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Innovative Applications of O.R.

A systems approach to access charges in unbundling railways

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Abstract

This article presents a systems approach to access charges in unbundling railways where an infrastructure manager charges services to operators on an open market. The motive for this research is the fact that until now no universal model of access charges has been defined. We define a universal access charges model for an essential service package for a mid- and small-size network based on a systems approach to recovering the costs that are incurred as a result of the operation of a train. System elements are a railway network, trains and costs. Having in mind the system complexity a combination of an analytical and engineering approach has been used for access charges modelling. The model has been developed for a Serbian mid-size railway network and tested on real data. The numerical results of model application indicate that with charges defined in this way it is possible to track cost and cost management by services.

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1. Introduction

The European Union (EU) railways have decided to open the railway market (directive 1991/440 as an act of EU) and to introduce competition among the operators on the railway infrastructure. This is, at the same time, a way to respond to the EU’s demands for increased railway system efficiency and for a higher share of this system in modal share. With the reform of railways that requires a separation of historical railway companies into an infrastructure manager (IM) and an operator, the railway infrastructure ceases to be only a technical system and a cost category in the traffic management and operation of rail service. It becomes a special system which should be managed on a commercial basis. Now operators have to pay the access charges (AC) for railway infrastructure use to infrastructure managers. At the same time, these charges represent the infrastructure managers’ instrument for achieving business operations efficiency.

Under EU directives (Directive 2001/14), types of services in railway infrastructure use are standardized. These are: essential service package (include charges for a minimum access package and charges for track access to the service facilities and supply of services), additional service and auxiliary service. An essential service package might include charges: for the scarcity, reservation, environment and others. However, access charges modelling are not restricted by either European transport policy or EU regulations. Each country is allowed to specify freely its access charges model, including the choice of an economic principle of charges. The marginal costs (MC), full costs (FC), full cost minus (FC−), marginal cost plus mark-up (MC+) and marginal cost + Ramsey (MC + Ramsey) principles has been recommended by European Conference of Ministers of Transport (ECMT, 2005).

Although twenty years have passed since the introduction of access charges, no generally acceptable universal model of charges has ‘proved’ to be recommendable for several reasons. One among the key reasons includes different sizes and complexities of railway networks, which are classified into small, medium and large, according to World Bank (2011) and Eurostat (2012).

In an attempt to eliminate some of the drawbacks from previous work, this research first reviews the access charges elements and cost modelling and application reported in the literature and then develops an access charges modelling algorithm based on a systems approach. As a result of systems approach, our access charges model consists of three modules: cost, network and traffic. An analytical approach, a combination of bottom-up allocation method and statistical distribution method, is used for cost module due to system complexity and data collection. Based on statistical data analysis of train serving in the node and direct attribution of traffic by train type and traction category to the nodes and sections, the traffic module is determined. The network is presented by an un-oriented graph where links and nodes represent specified network segments. The first objective of the access charges model is to formulate a relation of costs to a train type, traction category...
and network segments for an essential service package. The second objective is to permit the access charges model structured in this way to enable infrastructure cost management by services. The model has been developed for a Serbian mid-size railway network.

The model has been tested on real data collected on Serbia’s railway network. Output results include the values of access charges for various passenger and freight train categories and weights, on various paths. A comparative analysis of the obtained access charges values by model and other European railway networks is given. The effect of a change in traffic volume and mark up on the coverage of total infrastructure cost is analyzed. The numerical results confirm that the defined universal model can serve as a tool for managing the coverage of total costs by revenues from charges for a mid- and small-size network.

An advantage of systems approach is that it observes the network characteristics, traffic volume and access charges principles as elements that influence modelling and recovering the costs in the framework of essential service package. In addition, it is not necessary to remodel access charges with increase of network efficiency and with changed economic principles. In this study, we restrict our attention to model advantages and applicability under European conditions. To become applicable to non-European railway networks, the model should be studied much more extensively.

The remainder of the article is organized as follows. In the second section, a literature review pertaining to access charges elements, cost management for network systems, cost modelling and access charges implementation is provided. The proposed access charges modelling framework is presented in the third section. This is followed by a detailed description of the model and its all three modules for the Serbian Railways which represent a mid-size network. In the fifth section, the application, results and discussion of the proposed model are given. Finally, conclusions and possible future research directions are presented.

2. Literature review

When reviewing literature in the field of access charges, one can note that the number of scientific research studies exceeds the number of publications in journals. The reasons are multiple and the most important are: the topic is very complex and requires a multidisciplinary approach; it requires research which needs extensive work and financial support; it concerns an area within the most important are: the topic is very complex and requires a number of publications in journals. The reasons are multiple and note that the number of scientific research studies exceeds the possible future research directions are presented.

An advantage of systems approach is that it observes the network characteristics, traffic volume and access charges principles as elements that influence modelling and recovering the costs in the framework of essential service package. In addition, it is not necessary to remodel access charges with increase of network efficiency and with changed economic principles. In this study, we restrict our attention to model advantages and applicability under European conditions. To become applicable to non-European railway networks, the model should be studied much more extensively.

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of partially missing data. Reasons lie in loosely structured data on costs by service types with all infrastructure providers, too. Therefore, to fill in this niche and to better deal with defining access charges, in this study we propose a new access charges model. Our model is based on a systems approach including formulation of relations among covering of costs, complexity of network and traffic volume. With access charges defined in this way it is possible to track and costs management by services for small- and mid-size network. The proposed approach has been applied to Serbian railways.

3. Problem description

The given literature review has shown that the model of access charges for an essential service package\(^1\) should reflect infrastructure use and be stimulating to various market actors. Such an approach results from a concept that an infrastructure owner, and not users, should bear the costs incurred on other networks or lines. The largest difficulties arise in the initial period of market opening during which an infrastructure manager is not familiar with a competitor’s market and with the effect of access charges principles on the market.

AC modelling presented in this study starts from the following assumptions:

1. The model should reflect infrastructure costs in access charge calculation formula. Thus, the model will result in decreased infrastructure costs in two ways: (1) by increasing infrastructure cost manageability with respect to certain service categories by IM, (2) by directly stimulating the operator to decrease infrastructure wear and tear costs with the same consequences.

2. Establishing high correlation between costs and charges with an action on their reduction. The charge model should lead to increased competitiveness of railway operators on the transport market and to a larger traffic volume (especially in freight transport).

3. Increased competitiveness and transport volume further lead to a spiral decrease in transport cost per transport unit (train-kilometer or gross tonne-kilometer or passenger-kilometer or trains) and these, in turn, result in lower access charges per transport unit and higher competitiveness and larger traffic volume.

Thus, the model should be based on a systems approach and should have such a structure that will allow establishing a visible spiral of reducing infrastructure cost per transport unit, higher competitiveness of railway infrastructure and railway operators as well as a higher traffic volume. This means that the basic assumption of the model is establishing a high correlation of infrastructure costs with services in charge calculation formula. A well known fact to be kept in mind is that railway accounting is characterized by very loosely structured infrastructure costs by services. How have we established this correlativity between costs and charge amounts in the model proposed?

It is necessary to define an access charges model for an essential service package in a way that it allows the allocation of different cost coverage to different train categories and service categories. The starting requirement is that the model is applicable to various principles of access charges, i.e. that it can be used upon a changed access charges principle on a network.

Many authors emphasize that, unlike air and road transportation networks, railway networks involve fewer alternative lines, parallel paths, a large number of facilities and elements and railway operators are more dependent on physical rail network infrastructure (Adler, Pels, & Nash, 2010), so, to define charges, it is very important to determine the type of network for which the problem is solved and to cover well network characteristics. As has been stated, European networks can be classified into small-, mid- and large-size networks as far as their basic performances, such as total length, traffic volume, infrastructure cost, track productivity and employee productivity, are concerned. In small- and mid-size networks it is easier to define network elements and allocate costs according to network use services.

To determine a charge for an essential service package per train for a selected path, it is necessary to define unit costs according to network and traffic characteristics and then according to access charges in the frame of an essential service package. Fig. 1 presents a general algorithm of the model defined on the previously stated assumptions.

Basis for establishing relations among model elements are data on costs, traffic and network. The inputs to the model can be listed under two headings. The first group of inputs will determine the cost elements. These elements will be presented in more detail in the explanation of cost module. The second group of inputs represents data on network and traffic performances. In addition to these, input data also include weights which show the influence of certain train characteristics and of different infrastructure wear and tear characteristics.

To formalize the access charge model, a railway network is treated as a complex system consisting of several categories of sections and nodes (Object 1 in the algorithm). On the basis of defined sections and nodes and relations among them, a matrix of possible train paths (Object 2 in the algorithm) is formed for the whole network. Certain routes may be realized in several ways, i.e., there are several paths interconnecting the origin and destination points of these routes. Calculation of the AC will be done for a chosen, fixed train path.

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1 The term ‘access charges model’ will be used in this text further instead of the term ‘the model of charges for an essential service package’

### Table 1

<table>
<thead>
<tr>
<th>Literature</th>
<th>Principle</th>
<th>Basic network elements</th>
<th>Cost model (applied method)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ronai (2008) / Austria</td>
<td>MC+</td>
<td>6 Line and 5 traffic categories</td>
<td>Cost distribution is related to statistical analysis of cross sectional and/or time series data</td>
</tr>
<tr>
<td>Rock (2008) / Belgium</td>
<td>FC−</td>
<td>1 Line and 7 traffic categories</td>
<td>Cost are directly allocated to individual services/account oriented approach</td>
</tr>
<tr>
<td>Crozet (2004), Benchekroun (2008) / France</td>
<td>MC+</td>
<td>9 Line and 4 traffic categories</td>
<td>Relations between cost and traffic volume has been defined by regression models</td>
</tr>
<tr>
<td>Link (2004) / Germany</td>
<td>FC−</td>
<td>12 Line categories</td>
<td>Simple cost reallocation on the required train-path kilometer</td>
</tr>
<tr>
<td>Denesfalvy (2010) / Hungary</td>
<td>FC−</td>
<td>3 Line and 4 traffic categories</td>
<td>Cost allocation is based on the accounting management system – linking cost codes to activities</td>
</tr>
<tr>
<td>Nash (2005) / Great Britain</td>
<td>MC+/MC+</td>
<td>2 Line and 2 traffic categories</td>
<td>Cost allocation is related to top down allocation model combined with engineering based/modelled assessment</td>
</tr>
</tbody>
</table>

\(^a\) AC level depends from vehicle characteristics and market segmentation too.
Modelling of train traffic in the network is based on the statistical distribution of train operation indicators by network segments and train types and traction categories (Object 3 in the algorithm). Since data on infrastructure use are not recorded in detail (by train and origin), they are modelled using an analytical approach. Costs to be included in defining unit costs of infrastructure use depend on the principle of charges. Relations among the basic cost categories and the costs of operation units are based on a bottom-up cost allocation method (Object 4 in the algorithm). Costs distributed in this way are allocated, on the basis of the statistical and engineering analyses of cost to network segments relations, to appropriate network segments (Object 5 in the algorithm). Pairing the allocated costs and traffic with network segments gives units’ costs as a function of network and traffic.

Regarding directive 2001/14/EC, an essential service package includes charges for (a) a minimum access package and (b) charges for track access to the service facilities and supply of services. For the charges model to reflect an essential service package for a corresponding train and network elements:

(a) Minimum access package are charges for train operation on the sections out of node (CI).
(b) Charges for track access to the service facilities and supply of services are divided into two separate parts: Charges for a train passing through the nodes (CIIa) and charges for the service in the nodes (CIIb).

Fig. 1. A generic access charges model algorithm.
Therefore, a train on a selected path may be on sections, or pass through nodes or be serviced in nodes \(^{2}\) which is charged in accordance with unit costs allocated by network elements (Object 6 in the algorithm). Units for calculating unit costs are: train-kilometer, gross tonne-kilometer and trains.

The basic goal of access charges model, establishing strong correlation of infrastructure with services, in the formula for charge calculation has been attained in this step of the model. A charge for the essential service package of infrastructure use is a result of the interdependence among network elements, costs and traffic for a particular path (train) and represents a basis to IM for managing infrastructure costs.

Access charges from realized trains are aggregated (Object 7 in the algorithm) and represent the total revenue from infrastructure management charge. IM compares cost coverage attained by charges with the total operations cost. It should be kept in mind that a dominant majority of European IMs obtains state subsidies. Under such circumstances it is necessary to balance between revenues from charges plus subsidies with total expenditures. Our model permits this to be done through iterations to external effects (e.g., state budget possibilities). If the difference between them is negative, IM modifies certain model elements.

Modifications may include changes in the principles of charges or unit costs of material or labour. In this way, the structure and value of access charges are improved iteratively in accordance with given conditions. Monitoring the effects of modifications on the amount of cost coverage allows the second objective to be attained – infrastructure cost management with respect to charges – essential service.

4. Access charges model

In this section we present an access charges model and its mathematical formulation. Based on the problem definition and the assumptions, we first introduce the following notation that will be used in the model developed.

4.1. Notation

\(i\) the service on sections

\(m_{a}\) the service to a train passing through nodes

\(m_{b}\) the service in nodes

\(s\) the section

\(k\) the section category, \(k = 1, \ldots, K\)

\(l_{s}\) the length of section \(s\)

\(v\) the node, \(v = 1, \ldots, H\)

\(l_{v}\) the average length of the sections used by trains through the node \(v\)

\(i\) the train type, \(i = 1, \ldots, I\)

\(j\) the traction category, \(j = 1, \ldots, J\)

\(m\) the cost category, \(m = 1, \ldots, 4\)

\(n\) the cost attributed to operation unit, \(n = 1, \ldots, S\)

\(C\) the access charges

\(A\) the train

\(P\) the train path

\(G (A)\) the weight of the train \(A\)

\(\text{Sec}^{k}\) the set of sections of category \(k\)

\(\text{Nodes}\) the set of nodes on network

\(\text{NodesS}\) the set of nodes where the train \(A\) is serviced

\(\text{Sec} (P)\) the set of sections on the path \(P\)

\(\text{Nodes} (P)\) the set of nodes on the path \(P\)

\(\text{NodesS} (A,P)\) the set of nodes on the path \(P\) where the train \(A\) is serviced

\(p_{nmk}\) the percentage of cost variability for cost attributed to operation unit \(n\), cost category \(m\) and sections category \(k\)

\(p_{nmv}\) the percentage of cost variability for cost attributed to operation unit \(n\), cost category \(m\) and the node \(v\)

\(m_{ark}\) the percentage given to the train type \(i\)

\(D_{nk}\) the weight of cost attributed to operation unit \(n\) on sections of category \(k\)

\(D_{nv}\) the weight of cost attributed to operation unit \(n\) in the node \(v\)

\(N_{ijk}\) the annual number of trains type \(i\) and traction category \(j\) on sections of category \(k\)

\(N_{ijv}\) the annual number of trains type \(i\) and traction category \(j\) passed through the node \(v\)

\(N_{ik}\) the annual number of trains type \(i\) and traction category \(j\) serviced in the node \(v\)

\(N_{Ak}\) the total annual gross tonne-kilometer for trains on sections of category \(k\)

\(N_{Aik}\) the total annual gross tonne-kilometer for trains that passed through the node \(v\)

\(N_{Aiv}\) the total annual number of trains that passed through the node \(v\)

\(N_{Aiv}\) the total annual number of trains serviced in the node \(v\)

\(N_{Aiv}\) the total annual number of trains on sections of category \(k\)

\(N_{Aiv}\) the total annual number of trains on sections of category \(k\)

\(TA_{nmk}\) the total annual cost attributed to operation units \(n\) and costs category \(m\) of trains on sections of category \(k\) in train-kilometer

\(TA_{nmv}\) the total annual cost attributed to operation units \(n\) and costs category \(m\) of trains on sections of category \(k\) in gross tonne-kilometer

\(TA_{nm}\) the total annual cost attributed to operation units \(n\) and costs category \(m\) of trains that passed the node \(v\) in gross tonne-kilometer

\(TA_{nm}\) the total annual cost attributed to operation units \(n\) and costs category \(m\) of all trains that passed the node \(v\)

\(VA_{k}\) the total annual variable cost of trains on sections of category \(k\) in train-kilometer

\(VA_{k}\) the total annual variable cost of trains on sections of category \(k\) in gross tonne-kilometer

\(VA_{v}\) the total annual variable cost of trains that passed through node \(v\) in gross tonne-kilometer

\(VA_{v}\) the total annual variable cost of trains that passed through node \(v\)

\(VA_{v}\) the total annual variable cost of trains serviced in node \(v\)

\(v_{jk}\) the unit variable cost for train type \(i\) and traction category \(j\) on sections of category \(k\), per train-kilometer

\(v_{jk}\) the unit variable cost for train type \(i\) and traction category \(j\) on sections of category \(k\), per gross tonne-kilometer

(continued on next page)
the unit variable cost for train type $i$ and traction category $j$ in the node $v$ per train

$V_{ij}^T$ 

the unit variable cost for train type $i$ and traction category $j$ in the node $v$ per gross tonne-kilometer

$V_{ij}^{GK}$ 

the unit variable cost for train type $i$ and traction category $j$ served in the node $v$ per train

$T_{ij}^S$ 

the unit cost for train type $i$ and traction category $j$ on sections of category $k$ per train-kilometer

$T_{ij}^{GK}$ 

the unit cost for train type $i$ and traction category $j$ on sections of category $k$ per gross tonne-kilometer

$T_{ij}^T$ 

the unit cost for train type $i$ and traction category $j$ passed through the node $v$ per train

$T_{ij}^{GK}$ 

the unit cost for train type $i$ and traction category $j$ passed through the node $v$ per gross tonne-kilometer

$T_{ij}^S$ 

the unit cost for train type $i$ and traction category $j$ served in the node $v$ per train

4.2. The mathematical formulation

The access charges model consists of three modules: a cost module, a traffic module and a network module. The cost module has been designed so that it is possible to allocate costs as a function of train types, traction categories, network segments and chosen charging principle. By the formulation of costs relations with train types, traction categories and network segments, it is possible to calculate the access charges for different train types with respect to certain service categories as well as the application of different charging principles.

The key functions of this model are access charges for an essential service package for a train $A$ on a path $P$ whether a train can have several possible paths or whether the path is fixed. Variables are:

- Infrastructure unit costs depending on the access charges principles, traffic parameters (operation indicators) and train paths.
- Transport units for calculating the unit costs are train-kilometer, gross tonne-kilometer and trains. A train is an object in the model. Our model uses following parameters of each train $A$: train type $i$, traction category $j$ and weight $G$. The train $A$ on the path $P$ can be found on sections that pass through nodes or can be served in nodes. The relations among model elements are the result of the interdependency of the network elements, costs and traffic. A graphical presentation of the access charges model structure is shown in Fig. 2.

Hence, the output elements of the access charges model for the train $A$ on the path $P$ are the access charges for an essential service package $C_{ij}(A,P)$ whose elements are access charges $C_i$, $C_{ij}$, and $C_{ijb}$.

The formula used for the access charges for an essential service package calculation is as follows.

$$C_{ij}(A,P) = C_i(A) + C_{ij}(A,P) + C_{ijb}(A,P)$$ (1)

where for train $A$ on a given path $P$

- $C_i(A,P)$ – the access charges for train service on the sections.
- $C_{ij}(A,P)$ – the access charges for train passing through the nodes.
- $C_{ijb}(A,P)$ – the access charges for the service in the nodes.

i.e.

$$C_{ij}(A,P) = \sum_{k=1}^{K} \sum_{s \in \text{Sec}(P)} l_s \left( T_{ij}^{GK}(A) + G(A) \cdot T_{ij}^{GK}(A) \right)$$

$$+ \sum_{v \in \text{Nodes}(P)} \left( T_{ij}^T(A) + G(A) \cdot T_{ij}^T(A) \right) \cdot l_v$$

$$+ \sum_{v \in \text{Nodes}(S(P,A))} T_{ij}^S(A) \cdot l_v$$ (2)

where $\text{Sec}(P)$ is the set of all sections of category $k$ on the path $P(A)$

4.3. Modules of access charges model – network, traffic and costs modules

Details of the modules development are given in the following.

4.3.1. Railway network module

Along the network, the morphological and technological characteristics and the commercial operating conditions vary significantly. A network is an asset which generates revenues on its exploitation and its total operating costs should be covered. Since not all network segments produce the same expenses and revenues, the network segmenting is one of the very important elements for costs covering within the access charges. Network segmenting has been performed into elements which create a homogeneous entity as regards: (1) technical characteristics and possibilities of network, and the characteristics of traffic operations, and (2) origin of costs and revenues. That means network segmentation into the homogeneous elements that can be managed as far as maintenance, traffic and commercial sense are concerned. Such network segmentation enables efficient cost management. The main railway network elements are sections and nodes (Boskovic, Bugarinovic, Lasica, & Jankovic, 2010).

The railway network is presented by an unoriented graph (Fig. 2). The graph links represent sections while graph nodes represent the railway network nodes. Definitions of a section and a railway network node are:

- A section $s$ is railway track between the two stations on which the train structure does not change and it has an almost homogeneous structure concerning the characteristics of the superstructure and the permanent way as well as the technology of train operation. Taking into account the volume of traffic that caused the costs of using the infrastructure, sections are classified into $K$ categories. The length of the given section $s$ will be denoted by $l_s$, while its category will be denoted by $k_s$.

[Fig. 2. Graphical presentation of access charges model structure.]
A railway network node \( v \) is a set of stations where several network lines join. Each node form system the operation of trains and require unique management in a commercial and technical sense. There are \( H \) nodes in the network. The length of given node \( v \) is \( l_v \). The \( l_v \) is the average length of the sections in the node \( v \) used by trains that have passed through and have been served in node \( v \) annually.

According to the defined sections and nodes, and the connections between them, a matrix of the possible movement of trains i.e. trains paths \( P \) is formed for the whole network. Based on the network model, the train path \( P \) is characterized by:

- \( \text{Sec}(P) \) as the set of sections on a path \( P \).
- \( \text{Nodes}(P) \) as the set of nodes on a path \( P \).

Moreover for the given train \( A \) and path \( P \) we also defined \( \text{Nodes}(A,P) \) as the set of nodes on a path \( P \) where a train \( A \) is served. Clearly, a set of nodes in which train \( A \) is serviced is a subset of the set of all nodes through which a train passes i.e. \( \text{Nodes}(A,P) \subseteq \text{Nodes}(A,P) \).

### 4.3.2. The traffic module

Traffic modelling is based on the statistical distribution of train operation indicators according to the network segmentation. In order to establish detailed and precise relations between costs, traffic and network models a statistical distribution of train operation indicators is introduced according to the train section and traction category. The traffic module of the trains \( (i, j) \) represents the allocation of the annual train operation indicators, i.e. the annual number of train-kilometer and gross tonne-kilometer to each section of category \( k \), the annual number of the gross tonne-kilometer to each node \( v \), as well as the number of the trains \( (i, j) \) which pass and which are serviced in each node \( v \).

The total annual train operation indicators, for trains on sections of category \( k \) are:

- \( NA_{kx} \) as total annual train kilometres. Obviously \( NA_{kx} = \sum_{i=1}^{J} \sum_{j=1}^{I} \sum_{v=1}^{S} N_{ijk} \cdot l_i \) (train-kilometer).
- \( NA_{kx} \) as total annual gross tonne kilometres. Obviously \( NA_{kx} = \sum_{i=1}^{J} \sum_{j=1}^{I} \sum_{v=1}^{S} G_{ijv} \cdot N_{ijk} \cdot l_i \) (gross tonne-kilometer).

The total annual train operation indicators for the trains which passes through the node \( v \) and serviced in the node \( v \) are:

- \( NA_{k} \) as total annual number of trains that passed through the node \( v \). Obviously \( NA_{k} = \sum_{i=1}^{J} \sum_{j=1}^{I} \sum_{v=1}^{S} N_{ijv} \) (trains).
- \( NA_{k} \) as total annual gross tonne-kilometres of trains passed through the node \( v \). Obviously \( NA_{k} = \sum_{i=1}^{J} \sum_{j=1}^{I} \sum_{v=1}^{S} G_{ijv} \cdot N_{ijv} \cdot l_i \) (gross tonne-kilometer) and
- \( NA_{k} \) as total annual number of trains serviced in the node \( v \). Obviously \( NA_{k} = \sum_{i=1}^{J} \sum_{j=1}^{I} \sum_{v=1}^{S} N_{ijv} \) (trains).

The traffic module has been integrated with the network model by allocating an appropriate operation indicator to each sections of category \( k \) and node \( v \), i.e. \( NA_{kx}^{TN}, NA_{kx}^{GS} \) and \( NA_{k} \). Having in mind that certain train types do not have the same effect on the infrastructure wear and tear, nor do they demand the same service quality, cost weight \( Dv_i \) for a train type \( i \) is entered into the module.

### 4.3.3. Costs module

A cost module considers the projected costs for the period for which the access charges are calculated and they are the parameters of cost module design. The projected costs represent the realized costs increased by: the projected traffic volume growth factor, the projected efficiency factors which represent a change in work volume, namely spent working hours, materials and services, and productivity factor.

The costs of the use of infrastructure are modelled by using the analytical approach based on the integration of the bottom-up allocation method, statistical and engineering analysis and the expert estimation. The cost covered by access charges depend on charging principle. The allocation of different costs (full, variable) is in accordance with the network segments, train types, traction categories and services. Our bottom-up costs allocation model in the costs module uses the following cost characteristics for each section of category \( k \) and node \( v \): cost category \( m \) and costs attributed to operation unit \( n \). Cost allocation by the place of inaccuracy in the network elements, sections of category \( k \) and node \( v \), is based on the analyses of relations between costs and network segments. Having in mind the infrastructure costs data collection, a key for the allocation of costs to network segments is related to statistical and engineering analysis of operation units’ hours work.

As regards the cost category denoted by \( m \) and the level of detail to which data are kept, costs are distributed to the costs of material and energy \( m_1 \), labour \( m_2 \), services \( m_3 \), administrative costs \( m_4 \), renewal cost \( m_5 \) and financial cost \( m_6 \). Considering the operation units that participate in the process of services, costs attributed to operation unit denoted by \( n \) are allocated to the costs of infrastructure maintenance \( n_1 \), costs of the maintenance of electro traction facilities, power supply equipment and overhead facilities \( n_2 \), the costs of the maintenance of facilities, plants and signalling equipment, telecommunication and other electric equipment \( n_3 \), the costs of the operation of trains \( n_4 \) and the costs of train servicing in nodes \( n_5 \).

The costs of infrastructure maintenance \( n_1 \) are the result of infrastructure wear and tear due to the operation of trains of different categories and weights. Infrastructure maintenance, i.e. infrastructure “recovery” depends on the number and weight of trains. They are used for the unit cost calculation per gross tonne-kilometer for each train \( (i, j) \) and sections of category \( k \) and for the calculation of the unit cost per gross tonne-kilometer for each train \( (i, j) \) in the node \( v \). The costs of the traction facilities, power supply equipment and overhead facilities \( n_2 \), the costs of the maintenance of electro traction facilities, telecommunication and other electric equipment \( n_3 \), the costs of the maintenance of objects, plants and signalling equipment, telecommunication and other electric equipment \( n_3 \), and the costs of train operation \( n_4 \) are included in the unit costs per train-kilometer for each train \( (i, j) \) and sections of category \( k \) and in the unit costs of train \( (i, j) \) in node \( v \). The costs of train servicing in nodes \( n_5 \) are included in the unit costs per train-kilometer for each train \( (i, j) \) and sections of category \( k \) and in the unit costs of train \( (i, j) \) which is serviced in node \( v \).

Having in mind that various expenditure data are kept, the module permits the allocation of all costs, from the full to the variable and fixed costs. In this module, based on the expenditure category data recording and job types, variable costs include the costs of: track wear and tear resulting from train movement, train traffic regulation and signalling, timetable scheduling and administrative
4.4. Unit costs calculation

In order to simplify the presentation of the model, we present the unit costs calculation for only one example of cost covering, for MC+ charging principle. Interested readers can apply the other charging principles (FC, FC→, MC, MC+ Ramsey) in the same way.

The parameters of the model design are introduced in the module in order to define the train unit costs and to define the relationship between the charging principles and costs allocation. The parameters of the cost module are: \( p_{mk}, p_{mnv} \) as percentage of cost variability for costs attributed to operation units \( n \) and costs category \( m \) and network elements and \( \text{mark}_k \), defined as a percentage given to the train type \( i \) respectively. The importance of each cost attributed to operation unit \( n \), depending on network elements is included in the cost module in the form of weights \( D_{mk} \) and \( D_{nv} \).

Since marginal costs are approximated by variable costs, train unit costs based on the principle (MC+) are calculated on the basis of variable costs increased by the markup value which depends on the train type \( i \). The total annual variable costs \( VA \) of all trains that operate in the network are:

\[
VA = \sum_{k=1}^{K} VA_{ik}^{TK} + \sum_{k=1}^{K} VA_{ik}^{GK} + \sum_{v=1}^{V} VA_{iv}^{T} + \sum_{v=1}^{V} VA_{iv}^{S}
\]

and the unit variable costs for sections of category \( k \) and nodes are obtained as follows:

per train-kilometer for the sections of category \( k \)

\[
VA_{ik}^{TK} = \sum_{m=1}^{M} NA_{ik}^{m} \cdot VA_{imk}^{TK} \cdot D_{mk}
\]

and

per gross tonne-kilometer for the sections of category \( k \)

\[
VA_{ik}^{GK} = \sum_{m=1}^{M} NA_{ik}^{m} \cdot VA_{imk}^{GK} \cdot D_{mk}
\]

and

per train-kilometer for the sections of category \( k \)

\[
VA_{ik}^{GK} = \sum_{m=1}^{M} NA_{ik}^{m} \cdot VA_{imk}^{GK} \cdot D_{mk}
\]

and

per gross tonne-kilometer for the sections of category \( k \)

\[
VA_{ik}^{GK} = \sum_{m=1}^{M} NA_{ik}^{m} \cdot VA_{imk}^{GK} \cdot D_{mk}
\]

As said before, many studies are focused only on providing concrete evidence on what actually happens to costs when traffic volumes change. The latest evidence from such studies is summarised in Wheat and Smith (2008). Cost elasticity from such studies is generally in the range of 0.1–0.3, with the study of Gaudry and Quinet (2009) on French data being the sole higher value at 0.37. For defining the mark up as a percentage that is a function of train type, the statistical analysis of the accounting records of the resource utilisation by type of resource at the level of train in the combination with the expert estimation is applied.

Thus, train unit costs based on the marginal cost plus principle \( VM_{ik}^{GK} \), \( VM_{ij}^{GK} \) for trains of type \( i \) and traction category \( j \) on the sections of category \( k \) and \( VM_{ij}^{GK} \), \( VM_{ij}^{GK} \) for trains of type \( i \) and traction category \( j \) in the node \( v \) are determined with the corresponding unit variable costs increased by the mark \( \text{mark}_k \) for the train type \( i \) as follows:

\[
VM_{ik}^{GK} = VA_{ik}^{GK} \cdot (1 + \text{mark}_k), \quad VM_{ij}^{GK} = VA_{ij}^{GK} \cdot (1 + \text{mark}_j)
\]

5. Numerical example

The defined access charges model has been applied to an example of a mid-size and developed regional railway network. Considering the network size, configurations and circumstances under which trains are operated, a representative of such a network is the railway network of Serbia. Serbian rail network includes 3293 kilometer of lines, 543 stations and stops in service. In 2006, 156,487 passenger and 23,286 freight trains carried about 14.1 million passengers and 12.6 million tonnes of goods and performed 4232 million gross tonne-kilometer and 864 million passenger’s kilometres. The transit freight traffic is dominant in the network. The average capacity utilisation on the main line is up to 60%.

5.1. Input data

The Booz Allen Hamilton (2007) study is used as a key document for input data values. On the network passenger and the freight trains \( J = 2 \) operate with electric and diesel traction (\( J = 2 \)). In accordance with the definition of a section and node (chapter 4), the network is segmented into 6 nodes (344 kilometer total length) and three categories of sections (2949 kilometer total length): 23 sections of the main category \( (m) \), 17 sections of the regional category \( (r) \) and 10 sections of the local category \( (l) \).

Train movement between origin and destination points on a line can be performed through various stations, so a maximum of 5 combinations of train movement (path) have been defined for one route. The matrix of train paths consists of 7149 paths in the network. Servicing of trains by nodes is calculated on the basis of the statistical analysis of planned passenger and realized freight train paths which are serviced by nodes. The percentage of the train services by nodes is a result of the statistical analysis of the available data combined with expert estimation from the operating personnel in the nodes.

In 2006, the costs were 128.52 mill EUR, the reconstruction costs were 64.05 mill EUR and 6.36 mill EUR were the financial costs. Projections of traffic, costs and revenues for 2010 are shown in Table 2.
For the cost model according to the operation units that participate in the process of train servicing, the costs incurred by civil work, traffic regulation, electro, electro-signalling and vehicle inspection have been selected. According to the economic nature of costs the costs of the material and energy, labour, services and administrative costs have been selected. The value of the variable costs for 2006 has been determined based on the approximation of total costs. The percentage of variability for each cost is obtained on the basis of (1) a statistical and engineering data analysis by the Serbian railways experts (2) and data taken from the literature – lit. (Booz Allen Hamilton TTCI UK, 2005; Thomas et al., 2003). Based on certain infrastructure states from the maintenance aspect and the amount of maintenance effort and available financial funds two scenarios have been defined: C1 (ideal conditions) and C2 (current conditions). Cost variability for the network is presented in a Table 3. The analysis of Serbian railways’ revenues and expenditures shows that the mark up value is in the range from 20% to 50% depending on the train type and traction category. As freight traffic dominates, the mark up value for freight traffic is 50% and 20% for passenger traffic.

The presented access charges model has been tested for train paths on different lines, for the charging principle MC+ and for the cost variability percentage established according to the scenario C2.

5.2. Results and discussion

The analysis of access charges value per train-kilometer for passenger and freight trains of an average weight 500 t, presented in Table 4, indicate that there is a significant difference between access charges values regarding line category and train type. The results show that access charges for freight trains on electrified lines are up to 44% higher than those for passenger trains on the same lines. On non-electrified line the access charges for passenger trains are 23% lower than for freight trains. If the amounts of access charges are considered according to a line category, the access charges for main line are higher than access charges for the regional lines for both line traction categories. As can be observed in this way infrastructure managers want to attract new operators and to increase the efficiency of regional network usage.

Comparison of the access charges amounts on EU member states’ railway networks and Serbia railway network, for an average passenger train (450 tonnes) and an average freight train (960 tonnes) under present conditions are shown in Fig. 3. Although Fig. 3 is based on 2008 data (ITF-OECD, 2008), the structure and level between EU countries has remained essentially unchanged up to today. Access charges for an average passenger train range from 0.73 to 6.12 EUR per train-kilometer and from 0.40 to 9 EUR per train-km for an average freight train. As can observe, according to the network size and characteristics, we obtain the AC amounts on Serbian railway network for passenger and freight trains in the proposed range, which demonstrates the practical use of the proposed solution scheme.

Fig. 4 shows the access charges associated to typical freight transit trains on a main line with electro traction and servicing in two nodes. It can be seen that the relationship between the freight train weight and the total amount of access charges, according to our access charges model is linear. In analysis of the calculation of charges for Bulgaria’s infrastructure network, which also belongs to the group of small- and mid-size networks, Nikolova (2008) also shows the existence of a linear dependence between the total amount of access charges and train weight. As can be observed, the relationship between the freight train weight and the total amount of access charges for small- and mid-size network is linear. It demonstrates, at this stage of the market development, the IMs intention that AC reflect the direct cost of train operation to the infrastructure.

The empirical results of access charges for the characteristic passenger and freight trains that are not services in nodes for the 2010/2011 timetable are summarized in Table 5. In the table, we present the values of access charges for a train service on sections (C1) separated from access charges for a train passing through nodes (C2). For the 2010/2011 timetable train weights range from 400 to 700 t for passenger and from 700 to 1690 t for freight traffic. For international freight trains whose weights are approximately twice larger than the weights of international passenger trains, charges per train-kilometer, on Belgrade-Nis and Belgrade-Sid and Belgrade – Subotica lines are higher by 34–203% than on other relations. In other words, these relations present the infrastructure manager’s strategy to charge more the infrastructure wear and tear for freight transport in the initial stage of market opening. This is also expected, since all costs are not collected according to the place of origin and only the costs of infrastructure wear and tear can be quantified the most precisely. This situation is the same in the majority of railways in Eastern Europe, but this is contrary to what happens in Western Europe, where infrastructure managers appear with the attitude that short distance passenger service to carry a higher portion of cost contribution than freight services (ITF-OECD, 2008).

In the access charges of one passenger train path, the largest share goes to access charges for a train service on sections (C1) and it ranges from 83% to 98%. On the other hand, in the price of one freight train path the largest share goes to charges expressed in gross tonnes-kilometer and it ranges from 75% to 90% for a main line and from 84% to 88% for a regional line. Such relations between the access charges show that railway wear and tear is charged primarily through the access charges. The time occupation of

| Table 2 | Projection of traffic, costs and revenues for 2010. |
| Railway network indicators | Growth factor pass/freight traffic (%) |
| Passenger kilometres | +19/0.0 |
| Gross tonne kilometres | +0.0/+3.2 |
| Number of trains | +28.8/+13.6 |
| Cost | +7.8/+21.6 |
| Revenues | +8.3/+20.4 |

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| Table 3 | Cost variability for the network. |
| Category of work | Category of cost Variability (%) |
| | Salaries | Material and energy | Services | Renewal and cost of finance |
| | C1 | C2 | lit. | C1 | C2 | lit. | C1 | C2 | lit. |
| Electro | 9.0 | 24.0 | 37.0 | 15.0 | 38.0 | 57.0 | 18.0 | 24.0 | 35.0 | 10.0 | 27.0 | 4.0 |
| Electro-signalling | 9.0 | 24.0 | 37.0 | 15.0 | 38.0 | 57.0 | 18.0 | 24.0 | 35.0 | 10.0 | 27.0 | 4.0 |
| Traffic related | 20.0 | 28.0 | 5.0 | 26.0 | 26.0 | 7.0 | 1.8 | 18.0 | 4.0 | 20.0 | 27.0 | 5.0 |
| Civil related | 8.0 | 22.0 | 5.0 | 14.0 | 39.0 | 5.0 | 31.0 | 35.0 | 3.0 | 13.0 | 28.0 | 5.0 |
| Vehicle inspection | 59.0 | 59.0 | 23.0 | 61.0 | 61.0 | 42.0 | 22.0 | 22.0 | 38.0 | 58.0 | 58.0 | 3.0 |
infrastructure has a secondary influence on the efficiency of infrastructure usage because the competition is still small. Serbia’s railway network involves mixed traffic where freight traffic is dominant and, because of this, the share of charges for gross tonne-kilometer reflects well the relations among traffic, costs and network characteristics, i.e., they are a result of the stated cost principle as a aim. All these empirical results demonstrate the correctness of the model and the defined analytical approach has been formulated well.

The way in which network cost data have been recorded up to now does not enable cost allocation directly to network segments. Our model does perform infrastructure cost allocation to the segments of network module and traffic module (Table 6). Empirical results have shown that costs at nodes for all trains are considerably higher (77,932 EUR/kilometer of nodes) than those at sections (34,493 EUR/kilometer of section). In addition, empirical results have also shown that more than twice larger passenger traffic volume (in train kilometer) causes costs higher by 4% compared with freight traffic. This is one of the examples why the model-defined cost allocation permits identifying inefficiency “places” where costs should be reconsidered and reduced. This is one among the requirements imposed on model construction – the model should allow cost management as a management perspective.

Having in mind the method of network module definition, it is possible to calculate access charges for the same route but along different paths. In Table 7, the example of a passenger train on Belgrade – Subotica route shows that the model reflects well the interdependence among a network segments, cost and access charges amount. The possibility of choosing more than one path for the route enables the infrastructure manager to offer a train operator a path with different lengths or access charges amounts. Such a possibility helps a train operator in making a decision according to a specific type of service or willingness to pay a level of access charges.

Fig. 5 presents the empirical results obtained by testing the model for various economic principles of charges (MC, MC+ and FC) which include different infrastructure costs covering. We conduct a sensitivity analysis of the access charges amount with respect to a passenger train weight for different economic principles for Belgrade-Subotica line. Model flexibility with respect to the use of different economic principles permits making decisions in the sense of increasing infrastructure manager’s efficiency and the degree to which infrastructure costs are covered by access charges. Applying and testing different charging principles in cost models enable cost management and making a right decision timely.

It appears that the approach to defining a charges model used so far (presented in Section 2) has not been a systems approach. This approach has included models with an accepted access charges principle without a previous validation of it. We defined access charges model based on a systems approach that permits the shortcomings of previous models to be overcome and efficiently research of the solution area decreases mistakes.

<table>
<thead>
<tr>
<th>Line</th>
<th>Access charges (EUR per train-kilometer)</th>
<th>Freight</th>
<th>Pass</th>
<th>Proportion freight/pass</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electro</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Main</td>
<td>2.65</td>
<td>1.84</td>
<td>1.44</td>
<td></td>
</tr>
<tr>
<td>Regional</td>
<td>1.48</td>
<td>1.31</td>
<td>1.13</td>
<td></td>
</tr>
<tr>
<td>Diesel</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Main</td>
<td>1.95</td>
<td>1.59</td>
<td>1.23</td>
<td></td>
</tr>
<tr>
<td>Regional</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Example: gross weight 500 tonnes, 1 train, distance 1 kilometer.
Achieving a balance among revenues from charges, subsidy and total expenditure is very important for infrastructure manager. The model permits monitoring the achievement of this balance under changes in traffic volume, the amount of mark up, charges and

### Table 5

Railway infrastructure charges for the characteristic train paths without services in the node for the timetable 2010/2011.

<table>
<thead>
<tr>
<th>Train path</th>
<th>Path length (m/r/l) (kilometer)</th>
<th>Type of traction</th>
<th>Train weight (tonne)</th>
<th>Amount of access charges</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Freight</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Subotica-C.Krst (Niš)</td>
<td>437/0/0</td>
<td>Electro</td>
<td>1300</td>
<td>1608.01</td>
</tr>
<tr>
<td>Dimitrovgrad/C.Krst (Niš)</td>
<td>104/0/0</td>
<td>Diesel</td>
<td>1465</td>
<td>415.68</td>
</tr>
<tr>
<td>Subotica-Begovgrad r.</td>
<td>184/0/0</td>
<td>Electro</td>
<td>1100</td>
<td>1585.53</td>
</tr>
<tr>
<td>Šid-Novs Sad r.</td>
<td>128/0/0</td>
<td>Diesel</td>
<td>1600</td>
<td>808.08</td>
</tr>
<tr>
<td>Šid-Begovrad sp.</td>
<td>120/0/0</td>
<td>Electro</td>
<td>700</td>
<td>287.78</td>
</tr>
<tr>
<td>Šid-Lapovo</td>
<td>239/0/0</td>
<td>Electro</td>
<td>1400</td>
<td>468.36</td>
</tr>
<tr>
<td>Lapovo-Kragujevac (Kraljevo)</td>
<td>85/0/0</td>
<td>Diesel</td>
<td>1100</td>
<td>2647.74</td>
</tr>
<tr>
<td>Preševo-Begovgrad r.</td>
<td>410/0/0</td>
<td>Electro</td>
<td>1200</td>
<td>1411.40</td>
</tr>
<tr>
<td>Preševo-Niš r.</td>
<td>157/0/0</td>
<td>Electro</td>
<td>1225</td>
<td>549.49</td>
</tr>
<tr>
<td>Niš-Prahaovo Pr</td>
<td>0/175/0</td>
<td>Diesel</td>
<td>1000</td>
<td>331.54</td>
</tr>
<tr>
<td>Dimitrovgrad/C.Krst-Niš</td>
<td>104/0/0</td>
<td>Diesel</td>
<td>1690</td>
<td>479.45</td>
</tr>
<tr>
<td>Beograd r. – Niš</td>
<td>253/0/0</td>
<td>Diesel</td>
<td>1300</td>
<td>932.05</td>
</tr>
<tr>
<td>B. Polje-Subotica</td>
<td>471/0/0</td>
<td>Diesel</td>
<td>1000</td>
<td>1694.04</td>
</tr>
<tr>
<td>Vrača-Rgd. sp. (Pancevo)</td>
<td>85/0/0</td>
<td>Renewable energy</td>
<td>1000</td>
<td>246.46</td>
</tr>
<tr>
<td>(Pancevo) Bgd. sp.-B. Polje</td>
<td>308/0/0</td>
<td>Diesel</td>
<td>1000</td>
<td>910.64</td>
</tr>
<tr>
<td>Kikinda-Subotica-Bijelo Polje</td>
<td>462/109/53</td>
<td>Diesel</td>
<td>1000</td>
<td>1811.33</td>
</tr>
</tbody>
</table>

**Passengers**

<table>
<thead>
<tr>
<th>Train path</th>
<th>Path length (m/r/l) (kilometer)</th>
<th>Type of traction</th>
<th>Train weight (tonne)</th>
<th>Amount of access charges</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Beograd-Subotica</td>
<td>184/0/0</td>
<td>Electro</td>
<td>500</td>
<td>245.13</td>
</tr>
<tr>
<td>Beograd-Šid</td>
<td>120/0/0</td>
<td>Diesel</td>
<td>600</td>
<td>200.61</td>
</tr>
<tr>
<td>Beograd-Niš-Dimitrovgrad</td>
<td>357/0/0</td>
<td>Electro</td>
<td>500</td>
<td>518.64</td>
</tr>
<tr>
<td>Beograd-Novs Sad</td>
<td>77/0/0</td>
<td>Diesel</td>
<td>500</td>
<td>113.16</td>
</tr>
<tr>
<td>Beograd-Bijelo polje</td>
<td>287/0/0</td>
<td>Diesel</td>
<td>680</td>
<td>530.99</td>
</tr>
<tr>
<td>Požega-Kraljevo-Lapovo</td>
<td>85/67/0</td>
<td>Diesel</td>
<td>400</td>
<td>161.03</td>
</tr>
<tr>
<td>Beograd-Niš</td>
<td>253/0/0</td>
<td>Diesel</td>
<td>700</td>
<td>478.66</td>
</tr>
<tr>
<td>Dimitrovgrad-Niš</td>
<td>104/0/0</td>
<td>Diesel</td>
<td>620</td>
<td>173.14</td>
</tr>
<tr>
<td>Beograd-Niš-Prahaovo Pr</td>
<td>410/0/0</td>
<td>Diesel</td>
<td>700</td>
<td>775.35</td>
</tr>
<tr>
<td>Beograd-Vrača</td>
<td>106/0/0</td>
<td>Diesel</td>
<td>550</td>
<td>160.36</td>
</tr>
<tr>
<td>Požarevac-Zaječarić</td>
<td>0/162/0</td>
<td>Diesel</td>
<td>400</td>
<td>144.39</td>
</tr>
</tbody>
</table>

Note: For the ratio of the RSD for 1 EUR was used average official middle exchange rate for particular year; m/r/l – main/regional/local lines.

### Table 6

Cost and traffic allocation to the segments of network and type of trains.

<table>
<thead>
<tr>
<th>Network module</th>
<th>Traffic module (10^3 train kilometer)</th>
<th>Cost module (10^6 EUR)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Freight</td>
<td>Passenger</td>
</tr>
<tr>
<td></td>
<td>Total main 37250</td>
<td>56683</td>
</tr>
<tr>
<td></td>
<td>Total regional 2557</td>
<td>27914</td>
</tr>
<tr>
<td></td>
<td>Total local 367</td>
<td>454</td>
</tr>
<tr>
<td></td>
<td>Node v1 – Novi Sad 270</td>
<td>358</td>
</tr>
<tr>
<td></td>
<td>v2 – Beograd 2724</td>
<td>6745</td>
</tr>
<tr>
<td></td>
<td>v3 – Lapovo 311</td>
<td>205</td>
</tr>
<tr>
<td></td>
<td>v4 – Niš 628</td>
<td>1196</td>
</tr>
<tr>
<td></td>
<td>v5 – Vrača 125</td>
<td>594</td>
</tr>
<tr>
<td></td>
<td>v6 – Subotica 613</td>
<td>441</td>
</tr>
</tbody>
</table>

### Table 7

Access charges for passenger train Belgrade – Subotica, with different via.

<table>
<thead>
<tr>
<th>Via</th>
<th>Length (kilometer) (m/r/l)</th>
<th>Weight (tonne)</th>
<th>Co (EUR)</th>
<th>Access charges (EUR/train-kilometer)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Novi Sad, Subotica</td>
<td>184/0/0</td>
<td>500</td>
<td>295</td>
<td>1.60</td>
</tr>
<tr>
<td>Pancevo, Zrenjanin</td>
<td>20/201/0</td>
<td>500</td>
<td>463</td>
<td>2.10</td>
</tr>
<tr>
<td>Vrbas, Sombor</td>
<td>175/0/53</td>
<td>500</td>
<td>535</td>
<td>2.35</td>
</tr>
</tbody>
</table>

Note: m/r/l – main/regional/local lines.

Achieving a balance among revenues from charges, subsidy and total expenditure is very important for infrastructure manager. The model permits monitoring the achievement of this balance under changes in traffic volume, the amount of mark up, charges and
subsidies. The effect of a traffic increase and mark up on the coverage of total costs by access charges has been tested for 2010 as a basic year, the C2 cost variability scenario and the accepted 50% mark up for freight service. The empirical results are summarized in Fig. 6. We observe that for traffic volume increases from 5% to 20% the coverage of total costs by access charges increases from 37% to 39%. In case of mark up for passenger service increases from 20% to 25% the coverage of total costs by access charges increases from 39% to 43%. It should be kept in mind that an increase in passenger traffic volume requires a higher quality of service which results in higher network maintenance costs; therefore, the percentages of network cost coverage increase considerably slower than traffic volume increase.

The examples of empirical results shown here illustrate that our model gives a good analytical picture of infrastructure usage costs, allows cost allocation, identifies “places” where costs are inefficient and permits IM cost management using relations among revenues from charges, costs and subsidies. In other words, the model allows managing the balance among revenues, costs and subsidies if is caused by changes in traffic volume, the amount of charges or the amount of subsidies.

6. Conclusion

In this study is proposed a universal access charges model for an essential service for a European mid- and small-size railway network based on a systems approach to recovering the costs that are incurred as a result of operation of train. We suggest a system approach as a new approach to make a correlation among costs, network and traffic characteristics. The first advantage of an access charges model defined in this way is that defining of AC is treated as a specific allocation problem viewed as a pre optimization task. The second advantage of this approach and modelling is that they enable testing of the effects of the implementation of different access charges principles and the cost recovery for the operation of train according to the cost origin and cause. The model establishes strong correlation of infrastructure costs to services which allows an IM to manage infrastructure costs by using access charges.

Network segmentation is performed on the elements which create a homogeneous entity in terms of the technical characteristics and concentration of the traffic, revenues and costs. Defined sections and nodes represent a specific and original characteristic of this model. The proposed model consists of modules that can be easily adapted to the internal and external determining factors of rail network, cost and traffic. It can be adapted to European mid- and small-size network with the diversity of railway lines and rail transport services with only a limited modification.

The presented numerical example based on real data and testing for passenger and freight traffic on the Serbian railway network, points out the theoretical and practical effects of the implementation of the access charges model. Obtained results and conclusions are in line with results from reports in ITF-OECD (2008). The usefulness of our model lies not only in the fact that it can be used to obtain access charges value but also in that it can be used for the planning and management of infrastructure usage.

Application of this model and approach in similar non EU networks is a good extension of the current research. Lastly, further research can be directed towards combining our systems approach with the path allocation approach. This approach will introduce infrastructure cost elements early in the overall time table generation process and can be done by using the mathematical programming method.

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References


