Available online at www.sciencedirect.com
ScienceDirect
Procedia Technology 22 (2016) 991 – 998
Procedia Technology

9th International Conference Interdisciplinarity in Engineering, INTER-ENG 2015, 8-9 October 2015, Tirgu-Mures, Romania

Options for Long Distance Passenger Land Transport Infrastructure Expansion. Analysis Regarding Network-based Sustainable Development

Oana Dinu[a,]*, Stefan Burciu[a]

[a]*University POLITEHNICA of Bucharest, Transport Faculty, 313 Splaiul Independentei, 060042 Bucharest, Romania*

Abstract

In the global reality of intense competition for financial resources, models for transport infrastructure and operational technologies development are to be taken into consideration in order to ensure that both service and physical network provision serves society's wider need. Proposed paper presents a detailed methodology for the substantiated choices of transport infrastructure development in case of long distance haul and high speed passenger travel, adequate for efficient resources consume (space, energy, finances). Practical aspects are revealed in the present comparative study regarding space and equivalent energy consumption, conducted for two land infrastructures, highway and high speed rail, connecting the same origin and destination points. As a result, although both services have their benefits and costs, high speed rail is recommended as a sustainable development action, ranking better than highway infrastructure. Recommendations concerning methodological clarifications and practical aspects are made in order to insure the best practice considering a sustainable network based transport infrastructure assessment process.

Peer-review under responsibility of the "Petru Maior" University of Tirgu Mures, Faculty of Engineering

Keywords: transport infrastructures; sustainable development; decision-making criteria.

* Corresponding author. Tel.: +0-074-550-4092; fax: +0-021-318-1012.
E-mail address: oana.dinu@upb.ro

Peer-review under responsibility of the "Petru Maior" University of Tirgu Mures, Faculty of Engineering
doi:10.1016/j.protcy.2016.01.124

1. Introduction

Taking into consideration the complexity of the transport network design and development problem, formulated as a mathematical optimization task, there is a large amount of literature debating this topic, merging the fields of transportation science, mathematics, geography, considering both financial perspective and socio-economic perspective. The difficulty in solving the problem consists in the existence of a multitude of variables and constraints that must be taken into consideration and thus limiting the number of possible solutions, leading to efficient methods to find results near the optimal one, ranging from mathematically based methods such as branch-and-bound techniques to heuristic research approaches [1, 2, 3]. Alternative approaches can be found in literature and consist in development of design methodologies, systematic stepwise procedures [4, 5], thus avoiding the limitations of optimization techniques or methodologies using for support artificial intelligence or knowledge-based techniques where the designer himself makes the choices he considers appropriate.

Basically, two different situations of the transport network development problem can be identified: first one - developing a new network from scratch, in this case a set of nodes is given and the task is how these nodes should be connected with either transport services [6, 7, 8, 9] and/or with physical links [10], such as a road or rail network and second one – expanding an existing network, in this case not only is a set of access nodes given but also the existing network. The question then is whether transport services or links should be added to or removed from the network [11, 12, 13], or if the capacity of existing services or links should be increased [14, 15, 16, 17].

Present study aims to identify, in the context of the complexity needed to apply theoretical principles to real life infrastructure development situations, ranking performance indexes correlated both with highway and high speed rail.

The paper is structured as follows: first section is an introductive one, in the second section the method of research is presented and discussed, then in the third section the comparative study is performed in relation mainly with selected land infrastructure space consumes and with energy consumption. The main findings conclude the paper and practical consequences are underlined.

2. Method of analysis: performed indexes for transport infrastructure development

A key difference between performance measurement in the service sector and performance measurement in transportation is that the overriding motive in the private sector is profit. In transport infrastructure development, on the other hand, the process is seldom guided by profit motive alone, but must consider numerous other motives such as equity and external effects [18]. Transport network service performance not only concerns travel quality but also evaluates access to different facilities; on the other hand it is integrated in a global mobility system consisting in infrastructures, modes and services ensemble.

Performance indexes role is to combine and distill various measures, potentially covering multiple dimension or goal areas, into a single measure and they can reduce the complexity and volume of data that must be regularly monitored. A single – sufficient performance index cannot be identified for transport infrastructures because they are designed, developed and operated technological in order to serve society's wider needs. As a result, infrastructure performance must be measured in the context of society's objective fulfillment and of multiple decisional factors. From travellers point of view, there can be outlined the society's objectives and transport network performance indexes shown in Table 1.

Concluding, it is necessary a multi criterion performances assessment of transport infrastructures, using indexes that are able to reflect society's wider needs that can sometimes be antagonistic. Some performance indexes are suitable only for specific situations while others can be extensively relevant. For instance, "good ratio (social) cost/ quality guaranty" index from Table 1, is a synthetic one, designed on multi decisional bases and gives a big picture on transport network performance and allows dynamic examinations and comparisons to other networks.

Table 1. Performance indexes correlated with society's objectives

Socio - economic objectives	Transport network performance indexes
ACCESSIBILITY in a certain area to all citizens (through an adapted transport infrastructure)	Space accessibility, proportional with network access points number and distribution (transport infrastructure network area coverage)
MOBILITY	Relative encountered movement difficulty
ECONOMIC DEVELOPMENT	Good ratio (social) cost/ quality guaranty;
	Insure that system functioning is economical acceptable for both travellers and comunity
QUALITY OF LIFE	Life quality dinamics on local and global level
ENVIRONMENTAL AND RESOURCE CONSERVATION	Environmental dinamics on local and global level
SAFETY	Accident number and gravity dinamics
OPERATIONAL EFFICIENCY	Productive efficiency, expressed as ratio between input resources (space, energy, finances) and output results (passenger km, seat km, commercial speed etc.);
	Commercial efficiency , when results concern passenger*km, incomes, etc.

3. Comparative study regarding space and equivalent energy consumption conducted for two surface infrastructures

3.1. Main characteristics of transport networks

Two different categories of transport networks are to be taken into consideration when analyzing a certain area [19]: physical networks or traffic service networks, seen as an assembly of road, rail, water or other considered infrastructures and transport service networks, seen as a system of utilities that are provided by buses, trains, ships.

It is obvious that transport service network is connected to physical network, since the second one represents the base for the first one. If for private transport seams sufficient to characterize the physical network then for public transport it is compulsory to characterize the service network in order to analyze the fulfilled degree of mobility.

If we analyze transport network from the traveller's point of view, travel costs and travel time are the most relevant features. This two attributes are directly determined by network characteristics, such as:

- Space accessibility, depending on the network access points number and their distribution;
- Time accessibility, which is usually considered to be unlimited for private transport road supported and, on contrary, for public transport, rail supported, the time accessibility is synthetically described by timetables;
- Network speed: the average speed while travelling on the network, which is determined by the network structure and the design speed, but also depending on traffic volume on each link.

If we analyze transport network from the financier's and the operator's point of view, costs are the most relevant features. The most important and well-known are:

- Invested capital, consisting in expenses for building the physical network, proportional with infrastructure type (rail, road, water);
- Maintenance costs, proportional to the level of performance imposed on the infrastructure and with infrastructure's age;
- Operating costs, these costs are especially related to transport service networks and include costs such as operating the vehicles, proportional with the quality of service offered.

Time accessibility and operating costs are directly connected to transport service network while investment and maintenance costs are mostly connected to physical network. Especially in public transport services with dedicated infrastructures, such as high speed rail, these costs become an issue that needs to be considered.

Two more characteristics are frequently used as decisional variables in transport networks design and development process: infrastructure capacity and connected operational technologies.

Capacity becomes an important feature when physical infrastructure network is no longer able to satisfy the demand at a quality level considered sufficient, level that is, most of the time, directly connected to expected travel time. Therefore, capacity of the network or of its elements should be such chosen to guarantee the expected quality level and network speed.

Connected operational transport technology can be considered another noticeable feature of a transport system, especially on public transport services, because technologies, to some extent, determine the fundamental characteristics of a transport infrastructure.

3.2. Capacity evaluation

Practical aspects of the theoretical approach previously presented are revealed in the comparative study regarding space and equivalent energy consumption that is conducted for two surface infrastructures, one for highway and one for high speed rail, connecting the same origin and destination points. This comparative study is possible because nowadays limitations in design phase, concerning minimal values (radius values, radius lengths, minimal distance between two successive curves) and maximal values (longitudinal gradient) became consistent and allows theoretical developments of common platforms for highway and high speed rail.

Capacity and traffic flow evaluation for each of the infrastructures, in different operational conditions regarding organization process, leads to computation of a specific space index.

In this study, we consider the case of High Speed Rail infrastructure used exclusively for passenger services, 250 km long and a 200 km/h maximum commercial speed, with adequate slopes (not exceeding 0.2% to 0.4%), and curvature radii (7 km radius for horizontal curves and 14 km radius for vertical curves) and very few stations (about one every 100 km), trigger acceleration of $0{,}3 m/s^2$ and maximal deceleration of $0{,}4 m/s^2$. For these conditions, route capacity (maximum traffic flow per single track) is evaluated for a homogenous traffic using analytical deterministic model at 42 train pairs per day.

One of the problems encountered in the development of train system is to determine a train configuration that can satisfy the given design task. There are some suggestions of train system configuration proposed and they are evaluated both qualitative and quantitative, using criterions shown in Table 2. We compared significant characteristics of three train configurations, including train weight, the number of passenger per configuration, energy consumption per passenger, travel time, axle load/unspring mass and available adhesion coefficient.

Table 2. Reviewed items for proposing a train configuration

Criterions for train design	Design target
Maximum speed	250 *Km/h*
Travel time	within 100 minutes
Ride quality	Same level with TGV-K
Energy consumption	Same level with TGV-K
Environmental effect	Same level with TGV-K
Passenger number	500 passengers
Adaptability of train configuration	Train system adaptable to international market in future
Costs	Life cycle cost, Initial costs, Costs management

Considering that capacity for selected train capacity is of 500 passengers, maximum transport capacity of the route is 42.000 passengers per day.

For most of European countries, a medium high speed train occupancy rate of 70% [20] is considered to be quite a high value, so if we apply it to previous results it leads to a passenger traffic flow of 29400 passengers per day, for homogenous high speed rail traffic.

Consequently, we consider the case of a highway, 250 km long and a 120 km/h maximum commercial speed, connecting the same origin and destination points as the high speed rail infrastructure, located in level or rolling terrain, each directional segment of two lane 3,75m wide, 1,8m distance to a lateral obstacle, C category LOS, with homogeneous cross sections and relatively constant demand volume and vehicle mix.

For these conditions, route designed capacity Q_{Sc} (traffic flow for selected C level of service) is evaluated at 3288 passenger-car equivalent/hour, leading to a value of 78912 passenger-car equivalent/day. For estimation of the value of medium annually flow rate, Q_{Sc} must be adjusted in order to apply the effect of directional distribution of traffic and of peak hour factor, leading to a value of 30712 passenger-car equivalent/day.

For most of European countries, a medium passenger-car occupancy rate of 1,5 [21] so if we apply it to previous results, it leads to a passenger traffic flow of 46068 passengers per day, for highway relatively constant vehicle mix traffic.

Previously, we obtained results concerning daily passenger traffic flow values on selected equivalent surface infrastructures, a high speed rail and a highway, both connecting the same origin and destination points. Corresponding to each type of infrastructure we can identify a standard cross section width (see Table 3) that allows us to compute a specific space index, a performance measure that characterizes how high space consuming a surface infrastructure is.

Table 3. Reviewed items for specific space index calculation

Surface infrastructure type	Standard cross section width *(m)*	Medium passenger traffic flow *(passenger-car equivalent/day)*	Specific static space index *(m/passenger)*
High speed rail	15	29400	0,00510
Highway	36	46068	0,00781

3.2. Equivalent energy consumption evaluation

Final energy consumption is the most important key figure for the calculation of total energy consumption and energy related emissions of transport. For the following calculation steps, final energy consumption must be differentiated for each energy carrier because different sets of emission factors and upstream energy consumption have to be considered for each energy carrier. Calculation depends on various factors, in particular, it should be pointed out that final energy consumption per passenger for rail and road is directly dependent on capacity utilization and thus the denominator of the equation (1):

$$CFE_{passenger*km,i} = \frac{CFE_{km,i}}{C_u \cdot U} \quad (1)$$

$CFE_{passenger*km,i}$	Represents final energy consumption per passenger km, for each energy carrier *i*, in *(MJ/passenger km);*
i	- index for energy carrier (e.g. diesel, electricity, HFO)
$CFE_{km,i}$	- final energy consumption of vehicle per km; normally depends on seat number related capacity utilization, in *(MJ/ km)*;
C_u	-payload capacity, in *(passenger)* ;
U	-capacity utilization, in *(%)*

In most european countries, for rail energy consumption calculation, a passenger kilometre weighted average value for each service type is used. These values include the average country and service type specific load factors and are used as standard for the emission calculation [21]. For the model feature of maximum ultilization, the specific energy values per seatkm considering a load factor of 100% are used. The specific energy consumption values presented in Table 4 are derived from the UIC Energy Database for the year 2007 /UIC 2009.

For the journey with passenger cars it is necesary to define different vehicle types, considering folowing criterias: emission standards (Conventional, Euro-1, Euro-2, Euro-3, Euro-4, Euro-5), energy (gasoline, diesel, LPG, Hybrid), size (Compact class <1.4l, Medium sized class 1.4-2l, Luxury class >2l) and load factor (average 1.5 persons or variations from 1 to 5 persons). Energy consumption and emissions of passenger cars are different for each road category (highway, rural, urban), include the extra emissions for cold start and evaporation. Assumptions listed in Table 5 are made for all parameter with influence on the energy and emission values of passenger cars [21].

Table 4. Average values for specific energy consumption of European trains (source [22])

	Electric *(Wh/Passenger km)*			Diesel *(g/passenger km)*	
	Highspeed	Intercity	Regional/Suburban	Intercity	Regional/Suburban
Average	70	77	110	17	25
	Electric *(Wh/seat km)*			Diesel *(g/seat km)*	
	Highspeed	Intercity	Regional/Suburban	Intercity	Regional/Suburban
Average	32	30	35	7,3	8,3

Table 5. Parameter settings for the estimation of road energy consumption and emission factors

Parameter	Values
Highway average speed *(km/h)*	100
Mileage degradation	
Mean fleet mileage Euro-1 / -2 / -3 / -4 *(km)*	100.000/ 70.000/ 40.000/ 20.000
Additional emissions for cold start and evaporation on congested roads (%):	
Fuel Consumption	+15%
NOx Gasoline	+100%
NO_X Diesel	+5%

Regarding equivalent energy consumption comparison for the High Speed Rail infrastructure used exclusively for passenger services, 250 km long and a 200 km/h maximum commercial speed and the highwayinfrastructure, 250 km long and a 120 km/h maximum commercial speed, connecting the same origin and destination points as the high speed rail infrastructure, we explored the central European transport network and selected the main origin/ destination nodes that are conected with a high speed rail and a highway similar in lenghts and travel conditions with the ones proposed for this study. Using EcoPassenger platform we were able to evaluate equivalent energy consumption presented in Table 6.

Table 6. Equivalent energy consumption for selected network

Route	High speed rail *(l/ passenger km)*	Highway *(l/ passenger km)*
Londra - Lille	0,012046	0,048103
Lille - Paris	0,004889	0,051613
Lille - Brussels	0,016964	0,051376
Paris - Brussels	0,019489	0,051495
Brussels - Amsterdam	0,031797	0,051691
Brussels - Cologne	0,039815	0,051389
Amsterdam - Cologne	0,04313	0,051923
Cologne - Frankfurt	0,042778	0,051309
Stuttgart - Strasbourg	0,035754	0,051613
Strasbourg – Basel	0,009286	0,045876
Paris - Strasbourg	0,005957	0,051534
Infrastructure proposed for this study	**0,02381**	**0,05072**

For the entire selected network, with no exception, equivalent energy consumption for high speed rail utilization is substantially lower than for highway, as shown in Figure 1.

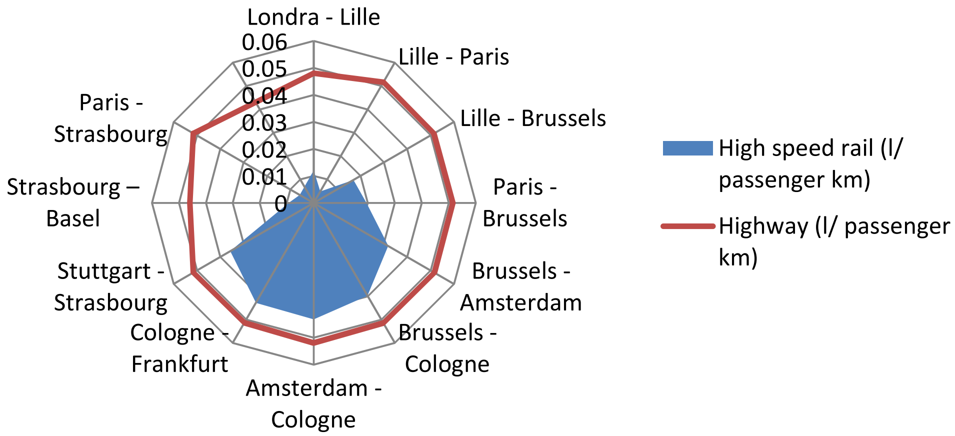

Fig. 1. Equivalent energy consumption comparison for high speed rail and highway infrastructure, in *(l/passenger km)*

4. Main findings

As a result from proposed comparative study regarding space and equivalent energy consumption, conducted for two surface infrastructures, connecting the same origin and destination points, the less space consuming infrastructure is rail, operated for high speed train homogeneous traffic with specific static space index 0,00510 *m/passenger*; if high speed trains are mixed with other train categories (using the same infrastructure) than route capacity falls to the point where rail infrastructure is no longer competitive with highway infrastructure with static space index 0,00781m/passenger , in respect with space consume. Evaluated equivalent energy consumption has the value of 0,02381 *l/passenger km* for high speed rail utilization and 0,05072 *l/passenger km* for highway utilization, so almost double for road infrastructure.

For the substantiated choice of long distance passenger high speed infrastructure development, adequate for efficient resources consume as space, energy and finances we can also add, to the results obtained in this study, cost values for building and maintaining selected surface infrastructure (Source data: International Energy Agency on UIC 2012, IRF 2012 and ITF 2011), presented in Table 7.

Table 7. Reviewed items for substantiated choice of long distance passenger high speed infrastructure development

Surface infrastructure type	Specific static space index *(m/passenger)*	Equivalent energy consumption *(l/passenger km)*	Invested capital *(mil euro/ km)*	Infrastructure maintenance costs *(% of invested capital)*
High speed rail	0,00510	29400	5 – 12	0,2 – 0,4
Highway	0,00781	46068	12-30	3

Proposed methodology concerning transport infrastructure assessment, in order to define objectives and to establish specific criteria used for selection of the most appropriate transport mode in a specific area, consists in a set of performance indices that are calculated for two concurrent surface infrastructures and their connected operational technologies. We applied them in a multi-criteria decision analysis method that leads to ranking given infrastructures. In the context of the complexity needed to apply theoretical principles to real life infrastructure development situations, although both highway and high speed rail, have their benefits and costs, high speed rail is recommended as a sustainable development action, ranking better than highway infrastructure.

The results from present study and the measurements we obtained from practice conclude our recommendation in favor of high speed rail development as a substantiated choice for long distance passenger surface transport infrastructure expansion although reality shows the opposite, especially in South East part of Europe and the emerging countries; where highway infrastructure development appears to be headway.

The design and future development problem then is to constitute a network that balances these two opposing objectives conflict between traveller's and the investor or operator's perspectives [23]; the traveller prefers direct connections between any origin and destination, and, if time accessibility also plays a role, at any time while the investor or operator favors a minimal network in space, and in time, thus reducing all cost factors.

Acknowledgement

The work has been funded by the Sectoral Operational Programme Human Resources Development 2007-2013 of the Ministry of European Funds through the Financial Agreement POSDRU/159/1.5/S/132397.

References

[1] Magnanti TL, Wong RT. Network design and transportation planning: models and algorithms. Transportation Science 1984; 18-1:1-55.
[2] Yang H, Bell MG. Models and algorithms for road network design: a review and some new developments. Transport Reviews 1998; 18-3:257-278.
[3] Van Nes R. Design of multimodal transport systems, setting the scene: Review of literature and basic concepts. TRAIL Studies in Transportation Science Series, No.S99/3, Delft: Delft University Press, 1999.
[4] Frank D & al. Mindestsiedlungsdichte für den ÖPNV, Internationales Verkehrswesen 1994; 46-1:25-30.
[5] Kirchhoff P & al. Rufbus-linien im Landkreis Erding, Der Nahverkehr 1996; 4: 29-32.
[6] Ma J, Schneider JB. Designing personal rapid transit (PRT) networks. Journal of Advanced Transportation 1991; 25-3:247-268.
[7] Baaj MH, Mahmassani HS. An AI-Based approach for transit route system planning and design. Journal of Advanced Transportation1991; 25-2:197-210.
[8] Shih MC & al. Planning and design model for transit route networks with coordinated operations. Transportation Research Record 1998; 1623:16-23.
[9] Janarthanan N, Schneider JB. Development of an expert system to assist in the interactive graphic transit design process. Transportation Research Record 1988; 1187:30-46.
[10] Furth PG. Zonal route design for transit corridors. Transportation Science 1986; 20-1:1-12.
[11] Xiong Y, Schneider JB. Processing of constraints in transportation network design problem. Journal of Computing in Civil Engineering 1995; 9-1:21-28.
[12] Solanki RS & al. Using decomposition in large-scale network design with a quasi-optimization heuristic. Transportation Research B 1998; 32:127-140.
[13] Boyce DE & al. Design of a toll system for a congested intercity road network: the Dutch road pricing system. Paper prepared for the North American Meetings, Regional Science Association International, Boston, 1990.
[14] Steenbrink P. Optimization of transport networks. Bristol: Ed. John Wiley & Sons; 1978.
[15] LeBlanc LJ, Boyce DE. A bi-level programming algorithm for exact solution of the network design problem with user-optimal flows. Transportation Research B 1986; 20-3:259-265.
[16] Yang H, Bell MG, Models and algorithms for road network design: a review and some new developments. Transport Reviews 1998; 18-3:257-278.
[17] Lo HK, Tung YK. Network design for improving trip time reliability. Paper presented at the 80th Annual Meeting of the Transportation Research Board, Washington: Transportation Research Board; 2001.
[18] NCHRP Report 446. A Guidebook for Performance Based Transportation Planning. Transportation Research Board, Washington: National Academy Press; 2000.
[19] Van Nes, R. Design of multimodal transport networks. A hierarchical approach. Setting the scene: Review of literature and basic concepts. TRAIL Thesis Series T2002/5, Delft: Delft University Press; 2002.
[20] Department of Transport. Statistics at DFT, www.dft.gov.uk/pgr/statistics, accessed may 2015.
[21] EcoPassenger. Ecological Transport Information Tool. Environmental Methodology and Data. Institut für Energie und Umweltforschung, Heidelberg GmbH, Heidelberg; 2008.
[22] UIC 2009. Energy database; updated energy statistics; 2009.
[23] Olaru D & al. About a Systemic Analysis of Transport Infrastructure Development. 15th International Congress on Cybernetics, Namur: Jean Ramaekers – l'Association Internationale de Cybernetique 1998, 15:66-71.