

MINIMIZING OPERATING COSTS BY SPECIFYING TRUCKS BASED ON OPERATIONAL STATISTICS

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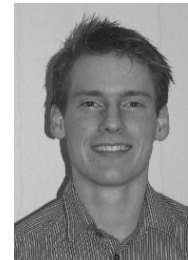
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Abstract

In the process of specifying a heavy truck optimized for its transportation task, several choices, balancing between performance and economy, are required. Traditionally, a market standard vehicle or a copy of the old vehicle specification has been offered to customers. Or at the best, a set of operational factors are put into an optimization program proposing the best vehicle specification.

This paper is presenting and comparing different approaches on specifying heavy trucks. The actual performance and operating economy is compared for vehicles specified using three different methods. The first vehicle is based on the market standards, the second is optimized based on operational factors given by the customer while the third is optimized using detailed operational statistics read out from vehicles in the customer's actual operation.

Results indicate that a large amount of fuel, money and CO₂ can be saved by optimizing truck specifications using operational statistics.

Keywords: Fuel economy, performance, optimization, transport efficiency, vehicle specification, operational statistics

1. Background

Today most large heavy truck manufacturers have a toolbox of vehicle components in several performance steps, which more or less independently can be combined into a truck adapted for a certain operation. Stronger and thus heavier or more expensive components should be used for trucks operating in tougher conditions, e.g. with high gross train weight, in very hilly topography, on rough roads or under extreme climate conditions, while light weight components can be specified when the operation is less severe. Thereby, transport operators with well defined transportation tasks and operational factors could be offered a heavy truck with a specification optimized for best operating economy and sufficient performance, indicating a maximised life cycle profit. Strength and service life is well balanced among dimensioning components, maintenance interval lengths are maximised while weight and fuel consumed and thereby carbon dioxide emissions are minimised.

1.1 Unbalanced truck specifications

Nevertheless, a number of aspects counteract the optimal specification, hindering a maximum growth in the transport sector. On emerging markets specifications tend to be under-balanced when investments in advanced technology, e.g. for decreased fuel consumption, are avoided due to lack of financial resources or knowledge. On mature markets on the other hand, specifications are often over-balanced due to a large number of reasons, not only technical and rational, but also emotional or originating in lack of knowledge. Examples are listed below.

- Not enough knowledge on components and specification possibilities among sales force.
- Difficulties in defining the operational factors.
- Overconfidence in own law-abidingness.
- Difficulties in making precise comparisons between specifications and brands.
- Trade-in value: salesmen and customers over-estimate the increased second-hand value of an over-specified component compared to the total increased vehicle life cycle costs.
- Misconception of the time loss in economical driving, thereby specifying for power.
- Local variations in operational factors that is difficult to predict e.g. temperature.
- Wish for flexible operation: customer specifies for worst case.
- Conservatism among sales force and truck operators: use what worked the last time.
- Wish for higher performance than necessary: the power race.
- Over-estimation of own skills and unwillingness to let the machine manage the driving: e.g. automatic gear changes and economical cruising.
- No acceptance for long payback period for optional equipment: e.g. air deflectors.
- The optimization procedure is time consuming: salesmen do not want to disturb the customer with many changes in specification and offered price.
- Specification dependencies at the truck manufacturer: components cannot be combined due to technical reasons: e.g. large engine with small cab.
- Over-specification it self: stronger engine requires stronger and heavier gearbox, etc.
- Inner factors e.g. cost rationalisation, spare part stock.
- Stock management: Difficult combine specifications variations with short delivery time.
- Standardisation due to e.g. minimising costs for type approvals and marketing.

Lack of knowledge, uncertainties, conservatism and emotions are obviously causes for unbalanced specifications. Thereby, different skills and techniques of specifying a truck affect the possibilities to minimise operating costs and maximising operating income.

Different truck specification techniques

Most truck manufacturers offer a large number of specification possibilities, implicating a large number of choices, balancing between performance and economy, when specifying a heavy truck optimized for its transportation task. This is difficult and time-consuming for the salesman, being dependent on support from the truck factory or being very experienced in the art of truck specification. Since the pressure from legislators and society is ever increasing, likewise the industrial competition, specification possibilities change and increase quickly over time as the product is being developed. In an ideal world, truck specifications on a market should thereby change continuously, being optimized in every moment. However, only in rare cases, e.g. when entering new segments and markets, the full optimization takes place.

In practise, the salesman instead most often has to rely on market standard vehicles that in the best case can be adjusted with respect to a few components to comply with a specific customer demand. This ***market standard*** way of specifying a truck is conservative since components tend to be preserved in the standard specification over time.

As an alternative to market standard vehicles, a ***copy of the old vehicle*** specification is offered to customers. This is probably an even more conservative specification method since components are changed only when they are discontinued by the manufacturer or when legislation requires higher performance than last time.

Some customers are very well-educated in the specification possibilities and the performance of different components available from a manufacturer. In those cases, the customer specifies the truck and the salesman obey. This is in some aspects a favourable method since the customer gets what is desired as long as the components are available in combination with each other. But the customer cannot however have the full knowledge of the component performance. Bad experiences, e.g. with failing components, tend to hinder improvements to reach the market for the benefit of too strong and heavy alternative components. Probably this customer also misses some newly developed components. Therefore, also this ***customer demanded*** method tends to be conservative.

A better approach to specifying a truck is to base it on an existing competitor vehicle or an offer from a competitor. Although there is a risk that the specification gets under-balanced during the iterative specification process, the salesman is forced to choose components that are the latest updates. The chance that the truck gets optimized with this ***competitor specification*** method is thereby greater.

A method indicating the greatest potential for optimized specifications in regard to operating economy includes full consideration of the transportation task, specification based on actual ***operational factors***. By this method the truck becomes compiled by components optimized for the operational factors that are known, at least roughly, by the customer and the salesman, or known in detail through operational statistics stored in the vehicle about to be replaced.

Operational factors and operational statistics

The ***operational factors***, expressing the operation in technical terms, are used to analyse the performance demand. Examples of operational factors describing load and requirements on performance are gross train weight (GTW), topography, traffic conditions, road roughness and climate. Most operational factors are measured by a truck and stored in the vehicle's on-board computers as ***operational statistics***. This data, the sum of the operational factors, describing

the total operating situation, has a direct impact on the requirements of the truck design, or more precisely, on the choice between different performing components. Figure 1 exemplifies the relation between load and strength, hence between operational factors and component performance. Obviously, trucks with operational factors corresponding to operation A will be unnecessarily strong if equipped with components of performance 2. Performance 1 is sufficient, consequently indicating a weight and cost savings potential. Trucks in operation B in contrast, require performance 2, since performance 1 indicates too many breakdowns; it is simply not strong enough for the operation as indicated in Figure 1, shaded area.

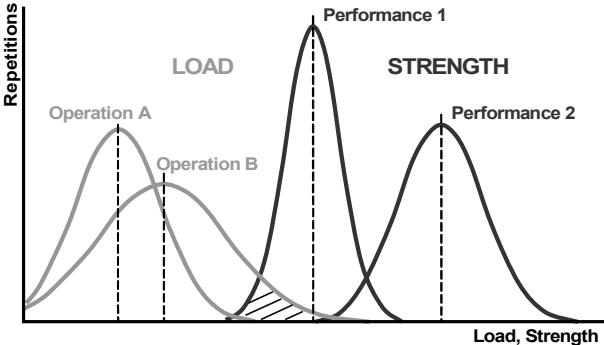


Figure 1 – Operation of trucks and performance of components.

In real life however, operation and performance are not always matched. An indication is given in European long haulage, where a large portion of the trucks are optimized for 100 % operation at legal weight and dimensions, e.g. 40 tonnes GTW. In reality, GTW is far below that for a great portion of the transports, i.e. they are volume limited. Trucks are also driven empty when there are no or small transportation needs on the return trip. Hence, trucks often use less than the full loading capacity. Details of load and speed are given in Figure 2.

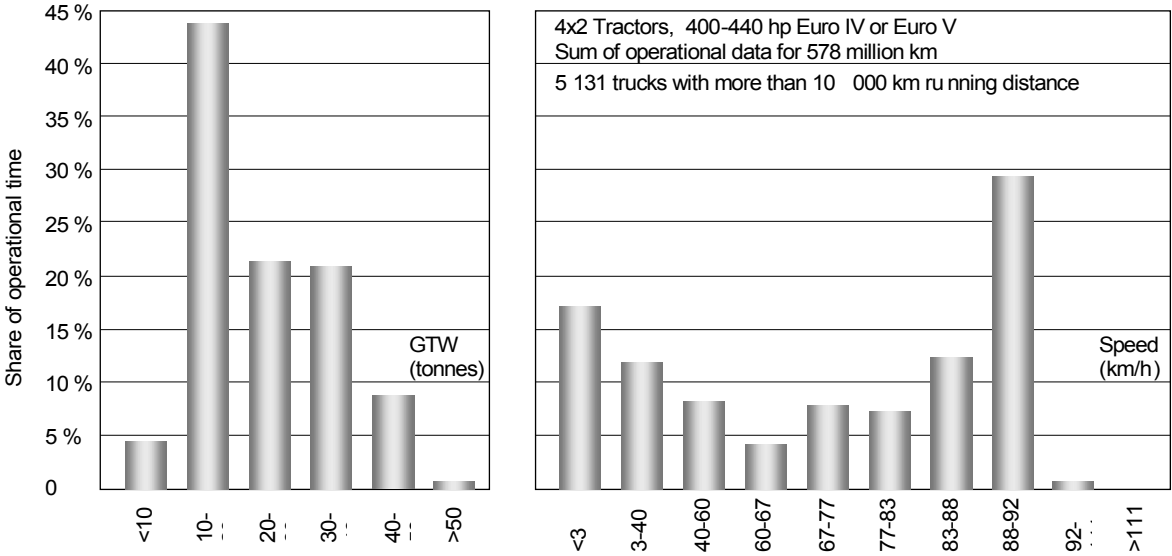


Figure 2 – Operational statistics from 4x2 tractors delivered in 2008 to EU countries.

The operational statistics from which Figure 2 is compiled, are collected from 5 131 Scania 4x2 tractors delivered in Europe during 2008. The statistics indicate that almost 30 % of the trucks exceed 30 tonnes GTW in less than 20 % of the time. The same statistics also indicate that the trucks are driven more or less empty almost 50 % of the time. Further, the cruising speed is most often 89 km/h as set by the speed limiter, rather than the legal 80 km/h.

There is a great difference between 30 and 40 tonnes GTW in terms of powertrain load. Additionally, 10 % difference in cruising speed between stipulated 80 and practical 89 km/h influences the choice of powertrain components greatly when optimizing for fuel economy. Therefore, when optimizing for the real need, there is a large savings potentials indicating lighter and more fuel efficient trucks, e.g. down-sized engines. By using real operational factors as input, trucks specifications could be better matched to the real transportation task.

1.2 Truck specification based on operational factors

As discussed above, the key to optimizing a truck specification lies within defining the operational factors and applying knowledge that connects components with the operational factors, as indicated in Figure 3, where operational factors influencing the choice of axle gear are connected to the performance steps of the gear via specification recommendations composed by knowledge that the truck manufacturer possesses.

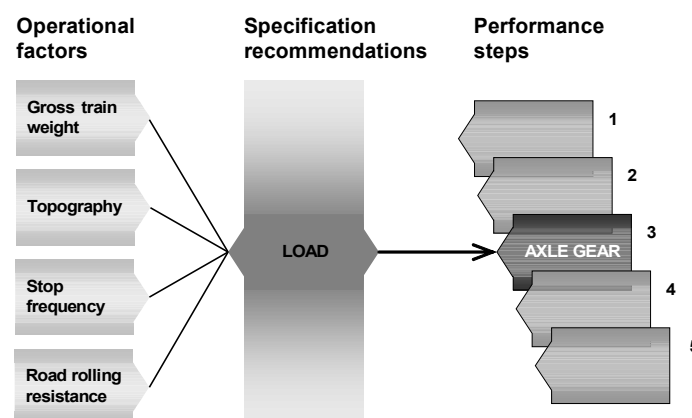


Figure 3 – Choice of components based on operational factors.

However, far from all trucks are optimized, but reasons for this can be eliminated if uncertainties on the real operational factors are removed and if these are presented to the salesman during specification. An optimized truck may be achieved if operational statistics are connected to truck specification via recommendations. This could be achieved by utilising operational statistics collected from a vehicle in the same operation as the one being specified, and an optimization program.

2. Method

By choosing a market standard long haulage truck from vehicles sold during 2008, using some of the most common powertrain components found on European long haulage tractors, it is possible to compare the standard specification against optimized specifications chosen with the help of operational factors and specification recommendations.

In order to validate possible savings in operating costs, two different specifications in a test fleet are evaluated. The fleet includes ten trucks specified based on a best guess of the coming operational factors, plus an additional four trucks ordered half a year later. The specification of the latter trucks is based on the first trucks' actual operation, collected from control units as operational statistics. The optimization balance operating costs and performance.

Fuel economy was chosen as the parameter to be optimized with respect to operating cost, while gradeability was chosen as performance parameter. Fuel economy is measured in units of litres fuel consumed per km and m³ goods transported since the goods in the example presented are limited by volume, i.e. low density. Alternatively, when the goods are limited by its mass, i.e. higher density, litres fuel per km and tonnes goods transported can be chosen. These measures correspond almost directly to kg CO₂ per km and m³ (tonnes) goods transported. Gradeability is measured in terms of maximum gradient (%) that is possible to climb at preserved cruising speed in any of the top gears.

In this work, primarily the powertrain is optimized, which starts by selecting the drive tyres. Second step is to determine minimum engine power required for the transport mission. In the third step, required powertrain component strength is determined based on GTW, type of operation and engine power. An optimization is important since the savings in vehicle weight contribute to transport efficiency either in that it saves fuel as volume limited transports gets lower GTW or in that it increases load capacity for mass limited transports. The last step is to decide total gear ratio on top gear from engine to the drive wheels in order to achieve best possible fuel economy.

2.1 Tests

Simulations for the three specifications are performed in Scania's in-house simulation and specification optimization programmes, Scop and Stars (Sandberg, 2001), plus Matlab. Operational statistics from 4x2 tractors were collected by Scania repair shops when the trucks stopped for maintenance. Measurements of fuel consumption were also conducted with fuel logs kept continuously from start of test fleet operation.

For evaluation, Scania Transportlaboratorium AB was used. Transportlaboratorium is a haulage company used by Scania to test trucks in real customer environment, with resources to conduct complete follow up of operation, performance and economy. The company purchased trucks at two separate occasions. Ten trucks were specified based on a proper evaluation of the transport mission during 2008. In early 2009 they exchanged four trucks to a new specification mainly based on operational statistics. Transportlaboratorium mainly transport wheel axles between the Scania factories in Södertälje, Sweden and Zwolle, Netherlands. Mixed cargo is transported on the return trip, cf. Figure 4. Both ways, the goods are volume limited, resulting in an average pay load of 14,5 tonnes (max 25 tonnes).

It is difficult to measure fuel consumption since errors are introduced due to influence of factors such as climate, traffic condition and driver behaviour. Therefore an evaluation over time is required, but this also has its drawback since it is difficult to have control of transport missions. In the Transportlaboratorium case however, it is as controlled as a real world transport missions can be, wherefore they are chosen when comparing the outcome of the different specifications. Since there are no trucks with the market standard specification within the company, only simulations are performed for this vehicle type.

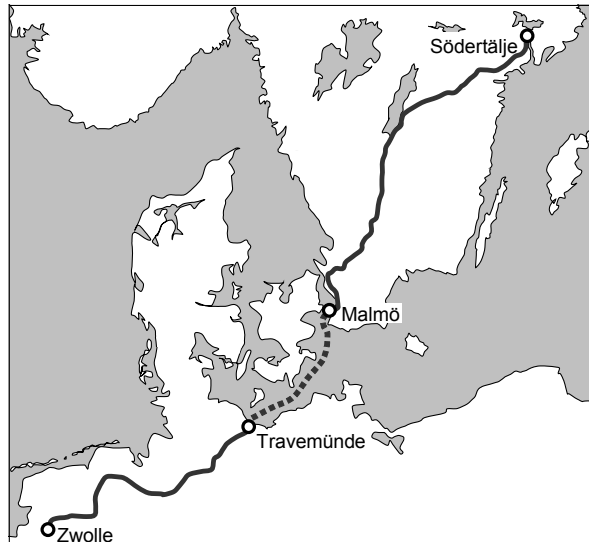


Figure 4 - Transportation route for Transportlaboratorium.

2.2 Specification of vehicle

Among all techniques, three are compared in this work, vehicle specification based on the market standard (specification A), based on analysis of transport mission (specification B) and based on analysis of operational statistic (specification C), cf. Table 1.

Market standard – specification A

A market standard vehicle specification differing from the optimized most often exists for marketing reasons. On emerging markets, this specification is often less powerful than the optimized, but on mature markets it is typically stronger, heavier and more powerful than required. On mature markets, the specification has typically evolved over decades due to product development, but also due to price competition, market conservatism and reflections from consumer product purchasing behaviour (i.e. truck owners also buy passenger cars and watches). “The power race”, i.e. the ever increasing maximum engine power of e.g. 4x2 long haulage tractors in Europe, is typically a result of value for price competition and reflections from the consumer economy. For several decades, the average maximum engine power on 4x2 tractors in Europe has increased by close to one horsepower per year. But only marginally has it contributed to increased productivity, the increase in average speed is typically in the range of a tenth of the increased engine power and in addition, a fuel penalty may occur.

In order to derive the specification corresponding to the market standard of powertrain components in European long haulage, the average maximum engine power on the market is chosen. In 2008, it was close to 440 horsepower (cf. Figure 4) with a maximum engine torque of 2000 to 2500 Nm, wherefore a 13 litre 440 hp EGR engine is chosen.

The market standard gear box in this segment is typically of split-range type with twelve speeds plus crawlers and an auxiliary brake but without overdrive. The axle gear corresponding to this segment has a strength dimensioned for a service life equivalent to the vehicle’s, at +40 tonnes operation in very hilly topography. The central gear ratio is chosen for an engine speed of roundabout 1300 rpm at cruising speed 80 km/h. Since the tyre dimension 295/60 R22.5 is a customer requirement due to maximum trailer volume and thereby lowest possible chassis height, gear ratio 2,71 is chosen for specification A.

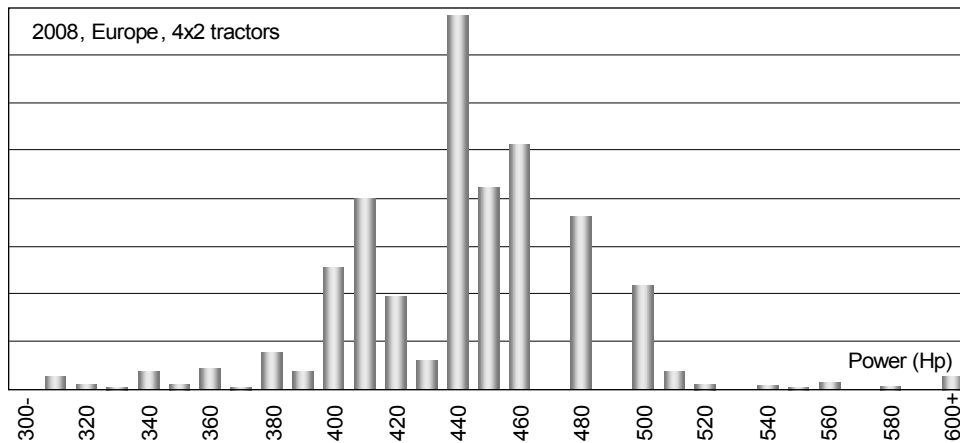


Figure 5 – Maximum engine power on delivered trucks in Europe during 2008.

Analysis of transport mission – specification B

Besides just using the market standard, salesmen and customers can better optimize the trucks by analysing transport missions and make adjustments to truck specifications. Analyze of a transport mission can be conducted in several ways. Either by asking the customer what he transports (weights, trailers, etc.) were he performs the transports (road surface, climate, altitude, topography etc.) and how transports are performed (number of starts, cruising speed, traffic situation etc) or by visiting the customer and documenting or making measurements.

In the derivation of specification B, the customer was interviewed and a specification optimization program was used. Several components were exchanged compared to specification A, cf. Table 1.

Analysis of operational statistic – specification C

In the late 1990's more advanced control units were installed in the trucks. The primary reason was to control the vehicle response to driver instructions. The secondary was to store information of vehicle operation. An example is given in Figure 6.

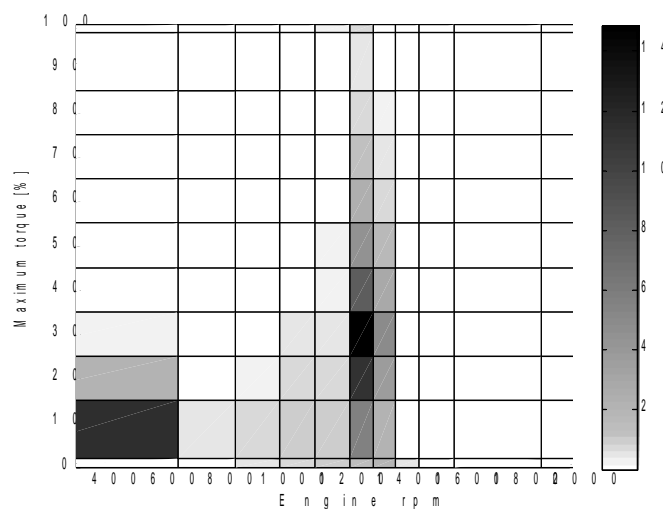


Figure 6 – Load matrix

Therefore operational statistics today exist in most trucks and can be collected to describe the customer operation. Since many customers stay with the brand when replacing old vehicles or increasing the fleet size, information collected from a customer vehicle or fleet of vehicles can be used as input for simulation and optimization.

Using the operational statistics of the original test fleet vehicles - Operational statistics collected from the original ten vehicles of the test fleet where analyzed in order to derive specification C (Curbo 2009). The tyre dimension was set by the choice of trailer. Engine candidates were chosen by looking at the operational statistics of the Load matrix, see Figure 6: engine rpm on the x-axis, percent of maximum torque on the y-axis. The degree of darkness corresponds to the percentage of the vehicles lifetime spent within the squares

Gearbox and rear axle candidates were decided based on operational statistics (weight vector, Figure 7 and load matrix, Figure 6) and specification recommendations as in Figure 3.

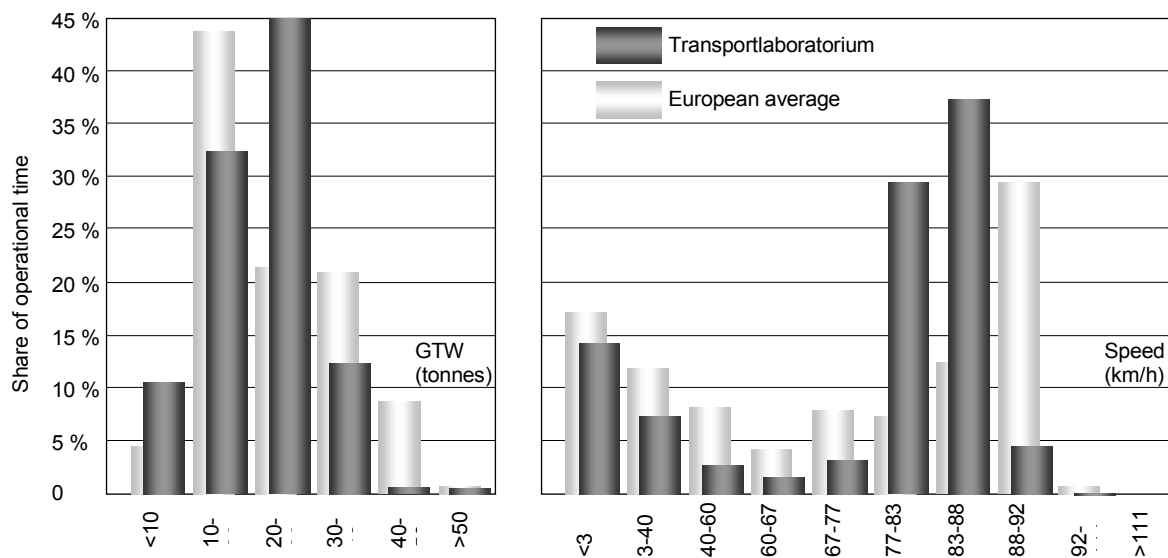


Figure 7 – GTW and velocity vector for Transportlaboratorium’s ten vehicles.

Next, suitable rear axle ratios were chosen for the engine candidates, ensuring that the engines worked in a good rpm area at cruising. The cruising speed was picked from the velocity vector, Figure 7 and input from the test fleet drivers. Finally, simulations were performed and the specification with best fuel consumption and acceptable gradeability was chosen.

Further analysis - The original ten vehicles of the test fleet were compared with the four new using operational statistics from both vehicle types as input in simulations (Curbo, 2009). It is shown that the operational statistics is very similar for both specifications, which is expected since the transport operation is the same regardless of vehicle specification. Therefore it is possible to combine operational statistics from the entire fleet, thus increasing the statistical material used in the simulations.

In simulations the two test fleet specifications are compared by calculating fuel consumption and vehicle performance. It is shown that by comparing fuel consumption and performance

with the original specification, the impact of crude measuring points in the operational statistics is reduced. The error originating in the operational statistics is deemed small enough to be acceptable. Using the operational statistics as described in Figure 3, the strain on the gearbox and rear axle is calculated. With this new information, it is shown that the rear axle is over dimensioned and thus, a lighter rear axle can be chosen in order to save weight and fuel.

General use of operational statistics - The powertrain components would typically be chosen as follow. First the tyres are chosen. These are determined by the trailer size, legal requirements, comfort, road conditions, cruising rpm and economical reasons.

Secondly, gearboxes strong enough for the operation are found by calculating the strain from the operation. Startability requirements, manual or automatic preference and minimum reversing velocity thereafter indicate possible gearboxes. Available rear axles are found with guidance from calculated strain. The lightest, being strong enough for the operation and having the correct gear ratio, is later chosen via simulations

Simulations are finally performed, using the operational statistics and the above mentioned specifications as input. The simulations test combinations of powertrain components and compare the fuel consumption and performance. The most suitable powertrain configurations are displayed to the customer. Ultimately, it is still the customer who knows the requirements and priorities in the operation.

3. Results

Fuel consumption is derived in three ways: simulations, logs from the petroleum company and from engine control units. Since Transportlaboratorium does not have trucks specified in accordance with the market standard (specification A), results for these are based merely upon simulations.

Cost comparisons between a truck using urea and one without are difficult since the urea price differs heavily both over time and between countries. In this paper, an average of the market prices in Sweden in January 2010 is used, which was 12,5 SEK (1,24 €) per litre diesel and 8,5 SEK (0,84 €) per litre urea.

Table 1 - Evaluated specifications

	Market standard (A)	Suggested by experience (B)	Based on operational statistics (C)
Engine	13 litre EGR 440 hp	12 litre SCR 420 hp	13 litre EGR 400 hp
Gearbox	12 speeds 2 crawlers Retarder	12 speeds Retarder	12 speeds 2 crawlers Overdrive
Central gear	Capacity 3	Capacity 3	Capacity 2
Central gear ratio	2,71	2,71	2,92
Tyre dimension	295/60R22.5	295/60R22.5	295/60R22.5
Rolling radius	0,447 m	0,447 m	0,447 m
Weight difference	0	-20kg	-145kg

Specifications in Table 1 are selected as described in the previous chapter, but some modifications were made on the actual vehicles of Transportlaboratorium. A stronger rear axle was chosen together with larger fuel tanks in order to achieve longer distance between fuel stops. This increases the vehicle weight with 215 kg, a weight increase estimated to result in an additional fuel consumption of precisely below 0,1 l/100 km.

Results presented in Table 2 indicate that, when including the urea consumption, the truck with specification C is the most cost efficient followed by specification B. The market standard (specification A) is indicated to be the least efficient. For comparisons, an average speed decrease by 1 km/h corresponds to fuel savings of roundabout 0,2 l/100 km.

Table 2 - Fuel consumption simulated and measured for evaluated specifications

	Market standard (A)	Suggested by experience (B)	Based on operational statistics (C)
Simulated average speed	82,8 km/h	82,6 km/h	81,5 km/h
Gradeability at 85 km/h	2,3 %	2,2 %	2,0 %
Simulated diesel consumption	35,0 l/100 km	33,8 l/100 km	33,8 l/100 km
Simulated urea consumption	N/A	1,4 l/100 km	N/A
Measured fuel consumption at pump station	N/A	28,2 l/100 km	28,5 l/100 km
Measured fuel consumption by truck ECU	N/A	27,2 l/100 km	27,4 l/100 km
Estimated urea based on measured fuel	N/A	0,56 l/100 km	N/A

Based on this, the simulated results indicate that the trucks with specification B requires 1,2 litres less per 100 m³ and 100 km than specification A (the mega trailer contains 100 m³), but in addition consumes 1,4 litres urea. That corresponds to 0,7 % savings for the propulsion, or approximately a 1 700 € savings per year and truck with annual distance 180 000 km. When specification C, derived from actual operational statistics collected from the control units, were used in the optimization, the vehicle consumed the same amount of diesel as specification B, but without use of urea, corresponding to 3,4 % savings compared to specification A, or 3 800 € per truck and year.

Measurements conducted show slightly different results compared to the simulations. Fuel consumption was just below 1 % better for specification B compared to specification C, and the urea consumption was much lower than expected. VDA (2010) indicate a urea consumption roundabout 5 % of the diesel consumption and simulations indicate above 4 %. Measurements however showed a urea consumption of 2 % of the diesel consumption only. The main reason for that is probably that the SCR-system has not been fully operational due to malfunction, low ambient temperature or an empty urea tank.

Based on measured values, savings for the trucks specified based on operational factors (specification B) are approximately 2 800 € per truck and year, while for the one based on operational statistics (specification C) the savings are 3 100 € per truck and year.

4. Discussion

Assumed that savings in the range presented above is applicable on 30 % of approximately 200 000 heavy long haulage trucks sold each year in Europe, a total of 130 000 m³ fuel could be saved given that they drive in average 180 000 km annually. This indicates that some 340 000 tonnes CO₂ less could be emitted annually from one year's population only. The transport efficiency in terms of volume (or mass) goods times the distance transported, could be increased by approximately 1,0 % without a considerable drop in vehicle performance.

Operational statistics will be a great help in new vehicle sales. Instead of customers approximating or guessing the operational factors, operational statistics collected from customer vehicles in operation will be used as input to the component selection. This will simplify the process and minimize the risk of unbalanced specifications. Consequently, salesmen will have confidence in performing the optimization of the specification, rather than specifying over-balanced for safety.

Ultimately, it is still the customer that decides states the preference between driveability, fuel consumption, initial cost and other performances. Operational factors and statistics should be used as guidelines only, not as rules.

5. Conclusions

The results indicate that a large amount of fuel, money and CO₂ can be saved by optimizing truck specifications using operational statistics collected from the vehicle's control units. Still large savings, but somewhat smaller, are achieved by optimizing the truck specification based on a customer estimation of the operational factors and an optimization programme.

The largest gain from optimizing specifications using operational statistics is probably that salesmen will have confidence in performing the optimization, since real data collected from the truck is used. The chance that the optimization will occur is simply much higher than if relying on manual estimations of operational factors. The result is less dependent on the knowledge and experience of the salesman, it is simply easier to make the best choices.

6. References

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