# Modelling operational costs of a future high-speed train

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## ABSTRACT

In the Swedish Green Train research project, a model for calculation of operational costs has been developed. The model is intended as a tool for making a new high-speed train concept efficient and economically feasible. Some results indicate that seating density, i.e. the number of seats per metre of train length, is one of the most important factors to achieve economic train operation. The load factor needs to be high. However, to select service and comfort levels and other supply factors, travel demand and passengers' willingness to pay also need to be considered.

## 1. INTRODUCTION

### 1.1 The Green Train research project

When developing a conceptual design of a new high-speed train, a successful approach might be to start with a frame of market demands for the train. This philosophy is used in an ongoing Swedish development and research project entitled the Green Train, principally financed by Banverket (The Swedish National Rail Administration) and Bombardier Transportation. The Green Train project aims to produce a conceptual design for a new high-speed train with improved performance, primarily intended for the classic network and considering special conditions, for example the climate, found in the Scandinavian countries.

High-speed services in Sweden have since 1990 existed as X 2000 long-distance connections on main lines. However, commercial speeds of X 2000 do not exceed 150-160 km/h at best on the classic network. On longer regional services with a high-speed standard, such as the Svealand line, commercial speeds are not usually higher than 110-120 km/h due to more frequent stops (Fröidh, 2005). These commercial speeds limit the accessibility range by train to approximately 400-500 km for a business trip without an overnight stay, and to 100 km for daily commuting due to individual travellers' time budget constraints. Faster trains would thus open up new markets, and regions would profit from greater accessibility, which might be a prerequisite for economic development (Fröidh, 2003).

### 1.2 Competition in the travel market

Competition in the travel markets consists of airlines, including low-fare airlines on longer routes, and coaches and cars over all distances. To be competitive, a new train concept must not exceed a certain level of operational costs. Operational costs include train staff, maintenance, infrastructure user fees, energy, and capital costs as well as administration and selling costs. Having the ambition to be competitive for leisure travel also requires active yield management, since the marginal cost for an extra passenger in a car is small. However, high speed is a means to achieve both low operational costs and higher revenues through a more attractive services supply.

The cost-minded approach in this research project presents new challenges for the conceptual train design. It is the intention to valuate the train concept, setting costs against benefits. As a tool, an economic model for operational costs is useful.

### 1.3 Cost models in the literature

The most interesting previous model seem to be the in-house study “Tåganalys” (Train analysis) by Kottenhoff (1999), who devised a similar model to calculate the costs of services on a line with different train concepts.

For purposes other than designing train concepts, more models that include at least some operational cost data have been built. Comparisons between high-speed train and aircraft operational costs can be found in Givoni (2003). A model for locating new high-speed lines in Taiwan is described in Chang, Yeh and Shen (2000). The LIME model, intended for planning the capacity utilisation and profitability of a railway line, has a similar approach but focuses on existing lines (Rosenlind, Lind and Troche, 2001). However, those models are not intended, nor are they accurate, for the optimization of a train concept.

## 2. THE GREEN TRAIN COST MODEL

### 2.1 Character of costs

Different costs can be characterized into, for example, direct operating costs and indirect operating costs (Doganis, 2002). The costs are swiftly, intermediately, or slowly manageable, i.e. more or less strongly dependent on the marginal operations. Direct operating costs, which are strongly dependent on operations, are energy costs and infrastructure user fees. Staff costs must in general be characterized as intermediate. Most staff receive a salary and cannot be employed and dismissed from one day to another, but possibly in a couple of months as long as it is a question of non-specialist competence. Capital costs for rolling stock and other long-term agreements are slowly manageable and might take years to change.

A typical empirical cost distribution might be 20-25% for train crew and 20% terminal and maintenance costs. Capital costs amount to about 25-30% of the total costs for a brand new train. Infrastructure user fees and energy (electricity) amount to approximately 5% each, and others (sales and ticketing, administration and planning) 15-25% (Effektiva tågsystem, 1997).

### 2.2 Origin and model development

The Green Train cost model has its origin in a cost model devised by adjunct professor Bo-Lennart Nelldal at KTH. The model has been extended and further developed by the author to suit the needs of different types of service, i.e. regional high-speed service, InterCity and Express respectively. The model will be further refined and calibrated as more accurate input data becomes available in the Green Train project.

The model has been validated against Kottenhoff's (1999) previous model "Tåganalys". The costs of train operations are also checked against different sources, such as "Effektiva tågsystem för framtida persontrafik" (1997), "Beräkningshandledning" (2005) and "Kalkylvärden och kalkylmetoder (ASEK)", (2005). Accuracy seems to be good, although not yet exactly computed.

### 2.3 Model structure

The model imitates authentic cases as closely as possible based on Swedish train operation cost structures. However, by assigning approximate or general values, many kinds of cases can be calculated, as well as generalized cost functions. Approximate or real values of train operations are used as input. Output is measures of operational costs in train traffic, by train type (see fig. 1), with corresponding accuracy.

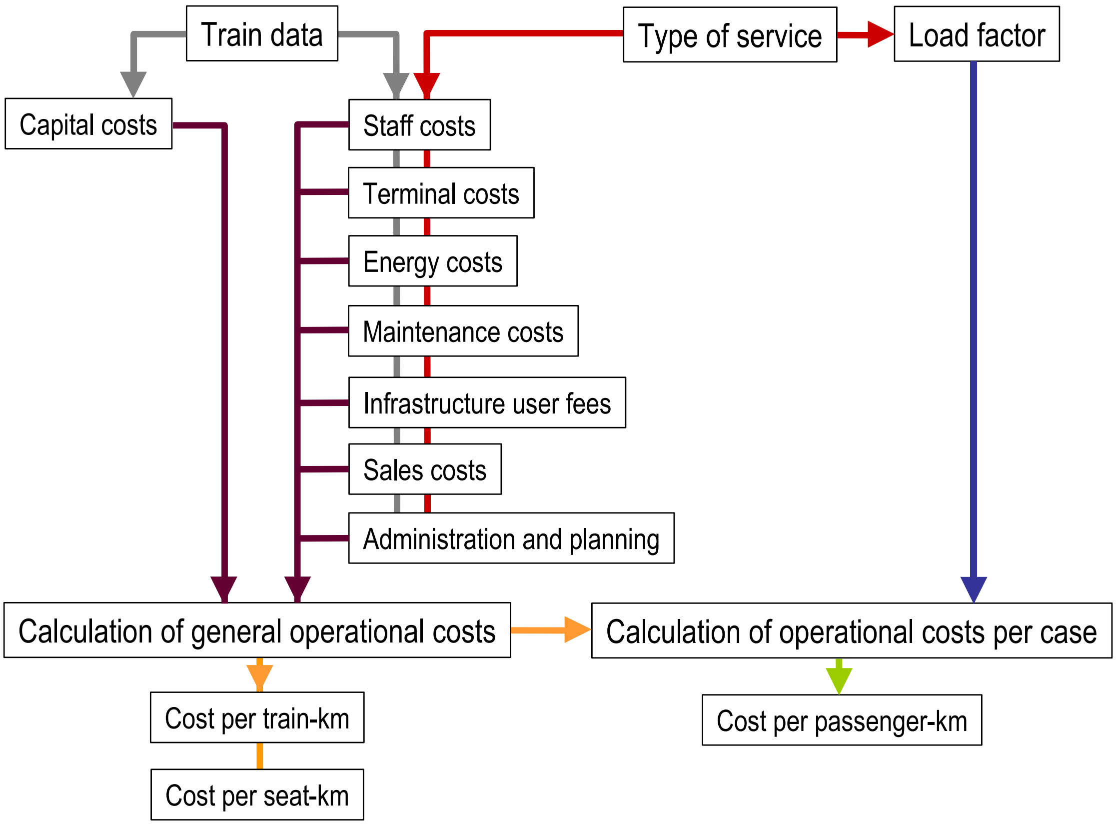

**Fig. 1 – Structure of the Green Train cost model.**

# 3. RESULTS OF MODEL CALCULATIONS

## 3.1 Prerequisites

In this example, all calculations are for InterCity services on the western main line between Stockholm and Göteborg. The line is 455 km long between the terminals, electrified, and upgraded for tilting trains with a maximum speed of at present 200 km/h. In the model, travelling time gains resulting from possible future speed increases are included. The new target speed is 250 km/h, although this can only be achieved on limited sections of the line due to a partly sinuous alignment. An InterCity train with about 6 stops can then make the journey in 3 hours exactly, which is about 10 minutes faster than with today's speed limit. As a default train configuration, a standard Electric Multiple Unit (EMU) of 4 cars (240 seats) with distributed power for 250 km/h is selected unless stated otherwise.

## 3.2 Results

### 3.2.1 Travelling time

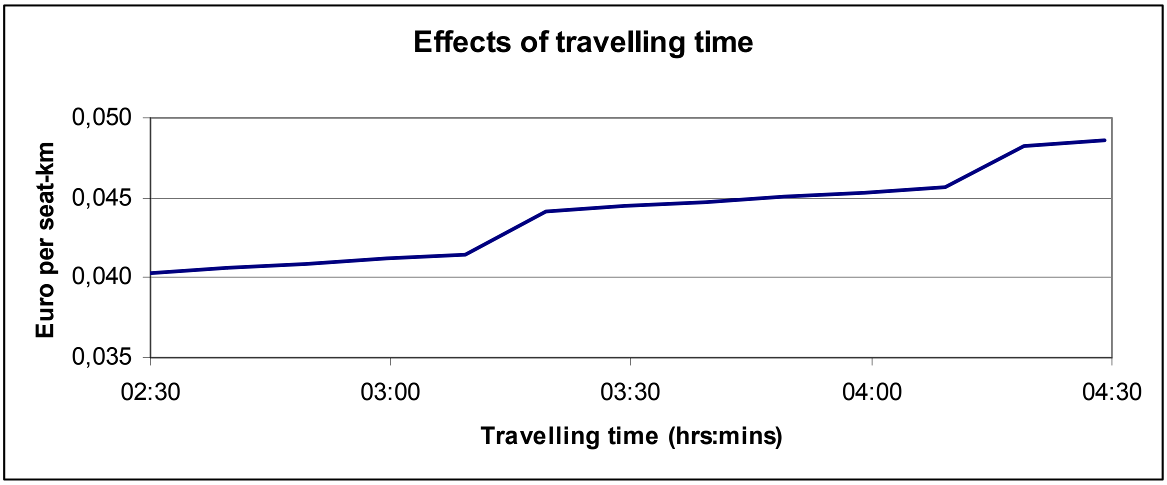

**Fig. 2 – Effect of travelling time on operational costs.**

Production costs as a function of travelling time for a single journey decrease largely in increments through shortened travelling times, as can be seen in fig. 2. The increment occurs for every trainset saved due to faster circulation. An additional continuous effect of shorter travelling times is the lower cost for onboard staff.

### 3.2.2 Train frequency

In this example (fig. 3), the total supply of seats between the terminals increases with train frequency, as travel demand is predicted to grow by frequency. The lowest value, 8 daily departures with 690 seats each, gives a total supply of 5,520 seats. The upper extreme with 60 daily departures and 170 seat trainsets, has a total of 10,200 seats per day. However, the operational costs increase with the number of departures. The main reason is that operational costs per seat kilometre increase with shorter trains (as can also be seen in fig. 4). Hence, higher train frequency is an interesting measure only if travel demand is considered.

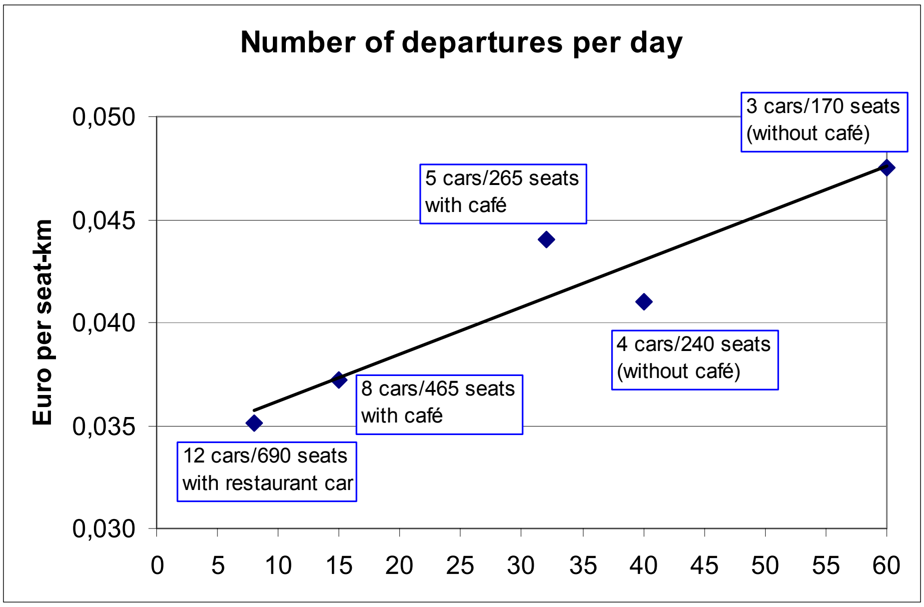

**Fig. 3 – Effect of frequency on operational costs.**

### 3.2.3 Train configuration

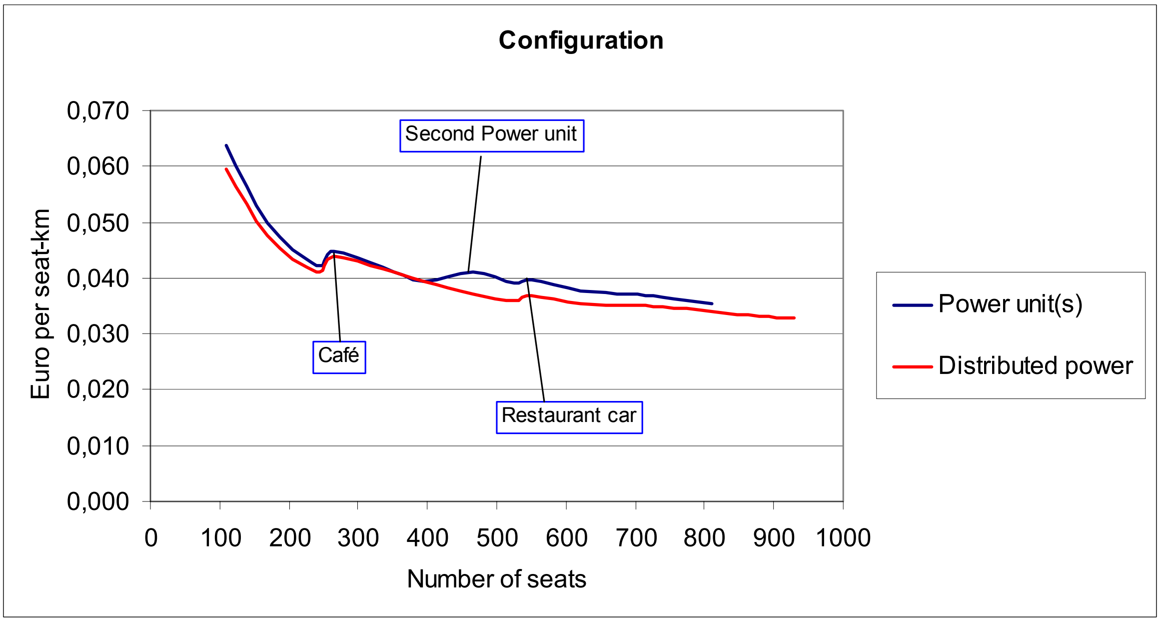

**Fig. 4 – Operational costs as a function of train configuration. Smallest train size two cars; largest configuration limited by 400 m platform length.**

An EMU can be configured in two principal ways; either with one or two power units (locomotives) and various numbers of intermediate trailers (cars), or with distributed power, i.e. all or most of the cars motorized and no locomotive. In this example, the power unit configuration has a power unit, 1 to 6 intermediate trailers, and a steering trailer. With 8 to 14 trailers, a second power unit replaces the steering trailer. An EMU with distributed power has 2 to 16 cars, limited by 400 m platform length as the power unit consist.

The effects of different purchase price and subsequently capital costs, and different levels maintenance and energy consumption are included in the model. Moreover, the power unit consist has slightly longer travelling times compared to the distributed power alternative when the power to weight ratio is unfavourable, i.e. 6-7 trailers per power unit.

The results (see fig. 4) show that the power unit consist has about the same operational costs as the distributed power consist in the range 265-395 seats, i.e. 5-7 trailers. For other train sizes, the EMU with distributed power has lower operational costs. This is especially visible when a second power unit is introduced (needed for 8 or more trailers).

The effect of introducing a café in half a car (the fifth car) is clearly visible. The tenth car is here presumed to be a full restaurant car, replacing the half café car, but the humps in the diagram are smaller due to larger passenger capacity in that train size.

### 3.2.4 Seating density

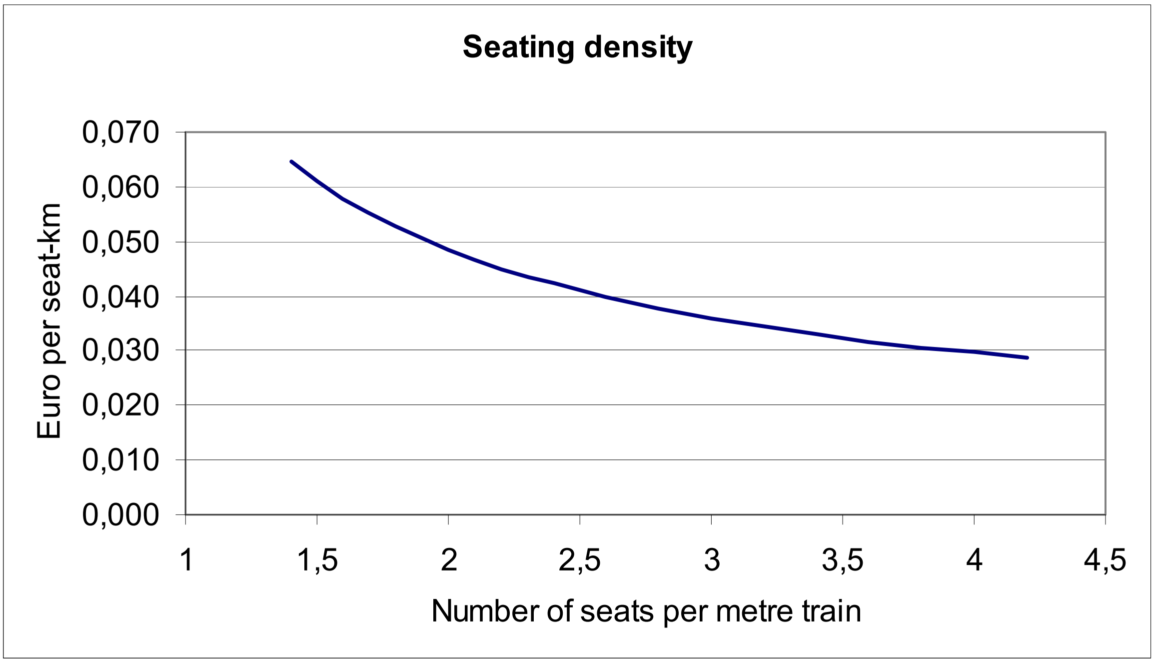

**Fig. 5 – Operational costs as a function of number of seats per train length.**

Many seats per metre of train length might decrease the production costs per seat. Typical values of seating density are around 2 seats per metre of train for European long-distance EMUs, within the UIC loading gauge. The lower extreme are pure 1st-class consists with around 1.5 seats per metre. Double-decker or wide-bodied trains have about 3 seats per metre. A higher extreme are the Japanese JR East E1 and E4 Max Shinkansen trains, featuring both wide carbody and two decks, giving more than 4 seats per metre (Effektiva tågsystem, 1997). As can be seen in figure 5, there is a clear connection between operational costs and seating density. The difference is a factor 2 between 1.5 seats per metre and 4 seats per metre of train length.

### 3.2.5 Staff costs

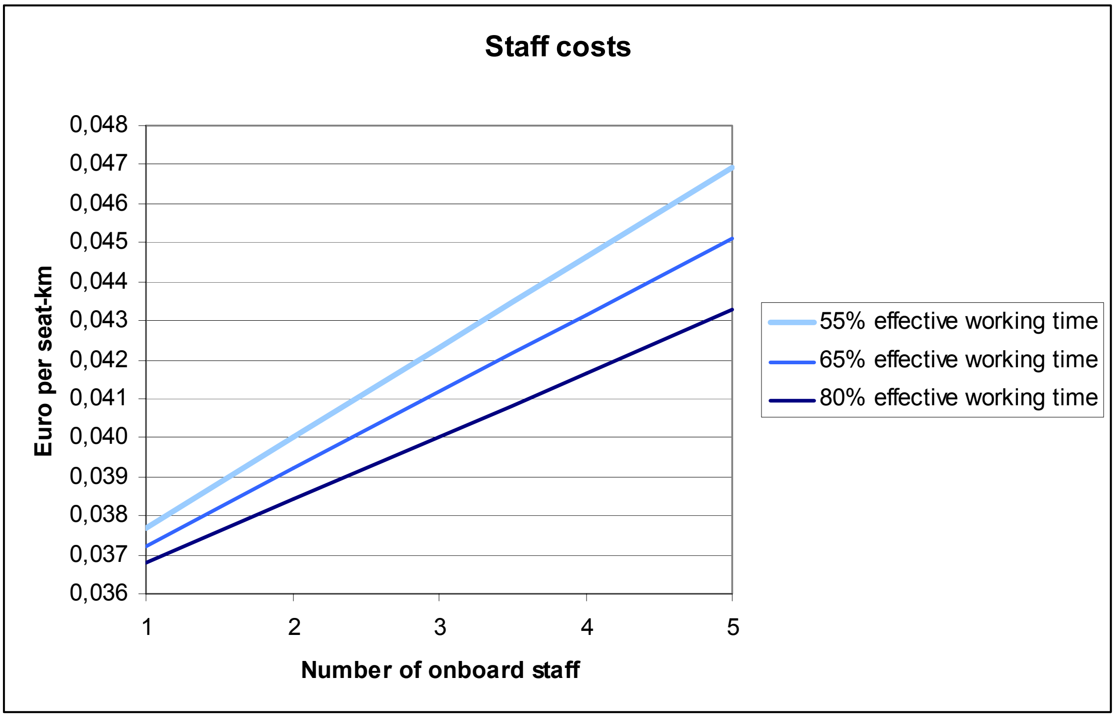

**Fig. 6 – Onboard staff and effective working time.**

In this example, the 4-car (240 seats) configuration is normally handled by one driver and one conductor, i.e. two onboard staff. More staff might be needed to provide more service, for example at-seat serving of food. The cost of increased manning is here assigned to the operational cost, not sales of extras such as food. Less than two staff, if permitted for safety reasons, requires automatic driving or stationary ticket control.

It should be noted that the model calculates staff expenses by travelling time, or the time printed in the public timetable. This time is approximately only 55% of the onboard staff's total working time. The rest, an "unproductive" 45%, is debited the travelling time, thus making the model insensitive to gains from more efficient staff circulation. However, if the proportion of effective working time could be increased, the economic effect would be the same as reducing the staff. Here, 65% and 80% effective working time respectively, are also calculated (fig. 6).

### 3.2.6 Administrative and sales cost

The overheads of administrative costs (management, planning) and selling (ticket purchase, sales systems, advertising) have fixed percentages in the model. Halved overhead costs will cut the operational cost by 0.0055 Euro per seat-kilometre, or 14%. Elasticity is consequently slightly less than 0.3.

### 3.2.7 Load factor

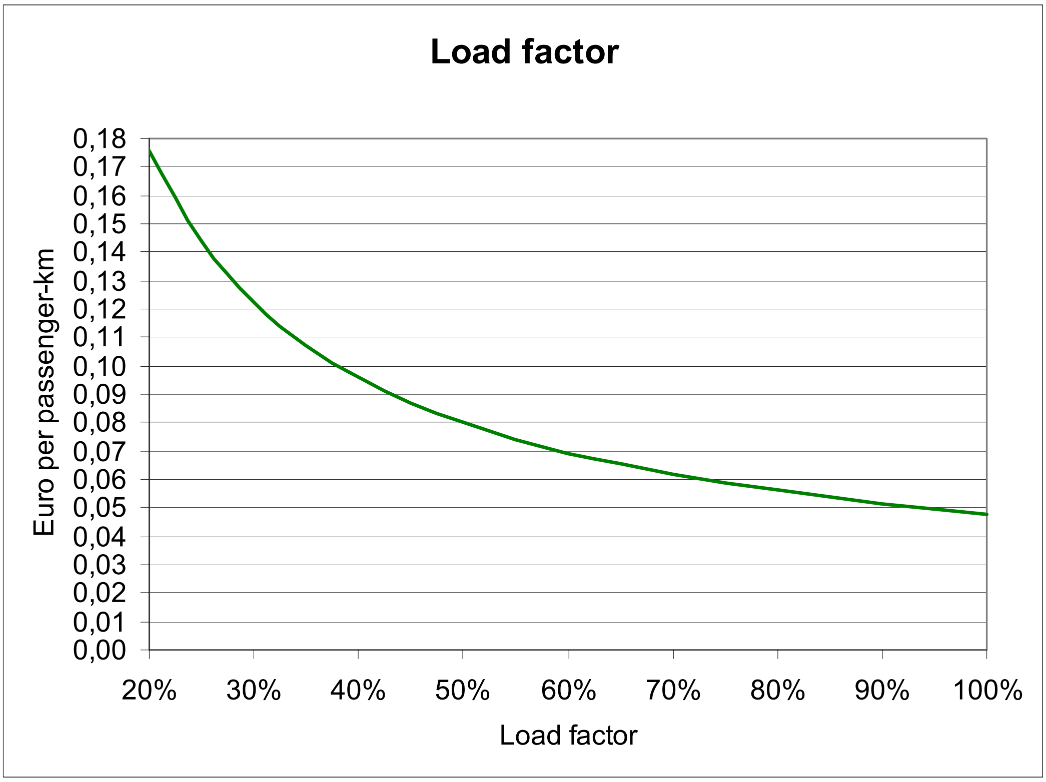

**Fig. 7 – Operational cost as a function of load factor.**

Load factors (also called cabin factor or occupation) should be measured as an average for a period of service. Since, from a cost point of view, an ideal load factor of 100% is seldom achieved, the load factor has to be considered. If the load factor is 50%, half of the seats are occupied on average, which might be a realistic target for long-distance services. At 50%, demand fluctuations will mean that some trains are full, while others might run with a great many empty seats.

The model calculations show that at a load factor of about 30%, the cost per passenger-kilometre is about twice as high as at 70%. Consequently, increasing the load factor from 30% to 70% could halve ticket prices. But such a radical fare reduction would in turn generate much higher demand, and possibly also in peak-hours when marginal costs for extra capacity are high, which will also entail higher operational costs (Rosenlind, Lind and Troche, 2001).

# 4 DISCUSSION AND CONCLUSIONS

## 4.1 Discussion

The model calculations in this example prove that some factors have a linear effect on operational costs, while others have an exponential effect. Train size and seating density are two non-linear factors of great importance. Longer train units and more seats per metre of train length give lower operational costs per seat-kilometre, and hence lower fares for passengers and/or higher profitability for a railway operator. This corresponds to earlier findings (Effektiva tågsystem, 1997; Kottenhoff, 1999). On the other hand, passengers valuate high frequency and high comfort as well. To be able to select standards and parameters, market valuation studies that consider both travel demand and supply costs need to be conducted.

How to arrange catering in a train also has an impact on the operational costs. A café in part of a car or a full restaurant car uses space that cannot be used for revenue seats. This increases the operational costs per seat-kilometre. But passengers might have a positive valuation of this service, making them willing to pay more for the journey. In the end, a market valuation study is also needed to choose an optimal concept for serving food or refreshments onboard.

The operational costs are weakly dependent on how many travellers actually use the services in the short and medium term. From that follows that in the short term, a railway company might be more profitable if they manage to stimulate travel demand and increase their income rather than try to cut their operational costs. Every measure taken to increase the average load factor is of importance for the economics of train operation.

In a longer perspective, preparing the operation for low production costs is indeed important. Acquiring up-to-date rolling stock designed to give low operational costs is one of the most important measures. Seating density is such an important factor that it needs special attention from the outset. The goal must be to design a train with an efficient layout, maintaining the high comfort often associated with train travel, and avoid making it cramped for passengers.

## 4.2 Conclusions

The Green Train cost model is intended to be a tool for designing a new high-speed train concept for economic operation. It gives guidance regarding the magnitude and importance of different factors. One of the foremost factors to achieve low operational costs is seating density, i.e. the number of seats per metre of train length. The load factor also needs to be high, which might be more relevant in the short term as a way of achieving profitability. However, in order to select appropriate service and comfort levels and other supply factors, travel demand and passengers’ willingness to pay also need to be considered.

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