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CO_2 efficiency in road freight transportation: Status quo, measures and potential

Jacques Léonardi *, Michael Baumgartner

Max Planck Institute for Meteorology, Bundesstr. 55, D-20146 Hamburg, Germany

Abstract

Road freight transport continues to grow in Germany and generates 6% of the country's CO_2 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 CO_2 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 CO_2 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.

Keywords: CO_2 mitigation; Energy efficiency; Road freight transport; Logistics; Scheduling; Telematics vehicle fleet management

* Corresponding author.
E-mail address: leonardi@dkrz.de (J. Léonardi).

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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 CO_2 emissions or about 6% of total CO_2 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 CO_2 emissions have been slowly falling in Germany since 2000 (Umweltbundesamt, 2003) (Fig. 1).

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-km, 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.

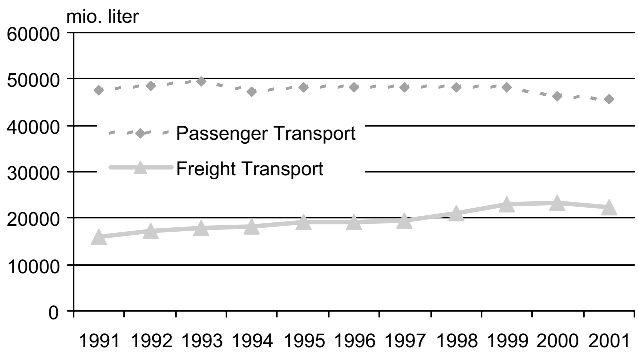

Fig. 1. Trend of fuel consumption in German road freight and passenger traffic (resulting correspondingly in CO_2 emissions) from 1991 to 2001.

2. Status quo of CO_2 efficiency in road freight traffic

The CO_2 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.

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 1).

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 tranport 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.

Table 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

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_1), allowing for exact measurement of transport performance in tonne-km, including empty runs. In terms of volume, we asked the drivers to estimate volume utilisation in % 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 t_2), 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-km 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%.

2.3. Results for CO_2 efficiency and the influencing factors

To calculate the emission efficiency, an indicator metric, tonne-km (tkm) per emitted kg CO_2 was used (McKinnon, 1999). For the sample, the mean CO_2 efficiency (E) is 10.4 tkm/kg CO_2. Emission efficiency shows a large variation of between 0.8 and 26 tkm for 1 kg CO_2 emissions (Table 2).

The question then arises as to what are the most important factors influencing CO_2 efficiency. Table 3 offers a correlation analysis. The survey confirms the influence of vehicle load weight factor and vehicle class on CO_2 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).

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 CO_2 efficiency, with efficient and inefficient transports taking place to a similar degree in every sector.

Table 2
Main parameter values for total sample, trucks >40 t and <40 t, 2003

Parameter	Sample $n = 153$	Trucks >40 t $n = 109$	Trucks <40 t $n = 44$
Vehicle use efficiency			
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
CO_2 efficiency			
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

Table 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)	$r^2 = 0.39$

Company size and fleet structure (vehicle weight classes) have a marginal influence on the CO_2 efficiency of truck transports. The average CO_2 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 CO_2 efficiency (Fig. 2).

In the sample a volume utilisation above 80% always corresponds to a tkm/kg CO_2 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

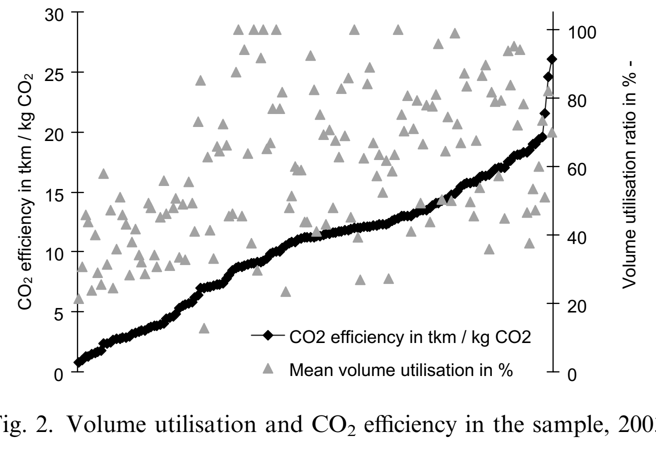

Fig. 2. Volume utilisation and CO_2 efficiency in the sample, 2003.

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 (E_{vu}) 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 (t_2) is added to the load of the freight (payload t_1), resulting in the total weight (m) of a vehicle.

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

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 CO_2 efficiency (E) in road freight transport with the unit tkm/kg CO_2 emitted. It is a factor directly influenced by the efficiency of vehicle usage E_{vu}, choice of vehicle class (v_c), driver behaviour (d) and route (r) parameters.

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

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 CO_2 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.

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 E_{vu} (Fig. 3). This shows that the main transport performance and the largest amount of emissions occur around an average of 0.36 tkm/mkm.

The best company showed an average of 0.56 for E_{vu} and had implemented a good but not exceptional level of efficiency measures. One simple hypothetical exercise consists of establishing the theoretical optimum of E_{vu} 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

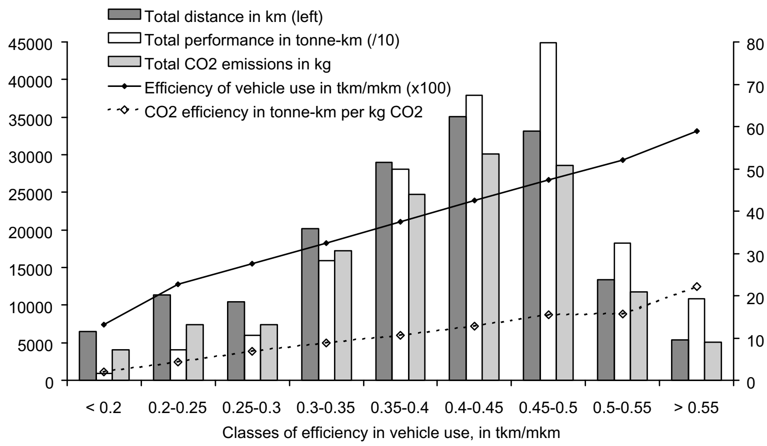

Fig. 3. Potential analysis: transport performance, emission amount (left scale), and efficiency of vehicle use and CO_2 efficiency (right scale).

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 40 t 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 E_{vu} values, this would result in an overall reduction of 20% in CO_2 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-km 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 exists 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. 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 (Fig. 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 CO_2 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 perfomance 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

Table 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 Leonardi, 2004; Deutsches Institut für Wirtschaftsforschung, 2002; Umweltbundesamt, 2002.

main survey, in the year before and the year after the system was introduced. The situation before introduction can be described as background or base-line 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-km.

The main parameters are presented together with the other survey samples in Table 4, and compared with the last statistical data available for Germany in 2001.

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 light-weight 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.

3.1. 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% (Fig. 4). The mean fuel consumption remained stable, CO_2 emissions rose by 2.5% and truck mileage increased at 2.2% a year. Compared to the overall changes in German from 2000 to 2001, these are relatively large.

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

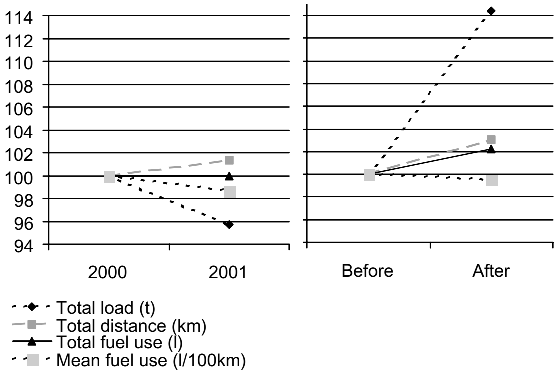

Fig. 4. Effects of IT-based scheduling on t, km and fuel use in the sample (right), compared with the German means for 2000 and 2001 (left).

not be that the CO_2 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 CO_2 emissions.

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.

4. Conclusion

A survey of trucking in Germany in spring 2003, found the mean CO_2 efficiency (E) is 10.4 tkm/kg CO_2. Emission efficiency shows a large variation between 0.8 and 26 tkm for 1 kg CO_2 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 CO_2 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 CO_2 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 CO_2 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.).

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