The relationship between travel distance and fares, time costs and generalized costs in passenger transport

by

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Introduction

In passenger transport, the perhaps most important explanatory factor for fare level on a journey is travel distance. This is reasonable because underlying factors such as operating costs and demand are influenced by travel distance. For the passengers this close relationship is regarded as fair because it implies increased fares as travelling distance increases. However, theoretical studies considering the relationship between public transport fares, generalised costs, fare elasticity and travel distance and how these relationships are affected by management objectives show that fares increasing with respect to distance are not necessarily optimal.

In addition to the monetary expenses of fares, the time related to travelling with a transport mode has a considerable alternative pecuniary value for the passengers'. A rationale passenger seeks to minimize the sum of monetary expenses (fares) and time costs when travelling. Hence, a passenger would rather choose a faster and more expensive transport mode than a cheap and slow alternative if it implies lower generalised costs for the journey.

The aim of this paper is to review empirical observations of the relationship between fares and travel distance and subsequently, using average rates for vehicle speed and time costs, derive the passengers' generalised costs for air transport, bus, fast craft vessel, ferry, and rail in Norway. A comparative analysis enables us to determine the preferred transport mode for a given distance. Further, time costs are presented and their share of generalised journey costs over different distances is derived for the transport modes.

The importance of travel distance

The pricing of transport services is a much studied topic. With the costs and demand characteristics as basis, the fare scheme is designed to maximize the underlying objective function of the company or the transport authority. Thus, it is reasonable that transport companies set fares according to profit maximization while transport authorities maximize the welfare of the society. Generally, the higher weight put on profit compared to consumer surplus, the higher are the fares for any distance (Jørgensen & Preston, 2005). However, as discussed for bus transport by Nash (1978), companies and transport authorities could maximize other objectives than profit and social surplus. For example, Mathisen (2003) consider goals relevant for managers such as sales and number of passengers when deriving the relationship between fares and travel distance.

The role of travelling distance is relevant to discuss because it influences both supply and demand through operating costs and generalised costs respectively. Jørgensen and Pedersen (2004) present theoretical interpretations of how fares are related to travel distance and management objectives and find an ambiguous relationship. Jørgensen and Preston (2005) have addressed this topic using two types of objective functions and three types of demand functions and finds that the relationship between fare and travel distance depends on the form of the functions and is not necessarily positive.

Empirical review

The empirical experiences with respect to fares and travel distance are limited. Some studies have focused on how operators marginal costs are influenced by travel distance in the

Norwegian bus industry (Jørgensen & Preston, 2003) and ferry industry (Jørgensen et al., 2004). Based on observations of relationships between fare and travel distance, some Norwegian studies have presented linear fare schemes; Kolstad and Solvoll (2000) for regulated bus services, Bomstad and Mjøs (2002) for rail and regional air transport and Mathisen (2003) for bus and air transport with low degree of regulation.

In such a comparative study, some of the underlying assumptions should be specified. First, the observed fares are ordinary fares (not discounted) on subsidised and highly regulated transport services. Second, some of the referred studies give quadratic and logarithmic fare functions in addition to the linear relationship. However, the difference in variance explanation (R^2) is so marginal that with respect to practical considerations and comparability only the linear relationships will be used. Third, some transport modes carry both goods and vehicles in addition to passengers but this survey considers passengers only. Finally, it should be noted that the studies are carried out at different years ranging from 2002 to 2004. The estimated fare schemes coefficients have been adjusted to 2005 average prices using the consumer price index (Statistics Norway, 2005) in order to ensure comparability.

The studied transport modes

Five different transport modes will be addressed, including public passenger transport by air, rail, road and sea: 1) air transport, 2) bus, 3) fast craft vessel, 4) ferry, and 5) rail.

Air transport is operated both on commercial and subsidised basis in Norway. A representative selection of the subsidised, and highly regulated, air transport services in the rural areas of Norway has been studied by Bomstad and Mjøs (2002). Empirical observations of the relationship between fare and travel distance for low regulated and commercially based air transport are described by Mathisen (2003).

Bus services are also operated on both commercial and subsidised basis. Kolstad and Solvoll (2000) have analysed the regulated bus services in Norway and has estimated the fare scheme for a representative county. Mathisen and Solvoll (2004) carried out a follow up study and estimated a fare scheme on a national basis. Although most bus services are highly regulated, there are express buses operating inter-city services on commercial basis and able to set the fares freely. These commercial bus services are studied by Mathisen (2003), revealing a surprisingly strict relationship between travel distance and fares even though they are free to set fares according to demand characteristics.

Fast craft vessels are high speed catamarans used for passenger transport in nine of the nineteen counties of Norway. Because this transport mode mostly operates in rural areas and requires substantial subsidies, it is regulated by the local transport authorities. Fares are publicly available and differ between counties. Distances between ports on the other hand are more difficult to reveal because of sailing lanes deviating from shortest distance. Still, on a national basis there are above 200 observations giving the basis for the estimated fare scheme. The data concern the year 2004 and was gathered for the purpose of this paper.

Ferries are vital for the transport and communication of the coastal areas of Norway. In 2004, there where about 175 ferries serving 131 crossings and about 20 million passengers. This transport mode operates mostly in rural areas and requires substantial subsidies. The Norwegian Directorate of Roads regulates the ferry industry and has implemented a national ferry fare scheme. There have been experiments with a new ferry fare scheme, which to a higher degree maximises social surplus, letting passengers travel for free regardless of distance (Solvoll & Jørgensen, 2001). Recently competition using competitive tendering (Bråthen et al., 2004) and free ferries (Jørgensen et al., 2005) have been proposed by the new government. Still, the basis for this paper will be the traditional national ferry fare system for passengers in 2003 presented by the Directorate of Roads.

Rail transport is highly regulated in Norway and receives substantial subsidies from the State. Bomstad and Mjøs (2002) have studied the pricing of services provided by the state owned monopolist operator and estimated a fare scheme. Recently, railway transport has been considered for privatization and exposure to competition has been initiated by the use of competitive tendering.

Linear fare scheme estimates

Table 1 show the relationship between fare and travel distance for different transport modes in 2005 prices using OLS regression. The fare scheme gives the fare in NOK[1] for a transport mode j, F_j, at a given distance in kilometres, D. More specifically, the variable D represents the distance the passenger experiences onboard the vehicle, whether it is by road, direct line by air or sailing lane by sea. The R^2 test indicates to which degree the variance in the fare (dependent variable) is explained by the travel distance (independent variable). The values for R^2 in Table 1 indicate strong relationships between the independent and dependent variables for all transport modes. It is worth noting that travel distance explains all variation in fares for the ferries.

Table 1 - The relationship between fare and travel distance for different transport modes (2005 prices)

Transport mode	**Fare scheme**	**R^2**
Air transport	$F_1 = 269 + 5{,}42 \cdot D$	0,92
Bus	$F_2 = 22 + 1{,}15 \cdot D$	0,97
Fast craft vessel	$F_3 = 13 + 2{,}19 \cdot D$	0,97
Ferry	$F_4 = 15 + 1{,}12 \cdot D$	1,00
Rail	$F_5 = 153 + 0{,}91 \cdot D$	0,96

The fare schemes in Table 1 indicate that linear functions, compound of a constant and a raising coefficient, gives good approximation of the relationship between fare and travel distance. The full fare for e.g. air transport, F_1, can be interpreted as a cost for the passenger of NOK 269 to enter the plane with an additional cost of NOK 5,42 for each kilometre travelled. Table 1 show that air transport has both highest constant and steepest slope, while fast craft vessel has the lowest constant and rail the flattest slope. The different fare schemes from Table 1 are graphically illustrated in Figure 1.

Not all of the estimated fare functions in Figure 1 are valid alternatives at all distances. Based on the distance intervals of the observed transport services it is reasonable to make restrictions for all transport modes using three roughly divided categories, short, medium and long. On land, bus is a valid alternative for both short and medium, rail for medium and long and air transport on long distance only. Fast craft vessels and ferries are obviously only alternatives in the coastal areas, but while ferries typically operate on short crossings the fast craft vessels are an alternative also for medium distances. Air transport, which is primarily intended for

[1] Currency rates at 3rd August 2006: 1 € = 7,87 NOK, 1 $ = 6,16 NOK

travelling over long distances, has a generally high fare level and is positioned at the upper part of Figure 1 while bus, fast craft vessel, ferries and rail groups together at the lower part. These fare schemes have low constants and a relatively little increase in fares with respect to travel distance.

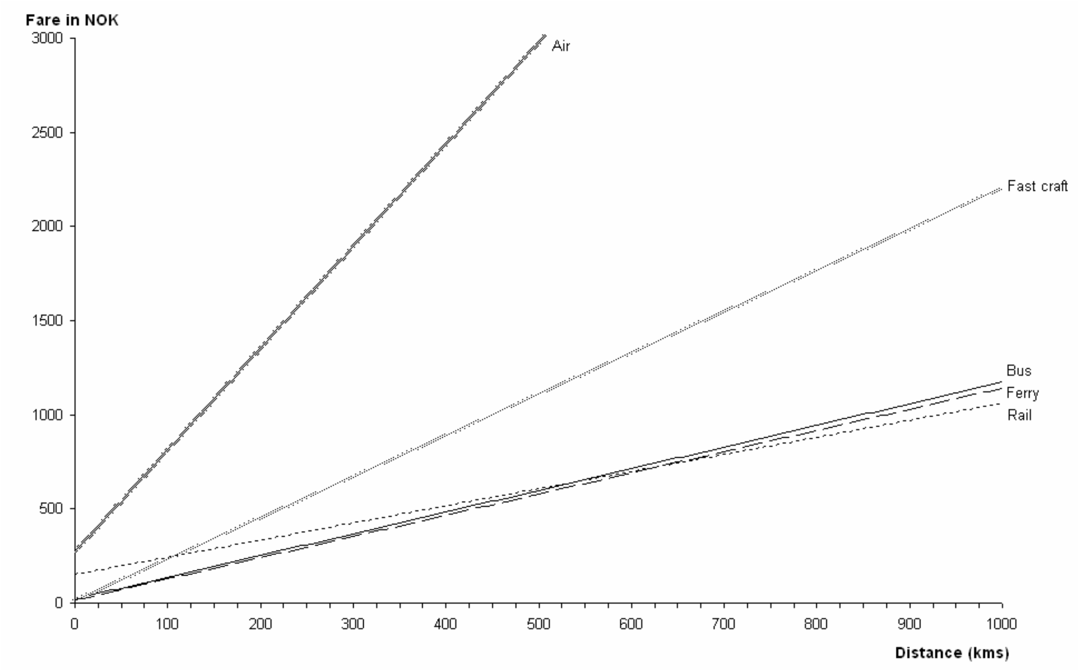

Figure 1 - The relationship between fare and travel distance for different transport modes

Figure 1 shows that the fares at a given travel distance differ substantially between transport modes. One could argue that the comparison has limited practical use, since the different transport modes are suitable for different travelling purposes. Still, for most trips two or more of the studied alternatives are usually present in addition to the car, especially between the larger cities. For example, public transport on the distance between the two Norwegian coastal cities of Bergen and Stavanger (180 kms by road including a ferry service) is provided by air, bus, fast craft vessel and rail.

Generalised journey costs

The demand for transport is explained by standard micro economic theories (e.g. Hensher & Brewer, 2001) and behavioural models (Gunn, 2000). It is assumed that a rationale passenger will not only consider transport against the cost of other goods but he will also choose the transport mode which gives the lowest generalised costs (travel resistance) for the specific travelling distance. Time has a price and alternative use and implies that passengers' time spent on board a vehicle could be allocated to other activities and has an alternative usage that can be given a pecuniary value (Becker, 1965; Bruzelius, 1979).

(1) $$GC = a_0 + p + \sum_i a_i q_i$$

By relating the fare schemes in section 2 to average speed and time costs of the respective transport mode, we are able to derive the total costs for passengers making journeys with different transport modes over different distances. The total costs are defined as the generalised journey costs in equation (1) (Balcombe et al., 2004). The generalised journey costs, GC, are the sum of monetary costs, p, and time costs, a_iq_i, where a_i is the value of the time q_i for time component i. Hence, the time component can be divided into a number of sub-categories (i's) in order to get a higher degree of detail in the analysis. In the following analysis only time onboard the vehicle will be considered and time components as walking and waiting will be omitted, i.e. i = {onboard}. The money costs, p, are determined by the fare schemes given in Table 1 and time costs, a_iq_i are based on averaged observed values from time travel studies.

The calculation of generalised journey costs

The generalised journey costs in this study consider the part of the trip onboard the vehicle only. In order to consider all time costs related to a journey, passengers' inconvenience of waiting before and after a trip should be included. Walking and waiting is, however, not considered to be important for the specific relationship between generalised costs and travelling distance and is omitted in this study to improve comparability between transport modes. In the following analyses the quality is not explicitly implemented in the model. However, because the used time costs per hour is based on observed values and specific for each transport mode, the quality variable is indirectly considered.

Total time costs for a trip, a_iq_i, is calculated by multiplying time costs per hour, a_i, by total travel time measured in hours, q_i (average speed divided by distance). Average speed on a transport mode is based on scheduled speed and compared with empirical experiences wher available. For example, estimates of bus average speed are given in a report by Balcombe et al. (2004) and of rail by the Norwegian National Rail Administration. Rates for passengers' time costs per hour is based on time valuation studies collected in a handbook for cost-benefit analysis prepared by the Norwegian Directorate of Roads (2005). The time costs for fast craft vessel and ferry are assumed to be equal to public transport service by bus on land.

Table 2 presents the average speed for different transport modes with the corresponding average time costs for the passengers. The handbook (Directorate of Roads, 2005) present hourly time cost for each transport mode specifically and the variation is considerable. Some of the differences in the observed values can be explained by different quality levels on the transport modes and different average travel purpose for the passengers. Air has for example higher share of business passengers than bus and thus higher average time costs. However, this can not explain all the difference between hourly time costs on air transport compared to other transport modes. It seems that passengers find it considerably less comfortable to spend an hour in air than on ground. This could be reasoned by lower comfort and a general inconvenience (or phobia) for flying.

Table 2 - Average speed and time costs (2005 prices)

Transport mode	Average speed	Average hourly time costs
Air transport	400 km/h	267 NOK
Bus	25 km/h	57 NOK
Fast craft vessel	40 km/h	57 NOK
Ferry	20 km/h	57 NOK
Rail	65 km/h	70 NOK

The information in Table 2 can be transformed to a linear function describing how time costs, $a_i q_i$, increases with travelled distance, D, by multiplying the time costs per hour with the time it takes to cover the specific distance. Subsequently, the generalised journey costs for a transport mode can be derived by summarizing fare schemes from Table 1 and time costs from Table 2 at any given distance. Because both fares and time costs are predicted using travel distance and assumed to be linear, the generalised journey costs will represent a perfect linear relationship increasing with distance and thus return an R^2 value on 1.

Figure 2 illustrates the generalised journey costs for an average passenger. The transport mode representing the lowest generalised costs is marked with bold at the lowest part of the figure. Which transport mode is preferred depend on the distance and two intersections are marked in Figure 2 to indicate the changes between best functions. Ceteris paribus, as marked by intersection A, the preferred transport mode for distances below 50 kms is fast craft vessel. Bus is the best alternative from 50 kms up to intersection B at 90 kms where rail is preferred for longer distances. For business travellers with higher time costs the intersections are at lower distances, and opposite for leisure travellers.

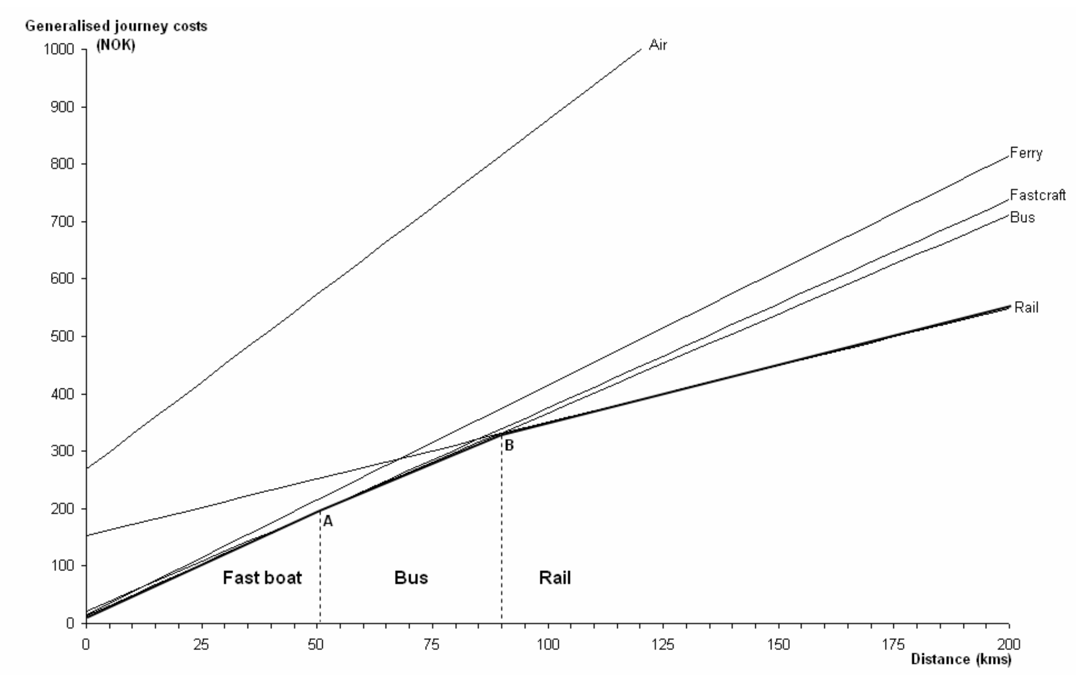

Figure 2 – Average passengers' generalised costs for different transport modes

The generalised journey costs in Figure 2 have the same constant as the fare schemes in Table 1. This is reasonable because a trip on zero kms implies no travel time onboard the transport mode. The raise with respect to distance in Figure 2 is the sum of the slopes of fares in Table 1 and the time costs derived from Table 2. This is the marginal generalised journey costs and indicates an average passengers' marginal cost for travelling one more kilometre.

The marginal generalised journey costs, representing the passengers' marginal costs of travelling another kilometre, is derived by differentiating the curves in Figure 2 with respect to distance and is equal to the coefficient of the slopes. As expected, the marginal generalised cost for travelling another kilometre is higher for business travellers than leisure travellers. For example on ferry, which is the slowest transport mode, the passengers' marginal costs for leisure travellers is about half the value for business travellers, while they are near equal for air transport.

Air transport and ferry are according to these calculations not the preferred transport mode for any distances. Still, ferries are often used of necessity because they operate in areas with difficult accessibility and are the only real alternative for many passengers. The use of air transport despite the high generalised costs can be explained primarily by three factors. First, the studied air transport services are full fares on services regulated by the authorities. Travellers using discounted fares in competitive markets would be able to considerably reduce the air transport fare level. Second, the figure is based on average hourly time values and passengers with high time costs will find air transport more attractive because of the high speed. Finally, air transport could simply be the only real alternative transport mode for some trips over long distances.

The composition of generalised journey costs with respect to distance

Because the time costs increases from zero they will represent a larger share of generalised costs as distance increases. If fares increase more than time costs with respect to distance there will not be any point where both costs components are equal, but the time costs share of generalised costs will increase towards an asymptote as the constant in the fare function are being spread on more kms. Because of the linear function form, this asymptote is the marginal time costs share of the marginal generalised journey costs.

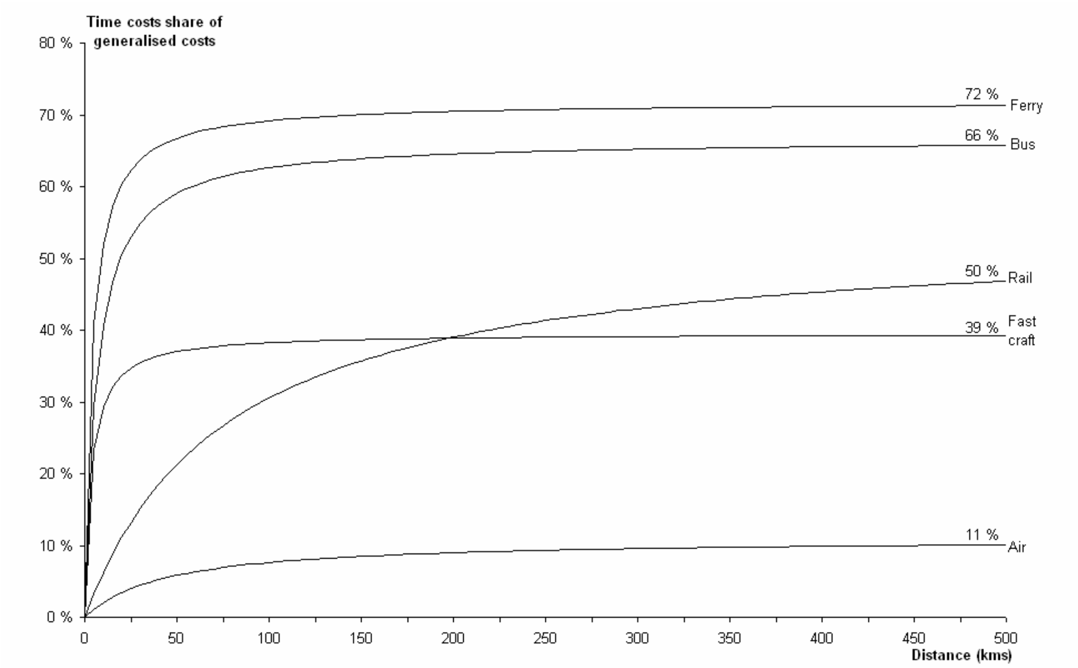

Figure 3 – Time costs share of generalised journey costs

Figure 3 shows that the marginal time costs share of marginal generalised costs varies considerably between transport modes and distance. The share is positively related to vehicle speed and air transport is thus in a special position with extraordinary low time costs per kilometre. Because air and rail has higher constants in the fare functions, their curves reach the asymptotic value at higher distance than the other transport modes. The share indicated at the far right of Figure 3 is the time costs approximate share of generalised costs for high distances. Even though time costs make a small part of the generalised costs for air transport, the pecuniary value is still relatively high compared to other transport modes because distances are long and the fares are high.

Using bus as an example, the fares are larger than time costs for short distances, but time costs are increasing more with respect to distance than fares. Figure 3 shows that the two cost concepts are equal for bus at about 20 kms. For longer distances the time costs make the majority (about 2/3) of the generalised journey costs. This implies that it is most important to minimize the time costs on long-distance bus trips, e.g. by increasing quality or increasing speed.

Concluding remarks

It is well recognized that travel distance is an important factor when determining the fare level for public transport. Theoretically, the relationship between fares and travel distance depends on underlying objectives and the costs- and demand functions. This paper has analysed empirical data of the relationship between fare and travel distance for different transport modes in Norway. Fare schemes are derived from the observations for five transport modes: air transport, bus, fast craft vessel, ferry, and rail.

A comparison of the estimated fare schemes for the different transport modes show that air transport has considerably higher fares than the other transport modes. As distance increases, the fares make a relatively smaller share of the passengers generalised journey costs. Hence, higher fares on long-distance transport modes can be reasoned by the higher quality level required to reduce the time costs share of generalised travelling costs as fares gets less important with respect to distance.

Presuming that all transport modes are valid alternatives on a journey, a comparison of a passengers' generalised journey costs can identify which transport mode is preferred for a given distance. The calculations are based on average values for travel purpose, vehicle speed and time costs per hour. There are two intersections when identifying the preferred transport mode. Fast craft vessel is the preferred alternative for trips up to 50 kms followed by bus up till about 90 kms where rail becomes the best alternative for longer distances. In practice, for many trips several of these transport modes will not be valid alternatives and the next best ranked transport mode will be the chosen.

The assumption of linear relationships implies that the generalised journey costs have the same constant as the fare schemes and a raise with respect to distance which is the sum of the slopes of fares and time costs. The marginal costs, derived by differentiating with respect to travel distance, indicate the costs for travelling one more kilometre. The marginal generalised journey costs for travelling one more kilometre depend on transport mode and vary from NOK 2 to NOK 6, of which the marginal time costs share varies from 11 % by air to 72 % by bus. These estimates rely on average speed of the transport mode and average time costs of the passengers. Hence, the passengers' marginal generalised journey costs will be higher 1) at services operating at lower speeds than average and 2) for business passengers with time costs above average.

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