EVALUATING AND RANKING INFRASTRUCTURE MANAGER STRATEGIES USING THE COMBINED AHP/DEA METHOD

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Restructuring of European Railway companies has resulted in creating new subjects within railway systems - infrastructure managers (IM) on the one hand and railway operators on the other. Each of these subjects strives for efficient operation within the boundaries dictated by regulatory bodies or government directly. In this paper we examine the efficiency and rank different business strategies of railway infrastructure managers using combined AHP/DEA method. Different strategies include different number of paths allocated (diferent capacity utilization index), different ratio of paths allocated to passenger and freight trains in case of demand for paths being higher than the capacity of the line and infrastructure access charges based on different principles. Each strategy examined is subjected to constrains such as the maximum capacity of the line and public service obligation considering the obligatory number of passenger trains in the timetable defined by the public authorities. The method applied for evaluating and ranking different strategies is a combined AHP/DEA method. Each strategy of the IM is regarded as a decision making unit (DMU) and as such, in the first stage of the model, paired with each of the remaining DMU's. The Data Envelopment Analysis (DEA) is run for each pair of units separately. In the second stage, the pair wise evaluation matrix generated in the first stage is utilized to rank scale the units via the Analytical Hierarchical Process (AHP). The results can be used for evaluation of efficient use of infrastructure capacity and financial efficiency of IM simultaneously.

Key words: Infrastructure manager, evaluating, ranking, AHP/DEA

1 Introduction

The need to create better managed, more commercially responsive and market-led railways has been widely recognized across Europe in recent years. This has resulted in economic reforms often described as railway restructuring, a process of creating new organizations, revised accounting methods, liberalization through the introduction of competition and regulatory reform. New subjects were created in railway market: infrastructure managers (IM) and railway operators (RO). IM is responsible for management and maintenance of railway infrastructure, allocating railway capacity (train paths) to RO's and organizing traffic along the network. For these services, IM receives compensation (in form of charges for the use of infrastructure and additional services, paid by operators) and tends to maximize its profit.

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IM operates as a company fully commercially responsible for the outcome of its business. Therefore, IM needs to maximize the efficiency and effectiveness of its operation. Those two criteria can be applied to analyze the operation of IM in two stages correlating to its duties and responsibilities. The first stage of the IM's efficiency analysis corresponds to the capacity production process (the process of maintaining and providing equipment in order to maximize the capacity of the available infrastructure). The second stage however, regards the efficiency of the mere allocation of the capacity produced in the first stage (allocating the available capacity in a manner that maximizes its profit from sold train paths). It is obvious that the output of the first stage represents the input of the second stage. In this paper we analyze discrete options of IM's business strategies aiming to maximize the efficiency of the second stage of its operation. In order to achieve this we use the combined AHP/DEA methodology. Each strategy is regarded as a decision making unit (DMU) in DEA and described through the inputs and outputs resulting from the application of that strategy. After determining the relative efficiency of each strategy considered, AHP is used for ranking them. The proposed decision support model is intended to enable the IM to direct the allocation process (in the phase of consultations with RO's and preliminary timetable development) towards the strategy which would grant him the highest profit.

Previous work regarding the efficiency of railway companies includes papers analyzing the integrated railway systems: Christopoulos and Loizides (2001), Yu and Oum (2004). Authors such as Friebel et al. (2004), Jensen (1998) and Cantos (2001) considered vertically separated and deregulated railway systems but focused on the efficiency and productivity of overall systems.

The rest of the paper is structured as follows: in section 2 we give the basics of both DEA and AHP as well as of the combined AHP/DEA method, section 3 comprises the detailed problem description, section 4 our proposed solution and conclusions are given in section 5.

2 AHP/DEA Methodology

In this section we will give the basics of DEA, AHP and the combined AHP/DEA methodology.

2.1. DEA theory and methodology

In recent years Data Envelopment Analysis (DEA) has been used to analyze the relative efficiency of entities (decision making units – DMU's) from various fields of production and services provision as summarized in [1]. DEA is found suitable for analyzing, comparing and evaluating the efficiency of entities which have similar inputs (resources used for production or service supply) and similar outputs.

A group of DMU's is selected and performance of each unit relative to the others within the group is determined. Performance of these units is evaluated in terms of efficiency i.e. ratio of weighted sum of outputs to the weighted sum of inputs. The basic DEA model, CCR is formulated in [2] in a following way:

$$Max\ h_k(u,v) = \frac{\sum_{r=1}^{s} u_r y_{rk}}{\sum_{i=1}^{m} v_i x_{ik}} \tag{1}$$

$$\frac{\sum_{r=1}^{s} u_r y_{rj}}{\sum_{i=1}^{m} v_i x_{ij}} \le 1, j = 1, 2, \ldots, n \tag{2}$$

$$u_r \ge 0, r = 1, 2, \ldots, s \tag{3}$$

$$v_i \ge 0, i = 1, 2, \ldots, m \tag{4}$$

Where h_k = relative efficiency of the k^{th} DMU; m = the number of inputs; s = the number of outputs; u_r = weight of the output r; v_i = weight of the input i; n = number of analyzed DMU's; This model is easily transformed into a basic linear programming (LP) model by introducing an additional constraint which levels the denominator of the equation (1) with 1. Solution to this LP problem are the optimal values of input and output weights (describing the importance of each input and output, respectively, and their contributions to the DMU's efficiency) which ensure the maximum relative efficiency of the observed DMU. If the value of the objective function (1) is equal to 1 then the observed k^{th} DMU is relatively efficient. On the other hand, if the value of (1) is smaller than 1, then k^{th} DMU is relatively inefficient and all units whose efficiency coefficient is equal to 1 (with using the optimal weights of unit k) form the reference set of unit k i.e. set of units whose efficiency the unit k is able to reach by either reducing some input(s), increasing output(s) or both.

The number of LP problems that has to be solved in carrying out DEA on a selected group of DMU's equals the number of selected DMU's. The results of DEA can be numerous depending on the application of the method. In this paper we use the matrix of mutual efficiency as the main outcome of DEA.

2.1 Analytic Hierarchy Process (AHP)

AHP is a widely accepted intuitive method, first stated in [6], for formulating and analyzing decisions.

Users of the AHP first decompose their decision problem into a hierarchy of more easily comprehended sub-problems. Once the hierarchy is built, the decision makers systematically evaluate its various elements by comparing them to one another two at a time. In the final step of the process, numerical priorities are calculated for each of the decision alternatives. These numbers represent the alternatives' relative ability to achieve the decision goal, so they allow a straightforward consideration of the various courses of action.

AHP is widely used for the variety of decision making problems and its application results in optimal decision, ranking or prioritization of alternatives within the given set.

2.2 Reasons for combining DEA with AHP and methodology

The combined AHP/DEA methodology has been stated and formulated in [7]. The method consists of two stages. In the first stage of the model every DMU is paired with each of the remaining DMU's. The Data Envelopment Analysis (DEA) is run for each pair of units separately. In the second stage, the pair wise evaluation matrix generated in the first stage is utilized to rank scale the units via the Analytical Hierarchy Process (AHP).

When applied separately both DEA and AHP have its limitations. The combined AHP/DEA method is therefore introduced to avoid these limitations and broaden the range of possible applications and results. DEA deals with classifying the elements (units) into two categories, efficient and inefficient without ranking them. All efficient units are equally good (with efficiency 1). AHP on the other hand uses the pair wise comparisons of criteria and alternatives with a significant subjective influence of the decision maker to rank the analyzed units.

Outcome of the first stage of the combined AHP/DEA method is the pair wise relative efficiency matrix which then represents an input to a single level AHP for fully ranking all units. Thus the limitations of both DEA and AHP are eliminated i.e. all units are ranked (limitation of DEA) without subjective influence (limitation of AHP).

3 Problem description

In this paper we analyze discrete options of IM's business strategies in order to maximize the efficiency of the second stage of its operation. Second stage represents allocation of the available capacity. This means selling the right to use train paths to operators. Input of the allocation process is the capacity of the observed line (number of train paths). UIC (International Railway Union) states that "Capacity as such does not exist. Railway infrastructure capacity depends on the way it is utilized". Methodology has been derived, which calculates capacity utilization through a pre-constructed timetable expressing market needs.

We assume that there is a general timetable constructed for the line with mixed traffic (both passenger and freight trains operate along the line) in a way which expresses the demand for paths. We do not deal with micro location of paths within the timetable. The number of paths in the timetable is limited and equal to the highest possible number of paths in a time interval on the limiting section. This determined number of paths can be allocated to trains with different traffic characteristics. This can result in slight changes of the capacity utilization index (CUI) of the line (± several percent) but these changes will not be considered in this paper due to their limited effect on the quality of the traffic.

The problem of IM which we consider is: how to allocate the given capacity of one line under the assumption that the demand for paths for each train type is at least as high as the capacity of the line, with regard to the following:

- Different traffic characteristics imply the heterogeneity of traffic which strongly affects the quality of traffic. We separate all trains in three groups on the basis of speed: freight trains, long-distance passenger trains transiting the limiting section and local trains stopping at both stations which bond the limiting section.
- Trains can also be separated into different general groups (direct freight trains, feeder freight trains and passenger trains) following criteria: costs incurred and revenue gained by the train operation.

Therefore, different ratio of types of trains will not only result in different quality of the services provided by IM but also in different costs and revenues of IM. On top of that, different types of trains dominating the timetable directly affect the principles for setting out charges which RO's pay for the right to use infrastructure. The optimal ratio of different train types will result in highest revenue of IM and highest possible quality of the service.

4 Proposed solution

4.1 General assumptions

Theoretically, the number of possible ratios of different train types operating along one line is big thus making a huge search space for getting the optimal solution. On the other hand, by following the reasonable logic of railway practice (public service obligation, statistical data, long term agreements between IM and freight or passenger RO's, train paths for international trains etc.) we are able to reduce the search space to several different sensible strategies for railway capacity allocation. In other words, under the assumption that IM normally has a pre defined number of train paths already allocated to international trains, trains that fulfill the conditions for public service obligation and train paths allocated on the basis of long term agreements, we base a statement that only a certain number of paths along the line (not all of them) are to be allocated in a manner which maximizes IM's revenue and the quality of service.

We regard the number of train paths to be allocated to either freight trains (direct or feeder) or passenger trains (local or long-distance) and the principles for setting out charges for the right to use infrastructure, directly resulting from the structure of timetable, as one strategy of IM. Each strategy of IM results in a certain revenue from collecting charges from railway undertakings and in a certain quality of traffic along the observed line.

This problem can be formulated as a multi objective linear programming problem. The objective functions would in that case be the maximization of revenue and of a coefficient introduced to depict the quality of traffic. The Pareto optimum can further be derived giving the optimal number of paths allocated to each train type considered. Constraints in such problem would be pre defined numbers of paths for every train type.

In this paper we propose the approach to this problem using the combined AHP/DEA methodology in order to examine the possibilities of its uses for strategic planning in transportation sector.

4.2 AHP/DEA approach

We first determine the number of strategies to be examined. Each strategy represents one DMU (Fig. 1) with its correlating inputs and outputs. Unit costs incurred by IM for operation of one train differ depending on the train type. Therefore we regard the number of trains of each train type as an input in one DMU. For the purpose of applying DEA we show the number of trains of each type through the cost incurred by IM from their operation along the line. It is obvious that the number of inputs is equal to the number of train types.

Each DMU will have two outputs that it tends to maximize: revenue of IM as a result of RO's use of infrastructure and the coefficient which quantifies the quality of traffic (punctuality of trains and stability and robustness of timetable as a function of the heterogeneity of traffic). Revenue can be calculated by means of using the unit values of charges for the right to use the infrastructure and applying an appropriate structure for setting out the overall charges. Quality coefficient and the method for its calculation are stated in [5] and [8].

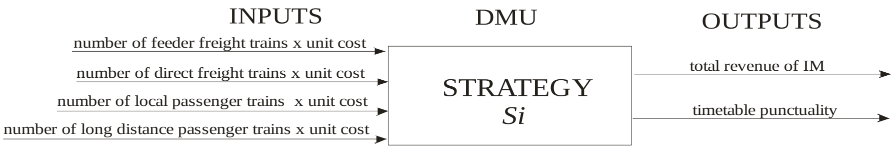

Fig. 1 IM's strategy *i* in form of DMU

When every defined strategy is expressed in form of a DMU we can apply the first stage of AHP/DEA. DMU's are paired up (each DMU with all other DMU's) and DEA is performed on each pair, two units at a time, disregarding the others. The outcome of the first stage is a set of ordered pairs for each performance of DEA (every pair of DMU's). When all sets of ordered pairs are presented in the matrix form (size n x n, where n is the number of strategies) showing relative efficiency between all DMU's we can apply a single level AHP.

Final result of both stages is the full ranking of all considered strategies. Ranking is done based on the criterion of efficiency of a DMU – efficiency of a certain way of allocating railway infrastructure thus enabling IM to choose the strategy which would grant him maximal efficiency of capacity allocation process. The strategy cannot be regarded as globally optimal because the search space was reduced followed by choosing the set of strategies to be analyzed.

5 Summary and Conclusion

The aim of this paper was to point out the necessity for efficient operation of the new entities in the railway market. It was focused mainly on the analysis of efficiency of railway infrastructure manager in the stage of capacity allocation i.e. its external efficiency. AHP/DEA methodology was proposed for determining the strategy of allocation process which would grant IM the highest possible efficiency. The proposed method enables IM to analyze its strategies based on criteria which are essential for any market oriented company, revenue maximization and the quality of services offered.

AHP/DEA methodology is introduced in the area of strategic planning. The drawbacks of its application in this area are those of any other planning and forecasting methods concerning the uncertainty of predicted data.

Future work on this topic comprises facing the model with realistic data as well as the necessary adjustments and fine tuning depending on its results. In this paper we give no numerical example due to the impossibility of collecting relevant data since PE Serbian Railways has not yet started the process of restructuring.

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