

MEASURING EFFICIENCY IN LOGISTICS

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Abstract:

Dynamic market and environmental changes greatly affect operating of logistics systems. Logistics systems have to realize their activities and processes in an efficient way. The main objective of this paper is to analyze different aspects of efficiency measurement in logistics and to propose appropriate models of measurement. Measuring efficiency in logistics is a complex process that requires consideration of all subsystems, processes and activities as well as the impact of various financial, operational, environmental, quality and other factors. The proposed models have a basis in the Data Envelopment Analysis method. They could help managers in decision making and corrective actions processes. The tests and results of the model show the importance of input and output variables selection.

Key words: efficiency, logistics, measuring methods, data envelopment analysis.

Introduction

Modern product and service markets are very dynamic with a great number of participants. In order to stay in the market, companies constantly have to measure and monitor their performances as well as to define appropriate corrective actions. Depending on industries and types of systems, there are a large number of different performances. One of the basic and frequently used performances is efficiency. Efficiency is a very important indicator of the analysis of companies' operations.

There is no universal and generally accepted definition of efficiency. Different authors define efficiency in different ways. In (Gleason, Barnum, 1982, pp. 379-386), the notion of effectiveness means the level of the goals accomplishment ("doing the right things"), while under the notion of efficiency they mean the accomplishment of these goals in the best possible way ("doing the right things in the right way"), i.e. accomplishing the

largest number of outputs while using the least amount of resources. In the past, both in literature and in practice, the greatest attention was paid to the operational efficiency. Operational efficiency can be defined as the ratio between the exploited resources and the accomplished results.

The efficiency measurement process in manufacturing companies is completely different from the efficiency measurement process in service companies. Raw materials and components in the production process are transformed in the final product. Tangibles and easy measurability of the final product and resource usage greatly facilitate the efficiency measurement of production processes. On the other hand, the final product in service companies is a realized service that is by its nature transient, intangible and quantity immeasurable, for which realization is often necessary to employ different measurable resources such as space, time, labor, etc.

Products of logistics companies as well as typical service companies are: transport services, warehouse services, material-handling services, freight forwarding services and other services. For their realization, it is necessary to use various resources such as transport and material handling equipment, warehouse space, time, energy, labor, etc. whose usage is not easily measurable. An additional problem of measuring efficiency in logistics is the complexity, integration and mutual dependence of both resources involved and realized services.

When defining performances of logistics systems, it is possible to make very different and even conflicting aspects of performances. Defining and measuring the efficiency of logistics systems as one of the most important performances in recent years is very significant. Existing models for measuring and monitoring efficiency are not fully applicable in logistics and contain a large number of constraints. The lack of models for measuring and monitoring the efficiency in logistics systems applicable in practice is evident. This confirms the lack of papers and models tested on real examples. The aforementioned problem and the importance of monitoring and measuring the efficiency of logistics services for practitioners and researchers are the main motive of this paper. Recently, an increasing number of authors have been advocating the use of approaches such as the Data Envelopment Analysis (DEA) method (Min, Joo, 2006, pp. 259-65). The DEA method is used for estimating the efficiency of homogeneous Decision Making Units (DMUs).

This paper provides an overview of models for measuring the efficiency in logistics. A special emphasis is placed on DEA models, the most frequently used method in efficiency measurement. The aspects of efficiency measurement in logistics are also investigated. Different models tested on real examples are described in this paper.

Aspects of measuring efficiency in logistics

Measuring efficiency in logistics can be viewed from various aspects. From the point of time and the significance of the decision-making, there are three hierarchical levels of efficiency measurement: strategic, tactical and operational level. In accordance with the mentioned aspects, it is possible to make a difference among the following efficiency measurement aspects in logistics: activities efficiency, processes efficiency, subsystems efficiency, systems efficiency and supply chain efficiency (Fig. 1).

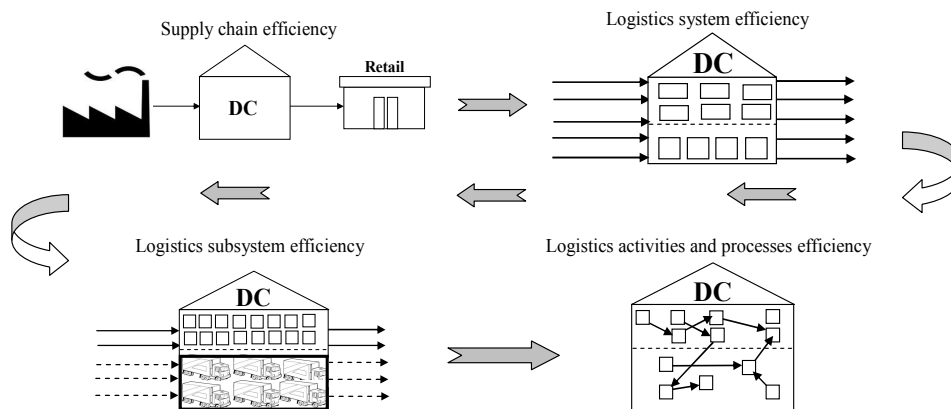


Figure 1 – Different perspectives on efficiency measuring
Slika 1 – Različite perspektive merjenja efikasnosti

Measuring and monitoring the efficiency of logistic networks, chains, systems, processes and activities primarily refers to the direct logistics flows, but the efficiency of reverse logistics flows is also important. In addition to monitoring and measuring the efficiency in logistic systems (freight forwarding, logistic centres, distribution centres, warehouses, etc.), it is necessary to analyze the efficiency of logistic activities and processes in systems whose main function are not logistic services (retail chains, hospitals, banks, etc.) For a successful measurement of the efficiency in logistics, it is necessary to consider a large number of inputs and outputs different in nature. Financial, technical, environmental, energy, social and many other factors expressed in different units influence efficiency in logistics. In this sense, it is possible to measure: energy efficiency, eco efficiency, cost efficiency, quality efficiency, etc. It can be concluded from the previous discussion that measuring efficiency in logistics is a complex

process that requires consideration of all subsystems, processes and activities as well as the impact of various financial, operational, environmental, quality and other factors.

Efficiency measuring models in logistics

From the initial works (Farrell, 1957, pp. 253-290 and Charnes, et al, 1978, pp. 429-444) and setting the basis of the DEA method as well as from introducing the notion of a DMU (Decision Making Unit), an expansion of the works from this area occurs. The suitability of application and the quality of the obtained results have influenced the application of this method in different profit and non-profit organizations: banks, libraries, hospitals, schools, universities, kindergartens, etc.

In the field of logistics, the DEA method is mostly used for the evaluation of the efficiency of 3PL (Third Party Logistics) providers from the perspective of customers and the provider (Min, Joo, 2006, pp. 259-65). The authors in (Zhou, et al, 2008, pp. 262-279), with the help of the DEA method, attempt to define the benchmark performances variables for 3PL providers in China. In their work, they consider the change of efficiency during a period of time as well as the interaction of certain factors upon the performances. In (Hamdan, Rogers, 2008, pp. 235–244), the authors apply the DEA method to measure the efficiency of 3PL providers with the stress upon the warehouse operations. Some papers refer to the estimation of distribution centres (DC) and warehouse efficiency. Thus in (Ross, Droge, 2002, pp. 19-32), the authors examine the efficiency of 102 DCs as parts of complex supply chains as well as the change of this efficiency over the course of time. A fuzzy DEA model for measuring the efficiency of transport quality is proposed in (Pamučar, 2011, pp. 40-61). In (Ilić, Andrejić, 2011, pp. 93-115), the authors analyse the efficiency of possible queuing models at gas stations using the large-scale queuing theory. Benchmarking and monitoring the international operators of the warehouse performances by applying the DEA method was given in (de Koster, Balk, 2008, pp. 1-10). The method has been in many ways applied to measuring efficiency in supply chains (de Koster, Balk, 2008, pp. 1-10).

Supply chain efficiency measurement

Supply chains are complex systems composed of many interrelated and conditioned processes. Supply chains and similar complex systems and processes are viewed as "black boxes" for a long time. Their structure and operating are not considered properly. For a successful efficiency evaluation of

supply chains, it is necessary to measure the performances of all participants in the chain, including suppliers, manufacturers, traders and end users.

Some papers in the literature measure the efficiency of independent participants in the supply chain using the DEA method. However, the number of papers that analyse the efficiency of supply chains is very small. The problem of measuring the efficiency of supply chains in the literature has been recognized as a problem of measuring the efficiency of multi-stage processes. The authors in (Cook, et al, 2010, pp. 423-430) have categorized DEA models into four categories:

- standard DEA approach;
- efficiency decomposition approach;
- network DEA approach;
- game-theoretic approach.

It is important to know that each supply chain member has its own strategy of achieving efficiency. Sometimes, due to possible conflicts between supply chain members, one member's inefficiency may be caused by another's efficient operations. For example, the supplier may increase its raw material price to enhance its revenue and to achieve an efficient performance. This increased revenue means increased cost to the manufacturer. Consequently, the manufacturer may become inefficient unless it adjusts its current operating policy. Measuring supply chain performance becomes a difficult and challenging task because of the need to deal with the multiple performance measures related to the supply chain members and the need to integrate and coordinate the performance of those members (Liang, et al, 2006, 35-49).

Two hurdles are present in measuring the performance of supply chains. One is the existence of multiple measures that characterize the performance of each member in a supply chain. The other is the existence of conflicts between supply chain members with respect to specific measures.

The problem of input and output variables classification is a big problem in supply chain efficiency measuring. Some measures linked to related supply chain members cannot be simply classified as "outputs" or "inputs" of the supply chain. For example, the supplier's revenue is not only an output of the supplier (the supplier wishes to maximize it), but also an input to the manufacturer (the manufacturer wishes to minimize it). Simply minimizing the total supply chain cost or maximizing the total supply chain revenue (profit) does not model and solve the conflicts. Therefore, the meaning of supply chain efficiency needs to be carefully defined and studied. Models need to define and measure the efficiency of a supply chain as well as supply chain members. A standard DEA approach uses two separate DEA runs for two supply chain members and calculates independent efficiency for each member. This approach does not treat common measure in a coordinated manner (Fig. 2).

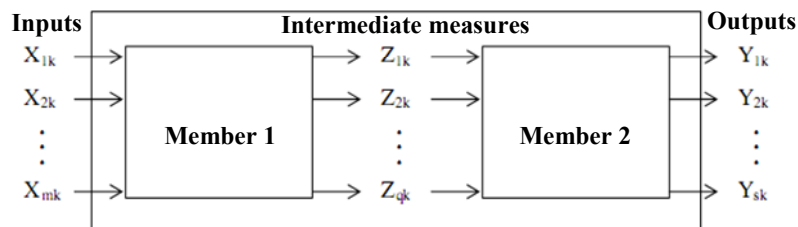


Figure 2 – Two-stage supply chain
Slika 2 – Dvoetajni lanac snabdevanja

Efficiency decomposition models define the efficiency of the overall two-stage process. This approach takes into account the equality of intermediate measures. In literature, overall efficiency is defined as the sum or the product of efficiencies of individual stages (members). Network DEA models analyse a complex structure where intermediate measures are not only inputs to the second stage. These models are applied in more general situations than two-stage processes.

The fourth type of approach uses game theory concepts. It originates from (Liang, et al, 2006, 35-49) where DEA is used to measure the performance of supply chains with two members (as in a manufacturer–retailer setting, for example). The concepts of the Stackelberg game (or leader–follower) and the cooperative game are used to develop models for measuring performance in supply chain settings. There are two main approaches: non-cooperative and cooperative models. In non-cooperative models, one-stage (member) is a leader while the other stage is a follower. The leader maximizes its efficiency regardless of the follower efficiency. The follower maximizes efficiency and with constraint that leader's efficiency is the same. The cooperative efficiency evaluation model maximizes the joint efficiency of the both members and forces the two players to agree on a common set of weights on the intermediate measures. In (Andrejić, Kilibarda, 2011, pp. 237–242), a practical application of this approach is tested.

Measuring efficiency of logistics systems and subsystems

DCs represent complex systems with a large number of interconnected subsystems, processes and activities. They also represent the basic hubs of the goods distribution process and connect a large number of participants in supply chains. In order to maintain the competitive edge, they have to monitor and measure the efficiency, but also define the sui-

table corrective actions, if necessary. The managers and employees in such systems are faced with several different tasks that are mainly connected with determining the optimal amount of the resources (input) for realizing a certain number of shipments, of a satisfactory level of quality. Only such systems can satisfy both the demands of the customers and their own demands. Apart from a DC as a system, this section describes in more detail two basic subsystems, which are the transport and warehouse subsystems. Regardless of the strong connection, these subsystems have different goals, in different cases even conflicts. Just as DCs, these subsystems strive to maximize the efficiency. In this sense, DC managers must at the same time take into account the efficiency of a DC as a system together with its subsystems.

Model formulation for logistics systems and subsystems efficiency measurement

In the process of applying the DEA and Multiple Objective Data Envelopment Analysis (MODEA) approaches, one of the most important steps represents the selection of the input and output variables (Boussofiene, et al, 1991, pp. 1-15). This work has evaluated the efficiency of 20 DCs of three trading companies who operate in the region of Serbia and who have similar sale networks, products ranges and distribution systems (Kilibarda, et al, 2011, pp. 996-1010). In order to estimate the DC and warehouse and transport subsystem efficiency, the variables describing their functioning in the best way have been used. The number of employees, the number of pallet places and the number of distribution vehicles at the DC disposal represent the main input variables, while the number of realized deliveries, the number of errors in the warehouse subsystem and the number of errors in the transport subsystem represent the output variables used in this work. The number of employees in a DC represents the common input variable, while the number of realized deliveries represents the common output variable in the transport and warehouse subsystem. It is assumed that DCs realize the deliveries the sizes of which are approximately the same. As the second input variable to estimate the warehouse subsystem efficiency, the number of pallet places in the DC has been used. On the other hand, the number of vehicles at DC disposal represents an input variable in the transport subsystem. The mentioned variables primarily refer to the estimation of the operational efficiency. In order to obtain the results whose quality and reliability are higher, as additional output variables, the quality indicators have been used. DCs of trading companies, but also DCs in general are characterized by a large number of indicators of realized deliveries. Errors in the transport and warehouse subsystems represent qualitative indicators which may be the

cause of dissatisfaction and complaints on the part of the customer, i.e. a low service quality level. Errors in the warehouse subsystem are mostly related to the errors in the order-picking process (shortage/excess in the delivery, articles mix-up, damage), but also to other processes such as bad inventory management, etc. Errors in transport primarily concern the delivery that is falling behind schedule, as well as the damaging and losing goods in the transport process. As it can be seen in Fig. 3, in order to estimate the DC efficiency, six variables have been used (three input and three output variables), while, in order to estimate the efficiency of its subsystems, four variables have been used per each system (two input and two output ones).

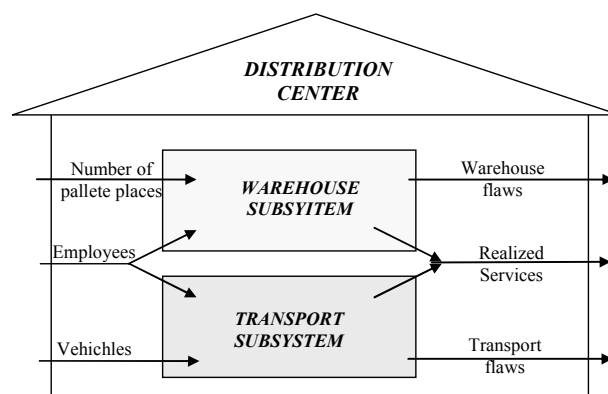


Figure 3 – DC and basic subsystems
Slika 3 – DC i osnovni podsistemi

The variables of input and output variables are given in Table 1. Table 1 also offers the descriptive statistics of the variables used in this paper. In order to obtain the results of higher quality and reliability, on the recommendation in (Klimberg, et al, 2010, pp. 79-93), the normalization of all variables has been performed. The number of errors in the transport and warehouse subsystems represents the output variables of the negative orientation, i.e. smaller variables are favorable. Regarding the fact that the DEA method perceives all output variables as positively oriented (larger variables are favorable), the change in the orientation of the mentioned variables has been performed. Prior to defining the model to estimate the DC and its subsystems efficiency, it is necessary to mention that the model proposed in this paper does not consider the external factors which may influence their efficiency, and do not come within the competence of the management of the company. The mentioned factors may be: weather conditions, market situation, industry branch, competition behavior, etc.

Inputs and output variables in DC

Table 1

Ulazne i izlazne promenljive distributivnog centra

Tabela 1

<i>DMU</i>	<i>Employees</i>	<i>Palette places</i>	<i>Vehicles</i>	<i>Realized deliveries</i>	<i>Warehouse errors</i>	<i>Transport errors</i>
<i>Mean</i>	98.26	3941.10	27.96	4544.95	483.65	749.25
<i>Standard</i>	56.10	1898.57	10.45	2730.54	375.48	444.78
<i>Max</i>	186	6793	45	9006	1336	1426
<i>Min</i>	34	684	13	1207	36	133

In this particular case, a DC (with warehouse and transport subsystems) represents a DMU whose efficiency is estimated. This work estimates the efficiency of 20 DCs and their transport and warehouse subsystems by means of applying the DEA and MODEA approach. The DEA method is a mathematical programming technique which gives an opportunity to compare different DMUs based on multiple inputs and outputs. This paper utilizes the DEA approach in order to estimate the efficiency of DCs and warehouse and transport subsystems. According to this approach, a logistic system or subsystem represents a "black box", i.e. the processes and activities that are not realized within the subsystem are not taken into consideration. From the group of DEA models, the basic CCR model has been chosen (Charnes, et al, pp. 429-444). By applying the CCR models, an independent estimation of the DC, warehouse and transport subsystems has been performed.

The described model belongs to the group of standard approaches which perform an independent estimation of the system efficiency without entering into the structure of the very system. In this manner, it is not possible to measure the DC efficiency taking into account the efficiency of the transport and warehouse subsystems, regarding the fact that these two subsystems possess common input and output variables. The CCR DEA models are not "sensitive" enough when evaluating the DMU efficiency, regarding the fact that they do not take into consideration the compromises and conflicts of independent DC subsystems goals. The MODEA approach offers the possibility of overcoming the mentioned problem (Klimberg, Puddicombe, 1999, pp. 201-232). The MODEA does not represent a simple set of independent standard CCR DEA models, but takes into account the common resources and multiple goals of the subsystems. In the model suggested in this section, the common input variable is the number of employees, while the common output variable is the number of realized deliveries. In most of the cases, the contribution of the common variable in one subsystem depends upon the contribution of the same variable in the other subsystem. In the ideal case, the ratio of the common variables sho-

uld be approximately 1 (the contribution of the common variable is identical). By further limitations upon the influence of the common variables in different goals on the part of the decision maker, the model becomes "closer" to the real state of affairs and good operational practice. The examination of the weights of the variables and their influence within the goals enables the decision makers to reach a suitable compromise. In the analyzed example, the set of decision making units makes 20 DC (DMU) ($k = 1, 2, \dots, 20$), with two subsystems each ($p=1,2$). The warehouse and transport subsystems are characterized by i input variables ($i=1,2, \dots, m_p$) and r output variables ($r=1,2, \dots, s_p$). In this particular case, the transport and warehouse subsystems have two input and output variables each ($m_1 = m_2 = s_1 = s_2 = 2$). The variable of the r -th output of the p -th subsystem of the k -th DC is marked by y_{rkp} , while x_{ikp} marks the variable of the i -th output of the p -th subsystem of the k -th DC. The weight coefficient assigned to the r -th output of the p -th subsystem u_{rp} and the weight coefficient assigned to the i -th output of the p -th subsystem v_{ip} represent the unknown variables (decision making variables). The coefficient φ represents the parameter of closeness of the common resources, assigned by the decision maker. In the concrete case, the MODEA model for measuring the efficiency of the k -th DC has the following form:

$$\text{Max} \sum_{p=1}^2 w_{kp} = w_{k1} + w_{k2} = u_{r1}y_{rk1} + u_{r2}y_{rk2} \quad (1)$$

$$\sum_{i=1}^{m_p} v_{ip} x_{ikp} = 1, p = 1, 2 \quad (2)$$

$$\sum_{r=1}^{s_p} u_{rp} y_{rkp} - \sum_{i=1}^{m_p} v_{ip} x_{ikp} \leq 0, \forall p = 1, 2; \forall k = 1, 2, \dots, 20 \quad (3)$$

$$1 - \varphi \leq \frac{\frac{u_{r1}}{s_1}}{\frac{u_{r2}}{s_2}} \leq 1 + \varphi \quad (4)$$

$$1 - \varphi \leq \frac{\frac{v_{i1}}{m_1}}{\frac{v_{i2}}{m_2}} \leq 1 + \varphi \quad (5)$$

$$v_{ip} \geq 0, p = 1, 2; i = 1, 2 \quad (6)$$

$$u_{rp} \geq 0, p = 1, 2; r = 1, 2 \quad (7)$$

In this paper, the efficiency of 20 DCs and their transport and warehouse subsystems has been analyzed. The set of the observed DCs can be deemed homogenous due to the fact these DCs operate in the same way and under the same conditions. The efficiency estimation has been carried out by applying the CCR DEA and MODEA approaches. The first three models refer to the MODEA approach, in which the coefficient φ (closeness parameter) takes the variables of 10%, 20% and 50%. By comparing the number of DC efficiencies obtained by applying the MODEA and CCR DEA approaches, it is pointed to a considerably larger number of efficient DMUs by applying the latter approach. This can be explained by the fact that the CCR model joins all indicators into a unique measure of efficiency with no separation or observation of the efficiency of its subsystems, i.e. it "overrates" the efficiency of DC.

By applying the MODEA approach, only 15% efficient DC can be obtained, while the CCR approach yields even 45% efficient DC. Such results can be explained by the fact that the CCR model does not take into consideration the efficiency of subsystems in a DC. On the other hand, according to the MODEA approach, a DC is efficient if the transport and warehouse subsystems are efficient. The average DC efficiency by applying the MODEA approach amounts to 1.1388 with the average efficiency of the warehouse subsystem amounting to 0.5158, and the transport one to 0.6229. The observed DC set can be considered as relatively inefficient and the largest portion of this inefficiency is a consequence of the warehouse subsystem inefficiency (Kilibarda, et al, 2011, pp. 996-1010).

The efficiency of one DC subsystem (warehouse or transport one) does not entail the DC efficiency. It can easily be concluded that the warehouse subsystem efficiencies are smaller than the transport subsystem efficiencies regardless of the variable of the parameter φ . By analyzing the obtained variables, it can be concluded that there is a certain number of DCs whose subsystems do not change the efficiency regardless of the approach. DMU 2, DMU 12 and DMU 17 represent the DCs with stable performances and efficient according to both the MODEA and the CCR DEA approach. Stable efficiency of these centres can be explained by a relatively small quantity of the used resources for the realization of a great number of deliveries with the number of errors in the transport and warehouse subsystems DMU 2 and DMU 12 considerably lower than the average (Kilibarda, et al, 2011, pp. 996-1010).

By analyzing Fig. 4 in more detail, three characteristic DC groups can be selected. The first group is comprised of the formerly mentioned efficient units. This group includes DMU 2, DMU 12 and DMU 17 whose transport and warehouse subsystems are efficient. The second group includes the units whose warehouse subsystems are significantly more

efficient than the transport subsystems. Such units are DMU 1 and DMU 11. As opposed to them, DMU 3, DMU 6, DMU 8, DMU 9 and DMU 13 have significantly more efficient transport subsystems. The last two DC groups, apart from inefficiency of at least one subsystem are characterized by the overall DC inefficiency. This confirms the claim that no DC can be efficient if one of its subsystems is inefficient.

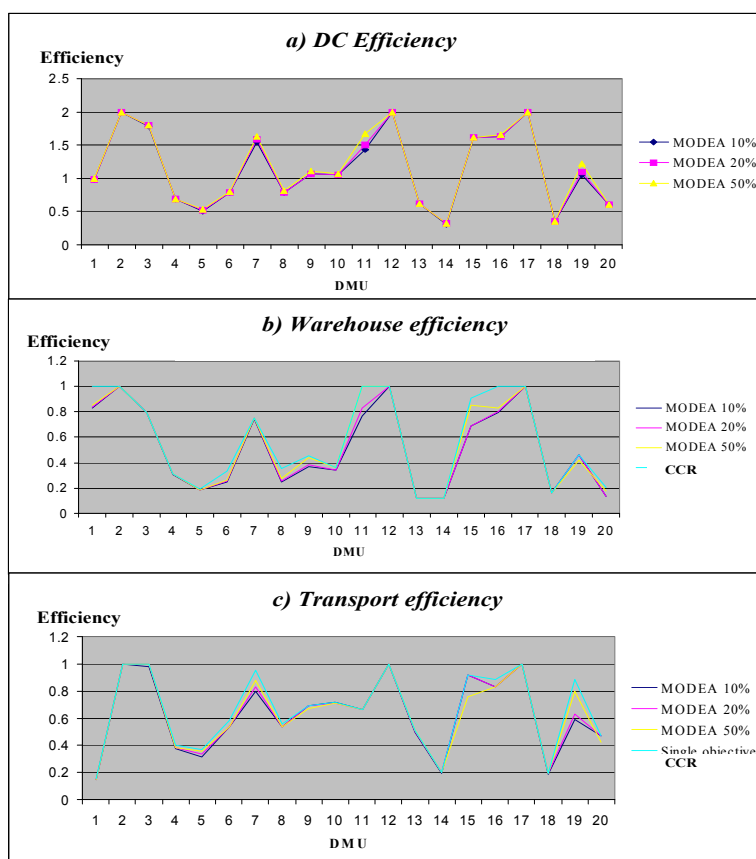


Figure 4 – Efficiency of a DC and its subsystems
Slika 4 – Efikasnost DC i osnovnih podsistema

Measuring efficiency of refrigerated warehouses

Energy efficient warehouses and distribution centers are integral components of supply chain strategies, especially nowadays in competitive global economy. Warehouses are moving beyond a simple storage function and today they offer high-tech inventory tracking and value-

added services as quality-control testing and repackaging. As warehouses grow more sophisticated, their energy consumption grows too. For example, in the U.S., warehouses only for lighting spend an average of 10\$/m². Energy costs for some warehouses are more than 10% of their total revenue. It does not matter whether a production, warehouse or distribution center is 1000 square meters or 500000 square meters, it is necessary to cut costs and to improve operating efficiencies. Refrigerated warehouses (RWs) represent special types of warehouses that use 2.8 times more energy for operating than conventional warehouses (Roy, 2010, pp. 64-70). RWs are very important links in a supply chain (ASHRAE, 2006). They are also large energy consumers.

Logistic systems, especially RWs, demand more energy for process operation. In a situation of increasing energy demand and rising energy costs, energy efficiency measures are becoming more important. The need for energy efficiency measuring and monitoring becomes a necessity. This paper uses one of the most frequently used methods for measuring efficiency – the DEA method for RWs energy efficiency measuring. According to this method, RWs are viewed as systems that use inputs (labor, electricity, fuel, water, space, etc.) to produce products and deliver services with a high level of quality. Management plays the key role in the energy consumption reduction. This paper presents a model for evaluating RWs energy efficiency, which should help managers to reduce energy consumption.

The constant return to scale (CRS) assumption is appropriate when all firms operate on an optimal scale. The CCR gives relative technical efficiency (TE). However, imperfect competition, government regulations, constraints on finance, etc., may cause a firm not to operate on an optimal scale. In contrast to the CCR, the model that assumes CRS (proportional increase in inputs results in a proportional increase in outputs), (Coelli, Prasada, O'Donnell, Battese, 2005) extends the original DEA model to variable returns to scale (VRS - increase in inputs does not result in a proportional change in output). This model is known in the literature as the BCC model. The BCC model measures the pure technical efficiency (PTE), and provides a measure of efficiency which ignores the influence of the volume of business, because RWs are compared only with other RWs of a similar scale. Scale efficiency (SE) indicates whether the observed RW operates with an optimal volume of operations. SE can be obtained for each RW by conducting both CCR and BCC models, and then by decomposing the TE scores obtained from the CCR model into two components, one due to scale inefficiency and one due to pure technical inefficiency. If there is a difference in CCR and BCC TE scores for a particular RW, then this indicates that the firm has scale inefficiency (Coelli, Prasada, O'Donnell, Battese, 2005):

$$TE \text{ (Technical Efficiency - CCR)} = PTE \text{ (Pure Technical Efficiency - BCC)} \times SE \text{ (Scale Efficiency)}$$

It is important to note that the overall efficiency of energy consumption consists of two factors: environmental factors and energy management factors. The environmental factors include weather conditions, occupant intensity, imperfect competition, government regulations, constraints on finance, etc. The energy management factors include equipment efficiency, operating strategy, etc. Due to the difficulty of separating the effect of the environmental factors from overall energy efficiency, there is little research analysis of the effect of energy management of RWs with the DEA. Therefore, we use the DEA to measure the overall energy efficiency in detail by examining the environmental factors and the management factors. Considering the fact that RWs can control energy consumption and reduce it in order to become more efficient, in this paper, we adopted the input orientation of DEA models.

Five inputs and two outputs are used for evaluating the efficiency of 15 RWs. The data are generated in accordance with the actual values of RWs in real systems (Andrejić, et al, 2011, pp. 313-319). The following inputs are taken into consideration (Table 2): RW size (m^3), labor, facility utilization (%), electricity consumption, other energy costs (water, fuel, gas, etc). The RW size presents the facility volume. It is better to use m^3 rather than m^2 when describing the warehouse space. The percentage of facility utilization is a good indicator for the rationalization of energy consumption. Electricity consumption is a basic measure for energy efficient measuring. As mentioned before, electricity costs are more than 50% of all costs in RWs, so a detailed analysis of this input is necessary. This measure is expressed in MWh/year. All other costs of water, fuel, gas, etc., consumption are incorporated in one measure – other energy costs, and they are expressed in thousands of monetary units (m.u.).

On the other hand, the proposed model uses two outputs: successfully realized services and goods deterioration. Successfully realized services are services that are realized according to customer requirements (right time, right place, right quality, etc). Goods deterioration is caused by poor handling and storing of goods (i.e. inappropriate temperature, pressure and humidity).

In accordance with the defined input and output values, as mentioned, we used the input minimizing orientation of CCR and BCC models, where the emphasis is on the maintenance or improvement of the level of service provided with the minimum use of inputs. In this paper, the analysis is carried out with the DEA software efficiency measurement system (EMS), developed by the Operations Research Department at the University of Dortmund (<http://www.ub.uni-dortmund.de/service/benuord.htm.en>). Table 2 presents the descriptive statistics for the outputs and inputs of the 15 RWs.

Table 2
Descriptive statistics for the inputs and outputs in refrigerated warehouses

Tabela 2
Deskriptivna statistika ulaznih i izlaznih promenljivih skladišta hladnjača

Inputs/outputs	Mean	Standard deviation	Max	Min
Size (m3)	51.67	23.29	92.72	26.36
Employees	74.68	29.72	132.69	31.95
Facility utilization (%)	69.20	17.64	98.20	44.48
Electricity consumption (MWh/year)	3993.44	843.75	5078.87	2420.65
Other energy costs (1000 m.u.)	26.66	11.04	48.01	11.73
Realized services (1000)	535.79	215.94	997.13	298.57
Goods deterioration (%)	9.54	5.89	19.37	1.12

The results of the DEA analysis, TE and SE scores for each RW are given in Table 3. Out of the 15 RWs, 8 (53%) were found TE with a score of 100%. The remaining 7 RWs (47%) were technically inefficient since they had a TE score lower than 100%. The average efficiency of 15 analyzed RWs is 85%, which roughly means that each RW can store and deliver the current quantities of goods up to 15% less resources during the observed period (in this case one year). In this way, the RWs can realize potential savings of 600 MWh in electricity consumption and 4000 m.u. in other energy costs in average. In average, the RWs could operate with 11 employees less. The average technical inefficiency of the observed RWs is 15%. Most of the inefficiency is in SE, about 14%, while about 1% of inefficiency corresponds to PTE. These results show the fact that most of the inefficiency is the result of the inadequate size of the facility, and the environmental factor rather than management (i.e. an RW does not operate on an optimal scale). In real systems, the inefficiency is often caused by bad management. The detailed analysis of the obtained results shows that the RWs can be classified into certain groups. Namely, the DEA analyses have found that there are 8 technically efficient and 7 inefficient RWs. As mentioned before, most RWs do not operate on the optimal scale. A reason for their inefficiency can be found in the size of RWs and the environmental factors (Andrejić, et al, 2011, pp. 313-319).

Table 3
RWs efficiency scores

Tabela 3
Efikasnost skladišta hladnjača

RW	TE (CRS)	PTE (VRS)	SE
RW 1	0.54	1.00	0.54
RW 2	1.00	1.00	1.00
RW 3	1.00	1.00	1.00

RW	TE (CRS)	PTE (VRS)	SE
RW 4	0.53	0.98	0.54
RW 5	1.00	1.00	1.00
RW 6	1.00	1.00	1.00
RW 7	0.80	1.00	0.80
RW 8	1.00	1.00	1.00
RW 9	1.00	1.00	1.00
RW 10	0.61	1.00	0.61
RW 11	0.97	0.98	0.99
RW 12	1.00	1.00	1.00
RW 13	0.50	0.91	0.55
RW 14	0.86	1.00	0.86
RW 15	1,00	1,00	1,00
<i>Average efficiency</i>	<i>0.85</i>	<i>0.99</i>	<i>0.86</i>
<i>Efficient units</i>	<i>8 (53%)</i>	<i>12 (80%)</i>	<i>8 (53%)</i>
<i>Inefficient units</i>	<i>7 (47%)</i>	<i>3 (20%)</i>	<i>7 (47%)</i>

The slack movements, which arise because of the sections of the piece-wise linear frontier that runs parallelly to the axes are reported in order to give an accurate indication of RWs TE. The analysis of slack values (Table 4) shows that there is a significant slack in the input variable. Much of the inefficiency is the result of scale inefficiency of the RW operating. Potential improvements are related to the average decrease in inputs, which range from 0.7% for other energy costs up to 11.21% for employees while maintaining RW current level of outputs.

Table 4

Potential savings in inputs

Tabela 4

Potencijalne uštede u ulazima

	Actual average	Average slack	Potential reduce
Size	51.67	3.51	6.79%
Employees	74.68	8.37	11.21%
Facility utilization	69.20	5.39	7.78%
Electricity consumption	3993.44	254.85	6.38%
Other energy costs	26.66	0.19	0.70%

Namely, RW energy efficiency heavily depends on the organization management, technologies, size of facility and awareness of employees in RWs, as well as of a number of external factors.

Conclusions

Measuring and monitoring the efficiency in logistics is one of the crucial success factors in the market. The main objective of this paper is to define some kind of efficiency measurement models review. This paper describes different aspects of measuring efficiency in logistics. The main efficiency measurement aspects in logistics described in this paper are: activities efficiency, processes efficiency, subsystems efficiency, systems efficiency and supply chain efficiency. The paper further describes the fundamental issues and models for measuring efficiency in certain areas. The tests and results of the model show remarkable importance of input and output variables selection. In this paper, the models for measuring supply chain, systems, and subsystems are described in more detail. They are also tested on real examples. The methodology for measuring refrigerated warehouses is also described in this paper.

In literature, there is a lack of case studies, i.e. model testing in concrete examples. This fact indicates the insufficient amount of research in this area. The efficiency of supply chains and logistic systems is also influenced by a great number of factors upon which the company management have no influence. In future models, it would be desirable to introduce certain indicators which, to a certain extent, can describe external factors such as: weather conditions, market situation, competition behavior, etc. The presented models are a good basis for the development of future models. Incorporating different performance indicators (quality, cost, environmental, social, etc.) in efficiency measurement models should be a subject of future research.

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MERENJE EFIKASNOSTI U LOGISTICI

OBLAST: logistika, operativni menadžment

VRSTA ČLANKA: pregledni članak

Sažetak:

Dinamično tržište i promene u okruženju u velikoj meri utiču na funkcionisanje logističkih sistema. Logistički sistemi moraju realizovati aktivnosti i procese na efikasan način. U radu se analiziraju različiti aspekti merenja efikasnosti u logistici i predlažu odgovarajući modeli merenja. Merenje efikasnosti u logistici predstavlja kompleksan proces koji zahteva sagledavanje svih podsistema, procesa i aktivnosti, kao i uticaja različitih finansijskih, operativnih, ekoloških, kvalitativnih i drugih faktora. Predloženi modeli bazirani su na Data Envelopment Analysis metodi. Oni mogu pomoći menadžerima u procesu odlučivanja i sprovođenja korektivnih akcija. Analizom rezultata testiranih modela potvrđen je značaj izbora ulaznih i izlaznih veličina.

Uvod

Savremeno poslovanje prvenstveno podrazumeva izrazito zahtevnu tržišnu borbu, bez obzira na to da li se radi o proizvodnji ili pružanju usluga u bilo kojoj grani industrije. Postupak merenja efikasnosti u proizvodnim kompanijama u velikoj meri se razlikuje od postupka merenja efikasnosti u uslužnim kompanijama. Za proizvodnju materijalnog proizvoda koriste se materijali, sirovine i komponente od kojih u proizvodnom procesu nastaje finalni proizvod. Opipljivost i laka merljivost finalnog proizvoda, kao i upotrebljenih resursa, u velikoj meri olakšavaju merenje efikasnosti proizvodnih procesa. Nasuprot tome, kod uslužnih kompanija finalni proizvod je realizovana usluga koja je po svojoj prirodi prolaznog karaktera, neopipljiva i kvantitativno nemerljiva, za čiju upotrebu se angažuju različiti, često teško merljivi resursi, kao što su prostor, vreme i angažovana radna snaga. Proizvod logističkih kompanija, kao tipičnih uslužnih kompanija, najčešće su transportne, skladišne, pretovarno-manipulativne, špeditorske i druge usluge, u čijoj realizaciji se angažuju različiti resursi, kao što su transportna i pretovarno-manipulativna sredstva, skladišni prostor, vreme, radna snaga, itd. čiju upotrebu nije jednostavno izmeriti. Dodatni problem merenja efikasnosti u logistici predstavlja kompleksnost, integrisanost i međusobna uslovljenost, kako angažovanih resursa, tako i realizovanih usluga.

Aspekti merenja efikasnosti u logistici

Sa vremenskog aspekta razlikuje se merenje efikasnosti na strateškom, taktičkom i operativnom nivou. Sa aspekta nivoa merenja efikasnosti moguće je razlikovati: efikasnost aktivnosti, efikasnost procesa, efikasnost podsistema, efikasnost sistema i efikasnost lanca. Kada je reč o merenju i praćenju efikasnosti logističkih mreža, lanaca, sistema, procesa i aktivnosti moguće je razlikovati efikasnost direktnih i povratnih logističkih tokova. Osim praćenja i merenja efikasnosti u logističkim sistemima (špedicije, logistički centri, distributivni centri, skladišta itd...) neophodno je analizirati efikasnost

logističkih aktivnosti i procesa u sistemima čija osnovna funkcija nije pružanje logističkih usluga (trgovinski lanci, zdravstvene ustanove itd.). Za uspješno merenje efikasnosti u logistici neophodno je sagledati veliki broj ulaza i izlaza koji su po svojoj prirodi raznorodni (finansijski, tehnički, ekološki, energetski, socijalni itd.) i izražavaju se u različitim mernim jedinicama. U tom smislu moguće je meriti energetsku, ekološku, troškovnu i druge tipove efikasnosti u logistici. Sa druge strane, često je neophodno sagledati pomenute aspekte i definisati jedinstvenu meru efikasnosti.

Modeli merenja efikasnosti u logistici

Za procenu efikasnosti distributivnih centara (DC) dugo su korišćeni „single ratio” pokazatelji, kao što su iskorišćenost opreme i produktivnost radne snage. S obzirom na to da pomenuti izmeritelji nisu najbolji pokazatelji efikasnosti, u (Min, Joo, 2006, pp. 259-65) ističu da se veliki broj autora zalaže za upotrebu Data Envelopment Analysis (DEA) metode. DEA metoda predstavlja jedan od najšire korišćenih alata za merenje efikasnosti. U oblasti logistike DEA metoda se najčešće koristi za procenu efikasnosti 3PL (Third Party Logistics) provajdera, kako iz perspektive provajdera (Min, Joo, 2006, pp. 259-65), tako i iz perspektive korisnika. U (Zhou, et al, 2008, pp. 262-279), uz pomoć DEA metode, pokušavaju da definišu benčmark vrednosti performansi za 3PL provajdere u Kini. Manji broj radova odnosi se na procenu efikasnosti DC i skladišta. Tako u (Ross, Droge, 2002, pp. 19-32) istražuju efikasnost 102 DC, kao delova kompleksnih lanaca snabdevanja i promenu te efikasnosti u vremenu. Metoda je višestruko primenjivana za merenje efikasnosti u lancima snabdevanja (Cook, et al, 2010, pp. 423-430).

Merenje efikasnosti u lancima snabdevanja

Iz perspektive DEA metode, kao najčešće korišćene metode za merenje efikasnosti višefaznih procesa, postoji veliki broj modela i metoda koje se direktno ili uz izvesne modifikacije mogu primeniti na lance snabdevanja. U ovom radu izrađen je pregled DEA modela za merenje efikasnosti lanaca snabdevanja. Prema (Cook, et al, 2010, pp. 423-430) pomenuti modeli mogu se klasifikovati u četiri grupe:

- standardni DEA modeli;
- modeli dekompozicije efikasnosti;
- mrežni DEA modeli;
- modeli bazirani na teoriji igara.

Merenje efikasnosti logističkih sistema i podsistema

Distributivni centri predstavljaju kompleksne sisteme sa velikim brojem međusobno povezanih podsistema, procesa i aktivnosti. Radi održavanja konkurentnosti, oni moraju pratiti i meriti efikasnost, ali i definisati odgovarajuće korektivne akcije, ukoliko je to potrebno. Pred menadžerima i zaposlenima u ovakvim sistemima postavlja se više različitih zadataka koji su uglavnom vezani za određivanje optimalne količine resursa (ulaza) za realizovanje određenog broja isporuka, odgovarajućeg nivoa kvaliteta. Pored DC kao sistema u radu su detaljnije analizirana i dva osnovna podsistema i to tran-

sportni i skladišni podsistem. Bez obzira na jaku povezanost ovi podsistemi imaju različite ciljeve, u određenim slučajevima i konfliktne. Kao i DC i podsistemi teže maksimizaciji efikasnosti. U tom smislu menadžeri DC moraju istovremeno voditi računa o efikasnosti DC, kao sistema, ali i njegovih podsistema. U radu je analizirana efikasnost 20 DC i njegovih transportnih i skladišnih podsistema. Skup posmatranih DC može se smatrati homogenim s obzirom na to da DC posluju na isti način i pod istim uslovima. Procena efikasnosti sprovedena je primenom CCR DEA i Multiple Objective Data Envelopment Analysis (MODEA) pristupa. Primenom MODEA pristupa dobija se svega 15% efikasnih DC, dok se CCR pristupom dobija čak 45% efikasnih DC. Ovakvi rezultati mogu se objasniti činjenicom da CCR model ne razmatra efikasnost podsistema u DC. Sa druge strane, prema MODEA pristupu (Kilbarda, et al, 2011, pp. 996-1010) DC je efikasan ako su i transportni i skladišni podsistem efikasni.

Merenje efikasnosti skladišta hladnjača

Energetski efikasna skladišta i distributivni centri sastavni su delovi strategije lanca snabdevanja, posebno danas u konkurentnoj globalnoj ekonomiji. U situaciji povećanja potrošnje energije i rasta troškova energije, energetska efikasnost postaje sve važnija. Potreba za merenjem i praćenjem energetske efikasnosti postaje nužnost.

Pet ulaznih i dve izlazne veličine korišćene su za procenu efikasnosti 15 skladišta hladnjača. Ulazne veličine korišćene u ovom modelu su: veličina objekta, iskorišćenost objekta, potrošnja energije, ostali energetske troškovi (naftni derivati, gas, voda itd.). Izlazne veličine, razmatrane u predloženom modelu, jesu: uspešno realizovane usluge i stepen kvarenja robe. Analizom rezultata zaključeno je da efikasnost skladišta hladnjača u velikoj meri zavisi od menadžmenta, tehnološke razvijenosti i odgovornosti zaposlenih, a mnogo manje od spoljnih faktora (Andrejić, et al, 2011, pp. 313-319).

Zaključak

Merenje i praćenje efikasnosti u logistici jedan je od presudnih faktora uspeha na tržištu. Osnovni cilj ovog rada je pregled modela merenja efikasnosti. U radu se opisuju različiti aspekti merenja efikasnosti u logistici, od kojih su osnovni: efikasnost aktivnosti, efikasnost procesa, efikasnost podsistema, efikasnost sistema i efikasnost lanca snabdevanja.

Rad detaljnije opisuje osnovne probleme i modele za merenje efikasnosti u pojedinim oblastima. Testovi i rezultati modela pokazuju izuzetan značaj izbora ulaznih i izlaznih promenljivih.

Ključne reči: efikasnost, logistika, metode merenja, Data Envelopment Analysis.

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