Efficiency of public transportation in the Czech Republic during the start of the crisis of 2020 studied by the DEA methods

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Abstract: Public transport companies play a key and irreplaceable role in the field of transport services for cities and urban agglomerations. The operation of transport companies is a highly demanding economic activity that is directly related to the strategy chosen by city representatives. The concern is primarily so-called subsidies for the operation of individual companies, that is, demonstrable loss always covered from the budget of municipalities. In a narrower economic context, however, a transport company is an economic entity that uses production factors (inputs) to generate outputs (typically transported persons, here). The efficient use of resources and the efficient functioning of companies is undoubtedly the goal of all cities. In the presented contribution, we make use of quantitative data envelopment analysis to verify relative economic efficiency of 12 Czech public transport companies in two particular years, 2019 and 2020, with the aim of demonstrating their ability to deal with the arrival of the crisis period of the covid-19 pandemic.

Keywords: efficiency, public transportation, data envelopment analysis
JEL Classification: C02, C52, C61, R40

1 Introduction

The main goal of our contribution is to measure and evaluate the efficiency of subjects by the methods of data envelopment analysis. The subjects in question are public transportation companies of 12 chosen cities in the Czech Republic; the choice was made with respect to the size and the situation of both the agglomeration and the company. We exclude companies incomparable by size and also the ones reforming their organization. We focus our attention on the years 2019 and 2020, as the timeline corresponds to the last pre-pandemic season and the first season under heavy pressure both by the pandemic and the restrictions implemented to slow it down. The selected aspects of the companies are classified into inputs and outputs. The inputs in our model are production consumption, depreciation, and personnel cost; the outputs are the sales and the number of transported people. The production-consumption is a sum of costs of material, energy and other supply with any supply from subcontractors, including products and services. Depreciation describes the change in prices of both intangible assets and tangible assets. This change of price means the systematic allocation of a percentage of the price of the asset during the whole time of its usage, not necessarily physical and moral amortization. Note that four of the parameters have a strictly financial nature but the fifth, the number of transported people, is of a different type, as meaningful efficiency analysis of the public transportation company should include some measurement of services provided and one should not focus on profit only. There are several different ways how to measure the scale of public services provided by the company, such as the area covered by transport means, the number of transport lines or the number of rides of the public transport vehicle, etc. However, the model requires limiting the number of outputs and using only the most significant ones. This last parameter, the number of passengers and demand for services in general, is obviously the one being reduced during the past two years in every city in the Czech Republic for several different reasons, such as safety reasons, increased usage of home office regime, closure of many services etc. At first sight, it seems in vain to study efficiency during a turbulent time pandemic, but our view is quite opposite: it is even more crucial to study the adaptability and efficiency of companies during the season of crisis as it reveals possibilities for improvements and tests the state of affairs. Before we test the companies, we could assume that the scale of damage

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caused by the pandemic may vary a lot, especially as the restrictions and crisis had different influences on different fields, for example, tourism was stopped almost totally, but construction works, heavy industry or agriculture were still going on in some slightly reduced forms. The convolution and synergy of econometric methods and economic aspects may provide insight both on theoretical and practical levels. The immediate practical outcome of the article is the revelation of the subjects coping with the crisis in a successful way, as their methods should inspire the less successful ones. The methods of efficient companies may be copied and implemented to help mitigate the effects of a similar crisis. Another outcome is complex usage and the evaluation of data itself. The data are obtained from annual reports and accounting evidence of companies. Authors have to point out discomfort in the diversity of reports that complicates collecting the data in a comparable manner. Our first recommendation is the unification of the forms of annual reports and accounting documentaries in order. This step may be beneficial not only from the academic point of view also but also for straightforward comparison of states of similar companies.

Historically, many authors from all over the world have devoted themselves to the research of the efficiency of transport companies, and the methods used correspond the state of scientific knowledge of their time. Around the 1970s, one can observe the first cases with well-founded capture of the efficiency of transport companies in selected cities (e.g., Merewitz, 1977, etc.), which were followed in the 1990s by deeper analyses of the efficiency of transport companies (e.g., Fazioli, Filippini, & Prioni, 1993; Kersten, 1996 et al.). To evaluate the efficiency of transport companies, multi-criteria decision-making methods were used first of all (e.g., Yeh, Deng, & Chang, 2000, etc.), but methods using *data envelopment analysis* (DEA) and its variants applied with regard to the nature of the region followed (e.g., Boame, 2004; Barros & Peypoch, 2010; Von Hirschhausen, & Cullmann, 2010; Hahn, Kim, Kim, & Lee, 2013; Ayadi & Hammami, 2015; Balboa la Chica, Mesa Mendoza, Suárez Falcón, & Pérez Castellano, 2016 et al.). The DEA methods are already capable of including more factors affecting the overall efficiency of production units. The Malmquist index is often used (Klieštik, 2009) if the time parameter is in question. In the Czech environment, e.g., Matulová and Fitzová (2016) recently reported on the efficiency of urban transport companies. Although e.g. Vavrek and Bečica (2020) return to the multi-criteria decision-making method, it follows from the research of recent years (e.g., Alfiero, Cane, Doronzo, & Esposito, 2018; Karim & Fouad, 2019 etc.) that DEA methods with their variants provide, when used correctly, a sufficiently accurate tool for evaluating the efficiency of transport companies. The obtained results enable the formulation of innovative recommendations, the main goal of which is to optimize the activities of business entities in the field of urban public transport.

Of course, the input/output variable selection vary across different studies. For example, the most frequently used inputs are the capital, labor, energy, material and services (e.g. Von Hirschhausen & Cullmann, 2010; Ayadi & Hammami, 2015). Other particular input variables are the total number of vehicles (e.g. Kerstens, 1996; Karim & Fouad, 2019 etc.), production consumption, depreciation, the number of employees (or number of bus drivers, e.g. Klieštik, 2009; Kerstens, 1996; Barros & Peypoch, 2010, Balboa et al., 2016, etc.), personnel costs (e.g. Balboa et al., 2016, etc.), the number of liters of fuel consumed (e.g. Kerstens, 1996; Barros & Peypoch, 2010, etc.), credit load (e.g. Klieštik, 2009 etc.), the length of the network (e.g. Karim & Fouad, 2019 etc.), the total number of seats, effective driving hours, seat kilometres per 1000 km (e.g. Klieštik, 2009; Von Hirschhausen & Cullmann, 2010 etc.), equipment (oil and tires), average age of the vehicle park, transportation working hours, maintenance working hours, insurance costs, vehicle capacity (e.g. Barros & Peypoch, 2010) etc. The most common outputs are mostly net sales, the number of passengers transported (e.g. Klieštik, 2009; Barros & Peypoch, 2010; Balboa et al., 2016, etc.) or the number of vehicle kilometres and the number of seat kilometres (e.g. Kerstens, 1996; Klieštik, 2009, etc.). Our actual selection of inputs/outputs specified at the beginning may be considered as more general, considering for example total company consumption as an input instead of its particular components.

2 Methods of data envelopment analysis

2.1Idea of data envelopment analysis

Data envelopment analysis (DEA) is a bundle of methods devoted to comparing the efficiency among a group of units, it means object measured by a set of inputs and outputs. By comparison to other units, we can decide if the unit is efficient, which means no better result can be achieved based on data of the group in some sense, or if the unit is not efficient, it means that similar but better results can be achieved as a combination of inputs and/or outputs of other considered units. Several extensions (such as the Malmquist index and its derivatives) may be used to the basic models in order to incorporate the time aspect into consideration. This may help us to identify the development of the unit and also the changes in the field of study, give for example technical progress or changes in the law or regulations by the government.

Even though the method is well established, we briefly describe the basic concept and aspects we consider. As we use the method in its most established form, we assume that input is something we intend to minimize and output is something we intend to maximize, also we assume that all data have non-negative values. The efficiency is calculated as the weighted sum of inputs divided by the weighted sum of outputs, conditioned by the requirement that the efficiency for any unit cannot exceed one, using the same weights for each unit considered. Indeed, consider an input vector $\boldsymbol{x}_0$ and an output vector $\boldsymbol{y}_0$ of an examined unit, with associated nonnegative weights $\boldsymbol{w}_x$ and $\boldsymbol{w}_y$ (whose optimal setting has to be found), and vectors $\boldsymbol{x}_k, \boldsymbol{y}_k, k = 1, \dots, K$ of inputs and outputs of all K units in question, then our aim is to find

$$\max \boldsymbol{\theta_0} := \frac{\boldsymbol{w}_y^T \boldsymbol{y_0}}{\boldsymbol{w}_x^T \boldsymbol{x_0}} \text{ subject to } \frac{\boldsymbol{w}_y^T \boldsymbol{y}_k}{\boldsymbol{w}_x^T \boldsymbol{x}_k} \leq \mathbf{1}, \ \boldsymbol{k} = \mathbf{1}, \dots, \boldsymbol{K}, \ \boldsymbol{w}_x, \boldsymbol{w}_y \geq \mathbf{0}. \qquad (1)$$

The method may be interpreted as multicriteria decision-making, but the main difference is, that DEA does not use the fixed weights to represent the importance of particular inputs and outputs, but the weights are set by optimization to get the maximal possible efficiency result. It means we search for the non-negative weights of the inputs and outputs such that the efficiency of all units would be smaller or equal to 1 and the efficiency of the studied unit would be maximal. If there is a set of weights such that the efficiency would be 1, we call the unit efficient.

2.2 Data choice and size

To perform DEA, we need a set of units and their inputs and outputs. All the units need to have the same type of data and if we consider time, the data must be available in all time values. The type of inputs and outputs should satisfy several conditions. First of all, the data have to be chosen based on importance, not based on availability. Second, the data should not be duplicated. It means we should not use two different values that have a big correlation, for example, if we consider restaurants, we should not use both the number of customers and the number of cooked meals, as most of the customers eat one meal and these two numbers have a significant correlation. Third, we need to have multiple times more units than data of inputs and outputs. If there are a lot of outputs and inputs and only a few units, most of the units are likely to appear to be efficient. The ratio between the number of units and the number of inputs and outputs combined is 2.4 in our study, which is almost a border case and if it decreased, the method should not be suitable. Nevertheless, the lowest possible threshold ratio varies in the literature (see e.g. Klieštik, 2009).

As stated in the introduction, we have selected three inputs (production consumption, depreciation, personnel cost) and two outputs (sales, number of transported people) to characterize each transport company. We provide some summary statistics of our set of inputs and outputs in Table 1.

Table 1 Summary statistics for input and output data

statistic	year	consumption	depreciation	personnel costs	sales	passengers
minimum	2019	35,001	12,578	95,596	59,360	15,719
	2020	34,586	12,623	97,834	46,683	13,294
mean	2019	171,785	93,700	300,349	198,322	48,303
	2020	155,408	97,509	312,099	156,957	41,277
standard deviation	2019	138,810	92,384	263,996	142,245	33,402
	2020	134,214	102,855	279,539	122,428	31,187
maximum	2019	554,515	315,165	1,035,924	543,938	124,977
	2020	543,434	348,162	1,092,492	470,778	119,524

Source: Own processing based on the collected data from annual reports of selected transport companies

2.3 The setting of the DEA models

There are several aspects of the DEA model, that may be derived from the basic idea represented by the optimization problem (1). First of all, this is the problem of so-called fractional programming which may be transformed (with an additional technical constraint addressing the ambiguity of solutions) to a standard linear optimization problem to find

$$\max \boldsymbol{\theta_0} := \boldsymbol{w}_y^T \boldsymbol{y_0} \text{ subject to } -\boldsymbol{w}_x^T \boldsymbol{x}_k + \boldsymbol{w}_y^T \boldsymbol{y}_k \leq \mathbf{0}, \ \boldsymbol{k} = \mathbf{1}, \dots, \boldsymbol{K}, \ \boldsymbol{w}_x^T \boldsymbol{x_0} = \mathbf{1}, \ \boldsymbol{w}_x, \boldsymbol{w}_y \geq \mathbf{0}. \qquad (2)$$

Equation (2) is known as the *multiplier form* of an *input-oriented model* under *constant returns-to-scale* (Charnes, Cooper & Rhodes, 1978). Its dual, the *envelopment form* of the optimization model

$$\min \boldsymbol{\theta_0} \text{ subject to } \mathbf{X}\boldsymbol{\lambda} \leq \boldsymbol{\theta_0} \boldsymbol{x_0}, \mathbf{Y}\boldsymbol{\lambda} \geq \boldsymbol{y_0}, \boldsymbol{\lambda} \geq \mathbf{0}, \boldsymbol{\theta_0} \text{ unconstrained}, \qquad (3)$$

emphasizes the possible modifications of the basic idea, in particular the focus on decreasing the inputs instead of incrementing the outputs (the output-oriented models), and the possibility to implement additional types of returns to scale conditions. Here, $\mathbf{X}$ and $\mathbf{Y}$ are matrices having as columns the input and output vectors, respectively, of the units considered. The decision vector $\boldsymbol{\lambda}$ provides, for a non-efficient unit, its reference inputs as the composition of the inputs of the other (efficient) units. The variable θ_0 is another decision variable here, and its position determines the orientation of the model; shifting it to $\mathbf{Y}, \boldsymbol{y}_0$-constraint and maximizing it instead of minimization, the resulting model is called *output-oriented*, with the aim to find a way to increase outputs instead of decreasing inputs of the examined unit. The constraint $\lambda \geq 0$ represents the constant returns-to-scale condition, that is, the outputs for an efficient unit are purely proportional to its inputs. *Variable returns-to-scale* may be imposed by adding the constraint $\sum_k \lambda_k = 1$ apart from the nonnegativity constraint on $\boldsymbol{\lambda}$ (Banker, Charnes & Cooper, 1984). The resulting production possibility set (the allowed combinations for the input and outputs of the units considered, or, equivalently, the feasible set of the optimization problem (3)) is then formed as convex envelopment (combination) of the input-output pairs of the unit considered. For example, the *output-oriented model* in *envelopment form* under *variable returns-to-scale* reads as to find

$$\max \boldsymbol{\theta_0} \text{ subject to } \mathbf{X}\boldsymbol{\lambda} \leq \boldsymbol{x_0}, \mathbf{Y}\boldsymbol{\lambda} \geq \boldsymbol{\theta_0}\boldsymbol{y_0}, \textstyle\sum_k \boldsymbol{\lambda_k} = \mathbf{1}, \boldsymbol{\lambda} \geq \mathbf{0}, \boldsymbol{\theta_0} \text{ unconstrained.} \quad (4)$$

Other convenient extensions and modification of these basic methods may be used; we refer the reader to the monographs Cooper, Seiford & Tone (2007) and Cooper, Seiford, Zhu (2011), in particular. Nevertheless, we will not leverage these extensions in our actual contribution.

3 Research results

In our research, we make use of three DEA models: an input-oriented model under constant returns-to-scale (CRS-I), and both input and output-oriented models under variable returns-to-scale (VRS-I and VRS-O). The output-oriented version of the CRS model is not considered as the efficiency scores are the same as for the input-oriented model. The production possibility set is a linear or convex envelope, respectively, of input-output pairs of 12 Czech public transport companies, individually in two years 2019 and 2020. Each year is considered separately, that is, we have 72 DEA optimization problems in total. Solving them, we finally obtain six lists of efficiency scores summarized in Table 2.

Table 2 Technical efficiencies of public transport companies for individual years, rounded to two decimal places

model	CRS-I		VRS-I		VRS-O	
city	2019	2020	2019	2020	2019	2020
České Budějovice	1	1	1	1	1	1
Hradec Králové	0.83	0.74	0.90	0.74	0.93	0.81
Jihlava	1	1	1	1	1	1
Karlovy Vary	1	1	1	1	1	1
Liberec–Jablonec n/N.	0.82	0.65	0.82	0.66	0.82	0.72
Most–Litvínov	0.85	0.76	0.87	0.76	0.88	0.78
Olomouc	0.99	0.93	1	1	1	1
Ostrava	1	1	1	1	1	1
Pardubice	1	1	1	1	1	1
Plzeň	0.98	0.94	1	1	1	1
Ústí nad Labem	0.66	0.57	0.66	0.60	0.68	0.59
Zlín–Otrokovice	1	1	1	1	1	1

Source: Own processing

Firstly, we notice that companies being technically efficient in 2019 have remained efficient also in 2020 regardless of the model. Secondly, the technical efficiencies of non-efficient companies are generally worse in 2020 than in 2019 – it means that the differences between efficient and non-efficient companies have been made more evident in covid-year 2020. Note, in this context, that the results are relative, the production possibility sets for 2019 and 2020 do not interfere here – we do not compare 2020 company inputs and outputs against 2019 ones in models presented in Table 2.

To emphasize previous claims, we add another list of DEA models in which the production possibility set is composed of data from both the 2019 and 2020 years together, in which we may better analyse the impact of covid conditions on the technical efficiencies of public transport companies. The results are provided in Table 3. The results confirm our previous claim that the efficiencies are generally worse for the year 2020: all companies holding technical efficiencies in the year 2019 lose it when passing to the year 2020. The only exception is the public transport company of Jihlava, which retains the technical efficiency even for the year 2020 in less restrictive models with variable returns to scale. In all models, the worse results are assigned to the public transport company of Ústí nad Labem, with a significant distance from other companies. On the opposite side, we find several efficient companies: apart already mentioned Jihlava we note the public transport companies of České Budějovice, Zlín-Otrokovice, Ostrava, Karlovy Vary, and Pardubice, all having technical efficiencies equal to 1 (in individual models with separated years), and sorted with respect to the efficiencies gained in 2020 in models with merged years. These are followed by the public transport companies of Olomouc and Plzeň, being technically efficient in less restrictive models with variable returns-to-scale.

To make an insight into the inefficiency of some units, we take the transport company of Ústí nad Labem, having the worst efficiency scores, as an example. In Table 4, we provide actual and reference (peer) inputs of this unit in four input-oriented model calculated using optimal λ in models (3) and (4). The reference units are České Budějovice and Zlín-Otrokovice (in CRS-I model), eventually extended with some other companies (e.g. Plzeň in VRS-I for 2019 and for merged years, or Jihlava in VRS-I for 2020).

Table 3 Technical efficiencies of public transport companies for years 2019 and 2020 merged, rounded to two decimal places

City	Year	CRS-I	VRS-I	VRS-O
České Budějovice	2019	1	1	1
	2020	0.98	0.99	0.99
Hradec Králové	2019	0.83	0.90	0.93
	2020	0.64	0.64	0.71
Jihlava	2019	1	1	1
	2020	0.84	1	1
Karlovy Vary	2019	1	1	1
	2020	0.80	0.88	0.80
Liberec–Jablonec n/N.	2019	0.82	0.82	0.83
	2020	0.60	0.60	0.65
Most–Litvínov	2019	0.85	0.87	0.88
	2020	0.69	0.69	0.71
Olomouc	2019	0.99	1	1
	2020	0.82	0.82	0.87
Ostrava	2019	1	1	1
	2020	0.87	0.88	0.87
Pardubice	2019	1	1	1
	2020	0.71	0.72	0.74
Plzeň	2019	0.98	1	1
	2020	0.82	0.94	0.96
Ústí nad Labem	2019	0.66	0.66	0.68
	2020	0.50	0.53	0.51
Zlín–Otrokovice	2019	1	1	1
	2020	0.94	0.95	0.94

Source: Own processing

Table 4 Reference inputs in input-oriented models for transport company of Ústí nad Labem

	year	actual input	reference CRS-I	reference VRS-I	reference CRS-I merged	reference VRS-I merged
consumption	2019	282,839	85,169	93,292	85,169	93,292
	2020	243,028	79,985	80,387	71,434	72,949
depreciation	2019	105,305	51,652	53,889	51,652	53,889
	2020	104,296	46,775	45,489	43,156	44,317
personnel costs	2019	250,893	165,084	166,533	165,084	166,533
	2020	269,310	154,670	161,588	134,339	143,288

Source: Own processing

To complement this investigation for Ústí nad Labem, it is also of interest that, in multiplier forms of all these DEA models, the optimal weights are nonzero only for the third input (personnel costs). It implies, firstly, that there are nonzero slacks (that is, so-called mix-inefficiencies) for production consumption and depreciation, and, secondly, the efficiency score for this company can be improved at the primal stage by decreasing its personnel costs. This is not the case for output weights: they are both nonzero (in all models) so that it is worth to increase both outputs radially (in the same ratio) to increase the efficiency score in output-oriented models. We can of course make similar investigation for the remaining units in the analysis; we do not provide these results due to limited space reserved for this contribution.

4 Discussion and conclusions

The results of the study primarily show that companies that were efficient in 2019 remained efficient in 2020, regardless of the model used. In 2020, the efficiency of transport companies, in general, deteriorated due to the covid pandemic, especially those that were already inefficient in 2019. The observed results indicate similar tendencies to the ones described in the cited publications. It is very surprising to us, that one unit achieved efficiency in several models using both data from 2019 and 2020 combined. Another surprising factor is, that despite regions being different by many factors, the influence of the crisis seems to hit all the inefficient companies on a comparable scale, even though we may expect significant varying based on urban specifics such as major industries and demographics. It seems that the influence of efficiency problems during a pandemic can be caused more by inefficiency before the crisis than by the crisis itself. Tough all results must be considered relative, they are nevertheless a good source for decision-making in the management of transport companies.

We can easily sum up the general necessity to analyze and do research about companies related to transportation. There are a couple of reasons. First, transportation and its performance are considered the key indicator connected with economic cycles. Second, transportation generates a huge part of social costs, and the aim of researchers should be to help reduce them. Especially in urban areas, effective operation of public transportation is very important. Questions necessary to answer are mainly frequency of bus connections, new investments into buses, scarcity of drivers, decreasing number of passengers and others. The mentioned financial or physical indicators are used in the model. Overall results can be very useful for the management of the companies for their decisions about future steps. Obviously, the biggest issue recently is increasing the prices of energy. With a little bit of hyperbole, we can assume that efficiency will not be the number one problem in companies. As we studied in the case of the past troublesome situations caused by the pandemic, similar questions about coping with inflation and especially energetic crisis should be asked and studied. We can not assume the outcome a priori, as many more factors would contribute. For example, previous investment in modernization and lowering consumption of vehicles or isolation of the buildings may provide huge benefits, which were kind of hidden and not measured enough in the models of us or the models of articles we studied.

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