Complex technological and economic efficiency assessment methods in freight transport and logistics with special emphasis on data envelopment analysis

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Budapest, 2012
Declaration

Hereby, I, Rita Markovits-Somogyi declare that I created the present PhD Thesis myself, and I utilized only the sources indicated within. By indicating the relevant source, I have clearly identified all parts that have been used word by word, or in a reedited way but with the same content from other sources.

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Rita Markovits-Somogyi
Curriculum Vitae

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Personal data
Place and date of birth Pécs, Hungary, 8th April 1981
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Degrees
1999-2004 MSc in Transportation Engineering (Buda
pest University of Technology and Economics (BME), Faculty of Transportation Engineering)
2002-2005 Post-graduate degree in Translation and Interpretation (BME – 
Institute of Languages)
2009-2012 BSc in Engineering Economics (BME, Faculty of Transportation Engineering)

Professional experience
2004-2007 Environmental Inspector, Civil Aviation Authority
2007-2009 Translator, Directorate-General for Translation, European Commission, Luxembourg,
2009- PhD-student (BME, Dept. of Transport Economics)

Further relevant professional activities
- Participation in Hungarian and international projects (HEATCO, EcoRailS, OTKA-CONTRA)
- Scientific editor of the Logistics Yearbook published by the Hungarian Logistics Association (2010-)
- External consultant of the Institute for Transport Sciences (In the project work regarding the Economic questions of the virtual contingency tower)

Language skills
1998-1999 English – ‘C’ type advanced level state exam
1999 German – ‘C’ type advanced level state exam
2009 French – ‘C’ type intermediate level state exam

Computer-literacy
ECDL exam, and national (OKJ) exam proving professional computational skills
Relevance of the research theme

The White Paper “Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system” laying down the long term objectives of European transport policy published in 2011, stipulates that “the paramount goal of European transport policy is to help establish a system that underpins European economic progress, enhances competitiveness and offers high quality mobility services while using resources more efficiently” (European Commission, 2011). Thus “increasing the efficiency of transport and of infrastructure” is such an explicit goal of European transport policy which is vital for reaching the long term objectives.

Emphasizing the significance of efficiency on European level is not an entirely new concept, the “Freight Transport Logistics Action Plan”, issued in 2007 also says explicitly that the “production and distribution networks depend on high-quality, efficient logistics chains to organise the transport of raw materials and finished goods across the EU and beyond (...) The present Freight Logistics Action Plan is one of a series of policy initiatives jointly launched by the European Commission to improve the efficiency and sustainability of freight transport in Europe (European Commission, 2007).”

Furthermore, in its “Freight Transport Thematic Research Summary”, the Transport Research Knowledge Centre assigned a separate chapter to logistics and supply chain management tools providing an overview of the tools and services developed by research to enhance the quality and efficiency of logistics and supply chain activities (Delle Site, 2009; for a summary on the relevant projects see Markovits-Somogyi et al., 2010). Resource-efficiency is a keyword in the strategic programmes Europe 2020 and Horizon 2020 as well (European Commission 2010 and 2011b). Consequently, the significance of sustainable quality and efficiency on European level is undeniable.

Regarding the national, Hungarian level it is also essential to make the efficiency of logistics and freight transport quantifiable, since it is the stated goal of the Hungarian Logistics Strategy developed for the period 2007-2013 to “make Hungary the centre of logistics services in the Eastern-European region and intercontinental cargo hub until 2013 (Gecse, 2008).”

Parallel with that, the significance of road freight transport and logistics is gradually increasing in the global economy as well, thus the optimization of the connecting business and technologic processes might provide a serious monetary advantage. Identification of the efficient stakeholders is a key task requiring integrated technological-economic approach which can contribute to revealing the best practices within the field. Besides, determining the efficiency of the different entities and providing their ranking might also be an incentive which enhances the holistic performance of the industry.

Research objectives

Within this research, evaluating efficiency should be carried out by way of efficiency assessment techniques, which investigate the efficiency of already operating companies, organisations or other system components, and which are capable of the parallel evaluation of several entities. Even though cost-benefit analysis (CBA) or multi-criteria analysis (MCA) is capable and sometimes applied for ex-
post efficiency analysis, still, they are mainly used for ex-ante examinations, typically in cases when a smaller number of alternatives are to be evaluated. Whereas parametric and non-parametric efficiency evaluation methods, and the simple indices constitute a separate family of efficiency assessment techniques, which generally examine a larger number of already operating entities. The analysis of these methods is in the focal point of the present research, and these methods are to be referred to hereafter as ex-post efficiency assessment methods.

The aim of the PhD Thesis is to review and critically analyse the methods applicable for the efficiency assessment of entities active in the road freight transport/logistics sector, and then to select a non-parametric technique, that can be adapted to the investigated field and which also disposes of the necessary background regarding applications. Non-parametric methods are chosen because their data needs are lower and they do not require the a priori assumption of a production function. Subsequently, the real life adaptability of the method on micro- and macroeconomic level can be investigated in the area of road freight transport and logistics.

Finally, as based on the relevant experimental results and experience from the industry, the methodological supervision of the method can be executed, which will bring along a modification in the methodology of the method, thus contributing to the improvement of efficiency evaluation in the field of road freight transport and logistics.

As based on these, the major objectives of the research are the following:

1) Investigating and defining efficiency with special view on the similar and/or surrounding peer notions, with special emphasis to
   a. Performance
   b. Efficiency
   c. Effectiveness, cost-efficiency, productivity

2) In-depth analysis of the ex-post efficiency measurement techniques to be found in the international literature, revealing their area of application, the possible interfaces, the selection of the method to be applied further on
   a. Use of indices
   b. Use of production functions
   c. Use of non-parametric methods
   d. Identification of the method to be applied, examination of the possible adaptations

3) Adapting the DEA-(Data Envelopment Analysis)-based efficiency evaluation method to road freight transport and logistics
   a. Adaptation on microeconomic level
   b. Adaptation on macroeconomic level

4) Methodical improvement
   a. The possibility and feasibility of full ranking
   b. Adaptation on microeconomic level
   c. Adaptation on macroeconomic level
Means of research

The ultimate aim of the present thesis is to investigate the efficiency of already operating entities active in road freight transport and logistics. In order to do that, first the notion of efficiency is to be examined from a theoretical point of view by means of literature review and its critical analysis. In everyday life, “efficiency” is often used parallel with “effectiveness” or “cost-efficiency”. It is important to be aware of the differences of these concepts, and also to give a clear definition of efficiency that can be reliably used in the later scientific investigations.

The possible ex-post efficiency assessment techniques are also to be critically reviewed, so as to be able to choose a method that can further be adapted to the field of road freight transport and logistics. There are basically three main approaches: the indices, the parametric and the non-parametric methods. Each area in itself could be a topic of a wide-ranging scientific research, so it was vital to choose one direction, in which to move on, in order to enable an in depth analysis of the efficiency of road freight transport and logistics companies.

Keeping in mind practical applicability, from this point on research was focused on non-parametric efficiency assessment techniques, as these do not require a priori assumptions about the production function of the units, and their data needs are also significantly lower. Thus, it could be expected that, even by scarce data availability, tests can be carried out in practice, on real-life data. Out of the known non-parametric methods, data envelopment analysis (DEA), a linear technique was chosen, because this is the method that is the most widely applied in the transport sector and this has the most reliable and most accepted mathematical background in the field.

The fact declared in the previous statement was established by an in-depth literature review. Here, the detailed mathematical background of data envelopment analysis is provided, focusing on the two main variants of the method, the DEA CCR (named after the initials of the authors Charnes, Cooper, Rhodes, 1978) and the BCC (Banker, Charnes and Cooper, 1984). Then, the application of DEA in the transport and logistics sector is analysed. Reviewing all available sources, the data of 69 transport applications were collected from the literature to investigate the utilized input-output structures.

Data from road freight transport and logistics application were also examined. However, the number of these was significantly lower. This confirmed the need for adapting the DEA method to the area of road freight transport and logistics.

First, it is verified using financial data and the complex efficiency index, that DEA can indeed be adapted to the road freight sector. Then the DEA investigation was extended to include technological parameters as well. As a second microeconomic application, DEA was applied to logistics centres too. Finally, the logistics potential of European countries was also tested by a DEA model. All three adaptations were conducted using real-life data.

During literature review and practical adaptation it became clear that there is a disadvantage of DEA that could be circumvented. DEA does not fully rank the different companies [in DEA terminology called decision making units (DMUs)], it creates a subgroup of firms which are all efficient, and these are not ranked. Looking at the different solutions to this problem, there was found one which can be further developed. This is the DEA/AHP (analytic hierarchy process) methodology, which is improved
in the Thesis to yield the new DEA-PC (pairwise comparison) method. By adapting the traditional and the new DEA-PC methodology in parallel, it is proven that the novel method is capable of better distinguishing between the DMUs and it can always provide full ranking.

New scientific results

1. Defining efficiency, clustering the available ex-post efficiency assessment and analyzing techniques; and investigating the existing applications and the possibility of extension

I have processed the available efficiency definitions and delimiting these, I have created the most adequate efficiency definition that can be used in road freight transport and logistics, with special view on its applicability later on. According to this, efficiency can be defined as “the ratio of the services and other results produced by the road freight transport or logistics firm and the resources utilised for this production.” (See Section 2.2).

As based on this efficiency definition I reviewed and categorized the relevant evaluation techniques, and taking into consideration the practical aspects of road freight transport and logistics, I recommended the use of DEA (Data Envelopment Analysis). (See Section 3.)

I critically evaluated the method of data envelopment analysis and investigated its existing applications in the transport sector. As based on this, I have shown that it is possible to adapt DEA to the road freight sector and in the logistics field, with a special view on the possible inclusion of technological and environmental parameters. (See Section 4.)

The definition of efficiency was developed with the aim of assessing already operating decision making units (DMUs). There are different methodologies in the literature available for this purpose (techniques using indexes, parametric and non-parametric methods). All of these dispose of a very wide background, methodological toolbox and area of utilization. Keeping in mind practical applicability, the investigations were limited to non-parametric methods, because here it is not necessary to have a priori assumptions about the inner operational structure before the efficiency analysis, thus, their input data need is also significantly lower. Within non-parametric methods, the general methodological background of data envelopment analysis is developed in much detail, and a sufficient number of practical applications are available. The literature review revealed 69 studies utilizing data envelopment analysis in the field of transport. The detailed research into the transport applications was aimed to gain sufficient expertise in the development of input and output structures, which is the most complicated part of DEA modelling (see Section 4.2.1).

The review also showed that in road freight transport and logistics there are very few adaptations available, and these often only include financial parameters. Sometimes, these existing models can also be methodologically questioned. Thus, this justifies the need for elaborating DEA adaptations to the road freight transport and logistics sector.
Relevant own publications: (Markovits-Somogyi, 2011a); (Markovits-Somogyi, 2011d); (Markovits-Somogyi and Bokor, 2011); (Markovits-Somogyi, 2011c); (Markovits-Somogyi and Bokor, 2010); (Markovits-Somogyi et al., 2010).

2. Specifying DEA models in the area of road freight transport and logistics

I adapted special DEA models to road freight transport and logistics both on microeconomic and on macroeconomic level (see Section 5.). The models were tested on practical applications.

First, in the case of road freight transport companies, I verified the DEA-rankings as based on a pure financial analysis (Section 5.1), then, the input-output structure was extended to include technological and environmental parameters. The evolving DEA structures were tested on real-life data collected from financial databases and through phone surveys (see Section 5.2).

Then, within the framework of a second micro-economic adaptation, by an iterative and heuristic process I adapted the DEA-method to the efficiency assessment of logistics service centres from a complex technological and economic viewpoint (see Section 5.3). I refined the evolved input-output structure by way of sensitivity analysis.

On macroeconomic level, relying on existing applications, I created the technological and economic parameter system applicable for the efficiency evaluation of the logistics efficiency of European countries (see Section 5.4).

Relevant own publications: (Markovits-Somogyi, 2011b); (Markovits-Somogyi and Bokor, 2012a); (Markovits-Somogyi et al., 2011).

3. Developing a new method for full ranking within DEA

I elaborated a new method, called DEA-PC (pairwise comparison) for full ranking within the framework of data envelopment analysis (see Section 6.2.).

The DEA-PC method can be described by the following equation:

\[
\hat{F}_{AB} = \max \sum_{i=1}^{s} u_i Y_{iA} \tag{7.1}
\]

subject to

\[
\sum_{i=1}^{m} v_i X_{iA} = 1
\]

\[
\sum_{r=1}^{t} u_r Y_{rB} - \sum_{i=1}^{m} v_i X_{iB} = 0
\]

\[
u_r \geq 0, r = 1, ..., s, v_i \geq 0, i = 1, ..., m.
\]

where

\[
\hat{F}_{AB} \quad \text{the efficiency value resulting from the pairwise comparisons,}
\]
$A, B$       index of the two, compared decision making units (DMUs),

$X_{ij} \geq 0, Y_{rj} \geq 0$ the input and output values of the decision making unit to be evaluated (DMU$_0$),

$j = 1, 2, ..., n$ number of DMUs,

$i=1, 2, ..., m$ number of inputs,

$r=1, 2, ..., s$ number of outputs,

$u_r, v_i$ the weights determined by the linear program.

The received $\hat{F}_{AB}$ efficiency values are ordered into a pairwise comparison matrix known from the AHP method. Full ranking is then obtained by the coordinates of the eigenvector of the matrix.

Reviewing the full ranking techniques available within the DEA family, I have established, that modifying the existing DEA/AHP method an efficiency assessment tool disposing of a much higher distinction power can be created. After appropriate adaptation, this method is capable of delivering a full ranking in the area road freight transport and logistics as well, and so it can contribute to the enhancement of decision making processes.

**Relevant own publications:** (Markovits-Somogyi, 2011e); (Fülöp and Markovits-Somogyi, 2012); (Markovits-Somogyi, 2011f)

**4. Full ranking on micro- and macroeconomic level**

I verified the use of the road freight transport and logistics efficiency assessment method extended with the new full ranking feature on *microeconomic* level, both for the case of road haulage companies and for the case of logistics service centres (see Section 6.3.).

I verified the use of the road freight transport and logistics efficiency assessment method extended with the new full ranking feature on *macroeconomic* level by integrating novel aspects into the logistics efficiency assessment of countries. I delivered a full ranking of European countries as based on their logistics performance, and evaluated the results as compared to the outcomes of an independent international survey (see Section 6.4).

As based on the real life data of road haulage firms, I demonstrated by numerical results that the DEA-PC method disposes of a higher distinction power as compared to the original DEA/AHP method, and it can provide a full ranking more reliably. Beyond conducting pure financial analysis, serving the purposes of verification, I extended the novel DEA-PC methodology to technological and environmental parameters, with the help of which complex technological and economic efficiency assessments became possible (see Section 6.3.1).

Using the input-output structure developed by previous investigations (see Section 5.3), I adapted the new DEA-PC method to the case of logistics service centres, where it has again been proven that the modified technique is capable of delivering full ranking and is less sensitive to the sample size as compared to traditional DEA (see Section 6.3.2).
I demonstrated with a practical application how the new DEA-PC full ranking method can be adapted to the macroeconomic level by presenting the logistic efficiency assessment of European countries. I compared the ensuing results to the relevant indicator of the LPI survey (Logistics Performance Index). I have established that, due to its concept and refined algorithm, the recommended new efficiency assessment technique provides more balanced results for decision making.

**Relevant own publications:** (Markovits-Somogyi, 2012a); (Markovits-Somogyi, 2012b); (Markovits-Somogyi, 2012c); (Markovits-Somogyi, 2011b); (Markovits-Somogyi and Bokor, 2012b)

**Practical applicability of the results and possibilities of further development**

The use of parametric methods is often very much constrained by lack of data. Frequently, they require a very detailed data structure and in-depth data, which is not accessible to the researcher or even to the managerial level of the company; or if they are obtainable, they might not be consistent enough to be usable for comprehensive research. It has been shown that data envelopment analysis – for full ranking complemented with the DEA-PC approach – can be utilized in the cases when such detailed data are not available, and it can provide an efficiency evaluation using the input-output data of the decision making unit. Hence, it is a method that can be applied more easily and cost-efficiently than parametric methods.

As it has been seen, the main aim of utilization is to give a rank of decision making units. It is specifically capable of providing an evaluation where a larger number of firms or organizations are to be assessed in the presence of a limited number of factors (inputs and outputs). Thus, it is capable to provide a horizontal view of all the companies in the given field. If a business decision maker is interested to know the place of his/her company among its rivals, DEA and DEA-PC can provide him/her with this insight. Especially so, if it is not only financial aspects that are to be evaluated. By including all the relevant technological and environmental factors, DEA and DEA-PC can rank the companies from a holistic, technological-economic viewpoint. This is achieved even by scarce data availability, which is a merit; as business decision makers usually do not dispose of detailed information about the operation of their rivals. When the efficient decision making units are determined, their way of operation should be scrutinized, and if possible, the best practices are to be followed. This can enhance the operation of the company in question. Furthermore, by investigating economies of scale with the help of DEA, and also the ratio of allocative and pure technical efficiency, a guideline is given to the company, regarding how to proceed.

At the same time, DEA and DEA-PC can also be utilized in cases where the decision maker would like to establish the ranking of companies excluding his/her own. To give concrete examples: the executive officer of a producing firm would like to choose a supplier as based on different aspects. In this case DEA and DEA-PC can be an appropriate complementary tool to financial analysis. It could also be used as a supplementary tool in tendering, where the public administration has to select applicants as based on different aspects. Moreover, as it was demonstrated, it can also be applied on the macroeconomic level, thus it can also be utilized as an appropriate tool for the efficiency assessment of regions or even countries. It can also be applied this way by public administrations.
Advantage of the method, as mentioned before, is its ability to provide results using relatively easily accessible and not too detailed data, and the fact that it does not need an a priori assumption about the production function. However, it has to be known that the method is sensitive to outliers, and this might necessitate the need for preliminary statistical analyses. Also, as it is a relative method, the decision maker needs to be aware that the ranking provided will be relative, only extending to the decision making units involved in the investigation. Furthermore, the validity of the results relies strongly on the input-output structure utilized in the examinations, thus it is recommended to seek the help of an expert when developing a model in a new field. Generally, in the field of transport and logistics, it can be stated, that the inputs shall involve at least one factor from the following areas: capital, labour and – if possible – energy. Whereas, outputs usually extend to the two fields of financial and operational results.

Regarding the data used in the investigations: the constraint regarding the number of inputs and outputs has to be kept in mind, namely that the number of decision making units shall be at least three times the sum of the number of inputs and outputs. If this condition is not fulfilled, DEA cannot be applied. However, DEA-PC is not limited by this condition as it was partly developed with the purpose of overcoming this hindrance, so this new method can still be applied if this prerequisite is not met. Even though the microeconomic applications presented in the dissertation had very small sample sizes, this is the reason why they can still be viewed as methodologically valid. Moreover, DEA-PC is capable of analysing more complex input-output structures as well.

Nonetheless, it needs to be stressed, that DEA and DEA-PC is able to investigate efficiency and efficiency only. It is always necessary to complement it with some further assessment method or approach that explores effectiveness – the question whether the intended results are reached. Colloquially, DEA examines whether “things are done right”, while it is also to be seen whether “the right things are done”. This double sidedness of efficiency and effectiveness has always to be kept in mind when evaluating the achievement of “obligatory expectations” and the efficiency factors providing competitive advantage.

Regarding further scientific research, the models created for the efficiency evaluation of road freight transport companies and logistics centres could be extended to include parameters which explain different additional sides of efficiency. So, in case the view is to be shifted for example more towards sustainability, supplementary input and/or outputs can be incorporated into the models. Naturally, this enlarges the data need, and an increased sample size is inevitable as well.

A further possible step forward, including theoretic research, is to develop valid models for the case of parametric methods as well, and carry out in-depth comparative analysis on the results gained by these different methods. Even though e.g. stochastic frontier analysis is a widely accepted parametric method, it is seldom utilized in the Hungarian freight transport and logistics field. As mentioned above, the need for detailed data availability is much higher in this case, but provided they are

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1 Before developing the DEA-PC method, it was also considered to test the traditional DEA method with the help of non-real life, created data (and thus, on much larger samples), but due to the concept underlying data envelopment analysis, which necessitates the development of the efficiency frontier as based on real data, this approach was abandoned.
obtainable, it would be of academic interest to adapt this method to the Hungarian road freight transport and logistics sector, and then – keeping in mind the different concept of the methods – the results could critically be compared with those of DEA and/or the DEA-PC method.

The results and methodological approaches included in the thesis can well be incorporated into the different courses taught at the Faculty of Transportation Engineering and Vehicle Engineering at BSc and MSc level, such as the courses “Decision Making Methods”, “Logistics Management”, “Project management”, “Transport Economics” and “Operation of Logistics Systems”. Incorporating DEA and DEA-PC methodology into the agenda adds value on the theoretical side of the courses, while DEA case studies can contribute to making the courses more practice oriented.

Relevant own publications

8. Markovits-Somogyi, R. (2012a) Efficiency Analysis of Road Haulage Companies, PhD Workshop, Budapest University of Technology and Economics, April 2012
11. Markovits-Somogyi, R; Bokor, Z (2010) Ways to apply data envelopment analysis in the field of logistics (in Hungarian: A Data Envelopment Analysis (DEA) módszer alkalmazási
14. Markovits-Somogyi, R., Bokor, Z (2012b) Assessing the logistics efficiency of European countries by using the DEA-PC methodology (submitted to Transport)

Literature referred to in the present summary