the reactions of trucking companies to external changes in order to find out which legislative measures are most relevant to carbon emissions and which operational efficiency measures are most effective.
- The method described is not capable of monitoring total sums of fuel consumption and mileage covered for the whole of Germany, as it is tied to individual truck performance. It would also appear to be difficult to assess the efficiency increase yielded by introducing this kind of monitoring system on its own.

6.2 Operational considerations

One might ask why it is so important to have an evaluation method for monitoring the reactions of trucking companies to external changes by automated means without manual reporting routines. This kind of automated monitoring instrument may make it possible to answer the question as to which operational efficiency measures are highly relevant to carbon emissions and hence eligible. Secondly, it is also possible to evaluate the effectiveness of legislative changes in operational terms.

One section of this dissertation therefore deals with utilization, a fundamental efficiency parameter in trucking companies and a method for measuring its variations. Precise judgement of the success or failure of logistics measures (such as introducing CRS systems) needs systems for simultaneously monitoring the two parameters load factor and loading space utilization, whereby load factor monitoring is a standard process today. The dissertation proposes a method for automatic monitoring of loading space utilization as the missing parameter. A final assessment of changes in

utilization entails an analysis of the variation of load factor and loading space utilization over time. If loading space utilization is unknown, any variation in load factor can relate basically to two factors: either an actual increase in utilization, or a change in cargo structure. The importance of the loading space utilization parameter is stressed by one of the results emerging from the interviews; accordingly, in most cases, not even an intensive qualitative evaluation of underlying effects can explain the causes of a variation. The monitoring approach therefore offers substantial potential for operational, economic and environmental improvement. It is a method showing all relevant parameters which therefore gives the trucking companies a full management information system for supporting and improving efficiency decisions.

Since the method was released in 2005 there have been interesting discussions with major truck and trailer manufacturers, three of them operating on-board monitoring systems. Unfortunately those companies showed no real interest in licensing the method. The main argument was that there is inadequate market potential or customer interest compared to the investment costs. So the question arises as to how the data can be obtained, if not from a monitoring system. The study discusses the strategy of incorporating the loading space data from a planning tool such as a CRS system. The problem of adopting the data from other software systems leads to two different data acquisition systems, one monitoring system (load factor) and one planning tool (loading space utilization). In principle, our expert interview partners in the software industry felt that automated data acquisition using two different systems would be possible. Invoicing documents or balancing sheets could be a second possible source of data, with the same problem as above. Regrettably, it will be very difficult to obtain such data for scientific use, as it contains sensitive proprietary information. The study has identified further need for research in this area.

The respective study describes in detail that the utilization dimension is not the only parameter relevant to assessing transport efficiency as a whole. Even the preceding

discussion of the utilization dimension fails to include one central parameter: vehicle design with regard to lightweight construction and loading space optimization. This parameter is of fundamental interest as it draws the base line for any attempt to measure load factor and loading space utilization. It is important to keep that in mind when comparing data for different vehicles or when purchasing new vehicles.

On the basis of target-oriented criteria, the study identified altogether five dimensions and eight associated key performance indicators (KPIs) making up the essence of transport efficiency. The three criteria that have to be met by all KPIs included in the proposed concept are: the existence of operationally substantial potential for improvement, the feasibility for measuring the factor by automatic means, and the possibility of being influenced by the trucking company. In most of the KPI areas, particular performance influences the level of carbon emissions. The study has not assessed the significance of the individual KPIs in respect to carbon relevance. An estimated ranking would put them in the following order: utilization, route efficiency, carbon efficiency (such as vehicle properties and condition, driver performance and route characteristics), quality loss and time efficiency. It is important to add that monitoring the indicators only requires a few modifications and new development of the existing CRS systems and vehicle telematics, as discussed in detail in the study.

This study was criticized for not clearly distinguishing between the interests of society at large and private interests. The argument is that trucking companies often underutilize their capacity because they have to deal with other commercial and operational constraints. This is of course often true. But does it change the overall target (also of trucking companies) of achieving high utilization levels and low fuel consumption rates which were defined as a goal for the whole society? Are utilization and fuel consumption not a goal for trucking companies in their daily trade-off between various constraints? This set of KPIs was designed to evaluate the base line and to set the target by monitoring the status quo and the improvements for

individual businesses. Its mission is to create a win-win situation for society and private business by illustrating variations and weak points. Unfortunately, the method described is not capable of monitoring total sums of fuel consumption and mileage covered for the whole of Germany, as it is tied to individual truck performance and cannot provide any information about the total number of trucks in use. To this end, other data sets have to be taken into account such as nationwide fuel sale figures, toll income figures or national truck counts.

Besides the overlying question of how to measure transport efficiency in an individual trucking company, this dissertation has a second big topic: CRS and vehicle telematics systems. The respective studies look at whether the introduction of such systems in trucking companies leads to increasing transport efficiency and thereby to decreasing carbon emissions, and secondly whether it is possible to obtain further reductions in emissions by improving computerized routing and scheduling systems and vehicle telematics. Both questions were answered positively. The first study tried to quantify the effects. It showed just how broad the range of possible corresponding measures is, which makes it difficult to generalize. The sample consequently displayed a relatively broad bandwidth of efficiency changes. But in all cases, the introduction of such systems led to a decrease in transport-related carbon emissions. This survey showed how difficult it is to obtain representative results in the transport sector on an operational level in view of the large investments required in terms of research time and money. The conclusion follows that with hindsight, most of the work done and described in the studies has to be classified as non-representative case studies. It is therefore not possible to postulate any average carbon emission decrease by CRS and vehicle telematics systems in this dissertation. On the other hand it can be concluded that the introduction of CRS and vehicle telematics systems in trucking companies is very likely to decrease the carbon emissions of trucking companies. The study remained unclear as to the potential for further carbon reductions resulting from a broader penetration of the German transport market by such systems.

The second study from that area uses expert surveys to look at how CRS and vehicle telematic systems could be improved in order to have a positive impact on the carbon efficiency and the utilization of trucks. The broad range of options was filtered on the basis of carbon mitigation targets, whereby the study did not draw a conclusion about the numerical extents of the possible carbon reductions in a trucking company as a result of the innovations.

One issue is the current separation of CRS systems with telematics for positioning and data communication from the on-board monitoring systems. These are two analogue systems with almost identical hardware but with different ways of affecting carbon emissions; one by logistics and one by driver performance. Trucking companies have tended to choose between these options for reasons based on economic efficiency. Secondly, it remains highly probable that the introduction of semi-automated systems would lead to significant improvements in efficiency, given that the drastic reduction in the standard workload for schedulers would allow a greater focus on problems. On the other hand, route optimization, and sometimes, CRS, is not necessary in all contexts. However, semi-automated optimization is a relatively uncommon technology that brings leverage to bear on exactly the right point, which explains why this has such carbon relevance. As this technology already exists, the need is for further dissemination of such systems. Here another issue is whether CRS systems with semi-automated route optimization can be upgraded by incorporating technology from more complex trip optimization systems.

One contribution made by this dissertation is to introduce the mass-kilometre indicator, which includes the empty weight of a truck in the tonne-kilometre indicator. The calculation is analogue to the calculation of tonne-kilometres:

$$\text{Mass-kilometre} = (\text{Payload} + \text{Empty weight}) * \text{Distance driven}$$

Consequently mass-kilometres are related to fuel use or carbon emissions. It is thus possible to eliminate one weak point in the allocation of transport emissions. This indicator points out the importance of vehicle design in terms of lightweight construction.

Finally, this leads to the idea of defining a world class vehicle standard as a benchmark for comparing all vehicles of a year of construction. This could consist of an identification pass for all vehicles highlighting the individual performance of the respective truck in different areas compared to the actual world class standard in that group. Each trucking company could thus base its purchasing decision on information such as truck X uses 10 % more fuel, or truck and trailer combination Y is 20 % heavier than the world class standard in the respective vehicle class.

6.3 Economic considerations

The expert interviews with the trucking companies and their CRS and vehicle telematics suppliers revealed that the road transport sector has very little interest in climate problems or carbon mitigation. Even respectable cost reductions from fuel savings or higher utilization rates are at best a small incentive for trucking companies to invest in efficiency technologies. A lack of hard cash may be one of the hindrances; know-how deficits, market constraints, insufficient benefits or tradition may be some other reasons from a long list. This leads to the conclusion that significant carbon reductions in the road transport sector will not come from inside the sector. If no efforts are made from inside the sector, the question arises as to whether there are any measures from outside the sector which might stop the distinct increase in transport-related carbon emissions. The three studies have not targeted this question. This final section tries to point out some of the lessons learned during the studies.

The last decade has seen major changes in the German road transport sector. These changes have had a considerable impact on the understanding of further measures for

steering the transportation system towards a sustainable direction. The starting point was 1 April 1999 when the German government introduced an ecological tax to increase the price of energy in five steps. Step 5 came into force at the start of 2003. Since then the German “ecotax” adds €0.1534 to every litre of diesel and petrol purchased. There has been controversial discussion of the reform and its impacts ever since its introduction. This legislative measure has not been able to reverse the trend in road transport increase. From 1991 to 2005, total fuel use in German road freight transport showed a continuous increase of 38.2 % (Umweltbundesamt, 2006b), with the years since 2000 making no exception. There is additional criticism that the ecological tax reform causes refuelling tourism in neighbouring countries of an unknown magnitude. In contrast to the situation in road freight transport, there has been a slight reversal to the trend in fuel use and carbon emissions in private transportation since 2002 and 2005 (Umweltbundesamt, 2006b). Possible reasons include the ecological tax reform, the relatively weak economical situation at that point in time in Germany and refuelling tourism, whereby the percentage for each individual factor is only vague.

In late 2007 and the first half of 2008 the ecological tax reform was accompanied by a dramatic peak in crude oil prices. In November and December 2007, the barrel price for Brent crude oil futures nearly reached \$100, and nearly \$150 in July 2008. Thereafter crude oil prices fell till the end of 2008 to less than \$40.

The second important change in the road transport sector in Germany was the introduction of the road toll for heavy goods vehicles. Since 1 January 2005, toll fees are charged for trucks with a gross vehicle weight over 12 tons on motorways and a few major roads. The complex system is based on GPS data, on-board computers and mobile communication technology, with an alternative manual system in operation for infrequent users. The control (and communication) system installed on German motorways is an eye-catching feature. The average road toll adds up to €0.124 per

kilometre driven. Before it was launched, the road toll measure led to heavy protests with great uncertainty about the launch date and imminent cost increases not only in the transport sector. The measure is often criticized for causing heavier traffic volumes on parallel or alternative minor roads from vehicles trying to avoid the system. In 2006 the road toll generated total revenues of around three billion Euro. Up to now, the road toll has not produced any significant changes in transport performance increase (parallel to the “ecotax”).

1 May 2006 was the deadline for having digital tachograph vehicle units fitted as a mandatory measure to new in-scope vehicles. Further amendments were implemented from 11 April 2007 onwards. The social package for road transport contains the new regulation on drivers' hours with the intention of simplifying, clarifying and updating the previous 20-year old rules, making them easier to enforce by using the digital tachograph to record drivers' hours, together with several other changes. It has been alleged that compliance with the previous regulation still allowed drivers to drive for too long without break, leading to reduced road safety and a possible deterioration in the driver's working conditions. The new regulation led to clear changes in the behaviour of trucking companies in terms of complying with the driving hours. Many trucking companies started to schedule driver availability in the same way as vehicle resources had been scheduled on their own in the past. The regulation also led to price increases following the need to employ more personnel, with the positive benefit of creating new jobs. This measure proved very effective because of the possibility of exact monitoring. It is expected to become even more effective as the ongoing renewing cycle continues to replace old vehicles with new ones that have to be fitted with digital tachographs.

The fourth indication worth mentioning originates from the telematics branch. Every year, auspicious appraisals are written about the future market for vehicle telematics. The common and repeated expectation for this market is to take off in the very near

future. However this has not come to fruition up to now. To clarify, there is certainly a market for vehicle telematics, but every year the rate of new systems installed in vehicles remains below the annual forecasts. It appears that there would be certain hindrances to this technology, or perhaps it fails to produce the expected outcomes or savings. Possible barriers to system acceptance may include e.g. insufficient user benefits, high investment costs or high demands in terms of know-how and time.

The measures discussed above together with the findings obtained from all the interviews indicate that the majority of trucking companies will obey laws if there are monitoring systems in place and if there is no chance to bypass them. Secondly, the last decade has shown a slight trend to invest in efficiency measures (not only vehicle telematics), while remaining far below the predicted rates. Thirdly, up to now the two fiscal measures discussed above together with pronounced increases in oil prices have failed to bring about any carbon decrease in the road transport sector. Even so, any conclusions drawn in this context should not neglect the positive development in private transportation. Finally, the introduction of legislative measures in the transport sector is always accompanied by heavy protests and opposing lobbying activities, as seen again at the end of 2007 with the example of maximum permissible carbon values for new passenger cars and light commercial vehicles.

This leads to the conclusion that trucking companies take a reactive rather than proactive approach (at least in the area of scope). Secondly, considerable pressure needs to be applied. In other words, trucking companies will introduce major operational efficiency measures as a reaction to high external pressure. This also means that the desired “voluntary” increases in efficiency on the operational level are not achieved, success comes primarily by imposing top-down measures. Here it must be said that efficiency strategies have to be seen as a starting point. Efficiency increases such as higher utilization rates, for example, can at best buffer increases in transport performance, without actually solving the fundamental problem of increasing

transport demand. On the positive side, operational efficiency measures have the advantage of relatively low investment costs on an economic level. However, in the long run it will take a decrease in transport demand and/or carbon-free or -neutral solutions to reach the desired sustainable situation. This entails change on two levels; a change in societal values (such as higher value for regionalization despite continuing on globalization or reconsidering just-in-time transports) and a technological revolution.

At this point one could ask what total carbon reduction could be achieved by a near optimal mixture of operational efficiency measures. Unfortunately, this is difficult to gauge, even for single measures, because underlying data exists only in parts. The dissertation therefore proposes a monitoring method to find the most effective measures, but it does not discuss or sum up the cumulative reduction potential of operational efficiency measures. On a hypothetical level and in a perfect world scenario, carbon reductions of more than 30 % seem possible if a transport company is willing to invest in a maximum range of efficiency measures. Such a total package would include replacing conventional trucks with light-weight designs, increasing deployment of CRS systems and vehicle telematics, holding eco-driver courses and implementing on-board monitoring, monitoring and optimizing tire pressure, using fuel-efficient engine oils, keeping to speed limits, relieving time windows for better bundling options, and much more besides. Unfortunately, a transport company operating along these lines would not survive under current market conditions. A more realistic scenario therefore has to be developed. I estimate that an easy achievable and cost effective efficiency package can result in operational carbon reductions of 5 to 10 %, representing an annual carbon reduction potential of 2.5 to 5 million tonnes of CO₂ in Germany.

What initiatives are currently in progress on the European legislative level to support the implementation of efficiency measures? In 2007 the European Commission started

a discussion process along these lines, and on 23 January 2008 the European Commission put forward a package of proposals “that will deliver on the European Union’s commitments to fight climate change and promote renewable energy up to 2020 and beyond”. The Commission hopes to see the package adopted as a directive by the end of 2008. In the proposals the EU is undertaking the commitment to reduce its overall emissions to at least 20 % below 1990 levels by 2020. It has also set itself the target of increasing the share of renewable sources in end-energy use to 20 % by 2020.

This “Climate action and renewable energy package” sets out the contribution expected from each member state to meet these targets and proposes a series of measures to help achieve them. Central to the strategy is a strengthening and expansion of the EU Emissions Trading System (EU ETS). The system covers the sectors power generation, energy-intensive manufacturing industry and from 2012 aviation. Emissions from sectors not included in the EU ETS – such as transport, housing, agriculture and waste – should be cut by 10 % from 2005 levels by 2020. The package also seeks to promote the development and safe use of carbon capture and storage (CCS) technologies.

In the area of transportation there are three major measures currently under negotiation. Firstly, the national renewable energy targets include a binding minimum 10 % share for agrofuels in petrol and diesel by 2020, applicable in all member states. Secondly, the Commission has put forward a proposal to reduce the average carbon emission of new passenger cars to 120 grams per km by the year 2012 and 175 grams per km for new light commercial vehicles. Thirdly, in July 2008 the European Commission put forward a proposal for an improved infrastructure costs directive. This proposal allows the member states to include external costs incurred by noise, air pollutants and traffic congestion in their national road pricing systems, but does not allow them to include external and consequential costs resulting from climate change and accidents. Further proposals in the transport sector are not specified and it is up to

the member states to decide on how to mix contributions from the sectors not included in the EU ETS in order to reach their national targets, choosing the means that best suit their national circumstances. They will also be given the option of achieving their targets by supporting the development of renewable energy in other member states and third countries.

I judge these proposals as being insufficient to alter the continuous rise of transport-related carbon emissions. Furthermore, the agrofuel strategy is highly problematic from an ecologic and social viewpoint and needs to be reconsidered, in my opinion. This judgment still leaves the big question unanswered, what measures are needed to stabilize or reduce transport related carbon emissions. Under discussion are: Fiscal measures, such as taxes (on fuels, emissions, vehicles, parking space, et cetera) and road tolls, emission limit values (as currently proposed), compulsory light-weight vehicle design, a modal split change in favour of trains and ships (starting with the development of better modal interfaces at logistical hubs), speed limits, integrated land use planning, regulatory concepts in aviation (such as the proposed EU ETS system), cutting ancillary labour costs to promote regional production, strict safety regulations for drivers and trucks, et cetera. As this question is still unanswered, further research is needed in order to say what measures are necessary and in which priority, in order to reach a sustainable level. Such research should include empirical monitoring methods and economic modelling, as well as human behaviour analysis.

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8 List of abbreviations

CAN bus	Controller area network bus
CCS	Carbon capture and storage
CO ₂	Carbon dioxide
CRS	Computerized routing and scheduling
EU ETS	EU Emissions trading system
GDP	Gross domestic product
GHG	Greenhouse gas
GPRS	General packet radio services
GPS	Global positioning system
GSM	Global system for mobile communication
km	Kilometre
KPI	Key performance indicator
l	Litre
mkm	Mass-kilometre
OBM	On-board monitoring
OE	Overall efficiency
OVE	Overall vehicle effectiveness
pkm	Passenger-kilometre
SVA	Synchronized vehicle audit
t	Tonne
TE	Transport efficiency
tkm	Tonne-kilometre