

## DECISION-MAKING MODEL FOR SUPPORTING SUPPLY CHAIN EFFICIENCY EVALUATION

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**Abstract:** *This paper presents some approach for the formulation of the decision-making model in supporting the assessment of supply chain efficiency. Were presented factors affecting the efficiency of the functioning of individual links of supply chain. Was pointed out the technical, economic, organizational and reliability aspects affecting the efficiency and reliability of functioning of the supply chain both in terms of supply and distribution. Having regard to a comprehensive approach to assessing efficiency of the functioning of supply chains were proposed indicators for assessing the quality of functioning. Were distinguished technical, economic and quality indicators for which also were presented a formal record.*

**Key words:** *decision-making model, assessing the efficiency support, supply chain efficiency*

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### 1. Introduction

Organization of cargo flows involves the design of logistics network. In general logistics network is seen as the configuration of interconnected warehouse facilities, logistics centers, etc. by using financial and material flows of information (Witkowski, 2000). Regard to the general concept of network, defined, among others, as (Cecere, 2012; Witkowski, 2000):

- a set of interconnected and inter conditioned activities with designated start and end point (Blanchini et al, 1997),
- interaction between the elements of a particular process. The network is presented, in this case in the form of a graph in which the arcs map the actions (operations) of the process, and the nodes map the starting and finishing dates of their execution. Wherein, it is assumed that is designated start and end point of the process, and that the dates for commencement and completion of each activity are related to specific technological dependencies (Cecere, 2012),

the logistics network can be defined as the structure of entities performing material flows from suppliers to customers or intermediaries in these flows, interconnected functional, technological, economic and information interdependencies.

Speaking about logistics network, the authors of the publication (Jacyna-Golda, 2013; Pfohl, 1998; Witkowski, 2000) emphasize its aspect of destination, eg. functional, technical or economic. The functions and tasks of logistics network are

determined by the industry and the purpose for which the network is designed.

Logistics network is also identified with the distribution network and supply network (Jacyna-Golda, 2013; Stephens, 2001; Witkowski, 2000; Lewczuk, 2011; Pfohl, 1998) or alternatively with the supply chain (Brzeziński, 2007; Cecere, 2012; Fertsch, 2006; Witkowski, 2000). When analyzing the literature in this area it is sometimes difficult to separate the concept of supply networks and supply chain. It is emphasized here that the supply network is a broader concept, and the supply chain refers more to one industry or type of service uniform or a large company. Supply network consists of two or more legally separated entities connected by the flow of materials, information and funds. As entities operating in the supply networks are: manufacturers of parts, components or finished products, logistics service providers and customers (consumers of services or finished goods) (Ballou, 1984).

When defining the supply chain must be taken into account such factors as economic structure, object flow and the objectives of their implementation and functional scope and areas of cooperation between the entities involved in the chain. For example, if the supply chain is treated as a process<sup>1</sup>, then the analysis of the sequence of events will be subject to

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<sup>1</sup>A process we call phenomenon whose description has the form of relationships between the states of the system in time

the movement of goods, whereby these goods increase their value (Brzeziński, 2007; Christopher, 2000; Jachimowski and Szczepański, 2013).

Otherwise it will when analyzed structural aspect that allows the identification of a group of entities (companies) implementing joint actions necessary to meet the demand for certain goods throughout the supply chain - from raw material extraction to deliver the product (the product) to the final recipient. These actions include the processes associated with the production, sales, service, supply, distribution, resource management and support activities.

Speaking of the supply chain should highlight the role its cells such as mining companies, manufacturing and distribution. Their role and location in the structure of the supply chain due to the division of labor in the subsequent stages of production and sale of products. Among the important supply chain, replace the company performing service functions, eg.:

- logistics and transport and forwarding companies,
- warehouse facilities, distribution centers and logistics centers.
- brokerage firms involved in only information brokerage,
- recycling plants and storage of waste.

The role of logistics companies that transport and forwarding stems from delivery services, which,

apart from transport and forwarding operations include terminal services, ranging from cross-docking, by storing the completion and refining operations such as tagging, foiling, minor repairs, creating promotional sets and others. Depending between the processes of handling and storage can be represented graphically on a network depending on where the nodes are interconnected. In the storage facilities products are temporarily stored or transmitted on a different path, leading through a network of dependence (Fig. 1). This means that the implementation of logistic processes in the supply chain is a course of changes in status of the process in the supply chain execution within a certain period of time. Thus, dependence network is a sequence of consecutive state changes occurring in the supply chain between the initial state and the final state.

Taking the above into consideration when assessing the effectiveness of the supply chain must be defined performance indicators, guided by:

- adequacy, consisting of a good description of dependency and low sensitivity to changing external factors.
- ensuring uniformity and comparability in time and space specific aspects,
- capacity, according to which the measure should include key elements of the supply chain assessment,

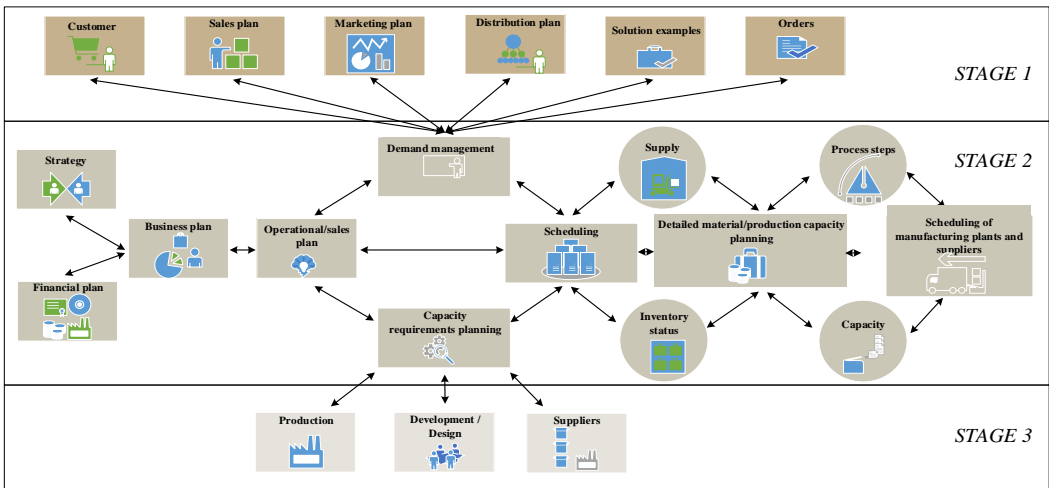


Fig. 1. The relationship network between the transport and storage processes in the supply chain  
 Source: own work based on (Cecere, 2012; Jacyna-Golda, 2013; Pfohl, 1998; Banomyong et al, 2015).

- adaptability, assessed in terms of the interpretation of the substantive content,
- economic dimension, which is to determine the relationship between the effects of the use of the meter and the cost of its calculation or obtain.

What is important efficiency measurement can be used both to evaluate the selection of equipment and means of transport to jobs and to assess whether the selection of applied technologies analysis and performance evaluation processes and the analysis and assessment of the implementation of tasks. Effectiveness can be measured both when choosing a particular action before it starts (*ex ante*) as well as in the evaluation of its implementation (*ex post*). This entails a number of factors. Thus developing a decision-making model supporting assessment of the functioning of the supply chain is a complex decision-making problem. This is determined primarily multiplicity of cells (entities) occurring in the supply chain on the one hand and on the other hand, the needs of individual participants throughout the supply chain.

## **2. Decision-making problems and supply chain efficiency**

### **2.1. Logistics processes and decision-making problems in the supply chain**

The implementation of logistics processes is a mapping of actions resulting in the effective implementation of the transformation taking place in the supply chain. At various stages of the process, which can be represented as in Fig. 2, it is desirable to control decisions relating to the implementation of the process. Efforts are made to control the course change was carried out in a manner that contributes to improving the quality of the logistics process implemented or are in the sphere of supply or in the sphere of distribution.

To be able to make rational decisions in supply chains, it is necessary to determine what these decisions are affected. Accordingly, the natural need is to identify the main decision problems occurring in the supply chain. Their definition and propose appropriate decision-making procedures leading to the optimal decision should contribute to improve the implementation of logistics processes and ultimately to improve the functioning of whole chain.

The study decision-making processes in supply chains use various tools, for example stochastic,

dynamic programming and the queuing theory. Extensive use in research and analysis of supply chains and processes occurring in them is queuing theory (Dukic and Opetuk, 2012; Lighthill and Whitham, 1955; Wasiak, 2009).

The problem of modeling decision-making in supply chains characterized by a generally high complexity requiring at his addressing the consideration of many aspects of various nature. Comprehensive analysis of the evaluation should therefore cover both technical aspects (m. In. Linear transport infrastructure and points, the availability of means of transport), economic, organizational and qualitative aspects of security but also the reliability of supply, environmental and social (Pyza, 2012).

As it points out in the literature (Ambroziak and Lewczuk, 2009; Ballou, 1984; Blanchini et al, 1997, Dukic and Opetuk, 2012) the technical aspects take into account the problems of m. in .: rational use of means of transport, efficient operation and their recovery- minimize expenditure on transport, maximizing the utilization of means of transport - minimizing empty runs. In contrast, economic and organizational aspects include such issues as cost minimization passing through each link in the supply chain, maximizing revenue and minimizing operational costs. Qualitative aspects are a separate group of research areas. Most often, in the case of issues related to quality aspects relate to: minimize the duration of the tasks in the individual supply chain, ensuring timely deliveries, minimizing the risks or completeness of deliveries. The primary determinant of assessing the efficiency of supply chains is striving to increase the efficiency of its functioning, and thus improve its competitiveness. The supply chain will be effective when provide implementation of the identified tasks at the required level of quality with the rational use of its potential. Analysis of supply chain efficiency should be based on its graduation from the global assessments to partial assessments relating to overall use of resources efficiency of the supply chain and the cost of the individual components of realization of deliveries. At the same time, a set of basic characteristics of expressing the efficiency of a given chain is built on the basis of relations between the variables that determine the efficiency of its functioning.

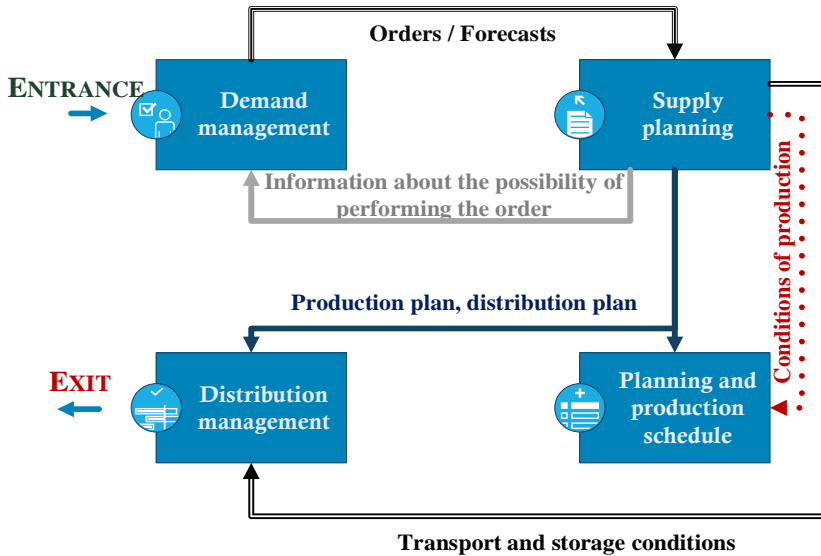


Fig. 2. Decision support during the implementation of logistics processes

Source: own work based on (Cecere, 2012; Jacyna-Golda, 2013).

### 2.2. The principles of measurement of the efficiency of the supply chain functioning

The efficiency of the supply chain is determined by the effectiveness of its actions and thus the degree of realization of its objectives. It boils down primarily to the proper use of the equipment provided, each link in the chain to achieve the objectives. The degree of realization of its objectives can be defined as the effects of the supply chain, while expenditure is the amount of resources mobilized to achieve the objectives (Dukic and Opetuk, 2012; Pyza, 2012; Żak et al, 2014). Thus, supply chain efficiency is also of evaluation of its performance and thus is a measure of the effectiveness of a particular its operation. Greater efficiency means that when incurring the same costs can achieve better results of operation. Determines how the effectiveness and efficiency of resources are used for the implementation of the objective of the supply chain. For example, transportation technology selection, i.e. the means of work used and how to implement the transportation process or storage process should ensure the greatest possible effectiveness of the system ensuring the effective implementation of the tasks set at the lowest possible expenditures.

Assuming that efficiency is understood as the relationship between expenditures and effects, it can be defined as (Żak et al, 2014):

- 1) the difference between effects and expenditures (Present Value, PV). The desired result should be greater than zero, which means that the results achieved are greater than the expenditures,
- 2) dividing effects to expenditures (Benefit-Cost Ratio, B/C ratio). The desired result should be greater than one, which means that expenditures are lower than achieved effects,
- 3) expressed as a percentage quotient of the difference between effects and expenditures to expenditures (return on investment ROI).

Assuming that is defined set **LD** of numbers of supply chains, in the form:

$$LD = \{ld: ld = 1, 2, \dots, LD\} \tag{2.1}$$

where *ld* –number of single supply chain, LD – total number of analyzed supply chains, and efficiency of the supply chain functioning can be written as a the ratio of useful effects  $\Xi Z(\tau, ld)$  to direct expenditure incurred  $\Xi N(\tau, ld)$  referenced to the time of the system operation, i.e.:

$$\forall ld \in \mathbf{LD} \quad \Xi(\tau, ld) = \Xi Z(\tau, ld) [\Xi N(\tau, ld)]^{-1} \quad (2.2)$$

where:

- $\Xi Z(\tau, ld)$  - values of obtained effects until  $\tau$  moment for  $ld$ -th supply chain from the beginning of its functioning
- $\Xi N(\tau, ld)$  values of expenditures used until  $\tau$  moment for  $ld$ -th supply chain from the beginning of its functioning

In the time interval  $(0, \tau)$  the function  $\Xi N(\tau, ld)$  is a non-decreasing function of time. Assuming that expenditures are part of the resource spent on the functioning of supply chain, it is assumed that in each of the elementary intervals of time  $\Delta\tau$  their values are not less than zero. This can be written as follows:

$$\forall ld \in \mathbf{LD} \quad \eta(\tau, ld) = \frac{d\Xi N(\tau, ld)}{d\tau} \quad (2.3)$$

The value of the function  $\Xi N(\tau, ld)$ , in the moment  $\tau'(\Xi N(\tau', ld))$ , depending on whether the function  $\eta(\tau, ld)$  is continuous or discrete, may be determined from the formulas:

$$\forall ld \in \mathbf{LD} \quad \Xi N(\tau, ld) = \int_0^{\tau'} \eta(\tau, ld) d\tau \quad (2.4)$$

$$\text{or } \forall ld \in \mathbf{LD} \quad \Xi N(\tau, ld) = \sum_k^{\tau'} \eta_k \Delta\tau_k(ld) \quad (2.5)$$

where:

- $\eta(\tau_k, ld)$  - value of expenditures incurred for in each of the time intervals  $\tau_k$  where interval with the number  $\tau_r$  ends in the moment  $\tau'$ .

Whereas function  $\Xi Z(\tau, ld)$  of obtained effects, in analyzed time interval, can take both positive and negative values. The value of obtained effects for a given supply chain can be written as:

$$\forall ld \in \mathbf{LD} \quad \mu(\tau, ld) = \frac{d\Xi Z(\tau, ld)}{d\tau} \quad (2.6)$$

As in the case of expenditures function, the value of the function  $\Xi Z(\tau, ld)$ , in the moment  $\tau'$  can be determined based on the values of elementary

functions  $\mu(\tau, ld)$  depending on whether they are continuous or discrete functions, ie.:

$$\forall ld \in \mathbf{LD} \quad \Xi Z(\tau, ld) = \int_0^{\tau} \mu(\tau, ld) d\tau \quad (2.7)$$

$$\text{or } \forall ld \in \mathbf{LD} \quad \Xi Z(\tau', ld) = \sum_{k=1}^{\tau'} \mu(\tau_k, ld) \quad (2.8)$$

Considering the above, the effect useful for the entire supply chain, assuming that the interval  $\Delta\tau$  is large enough,  $\Delta\tau = T > 0$ , can be written as follows:

$$\forall ld \in \mathbf{LD} \quad \Xi(T, ld) = \Xi Z(T, ld) [\Xi N(T, ld)]^{-1} \quad (2.9)$$

In the evaluation process is of a vital importance the ability to choose different variants of the organization. Variability of the supply chain organization facilitates selection of specific action to achieve assumed objective. Depending on the number of preferences included in the supply chain modeling, the partial values of performance indicators or the partial criterion functions of each of the organization variants, give the vector of useful values of realization of the objective of action. In this sense, a global assessment of efficiency of the functioning of  $ld$ -th supply chain can be written as a function of the form:

$$\xi(\tau, ld) = \Omega(\varphi_1(\tau, ld), \varphi_2(\tau, ld), \dots, \varphi_N(\tau, ld)) \quad (2.10)$$

where:

- $\xi(\tau, ld)$  - assessment of efficiency of the functioning of  $ld$ -th supply chain in implementing the tasks at time  $\tau$ ,
- $\varphi_n(\tau, ld)$  - assessment at time  $\tau$  of  $n$ -th indicator of efficiency of the functioning of  $ld$ -th supply chain, wherein  $n = 1, 2, \dots, N$ .

What is important, to compare the efficiency of the functioning of design solutions of variants of supply chain is necessary to define and determine the implementation effects of processes for each of the variants. This can also be a difference between the value of measures obtained for different variants and the basic variant. In this case, the efficiency can be determined as the quotient of difference of the values of measures for the designed variant of organization and the value of measure of variant set as basic, ie:

$$\Delta\Xi(\tau,ld) = \frac{\Xi\varphi_n(\tau,ld) - \Xi\varphi_b(\tau,ld)}{\Xi\varphi_b(\tau,ld)} \quad (2.11)$$

where:

- $\Delta\Xi(\tau,ld)$  – supply chain operation efficiency,
- $\Xi\varphi_n(\tau,ld)$  – value of  $n$ -th efficiency measure,
- $\Xi\varphi_b(\tau,ld)$  – value of basic efficiency measure.

Calculation of the value of efficiency  $\Delta\Xi(\tau,ld)$  allows to answer the question how much a percentage of the measure  $\Xi\varphi_n(\tau,ld)$  differs from the value of basic measure  $\Xi\varphi_b(\tau,ld)$ .

On the other hand, supply chain efficiency results from the efficiency of the single links in the chain, i.e.:

$$\forall ld \in LD \quad \Delta\Xi(\tau,ld) = \zeta(\Delta\Xi(1,\tau,ld), \dots, \Delta\Xi(v,\tau,ld), \dots, \Delta\Xi(V,\tau,ld)) \quad (-) \quad (2.12)$$

where:

- $\Delta\Xi(v,\tau,ld)$  – efficiency of operation of  $v$ -th link of the supply chain.

Efficiency measurement is carried out in different terms, depending on the scope of a system and the assessed area of activity. In this aspect we distinguish (Żak, 2013): organizational, economic and technical efficiency. Sometimes we speak also about the efficiency of quality.

Organizational efficiency concerns the assessment of the functioning of the system. In general, it defined as the adaptability of the system to changes in the environment and productive use of its resources to meet the set (Jacyna-Golda, 2014; Kowalska, 2011; Żak et al, 2014). In contrast, economic efficiency concerns rational management. In this case, as measures of assessment of treated relationship between increments effects and inputs, or a total partial expenditures for effects (Żak et al, 2014).

In the case of technical efficiency assessing the value of production using established spending on its lead. In this case, it must be remembered that the choice of technology is influenced by two aspects: to maximize output and minimize manufacturing costs. Efficiency is a qualitative measurement system more competitive in relation to other with similar or similar activity. Most often used as a measure of the percentage share of the market or

the utilization of the measure, resource etc. Hence indicators to assess the effectiveness of the supply chain can be a measure of evaluation:

- degree of utilization of the resource, which is the ratio of actual expenditure to norm or standard, related to expenditures. They depict resource consumption, i.e. cash, property, resources and reserves,
- level of productivity of a given element (cell), in the form of relation of a real effect to the actual expenditure, eg. mileage (spent fuel),
- degree of effectiveness inserted expenditures, which are the ratio of the actual effect of the effect in the form of norm or standard

Due to the complexity of the problem and large diversity of systems and how they work, measurement of efficiency depends not only on the field but also the assessment of the industry in which the system operates.

The authors of work (Żak et al, 2014) suggests three basic groups of measuring the efficiency, i.e.: indicators, Parametric and nonparametric. Wherein the ratio analysis comes down to constructing the relationship between various magnitudes and the choice of indicators depends on the purpose of research. Parametric Indicators are determined by the structure of the analyzed models. From the form of the structure depends an adequate number of estimated parameters. Nonparametric methods do not require knowledge of the functional relationship between expenditures and outcomes. They are characterized by greater flexibility, because the structure of models is not fixed, but is adjusted according to data.

### 3. Assessment measures of efficiency of functioning of the supply chain

#### 3.1. Logistics processes and decision-making problems in the supply chain

Efficiency measurement can have many uses. Among them can be distinguished for eg.: selection of means of transport to tasks, selection of applied technologies, increasing the efficiency of logistics processes, reducing the execution time of tasks, reducing costs, eg. reduction in fuel consumption, etc. Efficient use of resources of supply chain is associated with maximizing the workload while minimizing the cost of this work. Basically, efficient use of resources measures may be considered because of:

1. the involvement of means of transport, eg.:
  - the degree of effective work of the equipment, means of transport, etc.,
  - the degree of capacity utilization of means of transport in case of realization of freight in transport between the various links of the supply chain,
  - the share of given means of transport (device) in transport performance or labor consumption because of involved equipment, vehicles, etc.,
  - degree of utilization of internal transport equipment, eg. in the warehouse facilities,
  - unit cost of executed service,
  - annual exploitations costs.
  - others,
2. involvement of warehouse facilities, eg.:
  - the degree of filling storage areas,
  - daily working time of objects,
  - performance of reloading systems at the entrance compared to the performance of storage and processing material streams areas (zones),
  - the degree of used reloading capacities in relation to the theoretical reloading performance at the entrance and exit of the warehouse facility,
  - the transition cost of one unit of material through a warehouse facility
  - others,
3. organization of work in the supply chain, eg.:
  - average number of reloading operations per given unit load,
  - the ratio of shipment time to the waiting time for reloading operations, storage, etc. Given with regard to unit load,
  - unit lead time of logistic services divided into individual links of the supply chain,
 others.

### 3.2. Technical and economic indicators of efficiency assessment of supply chain functioning

Among the technical criteria for assessing efficiency of the functioning of the supply chain can be divided into criteria for assessing the degree of utilization of system resources for the implementation of logistics services, including transport services. As mentioned in paragraph 3.1 of one of the major problems in this respect is the proper use of the means of transport used for the implementation of the transport service.

Thus, from a technical and technological point of view should seek to maximize the capacity

utilization rates and capacity, or the course of the means of transport. As indicated in (Žak, 2013) for example in the assessment of the transport system applies to both indicators of capacity utilization, and capacity of vehicles and vehicle mileage utilization rates and the time ownership of the means of transport.

Analysis of the capacity utilization indicator of vehicles in the consider supply chain and vehicle capacity utilization indicator allows the assessment of adapting technical resources (in this case, means of transport) to the ongoing transport services. Both for logistic operators performing service and businesses have their own means of transport, it is important that these indicators take values as much as possible. Thus, maximizing both these indicators aim is to make the best fit parameters of means of transport to the task.

Assuming that is defined:

- set  $\mathbf{LD}$  of numbers of supply chains,  $\mathbf{LD} = \{ld: ld = 1, 2, \dots, \mathbf{LD}\}$ ,
- set  $\mathbf{ST}$  of numbers of types of vehicles,  $\mathbf{ST} = \{st: st = 1, 2, \dots, \mathbf{ST}\}$ ,
- set  $\mathbf{ST}(ld)$  of numbers of types of vehicles used in  $ld$ -th supply chain, in the form:  $\mathbf{ST}(ld) = \{st(ld): st(ld) = 1(ld), \dots, \mathbf{ST}(ld)\}$ . Function  $\alpha(st, ld)$  maps the possibility of using the means of transport of  $st$ -th type in the supply chain with the number  $ld$ .
- set  $\mathbf{V}$  of numbers of types of supply chain links ,  $\mathbf{V} = \{v: v = 1, 2, \dots, \mathbf{V}\}$
- set  $\mathbf{V}(ld)$  of numbers of types of links occurring in  $ld$ -th supply chain, in the form:  $\mathbf{V}(ld) = \{v: \beta(vt, ld)=1, ld \in \mathbf{LD}\}$ . Function  $\beta(v, ld)$  maps occurrence of  $v$ -th type of link in the supply chain with the number  $ld$ .
- $Q(st, ld)$  – the average capacity of vehicles  $st$ -th type used in  $ld$ -th supply chain in tonnes,
- $QP(st, ld)$  – the average capacity of vehicles  $st$ -th type used in  $ld$ -th supply chain in tonnes,  $m^3$ , pieces etc.,
- $LP(st, ld)$  – numbers of vehicles of  $st$ -th type used in  $ld$ -th supply chain in pieces,
- $DL(st, ld)$  – the average mileage of loaded vehicle of  $st$ -th type used in  $ld$ -th supply chain in km,

can be determined indicator  $\Xi\Theta(st, ld)$  of capacity utilization of vehicles and indicator  $\Xi\mathbf{P}(st, ld)$  of

capacity utilization of vehicles in  $ld$ -th supply chain, using the notation:

$$\forall ld \in \mathbf{LD} \quad \Xi\Theta(st, ld) = \frac{q(st, ld) \cdot DL(st, ld)}{\sum_{st \in \mathbf{ST}(ld)} Q(st, ld) \cdot LP(st, ld) \cdot DL(st, ld)} \quad (-) \quad (3.1)$$

$$\forall ld \in \mathbf{LD} \quad \Xi\mathbf{P}(st, ld) = \frac{q(st, ld) \cdot DL(st, ld)}{\sum_{st \in \mathbf{ST}(ld)} QP(st, ld) \cdot LP(st, ld) \cdot DL(st, ld)} \quad (-) \quad (3.2)$$

Other indicator important from the point of view of efficient use of vehicles is so called **the utilization indicator of vehicle mileage**:

$$\forall ld \in \mathbf{LD} \quad \delta(st, ld) = \frac{\sum_{st \in \mathbf{ST}(ld)} LP(st, ld) \cdot DL(st, ld)}{\sum_{st \in \mathbf{ST}(ld)} LP(st, ld) \cdot \sigma(st, ld)} \quad (-) \quad (3.3)$$

where:

- $\delta(st, ld)$  – utilization indicator of vehicle mileage of  $st$ -th mode of transport implementing tasks in the  $ld$ -th supply chain,
- $\sigma(st, ld)$  – the average loaded mileage of  $st$ -th vehicle used in  $ld$ -th supply chain in km.

Among the economic indicators can be identified indicators that are used to determine the value of carried transport work determining productivity of means of transport or the functioning of organization of a particular variant of the supply chain. To evaluate the efficiency can be used an indicator of unit cost of carried transport work. The value of this indicator can be determined from the relationship:

$$\forall ld \in \mathbf{LD} \quad \psi(ld) = \frac{\Xi K(ld)}{\sum_{st \in \mathbf{ST}} q(st, ld) \cdot DL(st, ld)} \quad (\text{PLN/tkm}) \quad (3.4)$$

$$\forall ld \in \mathbf{LD} \quad \zeta(ld) = \frac{\Xi K(ld)}{\sum_{st \in \mathbf{ST}} q(st, ld)} \quad (\text{PLN/tonne}) \quad (3.5)$$

where:

- $ld$  – variant of the supply chain organization,
- $st$  – type of mean of transport,

- $\psi(ld)$  – economic efficiency of performance of unit transport work using  $ld$ -th supply chain in PLN/tkm,
- $\zeta(ld)$  – economic efficiency of performance of unit carriage using  $ld$ -th supply chain in PLN/tonne,
- $q(st, ld)$  – the level of carriage performed by using  $ld$ -th supply chain in tonnes,
- $\Xi K(ld)$  – the cost of functioning of  $ld$ -th supply chain in PLN.

Of course, an effective supply chain is that provides the same or better results at lower or the same expenditures. Thus, the values of the indicators (3.1), (3.2.) and (3.3) should be maximized, while the values of the indicators (3.4) and (3.5) should be minimized.

#### 4. The rules for constructing the decision making model for the supply chain functioning assessment

In general, the goal of creating models is to understand the object, organize information about the object or look for opportunities to change the state of an object to achieve a specific desired state. For measurable objectives for creating models of supply chains may be included (Ambroziak and Lewczuk, 2009; Całczyński, 1992; Pfohl, 1998; Pyza, 2012):

- relationships and logical connections between the observed object properties and their effect on the observer - then we are talking about the so-called *explanatory models*;
- organization of information about an object without interference in the ownership of the object then we are talking about the so-called *verifying models*;
- determination of new facilities or to indicate changes in the existing facilities so as to meet the target contained in the analyzed issue - then we are talking about the so-called *decision models*

The process of constructing the decision model of the supply chain is a choice, acceptable, substitute (representative), including mathematical and logical relationships that will allow them to experiment with taking into account different boundary conditions. This means that the aim is to develop a model of decision-making for assessing efficiency of the functioning chain as a whole and its individual cell efficiency.



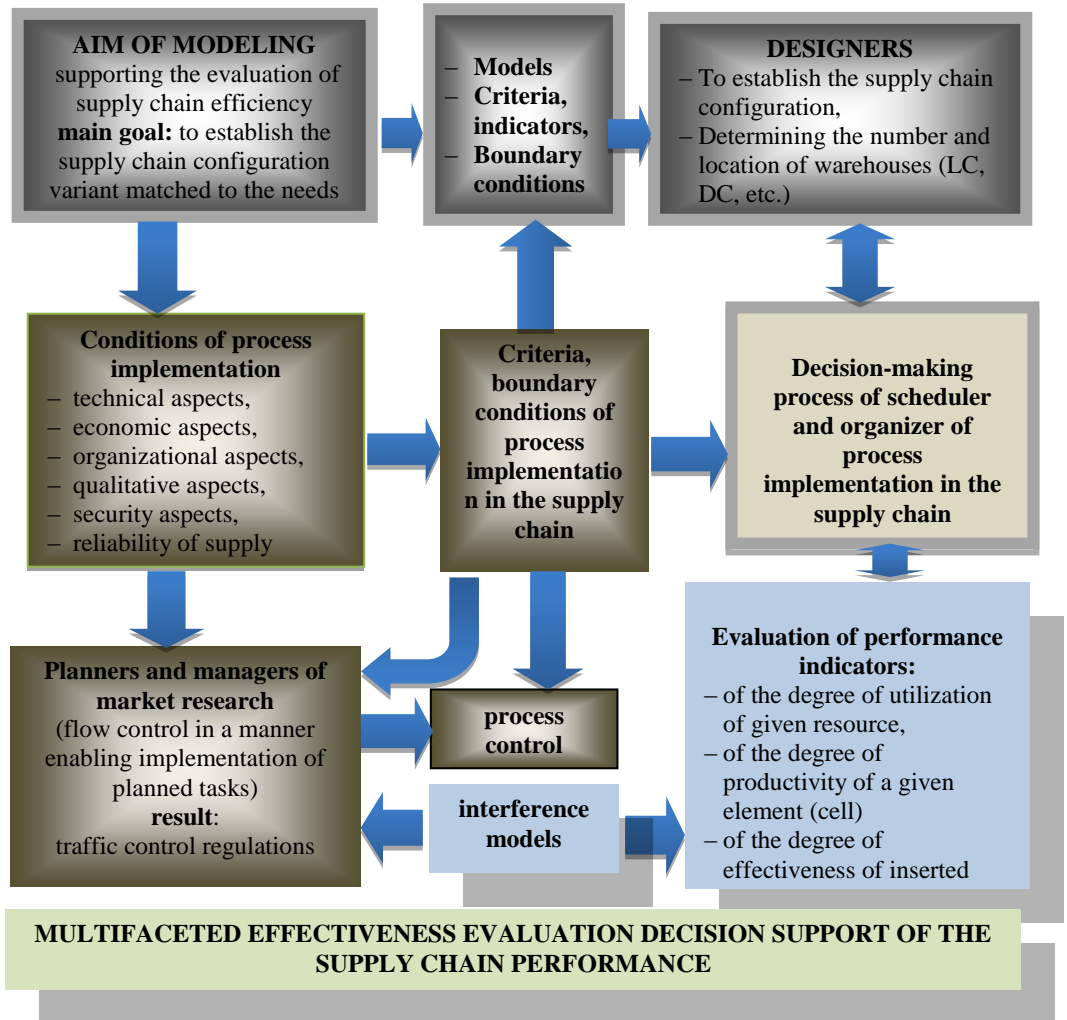


Fig. 3. Decision-making model of assessment of efficiency of functioning of the supply chain

This model will enable learning experimentation relationships between various factors. Fig. 3 shows a schematic construction conditions decision making model the assessment of efficiency of the functioning of the supply chain.

Of course, the purposes for which builds models of supply chains may be cognitive objectives, such as system identification (Ambroziak and Lewczuk, 2009; Całczyński, 1992; Jacyna-Golda, 2013; Pfohl, 1998; Pyza, 2012) to determine the relationship between quantities occurring in tested

system and determining the variation of these sizes, which may be the subject (aim) of the research.

The subject of research can also be utilitarian goals which boil down to:

- the search for optimal solutions, eg. the organization processes of supply or distribution processes,
- analysis and evaluation of the equipment variant of technical and organizational (potential) individual links in the supply chain

- selection of potential of the supply chain to the reported tasks (in supply and distribution sphere),
- planning changes to the configuration of the supply chain (search for locations for warehouse facilities, logistics centers, etc.),
- the process of scheduling processes in the implementation of the specific needs of customers with fixed resources and supply chain,
- controlling the processes in the supply chain for any given its initial state, defined entrances and accepted criteria for assessing the quality of the process.

The broad spectrum of problems that occur in modeling of supply chains means that constructing a decision model for the supply chain should be taken into account:

- compliance with the modeled supply chain, in the field of interested dependencies and ease of use - as intended,
- opportunity to evaluate the functioning of the supply chain depending on the service sector and service sphere - supply or distribution,
- the ability to analyze and evaluate controlling the process,
- study of relations of efficiency of logistics processes in individual cells from a wide range of factors.

Taking into account the above requirements should aim to choose the model of the supply chain decision was the result of a compromise intended conditioned model and the means at our disposal.

Assessment of efficiency of the functioning of the supply chain, as previously mentioned, belongs to the multi-faceted problems of decision-making based on multi-criteria optimization or multicriteria decision support. Multicriteria decision support, (Banomyong et al, 2015; Zeleny, 1982) aims to provide decision-makers the tools to solve complex decision problems, taking into account a number of usually opposing points of view. The assessment criteria supporting the work of the decision-maker to take optimal decision by Roy (1990a, 1990b) is a set, which should meet such requirements as:

- consideration of all possible aspects of the problem under consideration,
- consistency in evaluation, involving the proper configuration by each criterion global preferences of the decision maker,
- uniqueness range of criteria meaning

An important area of research the assessment of efficiency of the functioning of the supply chain is the analysis and evaluation of operating tangible goods (raw materials, components for production of finished products, etc.) in the point elements of the chain. Such of objects may include among others: warehouses, loading terminals of different modes of transport, seaports, airports, shopping centers and logistics centers in which there are three basic groups of processes: the entry, operation and exit of cargo stream. This enables the identification and selection of a suitable model for the processes listed in different groups.

## 5. Example of practical use of the decision making model to assess efficiency of selected links of the supply chain

### 5.1. Basic assumptions

The conducted numerical experiments evaluated four variants of the organization of freight distribution in the studied supply chain. It was assumed that for each of the variants of the characteristics of the supply chain and therefore its structure is constant. Is changed the method of obtaining initial solution, which then in the subsequent iterations is improved.

As a result, values were obtained characterizing the supply chain of analyzed distribution system. On this basis, was determined in terms of variant among others: number of deliveries, order processing time, mileage of routes, characteristics of the routes. For means of transport engaged to perform carriage tasks were calculated indicators: use of working time, payload and offered volume. In addition, costs were determined for each of the variants of distribution under consideration.

To the assessment of efficiency of the functioning was used MoDSuEFFECT package that was developed for decision support in the evaluation of efficiency of the functioning of supply chains. Diagram of the application is shown in Fig. 4.

The object of the research is supply chain company that manufactures and distributes cosmetics industry. The delivery is done using direct delivery, ie. direct deliveries to customers from warehouses near the factory. The study involved the efficiency of the supply chain after making changes to its configuration. For the analysis, the application MoDSuEFFECT was used.

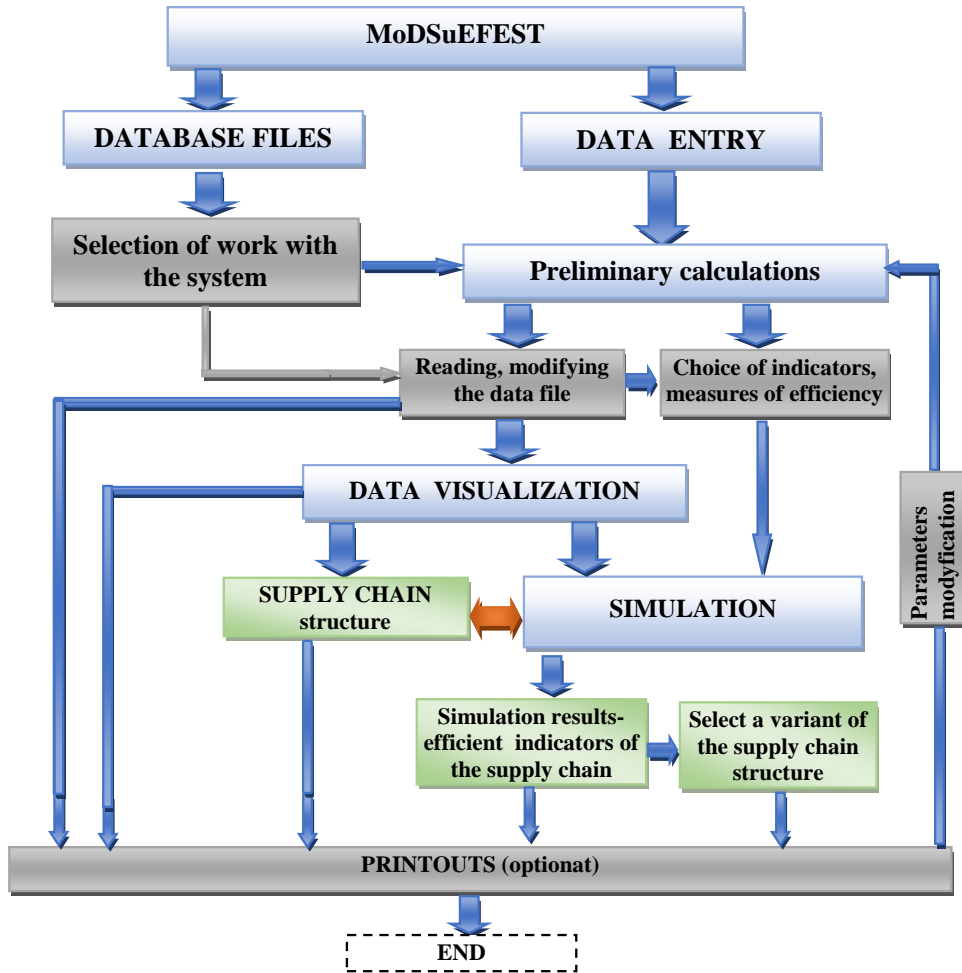


Fig. 4. Diagram of application MoDSuEFEST performance

## 5.2. Evaluation of efficiency of variants of the supply chain organization

Taking into account the specificity of cargo and the data obtained from the company assumes that the loading times means of transport in distribution warehouse and unloading at the customer and the service of documents are: for loading - 70 minutes, for unloading - 65.0 min. Recipients are served in hours 6.00 ÷ 22.00. Warehouse near the factory operates 24 hours a day.

Cost and performance parameters of the supply chain are summarized in Table 1.

Table 2 shows the percentage effect of the supply chain for the first, second and third variant relative to the basic variant.

For such data listed in Figure 5 were presented a comparison of these efficiency indicators of analyzed supply chain in terms of variant.

Table 1. Cost and performance parameters of the supply chain – present state

No.	Indicator	Unit of measure	Value Variant 0	Value Variant 1	Value Variant 2	Value Variant 3
1	Cargo capacity utilization indicator for transport on a monthly basis	%	40	45	54	52
2	Capacity utilization indicator for transport on a monthly basis	%	57	56	76	69
3	The number of kilometers that must be overcome in order to perform the contract in a month	km/month	11 440	11 440	11 440	11 440
4	Working time of means for one cycle ordering	h	59,20	58,01	54,30	53,50
5	Use of working time of means of transport for one month	%	68,8	72,2	82,6	79,4
6	The technical performance of means of transport in one cycle	tkm/h	1230	1320	1456	1421
7	Transport costs for one month	PLN	37764,08	33764,08	29700,95	27505,16
8	Transport costs on an annual basis	PLN	453169	405169	356411,4	330061,9
9	The norm of the vehicle combustion	EURO	III	III	V	VI
10	Unit costs of execution of carriage work	PLN/tkm	0,301	0,28	0,22	0,24
11	The utilization of mileage indicator	-	0,5	0,53	0,6	0,62
12	Time indicator of the vehicle involvement	-	0,578	0,678	0,795	0,894

Table 2 Evaluation of efficiency of variants of the supply chain organization

No.	Indicator	Value Variant 1	Value Variant 2	Value Variant 3
1	Cargo capacity utilization indicator for transport on a monthly basis – $\phi_1$	12,50%	35,00%	30,00%
2	Capacity utilization indicator for transport on a monthly basis – $\phi_2$	-1,75%	33,33%	21,05%
3	The number of kilometers that must be overcome in order to perform the contract in a month – $\phi_3$	0,00%	0,00%	0,00%
4	Working time of means for one cycle ordering – $\phi_4$	-2,01%	-8,28%	-9,63%
5	Use of working time of means of transport for one month – $\phi_5$	4,94%	20,06%	15,41%
6	The technical performance of means of transport in one cycle – $\phi_6$	7,32%	18,37%	15,53%
7	Transport costs for one month – $\phi_7$	-10,59%	-21,35%	-27,17%
8	Transport costs on an annual basis – $\phi_8$	-10,59%	-21,35%	-27,17%
9	The norm of the vehicle combustion – $\phi_9$	0,56	0,23	0,13
10	Unit costs of execution of carriage work – $\phi_{10}$	-19,62%	-17,80%	-25,70%
11	The utilization of mileage indicator – $\phi_{11}$	6,00%	20,00%	24,00%
12	Time indicator of the vehicle involvement – $\phi_{12}$	17,30%	37,54%	54,67%

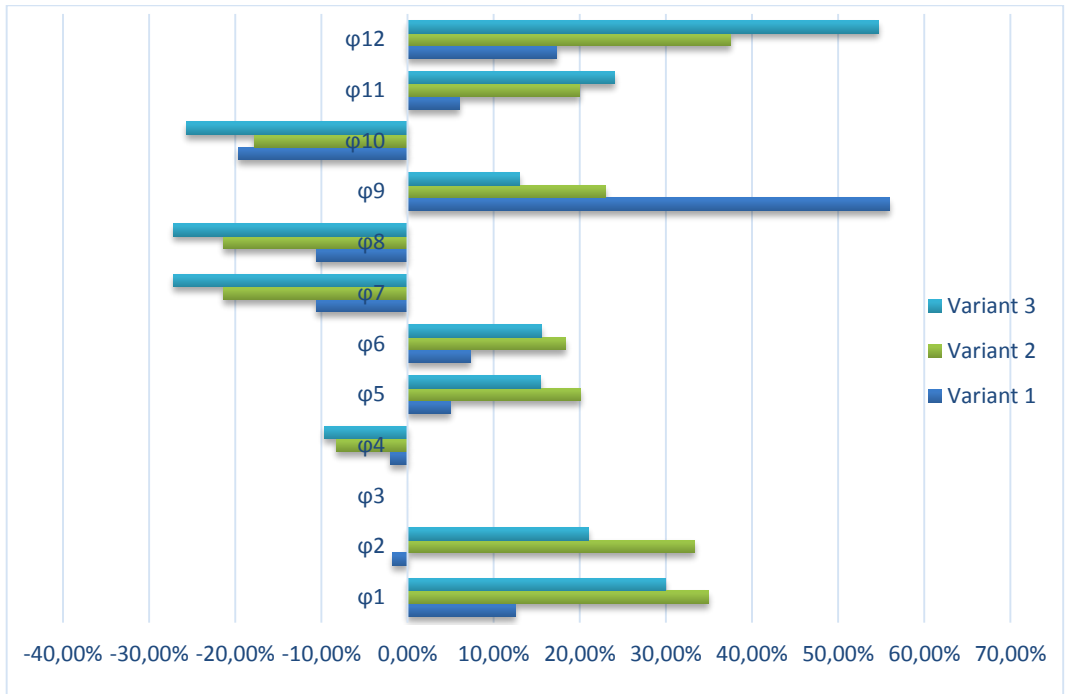


Fig. 5. Efficiency indicators of the supply chain functioning in terms of variant

## 6. Summary

The efficiency of the supply chain is a cumulative characteristics of quality throughout their supply chains, which can be expressed by means of specific characteristics. It determines the effectiveness of expenses to useful effects, eg. to reduce the waste of time of the process of logistics in the supply chain. Thus, it expresses first of all assess its functioning, suggesting that it is a measure of the effectiveness of specific actions and defines how effective and efficiency resources are used for the implementation of the objective of the supply chain. What is important is determined by the effectiveness of each link in the supply chain.

The efficiency of the supply chain, as well as the efficiency of each system, due on the one hand the efficiency of its operation, ie. the degree of achievement of the objectives, on the other hand possessed with the ability to use system components to achieve the objectives. Defining for example indicators to measure efficiency of the functioning the assessment of warehouse facilities in the supply chain, it is necessary to identify the

technical and organizational and economic developments and the related resources, determining the design of such facilities, including technical resources. Efficient use of resources inventory of infrastructure of objects as well as the entire supply chain resources associated with maximizing workload while minimizing the cost of the work.

From the point of view of performed tasks and functions, every link in of the supply chain significantly affects the effectiveness of the entire supply chain. This is due to the need to determine the best way to move goods from suppliers to customers through the selection structure supply system in such a way as to satisfy the demands of customers and minimize the cost of supplies. The main measure of efficiency is the unit cost of one unit of cargo pass through the entire chain.

Indicators to assess efficiency of the functioning chain can be a feature of the system, measurable and useful when comparing of supply chains of the class, expressing different aspects of in the different compartments depending on their purpose

and conditions of use. The supply chain will be effective when provided with implementation of the identified tasks at the required level of quality with the rational use of equipment throughout the chain. Therefore, supply chain efficiency analysis should be based on her graduation from global ratings for partial marks on overall resource efficiency and cost of the test chain execution tasks.

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