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DETERMINATION OF QUALITY PARAMETRES OF THE SERVICE SYSTEM ELEMENTS FOR RAIL TRACK AND MODELLING OF SERVICE QUALIFICATION PROCESS

Ph.D. theses

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1. HISTORY AND RELEVANCY OF THE RESEARCH TOPIC

Council Directive 91/440/EEC on the development of the Community's railways and Directive 2001/14/EC on the allocation of railway infrastructure capacity and the levying of charges for the use of railway infrastructure and safety certification created the new regulation of the European transport market through opening the market for international railway goods and services.

The railway enterprise restructuring dividing infrastructure operation and transportation functions raises the issue of the service system provided by the infrastructure manager and the connecting charging system. All members of the EEC[1] try to reform the operation of their incumbent railway systems through creating transparent market relations, settling the role of states in ordering public utility services, taking measures in order to develop competitiveness and making service contracts between demand and supply.

The topic of the thesis is relevant especially as there are not any harmonised, standardised and accepted infrastrutcure service systems existing while developing and using such a system is indispensable according to legal regulations and the economical interest of the market members. With the help of market regulator methods applied it is possible to determine the range, value, methodology and direction of developments of infrastructure services.

The subject of the thesis is topical as in the current situation of the domestic railway enterprise restructuring, when the basic task of Hungarian State Railways Co (MÁV) is operation and maintenance of the railway network and providing infrastructure services, it would be possible to develop and improve the service system on the basis of professionnal principles so thus making it able to adapt to changing market environment.

In my dissertation the expression quality is used in the meaning of commercial value, which expresses costs and expenditures in connection with the provided service from the infrastructure manager point of view, and the level of service (including capacity, accessibility) from railway undertaking point of view.

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[1] European Economic Community

2. OBJECTIVES

The aim of this Ph.D. dissertation is to develop such a model which helps developing the service and connecting charging system which adapts to market needs (creating conformity between supply and demand) with the help of genetic algorithms. The model should give the possibility of developing a service system which:

- reveals the range of infrastructure services,
- reflects the costs and expenditures if infrastructure services,
- is based on the quality level of service,
- can adapt to railway undertakings' needs, and
- is competitive to the service and charging systems of neighbouring countries.

In context with financing of incurring costs reasonable while providing services the quality requirements to railway infrastructure have to be determinable and controllable. The model should also help to identify low utilized weak points and bottlenecks of different services. Hereby, there should be possible to make railway development and rationalisation decisions which take market needs into account, economically reasonable.

In consequence of liberalisation infrastructure managers aim to utilizate their infrastructure beside impoving effectiveness, are obliged to increase their competitiveness against other infrastructure managers and other transportation modes. The main instrument to achive this is to develop attractive service structure in accordance with railway undertakings' needs.

While introducing and practicing of open accessly provided infrastructure service systems the following issues must be taken into account:

- Transportation policy (strategy, development policies, rate and field of state subsidies) of the given country and of the European Union,
- Legal regulatory framework and casemaps of the country and of the EU,
- Demands and possibilies of market members,
- „best practices" used in international practise.

3. APPLIED RESEARCH METHODS

During writing the dissertation I proved the factors which influence development of service systems: domestic and international legal regulations, effects and international practices of state subsidies, conditions of railway transportation policies, demands of railway undertakings, practice applied by neighbouring countries, arrangements which improve competiteveness and conditions of introducing new services.

I paid accentuated attention to the cognition of the structure of service systems used in international practice and the critical analysis of the used solutions, the identification of main contexts and analysed the terms of adaptation of the best practice in view of performance measurement and cost collection systems which form the basis of the domestic service system.

In the dissertation I used wide range of classical research methods. From these I emphasize the structured textual analysis used for processing practical experiences and benchmarks based on it, mathematical and representation technical methods (function analysis, frame of reference, map, table, figure, and diagram).

Based on domestic and international references I disclosed and valued the theoretical background of railway infrastructure service system (and connecting charging system) and different approximation methods. Among the most famous researchers who have been working on developing infrastructure charging systems in a market economical surrounding, I emphasise the publications of Mr. Chris Nash.

I must mention the work of Gyula Farkas dr. and Katalin Tánczos Dr. as the main domestic researchers of infrastructure services. Tasks of domestic railways in respect of EU-integration and legal-harmonisation were determined principally by Attila Rixer dr. and. Gyula Farkas dr. in Hungarian language. In the topic of operative cost calculation method in order to make exact basis for railway economic-management informatic systems the work of Zoltán Bokor dr. has to be emphasized. Adaptation of marginal cost theory in transport economy in connection with railways in Hungary was formulated firstly by Péter Rónai dr.. During writing my dissertation I also used the results of my former publications (Farkas – Dénesfalvy 2005, Dénesfalvy 2005a, Dénesfalvy 2006, Dénesfalvy 2007a, Dénesfalvy 2007b).

The new approach of mathematic methods (vector-, matrix operations, and genetic algorithm) used in the dissertation gives the opportunity of developing a model which fulfils the requirements identified in the course of the analysis and which:

- makes it possible to treat the station/line service categorisation, qualification methodology in a unified construction,
- is used for qualification, categorisation, ranking of stations/open lines based on continual or discreet mapping from any station/line basic data platform,
- beside qualification of services at the supply side it is suitable to fit dynamic data - reflecting the qualification of the side of demand – into the process of determining the commercial value of services. Thus making it possible to define the quality and the commercial value of station/line services which can follow demands flexibly.

4. NEW SCIENTIFIC RESULTS

4.1. I developed the networkmatrix structure model which is able to unifiedly store and treat all station and line feature datas in exact mathematic way, by unambiguously identifying the matrix components.

I defined the view-point system of determining the aspects of service features, the principles of determining feature categories inside features both at supply and demand sides. With the help of all elements of feature set developed according to these principles it is possible to generate the station, respectively line feature name vector (notation: $\underline{Ta}$, respectively $\underline{Tv}$), which shows the station respectively line features ordered in one column vector.

Buildups of station and line feature name vectors are the followings:

$$\underline{Ta} = \begin{bmatrix} (ta)_1 \\ (ta)_2 \\ \vdots \\ (ta)_n \end{bmatrix}, \quad \underline{Tv} = \begin{bmatrix} (tv)_1 \\ (tv)_2 \\ \vdots \\ (tv)_o \end{bmatrix}$$

Where $(ta)_i$ means the *i-st* feature name of stations,
n means the number of features in station feature name vector,
$(tv)_l$ means the *l-st* feature name of lines,
o means the number of features in line feature name vector.

In view of the content of station, respectively line feature name vector it is possible to determine station- respectively linevectors ($\underline{A}$, respectively $\underline{V}$), which contain the concrete station respectively line feature values for certain station respectively line according to $\underline{Ta}$ respectively $\underline{Tv}$ feature name vectors in the following form:

$$\underline{A}^a = \begin{bmatrix} (ta)^a{}_1 \\ (ta)^a{}_2 \\ \vdots \\ (ta)^a{}_n \end{bmatrix} \qquad \underline{V}^{a,b} = \underline{V}^w = \begin{bmatrix} (tv)^{a,b}{}_1 \\ (tv)^{a,b}{}_2 \\ \vdots \\ (tv)^{a,b}{}_o \end{bmatrix} = \begin{bmatrix} (tv)^w{}_1 \\ (tv)^w{}_2 \\ \vdots \\ (tv)^w{}_o \end{bmatrix}.$$

where $(ta)^a{}_i$ means the concrete quantitative, qualitative value of *i-st* feature name of stations on the station a,
$(tv)^w{}_l$ means the concrete quantitative, qualitative value of the *l-st* feature name of lines on the line w,

$\underline{V}^{a,b} = \underline{V}^{w}$ means the w linevector which illustrates the link between station a and station b and which contains o elements.

From station- and linevectors it is possible to build up a 3dimension networkmatrix ($\underline{\underline{\mathbf{H}}}$) (which elements are not constants but column vectors), which contains all features of stations and lines fixed in station- and linevectors and the network topology for the whole network as well.

The elements of $\underline{\underline{\mathbf{H}}}$ networkmatrix are:

$$\underline{\underline{H}}^{a,b} = \begin{cases} \underline{A}^{a}, & in \;\; the \;\; case \;\; of \;\; a = b \\ \underline{V}^{a,b}, & in \;\; the \;\; case \;\; of \;\; a \neq b \end{cases}$$

where meanings are the same as above.

Accordingly, stationvectors are in the main diagonal and linevectors are in other part of the networkmatrix, in the case of a network with f pieces of stations would look like:

$$\underline{\underline{H}} = \begin{bmatrix} \underline{H}^{1,1} & \underline{H}^{1,2} & \cdots & \underline{H}^{1,f} \\ \underline{H}^{2,1} & \underline{H}^{2,2} & \ddots & \vdots \\ \vdots & \ddots & \ddots & \underline{H}^{f-1,f} \\ \underline{H}^{f,1} & \cdots & \underline{H}^{f,f-1} & \underline{H}^{f,f} \end{bmatrix} = \begin{bmatrix} \underline{A}^{1} & \underline{V}^{1,2} & \cdots & \underline{V}^{1,f} \\ \underline{V}^{2,1} & \underline{A}^{2} & \ddots & \vdots \\ \vdots & \ddots & \ddots & \underline{V}^{f-1,f} \\ \underline{V}^{f,1} & \cdots & \underline{V}^{f,f-1} & \underline{A}^{f} \end{bmatrix}.$$

Meanings are the same as earlier.

The thesis is based on findings described in chapter 5.2.1 of the dissertation and the publication (Dénesfalvy 2006).

4.2. I developed the conversion rule system based on vector operations which is able to homogenise, quantificate heterogeneous station/line features, and with which help it is possible to make quantitative, standardised convertiated vectors from different heterogeneous station- and linevector data.

In order to treat heterogeneous station/line features uniformly on mathematic language, it is necessary to quantify textual station/line features, respectively to develop solutions for treating numeric features uniformly in order to compare different features. This is made by convertative vectors ($\underline{Ka}$, respectively $\underline{Kv}$). Station and line convertative vectors look like:

$$\underline{Ka} = \begin{bmatrix} (ka)_1 \\ (ka)_2 \\ \vdots \\ (ka)_n \end{bmatrix}, \qquad \underline{Kv} = \begin{bmatrix} (kv)_1 \\ (kv)_2 \\ \vdots \\ (kv)_o \end{bmatrix}$$

where $(ka)_i$ respectively $(kv)_l$ means convertative rule system (for quantification, homogenisation, uniformisation of features) of the *i-st* feature name of stations [$(ta)_i$] respectively of the *l-st* feature name of lines [$(tv)_l$].

After adopting convertative vectors to station- respectively linevectors (put station respectively line features in appropriate feature-categories, or – only in case of numerical/quantified features – value giving through continual mapping) you get station, respectively line convertiated vectors.

Convertiated vectors for *a* station and *w* line are the followings:

$$\underline{C}^a = \begin{bmatrix} c^a{}_1 \\ c^a{}_2 \\ \vdots \\ c^a{}_n \end{bmatrix} = \begin{bmatrix} (ka)_1\left[(ta)^a{}_1\right] \\ (ka)_2\left[(ta)^a{}_2\right] \\ \vdots \\ (ka)_n\left[(ta)^a{}_n\right] \end{bmatrix}, \qquad \underline{\mathrm{C}}^{\mathrm{w}} = \begin{bmatrix} \mathrm{c}^{\mathrm{w}}{}_1 \\ \mathrm{c}^{\mathrm{w}}{}_2 \\ \vdots \\ \mathrm{c}^{\mathrm{w}}{}_{\mathrm{o}} \end{bmatrix} = \begin{bmatrix} (\mathrm{kv})_1\left[(\mathrm{tv})^{\mathrm{w}}{}_1\right] \\ (\mathrm{kv})_2\left[(\mathrm{tv})^{\mathrm{w}}{}_2\right] \\ \vdots \\ (\mathrm{kv})_{\mathrm{o}}\left[(\mathrm{tv})^{\mathrm{w}}{}_{\mathrm{o}}\right] \end{bmatrix}$$

where $c^a{}_i$ namely $(ka)_i\left[(ta)^a{}_i\right]$ means convertiated value got by adopting $(ka)_i$ convertative rule to station *a* station feature *i*,
$c^w{}_j$ namely $(kv)_j\left[(tv)^w{}_j\right]$ means convertiated value got by adopting $(kv)_j$ convertative rule to line *w* line feature *j*.

As the result of conversion, vectors of elements between 0 and 1 are generated. From heterogeneous station- respectively linevectors I prepared such homogenised vectors which have – in the case of discrete mapping almost the same, in the case of continual mapping the same – meaning, and have quantified quality as well.

The thesis is based on findings described in chapter 5.2.2 of the dissertation and the publication (Dénesfalvy 2006).

4.3. With the help of networkmatrix structure model I developed the methodology of determining commercial value of services. With the help of this, it is possible to analyse and verificate the quality of services numerically, dynamically and informatically.

For determining quality from several infrastructure services point of view not all features are necessary so thus it is important to identify relevant features from the services point of view. After determining relevant features (according to professional knowledge), station respectively line service weightvectors sort out relevant features by a mathematical model and quantificate features according to their role in commercial value.

Station respectively line service weightvectors are the followings:

$$(\underline{Sa})^{m_j} = \begin{bmatrix} (sa)^{m_j}{}_1 \\ (sa)^{m_j}{}_2 \\ \vdots \\ (sa)^{m_j}{}_n \end{bmatrix}, \qquad (\underline{Sv})^{u_q} = \begin{bmatrix} (sv)^{u_q}{}_1 \\ (sv)^{u_q}{}_2 \\ \vdots \\ (sv)^{u_q}{}_o \end{bmatrix}$$

where $(sa)^{m_j}{}_i$ means the weight from m_j service point of view which belongs to the *i-st* feature name of stations [$(ta)_i$],
$(sa)^{m_j}{}_i$ means the weight from m_j service point of view which belongs to the *i-st* feature name of stations [$(ta)_i$],
$(sv)^{u_q}{}_l$ means the weight from u_q service point of view which belongs to the *l-st* feature name of lines [$(tv)_l$].

Elements of service weightvectors are between 0-1, they contain value differing from 0 only where convertation and convertiated vectors contains values for relevant features. Elements of service weightvectors means how important the station/line features are from service quality level point of view. The sum of elements of service weightvector gives 1.

I prepared commercial value from the station/line service point of view, as the result of weighting. This is a concrete number value, which means the quality of station/line services and with which help it is possible to correlate the given station/line to others from given service point of view.

Commercial value of station *a* from m_j service point of view, respectively commercial values of line *w* from u_q service point of view are the followings:

$$\mathrm{e}^{\mathrm{am_j}} = \mathrm{c^a}_1 \cdot (\mathrm{sa})^{\mathrm{m_j}}{}_1 + \mathrm{c^a}_2 \cdot (\mathrm{sa})^{\mathrm{m_j}}{}_2 + \cdots + \mathrm{c^a}_\mathrm{n} \cdot (\mathrm{sa})^{\mathrm{m_j}}{}_\mathrm{n}$$

$$e^{wu_q} = c^w{}_1 \cdot (sv)^{u_q}{}_1 + c^w{}_2 \cdot (sv)^{u_q}{}_2 + \cdots + c^w{}_o \cdot (sv)^{u_q}{}_o$$

Commercial value of a service can be between 0 and 1.

From commercial value of services it is possible to develop station respectively line commercial value vector (which contains the same number of elements as station- respectively line vector). Commercial value vector shows commercial value of all services of given station respectively line in vectorial form.

From station respectively line commercial value vectors the three dimension commercial value matrix ($\underline{\underline{\mathbf{E}}}$), can be built up, which contains the commercial values of all stations and lines from all services point of view.

Elements of $\underline{\underline{\mathbf{E}}}$ network commercial value matrix are the followings:

$$\underline{\underline{E}} = \begin{cases} \underline{E}^{a}, & ha \quad a = b \\ \underline{E}^{a,b}, & ha \quad a \neq b \end{cases}$$

According to the above, in the diagonal of network commercial value matrix station commercial value vectors can be found, on other places line commercial value vectors as followings:

$$\underline{\underline{E}} = \begin{bmatrix} \underline{E}^{1,1} & \underline{E}^{1,2} & \cdots & \underline{E}^{1,f} \\ \underline{E}^{2,1} & \underline{E}^{2,2} & \ddots & \vdots \\ \vdots & \ddots & \ddots & \underline{E}^{f-1,f} \\ \underline{E}^{f,1} & \cdots & \underline{E}^{f,f-1} & \underline{E}^{f,f} \end{bmatrix}.$$

Meanings are the same as earlier.

The thesis is based on findings described in chapter 5.2.3 of the dissertation.

4.4. I developed the methodology of determining common commercial value of infrastructure services, which with the appropriate rate of commercial value of supply and demand ensures that charge according to quality (commercial value) can be determined.

I developed such a service qualification model, which suits railway undertakings' quality aspects and demands, reflects costs and expenditures of infrastructure manager, namely harmonises and treats the commercial value for both railway undertakings (demand) and infrastructure managers (supply).

After determining services, qualification, in-service categorisation should be made by using vectorial method. Optimal common commercial value can be determined – in the course of qualification by using divided parameter set theory – from the commercial value of infrastructure managers and railway undertakings as the following:

$$e^{am_j vp} = x \cdot e^{am_j p} + (1 - x) \cdot e^{am_j v}$$

where

$e^{am_j vp}$ means common commercial value (which takes into account the aspects of infrastructure managers and railway undertakings as well) from m_j service point of view,

$e^{am_j p}$ means commercial value of infrastructure managers from m_j service point of view,

$e^{am_j v}$ means commercial value of railway undertakings from m_j service point of view,

x means in what rate the infrastructure manager's commercial value is taken into account (the following coherency is always valid that $0 \le x \le 1$).

In the course of qualification and charging of services I determine the value of x (namely the rate (the importance) of commercial value for railway undertakings and infrastructure managers) with the help of genetic algorithm.

The thesis is based on the findings of chapter 6.1.3 of the dissertation.

4.5. With the help of genetic algorithm I developed service qualification system model which harmonises the EU directives, and can be used in Hungary and (with fitting appropriate functions) in international networks as well. The model determines optimal common commercial value and charging system considering costs and expenditures of infrastructure managers and quality of service at the same time.

Figure 1 shows the process of qualification (determining common commercial value) and charging with the help of genetic algorithm.

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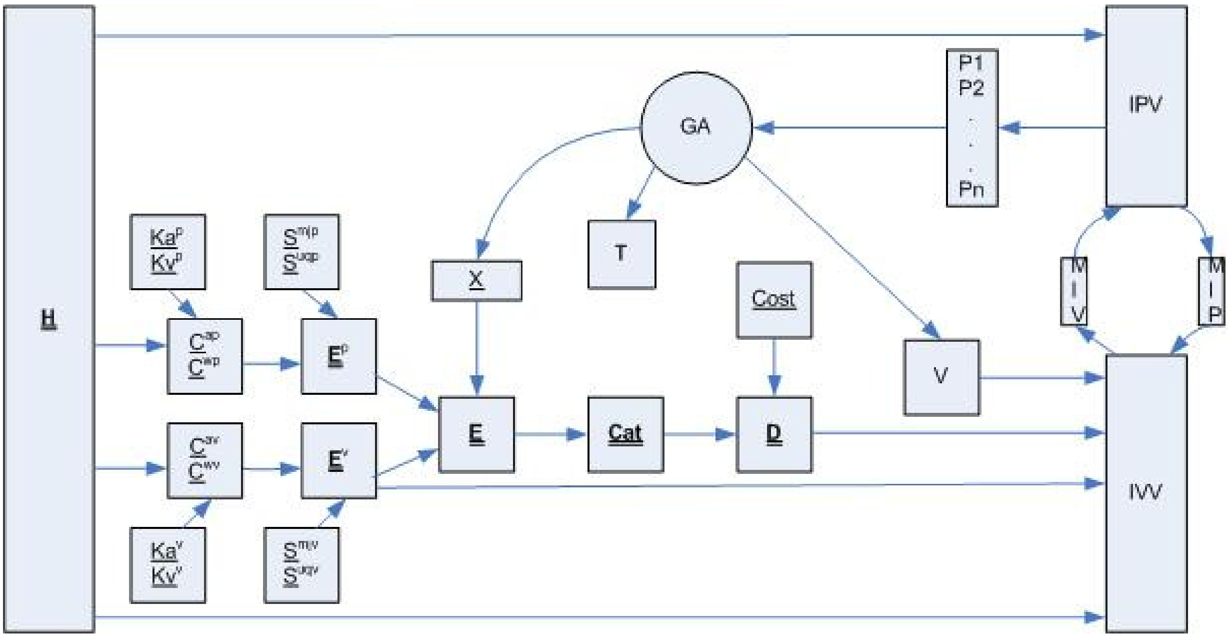

Figure 1: Model of determining common commercial value and charging with genetic algorithm

Meanings are the same as earlier or are to be explained in the following description. After determining quality of service, station a from m_j service point of view, respectively line w from service u_q point of view can be categorised, from which' elements category vectors and lastly categorymatrix ($\underline{Cat}$) can be developed.

Considering e.g. average cost of service categories of all station and line services, station respectively line costvectors can be made ($\underline{\text{Cost}}$). The charge of service with given quality (category) can be determined with the help of average cost and categorymatrix according to different charging principles. From charges the chargematrix ($\underline{\underline{D}}$) can be built up.

The infrastructure manager (IPV) answers (MIP) claims (MIV) of railway undertakings (IVV) (which are determined due to different transportation tasks generated by genetic algorithm) depending on their achievability. The claim can either be fulfilled (after iteration between IPV and IVV if there are changing requirements) or refused. The results of transportation are compared with the parameters determined in goodness criterias and measured in data puffers. Among goodness criterias other criterias that are in line with the requirements of the market members can be determined (like optimal capacity utilisation from infrastructure manager's point of view, payback of a certain level of cost of infrastructure manager from the state's point of view, minimalisation of full costs of a claim from railway undertaking's point of view). All results are saved in spooler (T). Genetic algorithm prepares x parameter of service qualification system according to goodness criterias, till the ideal qualification (proper rate of respect of $e^{am_j p}$ and $e^{am_j v}$, respectively $e^{wu_q p}$ and $e^{wu_q v}$) and charging is determined and parameters described as goodness criterias are best fulfilled.

The thesis is based on the findings of chapter 6.2.3 of the dissertation.

5. UTILISATION OF NEW SCIENTIFIC RESULTS

The results and reports of the thesis can be used in wide range both by theoretical and practical point of view from consultive preparation of decision making to education, and for either domestic or international applications.

Methods and examples shown in the dissertation can be built into training materials of Budapest University of Technology and Economics, and into European and domestic projects and reports of the Department of Transport Economics, not only on theoretic but on practical level (in form of case studies) as well. In form of scientific collaborations the results and reports are presented in other (domestic and foreign) research and higher education institutes and performing domestic R&D orders.

With the help of the developed networkmatrix structure model it is possible to determine commercial value (based on station/line quality level) of all station and line on the network of any infrastructure manager, what can form the basis of any cost and income calculation. Based on commercial value it is possible to determine categories of stations/lines and the charge for their usage. The principles above can be used in practice as well if all stations and lines are categorised by the method described by the infrastructure manager.

The optimal charging system can be developed with the domestic usage of service qualification system, taking into consideration the infrastructure costs and expenditures connected to services and the quality of the service. The method is possible to be used in practice in countries with similar endowments and specialities, furthermore after implementation in countries with different endowments and specialities, too.

Through collecting and arranging all features necessary for determining station/line categories the model gives the possibility to prepare a uniform database, in which any changes of any characteristics of any services can be seen across or modified. This kind of database that contains all standard attributes of stations and/or lines has not existed. Such a database can be the starting point of introduction, differentiation, categorisation and determination the charge of further services.

During the practical adaptation of the model it is possible to measure the frequency of usage of stations/lines with different categories, to measure which station/lines with which services are the most wanted ones. This helps to identify stations/lines which are necessary to be developed or derogated – depending on the construction of the network – from given service point of view.

With the help of the model there is enough information about overloaded stations/lines (bottlenecks), as well as "weak points" of the infrastructure thus supporting the substantiation of correct infrastructure strategy and policy decisions. The model makes possible to quantify how service level, quality and charge of service provided by domestic infrastructure managers' approach to the demand for services. This can be the basis of a competitive offer.

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