OECD

International Transport Forum

JOINT TRANSPORT RESEARCH CENTRE

Discussion Paper No. 2009-27
December 2009

Potential Economic Impacts of Technological and Organisational Innovations in Intermodal Access to Major Passenger Terminals

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ABSTRACT

This report deals with the potential economic impacts of innovations such as smart ticketing and instantaneous access to rail and modal connection information schedules. First, the qualitative role of TOIs (technological and organizational innovations) is explored within the framework of intermodality. Secondly, a simple, quantitative, parametric model is described. The model is then used to analyze the impact of TOIs on rail demand, accessibility and passenger welfare under the assumption of bounded rationality. Providing that the model captures the major processes in play, the results will show the potential effects of policy choices and technological innovations both on their own and in a combined form, thus enabling discussion of their relative merits and synergies. An analysis of quantitative results shows that the effect is positive, highly non-linear, and prone to cumulative effects due to far-reaching impacts related, for instance, to the economics of climate change.

1. INTRODUCTION

The High Speed Train (HST) is steadily becoming a flexible and convenient mode compared with alternatives such as the private car, bus and plane. Swift boarding; the possibility to work and/or have meetings while in transit; and the centrality of most of the HST stations in Europe, have all helped to increase the number of business trips involving train transport in the last decade. HSTs are also used for commuting in several European contexts (notably in Spain, where services connect Madrid to Segovia, Toledo, Guadalajara and Zaragoza; and Barcelona to Lleida and Zaragoza). The captive market represented by the current growth in commuter traffic sees new users making rational choices that offset escalating property prices in central locations with cheaper living costs in satellite cities that lie within a reasonable range.

Empirical evidence shows that white collar workers and those in the advanced tertiary sector account for the majority of weekly trips (figure 1). This market is attracted by ticket discounts for bulk purchases, flexible fares, and reliability. Another, more reduced, business market is insensitive to price. Occasional travellers preferring rail over plane favour stress-free trips to the increasing annoyances associated with air travel, and centrally located, urban rail stations to peripheral terminals that are often a long way outside city centres. Considering all these factors, intermodality has a definite influence on leaning frequent users towards the train and limiting car use to what has popularly been labelled as “the last mile”: the connecting trip from the last public transport mode to either home or work. Improved intermodality is widely seen as one of the major factors that can be used to promote widespread public transportation in Europe.

It is generally accepted that the success of the intermodal model largely depends on whether or not public transport is perceived as efficient and on how seamless the modal shift can be made (UITP, 2003). Within this framework, technological and organizational innovations (TOIs) may have a profound impact on intermodality. Newly-available technologies, including high-tech phones with internet access, combined with real time information on timetables and the possibility to make remote purchases of tickets at the last minute, reduce impedances in the rail business. Thus, TOIs increase efficiency on both the rail operator and user sides.

2. INTERMODALITY AND ACCESSIBILITY IN EUROPE

Improved intermodality is one of the cornerstones of a sustainable transport policy. One of the reasons for the widespread use of private cars throughout Europe is their ability to provide door-to-door transport despite problems associated with traffic congestion and the lack of parking spaces in most urban regions. Diseconomies associated with the use of private cars include: injuries and death due to road accidents; unproductive travel time due to accidents and traffic congestion; a dependence on non-renewable sources of energy; and damage and other negative effects associated with environmental pollution (Jakob et al., 2006). One way to palliate these effects would be to promote hybrid or electric cars. Another strategy would involve promoting a modal shift from the use of private cars to public transport. The basic idea would be to persuade travellers to only use cars on trips between their homes and public transport, instead of driving all the way to their final destination. There is growing recognition of the fact that sustainable mobility implies inter-connecting transport systems that must provide a door-to-door service (European Commission, 1999). In this respect, the intelligent planning of intermodality offers a means of increasing the sustainability of interurban passenger transport systems: the better that these resources can be combined and co-ordinated in an integrated manner, the greater the sustainability of the whole transportation system (European Commission, 2001).

The main nodal points in the intermodal networks of present day Europe are the European high speed train stations (HSTS). While the impedances in the rail network itself are related to environmental or physical constraints, such as slopes and the volume of rail traffic, and are difficult to overcome, friction resulting from the suboptimal intermodality of high speed train stations has much more of a planning component. It has already been shown that there is a clear hierarchy of stations with status being linked to their respective roles within the regional system and with strong constraints that prevent some stations from performing optimally and as truly intermodal nodes (Tapiador et al. 2009). In this context, TOIs may help to smooth out passenger flows.

An in-depth study that was carried out by the Task Force of the Transport Intermodality group highlighted modal imbalance in the EU transport system and identified obstacles that prevent the development of user-oriented door-to-door intermodal transport services. In that work, transfer point efficiency and the efficiency of intermodal networks were identified as two of six areas of major interest for advancing research into intermodality. A lack of information and the impossibility to investigate the way in which some services were organised were amongst other relevant factors. Alternative methods and tools for assessing potential modal shifts have been described by Tsamboulas et al. (2007). These include complete policy action plans that could be useful for decision makers.

Regarding accessibility, there is a clear connection between improved intermodality and increased accessibility. Accessibility is defined here as the ease with which an individual can reach or access a specific place, infrastructure, amenity, or job opportunity, or generally to participate in activities. The more accessible the activity is, the fewer travel barriers and less travel friction need to be overcome to reach or access it. This term is also used to specifically refer to the ease with which the disabled can use transit or transportation facilities. The difference between the two meanings lies in the fact that what can be generally seen as a cause of friction within the system (for example, a staircase at a two-level exchange) may represent a barrier for disabled people (if there is no lift available).

Accessibility is of great economic and social significance in the field of transport economics and policy and this has been recognised by the European Spatial Development Perspective (European Commission, 1999), which states that improving the accessibility of Europe’s regions is considered necessary for improving their competitive position and also the competitiveness of Europe as a whole. Accessibility influences the advantage of one location over others. For the USA, Kuby et al. (2004) examined the importance of accessibility (among other factors) in terms of light-rail station boardings, which they found to be significant. Estimates of accessibility have therefore been used to assess the advantages that households and firms derive from the existence, and use, of local transport infrastructure. It is supposed that areas with better access to points supplying input materials and offering markets will, *ceteris paribus*, be more productive, more competitive and more successful than those whose locations are more remote (Spiekermann, 2005).

3. PASSENGER PROFILING

Modelling the effects of TOIs in HSTS requires an indication of the composition and behaviour of the users. Passenger profiling from passenger surveys, such as that described by Burckhart et al. (2008) for the Madrid-Barcelona line, is a useful way of feeding a parametric model with empirical information for case studies (figure 1). The modal share offers an important way to quantify how TOIs may affect travel. For instance, underground and conventional rail users have less need for real time information as they can rely on stable timetables and generally have established habits and routines; but private car, bus and taxi users may prefer rail to other alternatives if timetables, ticketing and access information is promptly available anywhere and at any time. The relative proportion of each mode depends on the station in question (figure 2) and this constitutes an obstacle to proposing any kind of comprehensive quantitative model that would be valid for every location. Instead, the model has to be of the parametric type and allow adaptation and the incorporation of up-to-date data when this is available.

The reason people travel is also relevant when constructing a model. In the Burckhart et al. study (2008), most of the trips were work-related with a predominance of professional business trips (figure 3). The modal break-up, such as that shown in table 1, is a key input if we are to derive results that will be useful for planning because the effects of TOIs are modulated by cross-relationships between the transport mode in question and the reason for travelling.

4. FACTORS AFFECTED BY TOIS

TOIs have both direct and induced effects on rail transport welfare. Direct effects refer to those that have a simple functional relationship with TOIs. The function itself can be either linear or non-linear.

Induced effects are those motivated by other variables and/or those that have resulted from the internal dynamics of the model.

4.1 Direct effects

4.1.1 Increased intermodality

Intermodality is defined by the EC (2004) as "a characteristic of a transport system that allows at least two different modes to be used in an integrated manner in a door-to-door transport chain". TOIs favour such seamless journeys by reducing transit times and associated uncertainties. Precise information on parking space and/or remote bookings of crowded car parks, the ability to reschedule trips combining several modes (if for instance a meeting ends sooner than expected), and new tools to cope with delays due to traffic jams, all help users to organize their travel both from and to the HSTS.

4.1.2 Policy priorities

TOIs permit access to deals devised to fill demand gaps. Intelligent pricing, targeting specific markets (last-minute or early-bird travellers; pensioners or students); time slots (late trains) or seasons (summer doldrums) are now remotely accessible for a range of potential customers.

4.1.3 Timetable and ticketing information

Instant access to timetable information relating to several different modes helps to match travel plans. Price information favours consumers making rational choices on trip mode and scheduling. Flexible fares and a sensible and user-friendly interface reduce impedances in the purchasing process. On-line ticket purchases and smart ticketing for public transportation increase both the number of transactions made and passenger welfare. An example of good practice is provided by the Swiss system, where timetables are sensibly matched to minimize dead time and, at the same time, ensuring modal connections. Thus, for instance, transitions between rail and postal buses are coordinated so that passengers can reach remote locations without excessive waiting.

4.1.4 Modal connection and accessibility

Regarding organizational innovations, it is important to provide a smooth modal transition. Apart from obvious measures such as ensuring full accessibility for every passenger, connections should be clearly indicated to avoid confusion. This is also applicable to on-line interfaces.

4.1.5 Greenhouse gas (GHG) emissions

Increased passenger traffic in HSTS directly reduces road congestion and carbon emissions. For comparison, the respective per capita CO2 emissions associated with a 100 km trip are: about 13 kg for a small car; 26 kg for a large car, and 6 kg for a rail trip. In terms of international carbon emissions, travelling by rail offers substantial savings in carbon emissions. The current price per tonne of CO2 is about € 12.

4.2 Induced effects

4.2.1 Station carrying capacity

The carrying capacity of a station is increased if waiting times are reduced, as an increased passenger flux permits more clients to use the same space at different times. Optimal passenger use in an HSTS is achieved when passengers can easily change modes without either delays or rushing, and can also make economic transactions in the (short) time between transfers. This avoids crowding, discomfort, stress, and risks and helps to create a perception of rail travel as a pleasant experience.

4.2.2 Average stay

Increasing the time spent at the HSTS reduces both perceived quality of life and productivity. The potential effect on shop sales, and thus on rents is not linear: whereas a certain amount of spare time spent at the station makes some travellers buy goods, behaviour is parabolic after a certain threshold time (which varies according to the HSTS). This effect adds to the discomfort of a long wait and increases the tendency for passengers to avoid the station in question in the future. The sharing and dissemination of passengers' negative impressions also generates diseconomies. It is well known that some HSTS are perceived as comfortable and friendly, while others are regarded as uncomfortable and confusing, etc. Being located 'in the middle of nowhere' or at peripheral locations plus presenting an infuriating lack of information on connections or travel alternatives creates a very poor impression of the intermodality of some European HSTS.

5. QUANTITATIVE INSIGHT: A PARAMETRIC MODEL

To gain an insight into how TOIs may help the economics of rail transport, it is useful to construct a quantitative model that takes into account the factors presented above. Whereas other approaches, such as Data Envelopment Analysis (DEA), have been applied to transportation modelling (e.g. Tapiador et al. 2008), most of the techniques referred to in recently published literature require empirical data, which are not readily available in this case.

The model described here is dynamic and simulates the structure of the problem in a schematic way so the complexities of the system do not render the problem impossible to analyse. The aim of the model is to simulate –rather than predict- the effects of changes in the different parameters. Models used to perform such sensitivity analyses have proved useful in several other fields, including climate change. As this model does not include empirical data, it is called a parameterized model. The results are projections under a prescribed scenario and the conclusions must be understood as estimates of the potential effects of changes in the parameters.

Figure 4 illustrates the different variables and relationships. Behind this graphical layout lies the mathematical modelling of the problem. The model assumes the existence of a captive market (commuters) and a new market yet to be attracted. TOIs affect both markets and their effects are modulated by independent policy priorities. These may include strategic decisions taken outside the rail business, such as those serving potential corporate interests in joint flight-rail ventures. The modal split is considered a social feature and is therefore an independent variable in this model. It directly affects the new market by providing new users and also affects greenhouse gas (GHG) emissions by helping to take cars off the road.

The analysis used in the model is in the form of time-varying coupled differential equations. The model is run for full annual periods with slightly-varying initial conditions resulting in a large ensemble of trajectories. This procedure is deemed to account for sensitivity to initial conditions in dynamical systems. The resulting ensemble is then averaged to provide the mean behaviour of the system, which is the variable used to extract policy conclusions. The spread of the ensemble members is comparatively smaller than the internal variability of the model.

The variables in the model are related through a variety of linear and non-linear functions. The actual shape of every function is derived from observations, for some cases, and from hypothesis, for those cases for which no empirical evidence can be easily extracted. Thus for instance, the new market variable is modelled as a function of technological innovations linear function with support in [0,1], and modal spilt linear function also within the [0,1] domain; both modulated by a seasonal pattern function. Other variables such as overcrowding effects are considered as non-linear, and modelled as such. Thus, a normalized sigmoid function is used for agglomeration diseconomies as it is assumed that after a threshold the negative effects stabilize.

The accessibility variables used in the mode are as follows. The *station capacity* variable encapsulates accessibility and intermodality variables such as intermodal entropy and intermodal integral time (Tapiador et al. 2009). *Modal split* is considered as a separate effect as it is affected by demand fluctuations. Regarding TOIs, timetable and ticketing information and possibilities for on-line purchasing are normalized in the model. These factors affect both the passenger market and HSTS operations by reducing confusion and crowding (Lam et al. 1999). This variable also depends on the carrying capacity of the HSTS in question and on the average stay, which is also dependent on TOIs. Reducing the average length of stay is deemed to slightly reduce passenger spending at the HSTS. This is, however, a simplification, as businesses would tend to react to shorter stays by adapting their offer. Even so, the overall effect would be relatively small within the scope of the inter-annual modelling carried out.

Seasonal patterns in new and captive markets are also considered to model holidays and working days without lunch breaks, which are characteristic of the summer routines of Spanish state employees. Split shifts modify the behaviour of the model, but only have a limited effect on daily aggregations. The weekly pattern is explicitly accounted for in the model by including a stochastic component. The seasonal pattern is modelled as piece-wise.

Even models as simple as the one described provide a wealth of information in the form of sensibility graphs, scenarios and possible parameterizations of the variables involved. The results must be analysed with an eye to the problem in hand. The crux of modelling is to achieve a delicate balance between the beneficial effects of attracting more passengers and the potential diseconomies associated with doing so.

Among many other possible effects that can be explored is the coupling between phase-shift cycles and TOIs, and the probable saturation of the market. Applying this analysis to real cases would require a precise knowledge of the time-evolution of the variables involved. This could be achieved by surveys or by undertaking dedicated studies at key HSTS.

6. RESULTS AND CONCLUSIONS

Given the stochastic component of weekly and seasonal cycles, ensemble simulations were carried out to characterize the mean behaviour of the system. The rationale of ensemble techniques is to palliate sensitivity to initial-conditions (SIC) by running a model under numerous slightly-different initial conditions. Since nonlinear dynamical systems are highly sensitive to these conditions, the runs will provide a set of different forecasts, no matter how close the initial conditions are to each other (Tapiador and Gallardo 2006). The results of the simulations then exhibit the effect of TOIs for a variety of likely cycles, with the mean values embedding the actual dynamics. Sensitivity analyses using the Jacobian of the (linearized) model can then be used to trace back the effects of every choice.

Runs were performed for several combinations of potential use of TOIs. Considering the input data, the results can be regarded as the application of a set of policies aimed at increasing passenger comfort and welfare in a canonical case. Empirical evidence shows that differences in accessibility and HST demand are highly correlated. Those stations with low accessibility and intermodality are those less used, whereas well-connected stations present high passenger traffic. The relationship, however, is not simple as the physical size of some HSTS was designed considering expected traffic. In the model presented here, accessibility, intermodality and the size of TOIs impacts in relation to the generalised cost of travel is highly dependent on the assumptions made, but some general conclusions can be derived. By elaborating the results in qualitative, policy terms, several issues arise.

The implementation cost of TIs is several orders of magnitude lower than the costs in infrastructure and in improving accessibility and intermodality. Passengers using TIs are by definition connected, and act as nodal points of innovations. Organizational innovations are also comparatively cheaper, and their effects multiplicative. Thus, and recognising that the model presented here cannot provide a quantitative estimate of such impact, the benefits of TOIs for rail travel are non-linear. One euro inverted in TOIs (including the effect of advertising) is likely to produce a larger effect on demand than the same euro put into other branches of the business. Figure 5 shows the result of simulation for a year after TOIs are implemented. It is observed a slightly-exponential growth of passenger traffic, which is indicative of accumulative effects.

Everything else the same, the net effect of an increase or improvement in the TOIs is positive for welfare. The effects on the modal shift show a cumulative effect on the economics of climate change. Synergies appear when satisfied customers spread the benefits of rail travel. Non-linearities within the model yield reinforcing feedbacks that suggest that one of the most efficient actions would be to favour the modal split. This can be achieved by a number of actions, including: providing a free Kiss&Ride drive through; reducing or removing parking fees for commuters; and setting special fares for business trips (such a combined park and rail ticket). Another measure would be to allocate free, dedicated parking spaces for electric cars, and to set up solar-powered charging bays for them. This organizational innovation would help to further reduce carbon emissions, improve intermodality, and reduce road congestion.

Effects not considered by the model include measures that would benefit urban economies. It is dysfunctional to have empty parking spaces at rail stations alongside commuters' cars packing the neighbouring streets. Such action would only transfer costs to municipal authorities and neighbours, with the associated risks and increased insurance claims. Reducing congestion in the areas around HSRS improves their centrality and makes it possible to control their gentrification. The benefits of TOIs in reducing passenger stress and discomfort, in promoting new values (balanced family/work time), and in increasing personal safety and security (no money involved in phone transactions, nine times lower accident risk associated with travelling by rail as opposed to by car, etc.) shows the importance of TOIs for the future of interurban passenger transport.

ACKNOWLEDGEMENTS

This work was partially funded by research grants CGL2006-03611 and PAI06-0101 (innovation and knowledge-transfer packages); the I3 and Ramon y Cajal programs, and the FP-005 Water, Road and Rail 2005SGR01089 project (European Science Foundation).

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Figure and table captions

Figure 1. Modal split at the Madrid-Atocha HSTS (data from Menéndez et al. 2006)

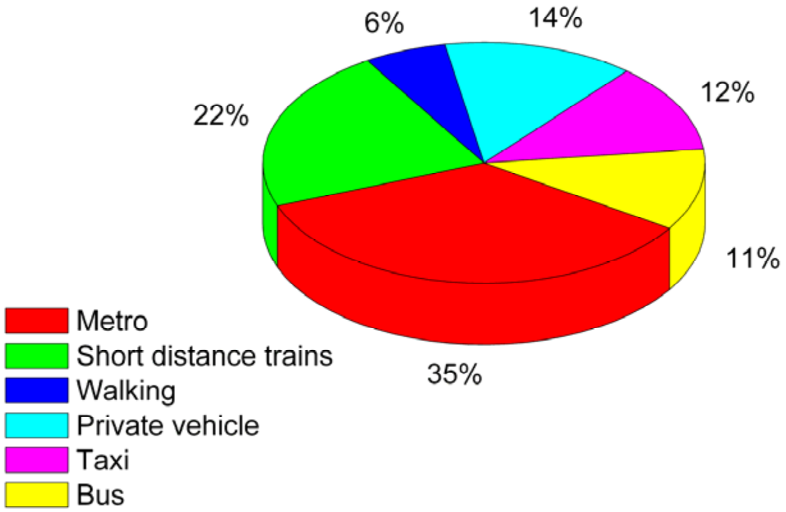
Figure 2. Modal split at the HSTS analyzed in Burckhart et al. 2008

Figure 3. Access times to the HSTS analyzed in Burckhart et al. 2008

Figure 4. Conceptual view of the quantitative model

Figure 5. Estimated evolution of welfare in a prescribed scenario. The x-axis represents the day of the year after implementing TOIs; the y-axis indicates the evolution of passenger traffic (arbitrary units).

Table 1. Cross relationships between mode and reason for travelling (expressed as a %, from Burckhart et al. 2008)



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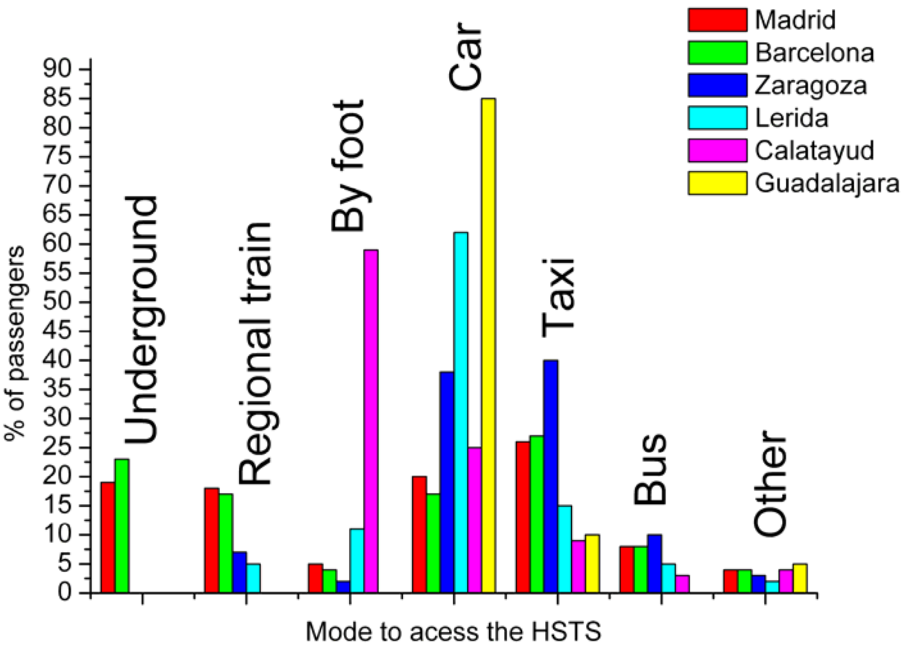

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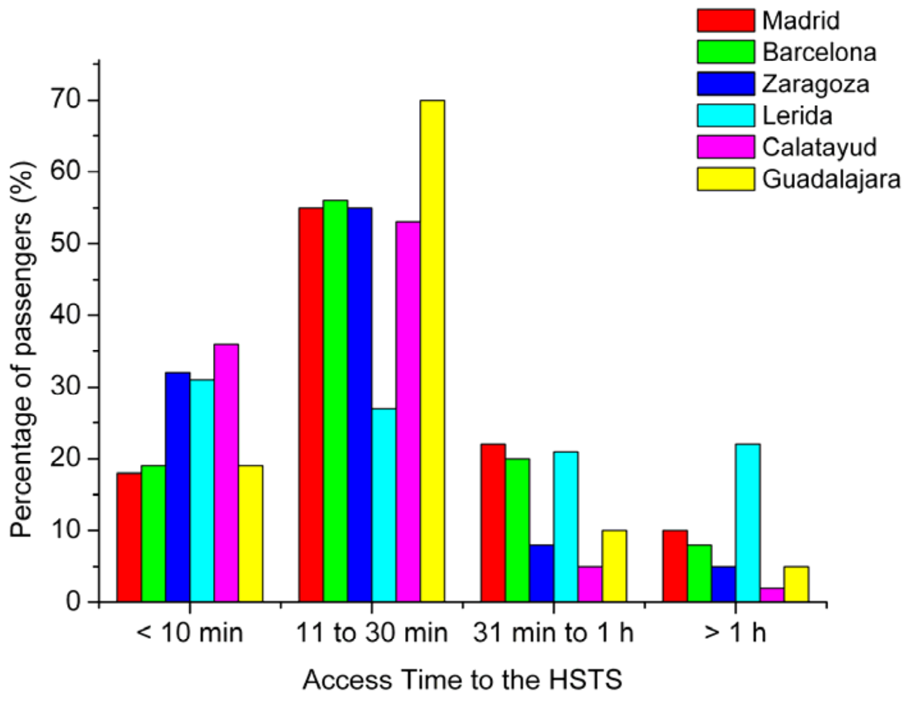

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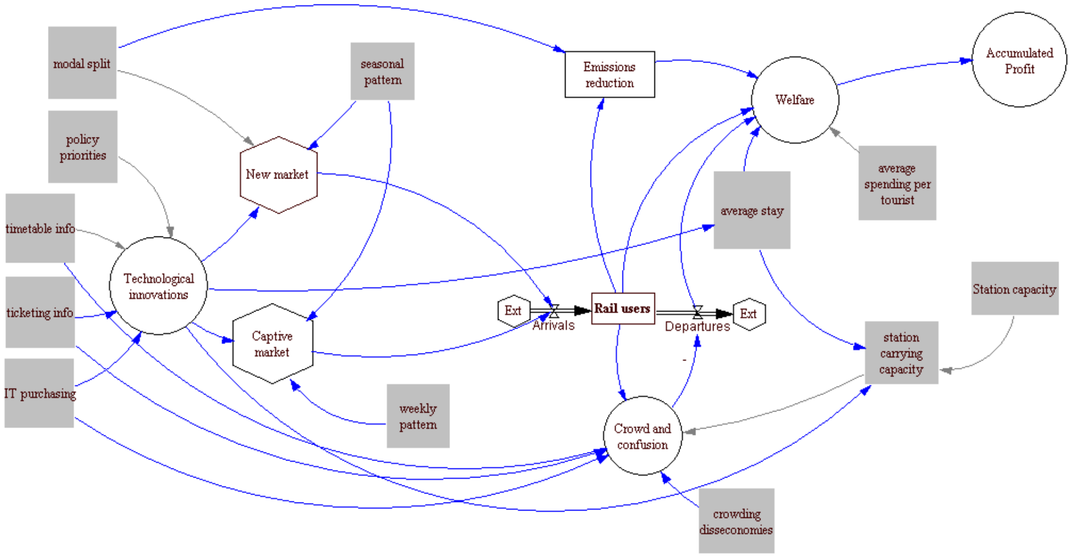

Figure 5. Estimated evolution of the welfare in a prescribed scenario. The x-axis represents the day of the year; the y-axis indicates the evolution of passenger traffic (arbitrary units).

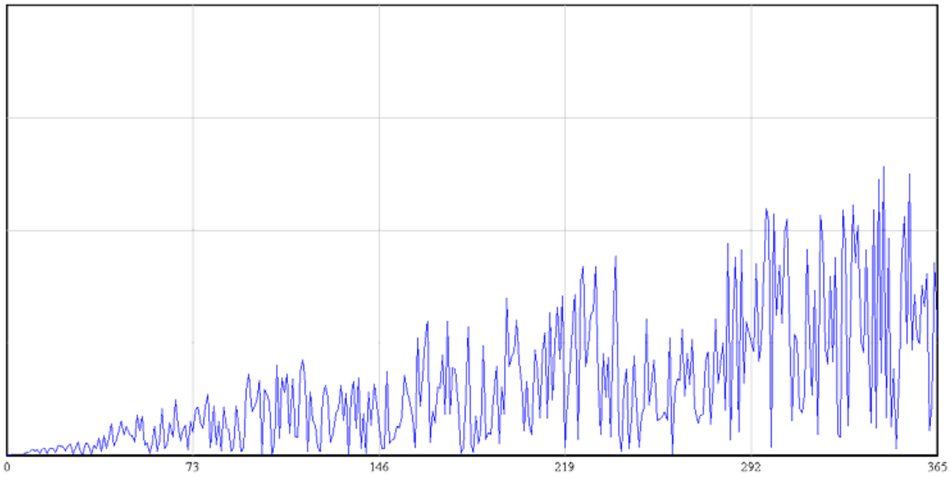

Table 1. Cross-relationships between mode and reason for travelling (expressed as a %, from Burckhart et al. 2008)

	Trip reason							
	Work	**Business**	**Tourism**	**Other**	**Family-related**	**Educat.**	**Health**	**Sum**
Car	7.1	15.7	4.0	1.0	5.3	0.9	0.4	34.5
Taxi	6.3	12.3	3.8	0.8	4.5	0.4	0.3	28.5
Bus	0.9	1.7	1.1	0.3	2.0	0.2	0.2	6.4
Other	0.7	1.6	0.5	0.2	0.4	0.1	0.0	3.5
Reg. Train	2.0	2.7	2.0	0.6	3.0	0.2	0.1	10.5
Underground	1.3	2.8	1.7	0.5	2.2	0.3	0.1	8.9
Walking	2.0	2.8	1.0	0.2	1.4	0.2	0.1	7.7
Sum	20.3	39.6	14.1	3.5	18.9	2.4	1.2	100