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TWO-STAGE MODEL FOR THE EVALUATION SUPPLIERS IN DIFFERENT TYPES OF SUPPLY CHAINS

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Abstract: *Purpose – The purpose of this paper is to, based on the model developed to improve supplier performance and models for supplier evaluation and ranking in different types of supply chains, contribute to the expansion of existing conceptual frameworks for measuring supplier performance, indicating that some key performance indicators used to evaluate and rank suppliers have a different relative importance in different types of supply chains.*
Design/methodology/approach – The research includes evaluation, ranking, and comparison of six suppliers belonging to an efficient type of supply chain and an agile type of supply chain. For the evaluation and ranking of suppliers by types of supply chains, the analytic hierarchy process (AHP) and the data envelopment analysis (DEA) are combined.
Novelty – Research in this field has dealt with supplier evaluation and ranking without taking into account the characteristics of different types of supply chains. The contribution of this paper lies in the development of a new model for supplier evaluation and ranking, taking into account the priorities of key performance indicators in different types of supply chains, providing management support in decision-making through simulation and finding the optimal solution for a particular supply chain.
Practical implications – Developed and proposed models provide company management with the opportunity to apply a multiple-criteria decision-making model as a support in evaluating and ranking suppliers in different types of e-supply chains.

Keywords: *Supply Chain Management, Key Performance Indicator, Key Performance measurement, Analytic Hierarchy Process, Data Envelopment Analysis*

1. Introductory remarks

All supply chain members, both upstream and downstream, influence the supply chain performance (in terms of quality, delivery, price, flexibility). The need to identify the adequate type of supply chain performance measures is vital, as they will influence decision making. Several studies emphasize the need for the appropriate type of performance measures in supply chains (Gimenez & Tachizawa, 2012; Bai et al., 2012; Bai & Sarkis, 2012; Genovese et al., 2013; Koh et al., 2007; Cabral et al., 2012; Saad & Patel, 2006; Vereecke & Muylle, 2006; Tadic et al., 2014; Gunasekaran et al.,

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2004; Aitken et al., 2003; Petroni & Panciroli, 2002; Lai et al., 2001; Lambert & Pohlen, 2001; Christopher & Towill, 2001; Gunasekaran et al., 2001; Landeghem van & Persoons, 2001; Holmberg, 2000). These studies have attempted to describe different performance measures used by various organizations. However, most researchers focus on a single organization within a supply chain, which implies that research results do not directly pertain to supply chain performance (Koh et al., 2007). Chibba (2007) presents a framework that indicates which performance measures should be given priority, depending on the type of supply chain. The paper mainly focuses on large production organizations, especially supply chain finalists. The framework includes three parts:

- Types of supply chain (efficient, fast, market-responsive, agile, lean, and hybrid);
- Types of supply chain performance measures (quality, delivery, costs, and flexibility);
- Supply chain measurement areas (functional supply chain, internally integrated supply chain, unilaterally integrated supply chain, and total supply chain).

There are several types of supply chains described in literature. The author considers:

- Efficient supply chain,
- Fast supply chain,
- Agile supply chain,
- Market-responsive supply chain,
- Lean supply chain and
- Hybrid supply chain.

Fisher (1997) develops a model that can be considered as a good way to choose the right type of supply chain. An efficient supply chain is suitable for functional products, while a market-responsive supply chain is suitable for innovative products.

Petroni and Panciroli (2002) argue that buyers usually choose suppliers who achieve the highest overall performance of price, quality, production flexibility, and delivery time. De Toni et al. (1994) claim that an efficient supply chain depends on achieving a high level of performance in terms of costs, quality, and lead time. Hayes and Wheelwright (1984) were the first to introduce methods for realizing an operational strategy using the four dimensions that an organization chooses to compete within the target market, such as quality, price, flexibility, and delivery. Their original formulation was applicable to all functions. Hill (2000) considers price, cost reduction, delivery reliability, delivery speed, quality, flexibility, etc. as priorities for achieving competitive advantage.

Lambert and Pohlen (2001) argue that a well-designed measurement system in a supply chain can lead to competitive advantage through service differentiation and lower costs. They also believe that the implementation of the supply chain strategy requires a metric that aligns performance with the objectives of other supply chain members. Supply chain performance can be seen as a system of measures, such as quality, delivery, flexibility, and costs/price. Traditional performance measures, such as profitability, are less relevant to measuring supply chain performance.

Establishing a measurement system requires knowledge of processes in the organization and those occurring between buyers and suppliers. In order to generate this knowledge, an organization must decide which performance measures it will use. According to Robson (2004) “without the knowledge of the exact circumstances under which a measurement system either will or will not improve the performance, it is difficult to genuinely justify the additional costs of implementing a measurement system”. Pagell and Krausse (2002) present a performance table for evaluating the organizational strategy. Their basic idea is to describe a priority, such as quality (reliability, durability, conformance), delivery (speed, reliability), flexibility (volume, mix), price (price, total price), and innovation (process, product). Also, the focus is on production and procurement of products. For example, quality (reliability) in production is defined as the ability to maximize the product use time to failure, while in procurement it implies the supplier's ability to provide reliable inputs. Lambert and Pohlen (2001) argue that most performance measures, known as supply chain metrics, are nothing more than logistics measures with an internal focus, and that they do not actually reveal how the organization derives value and profitability from the supply chain.

The supply chain performance metrics system consists of a set of parameters that can fully describe logistics and production performance of the entire supply chain, both from the perspective of end customers and any other member in the supply chain. However, there are several performance measures and metrics in the supply chain that can be evaluated. The most commonly used in practice, but also the most cited in studies, are the following measure attributes: quality, delivery, costs/price, and flexibility.

Hill (2000) indicates that the definition of the quality concept is expanded to include more dimensions. One of the reasons why organizations are not competing in the quality domain is due to the failure to clarify which quality dimension will provide the best results on given markets. One of the often quoted researchers who presented different dimensions of quality is Garwin (1988).

The listed quality dimensions are the general dimensions that can be applied to all types of products and services on all types of markets. These quality dimensions are well known and often cited. However, the term product quality, which is not mentioned above, can be described on the basis of how the buyer sees the product. The product quality focuses on the user of the product (or service, quality of service), i.e. the buyer in the supply chain. Quality as a measure of performance in the supply chain has several submeasures, such as quality conformity, quality reliability, and quality of the final product. In literature, quality and delivery are described as important measures for tracking the supply chain (Christopher & Towill, 2001; Aitken et al., 2003).

Several delivery-related performance submeasures are delivery time, delivery reliability, delivery frequency, delivery synchronization, delivery speed, etc. Delivery reliability relates to the delivery of ordered products on the agreed date. Therefore, production and distribution functions should take into account the on-time delivery (OTD). Hill (2000) argues that in many organizations this criterion is very important and highly used. The study of the Indian automobile industry (Saad & Patel, 2006) has shown that key factors for choosing a supplier are delivery time, order rejection rates, geographical proximity, and reliability. Hill (2000) claims that the organization wins an order through its ability to deliver faster than its competitors, or to fulfill the required date of delivery. The most frequently used delivery submeasures are delivery from suppliers, delivery within one's own organization, or delivery to buyers.

Reducing costs in the supply chain is vital to improving productivity. Hill (2000) argues that organizations generally do not concentrate their efforts in the area of high costs. Instead, they tend to reduce direct work costs. Gadde and Håkansson (2001) provide examples of indirect procurement costs. These costs can be defined as: procurement costs, product handling costs, storage costs, financial expenditures, costs related to dealing with suppliers, administrative costs, and development costs. Hill (2000) argues that the price is an increasingly important criterion when choosing an order, especially in stages of growth, maturity, and saturation of the product life cycle. This measure is also associated with suppliers, in terms of product procurement, but also with the cost of the organization's workforce.

Flexibility can be defined as “a measure in which an organization adjusts to market changes” (Beamon, 1999; Hill, 2000). This performance measure involves increasing the volume of demand, assortment (product mix), order timing, order size, etc. (Hill, 2000). Slack (1991) identifies four types of system flexibility, where each type of flexibility can be measured in terms of range and response: range flexibility (ability to change the range of products to be produced), response flexibility (ability to respond to changes in planned delivery deadlines), production mix flexibility (the ability to change the product range), and new product flexibility (the ability to introduce and produce new products).

Given that there are different types of supply chains, and that supply chains have different characteristics, each of them requires attention, in order to achieve optimum supply chain performance (Saad & Patel, 2006; Christopher et al., 2006; Mason & Cole, 2002; Christopher & Towill, 2000). Certain performance measures in the supply chain will be a priority depending on the type of supply chain. For an efficient supply chain, primary performance measures are costs, such as, for example, the total costs from the supplier through the internal supply chain to the buyer, or all types of costs that affect the cost of production. The metric can be expressed as a ratio of costs and products purchased. Fast, agile, or market-responsive supply chain (which have similar characteristics) have a shorter lead time, so the primary measure is delivery, but also flexibility (mix) of production and product quality. Shorter lead time from order to delivery is another important measure for lean supply chain. The hybrid supply chain focuses on time shortening, but without creating additional costs, in order to adapt to customer demands, so that primary performance measures are delivery, flexibility, and quality.

In this way, the relationship between the priorities of different types of supply chain performance measures and a certain supply chain type is established, which provides the basis for the development of the supplier evaluation and ranking model.

2. A model for improving supplier performance in different types of supply chains

The authors develop the model and test it in member organizations of automotive industry supply chains. The model covers the organization-supplier-buyer sequence, which is repeated throughout the supply chain, as each organization in the chain has its suppliers and its buyers. Given this fact, the model developed becomes applicable to each member of the supply chain. Target values and requirements in the supply chain are set by OEM and these requirements are transmitted along the entire supply chain. This obliges each organization in the supply chain to demand from its suppliers the same or to impose more stringent requirements and thus meet buyers’ requirements, and, therefore, the OEM requirements. In this way, each organization, while trying to achieve the goals set, continuously improves business processes and makes the entire supply chain have better performance.

The developed model for improving supplier performance in e-supply chain relies on four types of supply chains:

- Efficient supply chain,
- Lean supply chain,
- Agile supply chain and
- Hybrid supply chain.

and four performance measures attributes:

- quality,
- flexibility,
- cost and
- delivery.

For supplier performance measurement in automotive industry the following KPI were selected on operative, tactical and strategic level:

- on time delivery (SOTD),
- discrepant material report (SDMR)
- parts per million (SPPM)
- cost of poor quality (SCPQ)

- cost of inbound transport SCIT (inbound transport costs - regular – SITCR and inbound transport costs - extraordinary – SITCE).

The priority of the stated measure attributes is different depending on which type of supply chain they belong to. To measure the performance of an efficient supply chain, the first priority is attributed to costs, i.e. cost of transport. For an agile supply chain, priority is assigned to the delivery attribute; for the lean supply chain, priority is given to the quality and cost attributes, while for the hybrid supply chain priority is assigned to the attributes of quality and delivery.

In the quality attribute evaluation, PPM and DMR are monitored, in evaluating flexibility PPM, DMR, transport costs, poor quality costs, in evaluating costs, transport costs and poor quality costs, and OTD is monitored in the evaluation of the delivery attribute.

Figure 1 shows a model for improving supplier performance depending on the type of supply chain with the corresponding measure attribute priorities and defined key performance indicators.

For supplier evaluation by types of supply chains, the Analytic Hierarchy Process (AHP), as a method for supporting multi-criteria decision-making, and Data Envelopment Analysis (DEA) are combined and integrated. Steps and procedures of an integrated two-stage multi-criteria model for decision support in supplier evaluation and ranking in different types of e-supply chains are presented in Figure 2.

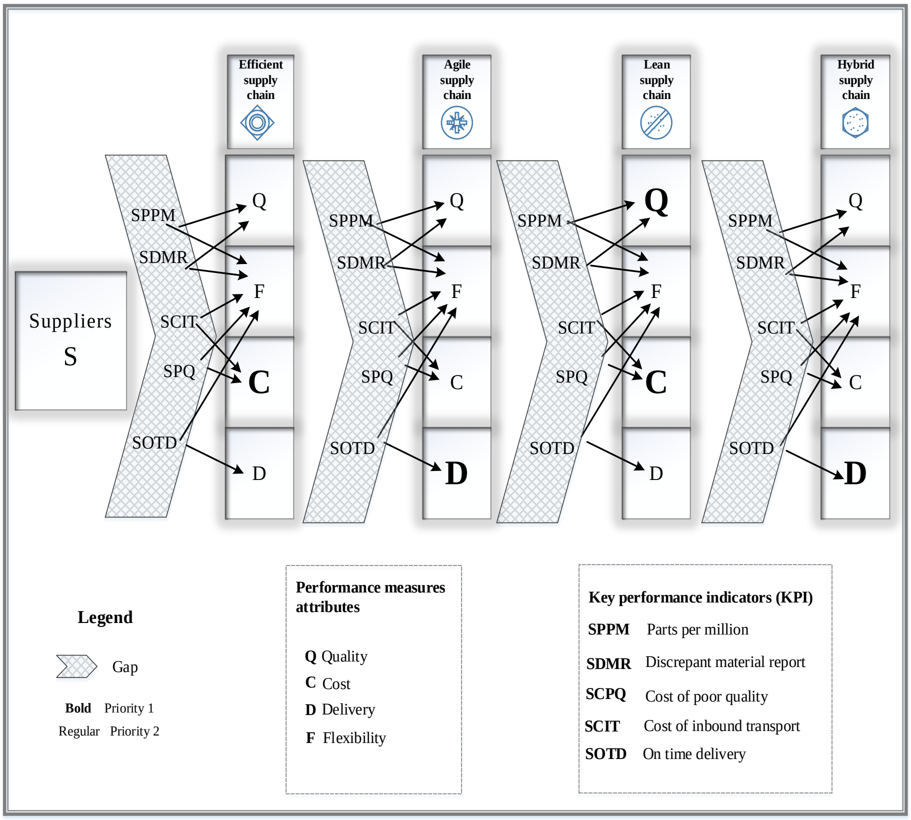

Figure 1. A model for improving supplier performance in different types of e-supply chain
Source:Authors

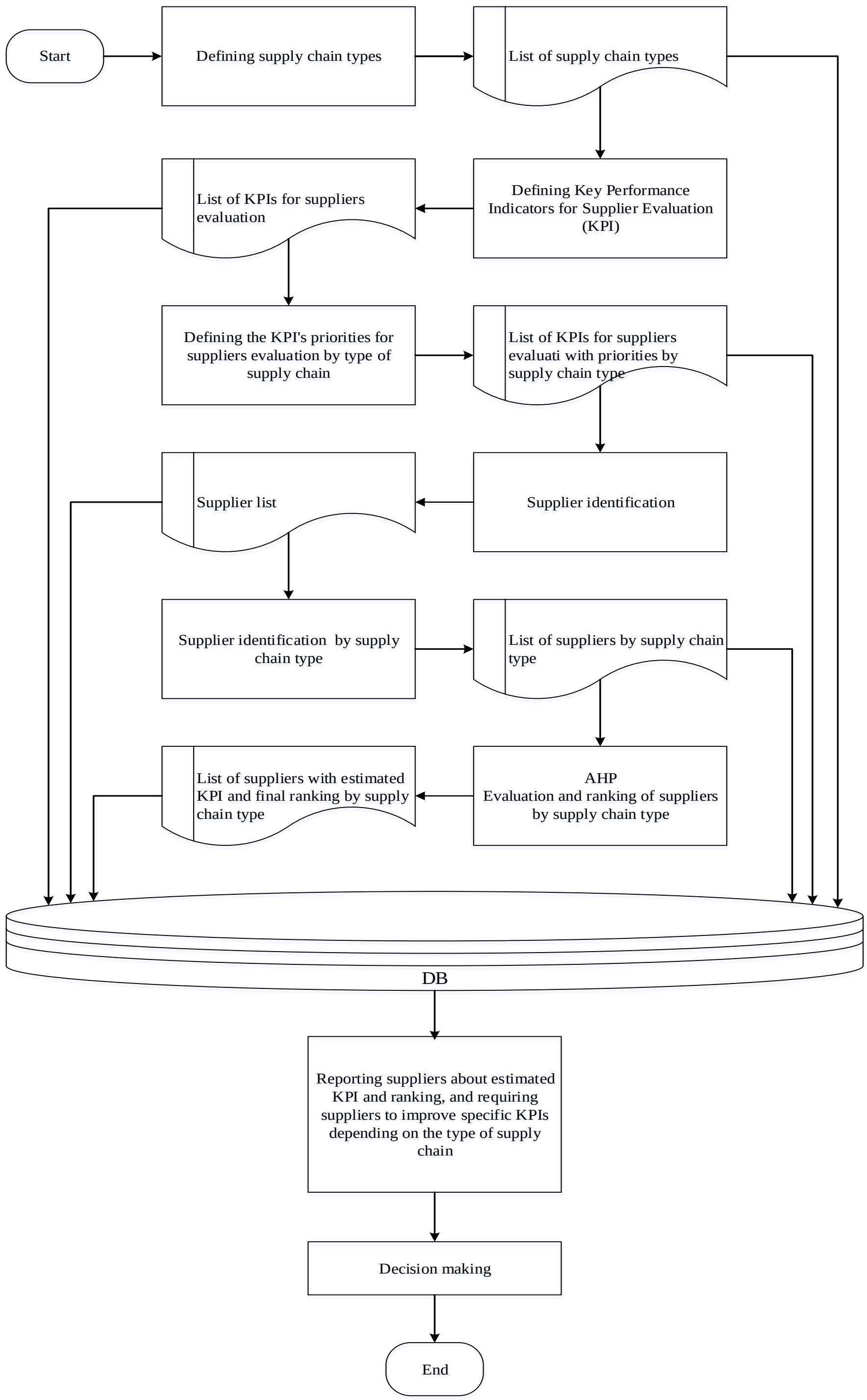

Figure 2. Steps and procedures of a multi-criteria model to support decision-making in evaluating and ranking suppliers in different types of e-supply chains
Source: Authors

3. Model for evaluation and ranking of suppliers depending on the type of supply chain

3.1. Methodology

Analytic Hierarchy Process (AHP, Saaty, 1980) is an intuitive method for formulating and analyzing decisions, based on hierarchical problem structuring and making pairwise comparison, based on a 1-9 comparison scale (Table 1, Saaty & Kearns, 1985). As a method that can be successfully used to measure the relative impact of a number of relevant factors on possible outcomes, as well as for prediction, i.e. distribution of relative probability of outcomes, it has been used in solving a number of complex decision-making problems. A good overview of AHP application was given by Vaidya & Kumar (2006), Ishizaka & Labib (2011), Deng et al. (2014) and Dweiri et al. (2016).

Table 1. The scale of relative significance 1-9 (Saaty & Kearns, 1985)

Intensity of relative importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Moderate importance of one relative to the other	Experience and assessment slightly favor one activity over another
5	Essential or strong importance	Experience and assessment strongly favor one activity over another
7	Demonstrated importance	One activity is strongly favored, and its dominance is demonstrated in practice
9	Extreme importance	Evidence favoring one activity over the other is of the highest possible order of affirmation
2, 4, 6, 8	Mean values of two adjacent assessments	When compromise is necessary
Reciprocity of the above non-zero numbers		If an activity has one of the above numbers (e.g. 3), compared to other activity, then the second activity has the reciprocal value (i.e. 1/3), when compared with the other

Data Envelopment Analysis (DEA, Charnes et al, 1978; Cook et al, 2001), is a mathematical, non-parametric approach for calculating efficiency, based on linear programming, which does not require a specific functional form. It is used to measure performance of decision-making units (DMU), by reducing multiple inputs to a single "virtual" input, and multiple outputs to a single "virtual" output, using weight coefficients, whereby for each organizational unit the corresponding linear programming model is formed and solved. DEA method has proven to be successful, especially when evaluating performance of non-profit organizations that operate outside the market, because, in their case, financial performance indicators, such as revenue and profit, do not measure efficiency in a satisfactory manner. All data on inputs and outputs for each decision-making unit is entered into a certain linear program, which is actually one of the DEA models. In this way, performance of the observed decision-making units is evaluated, which is the ratio of weighted output sum and weighted input sum. DEA points to relative efficiency, because decision-making units are observed and measured in relation to others. Efficiency ranges from 0 to 1, and any deviation from 1 is attributed to excess inputs or lack of outputs.

CCR DEA model, is formulated in the form of the following the following fractional programming problem:

$$E_{j0} = \frac{\sum_{r=1}^{s} u_{rj0} y_{rj0}}{\sum_{i=1}^{m} v_{ij0} x_{ij0}}, \quad (1)$$

subject to: $E_{j0} \leq 1,\ j = 1,2,,,n$

$u_{rj0}, v_{ij0} > 0,\ r = 1, 2, \ldots, s$

$i = 1, 2, \ldots, m$

$j = 1, 2, \ldots, n$

where:

y_{rj} – Output value

x_{ij} – Input value

u_{rj} - Weight coefficient of output y_{rj}

v_{ij} - Weight coefficient of input x_{ij}

$r = 1, 2, \ldots, s$ - Number of recorded products

$i = 1, 2, \ldots, m$ - Number of used resources

$j = 1, 2, \ldots, n$ – Number of DMU

Ramanathan (2006), proposes a hybrid DEAHP method as a way to overcome the shortcomings of partial application of DEA and AHP methods. In DEAHP problem model, DEA method is used for obtaining local decision-making priorities from the comparison matrix in respect of the observed elements in AHP model. Tables 2 and 3 show typical AHP method and DEAHP method comparison matrices, respectively. As Ramanathan suggests, elements a_{ij}, $a_{ij}>0$, $a_{ij}=1/a_{ji}$, $a_{ii}=1$ for each i in AHP comparison matrix become elements of DEAHP comparison matrix, adjusted to DEA method, in order to calculate local priorities. Each matrix row is viewed as a typical DMU, and each column as an output. In addition, matrix contains column with the so-called *dummy*, i.e. fictitious input, which takes a value of 1 for each DMU, to implement DEA method (Tables 4 and 5).

Table 2. Traditional AHP pairwise comparison matrix

	Element 1	Element 2	….	Element *n*
Element 1	1	a_{12}	…	a_{1N}
Element 2	1/ a_{12}	1		a_{2N}
….	…	…	….	…
Element *N*	1/ a_{1N}	1/ a_{2N}	…	1

Table 3. DEAHP pairwise comparison matrix and assessment of their effectiveness

	Output 1	Output 2	…	Output *n*	Fictitious input
DMU_1	1	a_{12}	…	a_{1N}	1
DMU_2	1/ a_{12}	1	…	a_{2N}	1
…	…	…	…	…	…
DMU N	1/ a_{1N}	1/ a_{2N}	…	1	1

Ramanathan proves that DEA method application with AHP comparison matrices provides objectified values of decision-making priority elements, thus reducing subjectivity of assessment using AHP method, and eliminating rank inversion, which occurs by adding or excluding an irrelevant alternative, which is a characteristic problem when applying AHP. The calculated DEA efficiencies can be interpreted as local priorities of decision-making units. Finally, DEA is used for aggregation of finite decision-making priority elements. When DEA approach is used in this sense, alternatives are seen as decision-making units, DMU, and their local priorities, calculated in relation to each criterion, as outputs, using dummy inputs column. On the other hand, unlike classic DEA approach, which measures relative efficiency only, DEAHP method, which implicitly includes the ability of AHP to include both quantitative and qualitative decision-making factors, results in more complete performance assessment of the observed decision-making units.

Table 4. AHP comparison matrix of alternatives and criteria

	Criterion 1	Criterion 2	….	Criterion *J*
Alternative 1	y_{11}	y_{12}	...	y_{1J}
Alternative 2	Y_{21}	Y_{22}		y_{2J}
….	...	...	....	...
Alternative *N*	Y_{N1}	Y_{N2}	...	y_{NJ}

Table 5. DEA(AHP) approach to evaluating the efficiency of alternatives in relation to the defined criteria

	Criterion 1	Criterion 2	….	Criterion *J*	Fictitious input
DMU 1	y_{11}	y_{12}	...	y_{1J}	1
DMU 2	Y_{21}	Y_{22}		y_{2J}	1
….	...	...	....	...	1
DMU *N*	Y_{N1}	Y_{N2}	...	y_{NJ}	1

3.2. Description of the problem and the formation of the AHP model

Defining the model objective is one of the most important steps in a decision-making problem. Decision-making is a process that completely depends on a person, and because of the expressed subjectivity element, the defined objective determines the way of solving the problem, as well as the selection of the criteria for evaluating alternatives. The same decision-maker, in unchanged conditions, can behave differently depending on what objective they want to achieve by analysis. The objective of this model is to evaluate and rank suppliers, depending on which type of supply chain they belong to.

With reference to the given theoretical assumptions, problem description, and the research purpose, and taking into account the circumstances, the corresponding AHP model is formed for the needs of evaluating supply chain performance, with four corresponding decision-making levels:

- Goal level – evaluation of suppliers by type of supply chain,
- Criteria level K1 (delivery efficiency), K2 (transport costs),
- Subcriteria level – a set of subcriteria based on common characteristics (on-time delivery (SOTD), discrepant material report (SDMR), parts per million (SPPM), cost of poor quality (SCPQ), inbound transport costs - regular – SITCR, and inbound transport costs - extraordinary – SITCE)
- Alternative level – a set of alternatives (S1, S2, S3, S4, S5, S6).

Each criterion is more explicitly explained through its subcriteria, which results in a more detailed and more realistic analysis level. Within each criterion, subcriteria are mutually compared in relation to the criteria they describe, also according to a 1-9 scale. At the same time, it means that alternatives are mutually compared in relation to each subcriterion, which allows the ranking of alternatives in accordance with the preferences of the decision-makers or the management that performs the evaluation. The hierarchical structure of the AHP model for supplier evaluation, ranking, and comparison is shown in Figure 3, while the target and realized values of key performance indicators for an efficient and agile supply chain are given in Table 6.

Table 6. Target and realized values of key performance indicators of observed suppliers in an efficient and agile supply chain (Autors)

KPIs	Target values of KPIs	S1 – Realized values of KPIs Efficient and agile supply chain	S2 - Realized values of KPIs Efficient and agile supply chain	S3 - Realized values of KPIs Efficient and agile supply chain	S4 - Realized values of KPIs Agile supply chain	S5 - Realized values of KPIs Agile supply chain	S6 - Realized values of KPIs Agile supply chain
SOTD	100.00%	99.00%	97.00%	99.20%	99.00%	98.90%	100.00%
SDMR	0 ppm	400.00	500.00	480.00	330.00	290.00	500.00
SPPM	0 ppm	150	160	155	150	140	40
SCPQ	0.00%	1.20%	1.10%	1.30%	0.80%	0.20%	0.05%
SITCR	1.00%	1.20%	1.20%	1.10%	1.20%	1.00%	1.00%
SITCE	0.00%	0.20%	0.25%	0.20%	0.20%	0.30%	0.15%

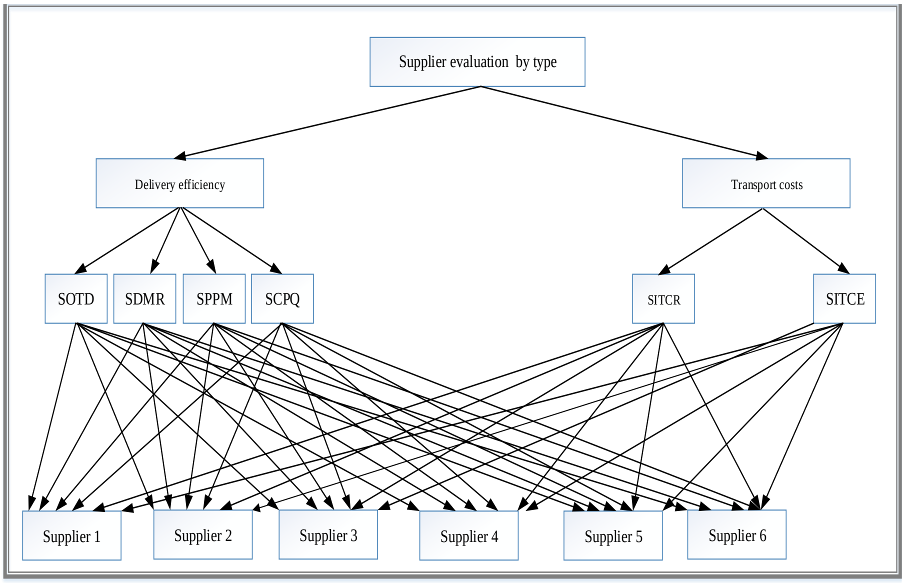

Figure 3. AHP supplier evaluation model, depending on the type of supply chain
Source: Authors

The research consists of evaluation, ranking, and comparison of six suppliers belonging to an efficient type of supply chain, as well as evaluation, ranking, and comparison of six suppliers belonging to an agile type of supply chain. Key performance indicators on the basis of which suppliers are rated, which determine their ranking in supply chains, are shown in Table 7.

Table 7. Key performance indicators that determine the rank of suppliers (Autors)

Name	KPI	Unit of measure	Target value
On time delivery	SOTD	%	100%
Discrepant material report	SDMR	ppm	0 ppm
Parts per million	SPPM	ppm	0 ppm
Cost of poor quality	SCPQ	% sales	0%
Inbound transport costs - regular	SITCR	% net sales	3,50%
Inbound transport costs - extraordinary	SITCE	% net sales	0%

3.3. Results of the model and their interpretation

By pairwise comparison of decision-making elements in accordance with the assumed dependences and data in Table 5, according to the usual 1-9 scale and with the help of the *SuperDecisions* software package, the priority is determined within the problem observed by the characteristic value method, and the criterion weight coefficients obtained, depending on the type of supply chain, which enable the ranking of the observed decision-making elements according to the preferences of the decision-maker who made the evaluation. In the case of multiple decision-makers, managers, experts, or stakeholders present in the evaluation and comparison process, it is possible to use the geometric mean as a way to combine and objectify evaluation (Saaty & Peniwati, 2008):

$$w_i = \sqrt[K]{\pi_{k=1}^{k=K} w_{ik}} \quad \forall \ i \qquad (2)$$

where w_i, is the final weight of the i-th element of the decision-making problem, and w_{ik} its relative weight, calculated on the basis of evaluation of the k-th decision maker.

By comparing the identified subcriteria, i.e. performance indicators, relative to the delivery efficiency and transport costs criteria, relative weights depending on the supply chain type are obtained and shown in Tables 8 and 9. In the efficient supply chain, it is estimated that transport costs have the higher relative importance (0.833) relative to the delivery efficiency criterion (0.167). Subcriteria comparison in Table 8 gives values of the weight coefficients, showing that, according to managers, SITCE has the highest relative weight (0.667) in an efficient supply chain type, followed by SITCR (0.167), etc. On the other hand, in the agile supply chain, delivery efficiency has a greater relative importance (0.833), relative to transport costs (0.167), and, as a result of comparison with such significant criteria, the highest weight coefficient is assigned to SOTD (0.461), then SPPM (0.221), etc. (Table 10). By comparing alternatives, i.e. suppliers, in relation to the as-valued importance of higher-level elements, i.e. subcriteria, and taking into account their real values presented in Table 6, the supplier ranking is done for both efficient and agile type of supply chain, which fully reflects the preferences of decision-makers or managers. Suppliers are more, less, or equally preferable from the point of view of whether and to what extent the achieved performance indicators in the analyzed types of supply chains approximate their target values, comparatively. Thus, in the efficient supply chain, according to manager preferences, the best ranked supplier is S4, with a priority of 0.309043, then S1 (0.157578), D2 (0.155528), and so on. (Table 8), while in the agile supply chain, the best ranked supplier is S6 (0.313916), then S4 (0.171523), S1 (0.160299), etc. (Table 10).

Table 8. Relative weights of criteria and sub-criteria priorities in the AHP supplier ranking model in an efficient supply chain (Autors)

Name	Normalized By Cluster	Limiting
Delivery efficiency	0.16667	0.055556
Transport costs	0.83333	0.277778
SOTD	0.06687	0.022289
SDMR	0.02493	0.008309
SPPM	0.01064	0.003548
SCPQ	0.06423	0.021409
SITCR	0.16667	0.055556
SITCE	0.66667	0.222222

Table 9. Final supplier priorities calculated using the AHP model in an efficient supply chain (Autors)

Name	Ideals	Normals	Raw	Ranking
S1	0.509891	0.157578	0.052526	2
S2	0.503258	0.155528	0.051843	3
S3	0.445236	0.137597	0.045866	5
S4	1.000000	0.309043	0.103014	1
S5	0.471414	0.145687	0.048562	4
S6	0.305998	0.094567	0.031522	6

Table 10. Relative weights of criteria and subcriteria priorities in the AHP supplier ranking model in the agile supply chain (Autors)

Name	Normalized By Cluster	Limiting
Delivery efficiency	0.83333	0.277778
Transport costs	0.16667	0.055556
SOTD	0.46120	0.153732
SDMR	0.07777	0.025924
SPPM	0.22111	0.073704
SCPQ	0.07325	0.024417
SITCR	0.02778	0.009259
SITCE	0.13889	0.046296

Final supplier priorities are given in Table 11, and DEAHP matrix (model) of alternative comparison is given in Table 12.

In order to eliminate the obvious subjectivity characteristic of the Analytic Hierarchy Process application, the existing model is combined with the DEA method on a double basis. Firstly, in the case of an agile supply chain, AHP evaluation of the criteria importance is integrated into the corresponding DEA model with respect to each individual criterion (Table 13), whereby the selected AHP criteria are observed as the output variables in the DEA model, while the input is dummy variable, whose values equal one for each DMU.

After that, an appropriate DEAHP matrix is formed, the elements of which correspond to the criteria weight coefficients (Ramanathan, 2006; Lin et al., 2011, Pakkar, 2015, etc.). The corresponding transformation of DEAHP matrix elements (Lin et al., 2011; Sueyoshi et al., 2009; Yang & Kuo 2003; Mahapatra et al., 2015), which includes the calculation of relative efficiency for each pair of decision-making units, without involving other DMUs, forms DEA-AHP evaluation matrix for the calculation of a characteristic vector whose components are DEA-AHP priorities, used to rank decision-making units or suppliers in this case.

Table 11. Final supplier priorities calculated using the AHP model in the agile supply chain (Autors)

Name	Ideals	Normals	Raw	Ranking
S1	0.510643	0.160299	0.053433	3
S2	0.242404	0.076095	0.025365	6
S3	0.406966	0.127753	0.042584	5
S4	0.546398	0.171523	0.057174	2
S5	0.479159	0.150415	0.050138	4
S6	1.000000	0.313916	0.104639	1

Table 12. DEAHP matrix (model) of alternative comparison relative to SDMR (Autors)

	I1	S1	S2	S3	S4	S5	S6
S1	1	1	3	3	1/3	1/5	3
S2	1	1/3	1	1/3	1/4	1/4	1
S3	1	1/3	3	1	1/4	1/4	3
S4	1	3	4	4	1	1/3	4
S5	1	5	4	4	3	1	4
S6	1	1/3	1/3	1/3	1/4	1/4	1

Table 13. DEAHP alternative priorities in relation to criteria (KPI)–agile supply chain (Autors)

DMU	SOTD	SDMR	SPPM	SCPQ	SITCR	SITCE
S1	1	0,75	0,429	0,222	1	1
S2	1	0,25	0,143	0,222	0,5	1
S3	1	0,75	0,286	0,111	1	0,355
S4	1	1	0,286	0,667	1	1
S5	1	1	0,286	0,778	0,226	1
S6	0,5	0,25	1	1	0,4	0,667

DEAHP models are formed identically in relation to the remaining KPIs. The calculated DEAHP priorities with respect to each KPI, using the appropriate input-oriented CCR DEA model (Charnes et al., 1978), are shown in Table 14.

To transform the DEAHP alternative priority into the DEA-AHP evaluation matrix, it follows that (Mahapatra et al., 2015):

$$a_{jk}= (E_{jj} + E_{jk})/(E_{kk} + E_{kj}) \quad (3)$$

i $a_{jj} = 1$, $a_{kj}=1/a_{jk}$,

where E_{jk} is an element of the j-th row and k-th column of the DEAHP alternative priority matrix relative to a particular KPI.

By applying the previous relationship, the values shown in Table 14, which represent the DEA-AHP alternative evaluation matrix, are obtained. By multiplying all the elements of each row of the matrix and by computing the sixth root, and finally by normalizing, we obtain a characteristic vector W = (0.196, 0.100, 0.164, 0.272, 0.127, 0.190), whose components are DEA-AHP alternative priorities on the basis of which suppliers are ranked in the agile supply chain (Table 15).

DEAHP alternative priorities in relation to criteria (KPI)–efficient supply chain is given in Table 16, while DEA-AHP assessment matrix – efficient supply chain is given in Table 17.

The supplier S4 has the best ranking, because it has the highest priority, 0.272. The same procedure is repeated for an efficient supply chain. The characteristic vector is W = (0.147, 0.209, 0.239, 0.235, 0.104, 0.119), the best supplier is S3 (0.239) (Table 18). Geometric mean of priorities calculated for both supply chains shows that the best ranked supplier is S4 (0.253), followed by S3 (0.211), etc. (Table 19).

DEA-AHP priorities of suppliers in different types of supply chains are shown on Figure 4.

Table 14. DEA-AHP evaluation matrix (Autors)

DMU	S1	S2	S3	S4	S	S6
S1	1	1,4	1,111	0,733	1,631	1,714
S2	0,714	1	0,379	0,283	0,612	1,363
S3	0,899	2,636	1	0,417	2,512	0,813
S4	1,364	3,534	2,398	1	1,660	1
S5	0,613	1,634	0,398	0,602	1	1,149
S6	0,700	1	2,695	1	1,195	1

Table 15. DEA-AHP priorities and the ranking of suppliers in agile supply chain (Autors)

	DEA-AHP priorities	Normalized	Ranking
S1	1,213	0,202	2
S2	0,632	0,105	6
S3	1,124	0,187	4
S4	1,636	0,272	1
S5	0,807	0,135	5
S6	1,145	0,190	3

Table 16. DEAHP alternative priorities in relation to criteria (KPI)–efficient supply chain (Autors)

DMU	SOTD	SDMR	SPPM	SCPQ	SITCR	SITCE
S1	1	0,4	0,333	0,143	0,667	0,667
S2	1	1	0,500	0,714	0,333	0,667
S3	1	1	1	0,833	1	0,333
S4	1	0,2	1	1	1	1
S5	1	0,6	0,333	0,286	0,333	0,667
S6	0,5	0,25	0,167	0,429	0,333	0,667

Table 17. DEA-AHP assessment matrix – efficient supply chain (Autors)

DMU	S1	S2	S3	S4	S	S6
S1	1	0,7	0,667	0,572	1,250	1,428
S2	1,429	1	0,75	1,428	1,429	1,818
S3	1,499	1,333	1	0,917	3,003	1,598
S4	1,748	0,700	1,090	1	3,23	1,825
S5	0,800	0,699	0,333	0,310	1	1
S6	0,700	0,550	0,626	0,548	1	1

Table 18. DEA-AHP priorities and the ranking of suppliers in efficient supply chain (Autors)

	DEA-AHP priorities	Normalized	Ranking
S1	0,884	0,147	4
S2	1,259	0,209	3
S3	1,437	0,239	1
S4	1,410	0,235	2
S5	0,622	0,104	6
S6	0,714	0,119	5

Table 19. DEA-AHP priorities and final ranking of suppliers (Autors)

	DEA-AHP priorities in efficient supply chain	DEA-AHP priorities in agile supply chain	Geometric mean	Ranking
S1	0,147	0,202	0,172	3
S2	0,209	0,105	0,148	5
S3	0,239	0,187	0,211	2
S4	0,235	0,272	0,253	1
S5	0,104	0,135	0,118	6
S6	0,119	0,190	0,150	4

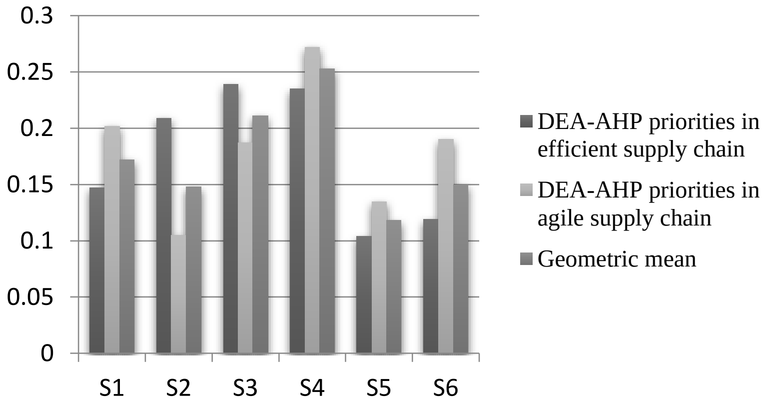

Figure 4. DEA-AHP priorities of suppliers in different types of supply chains
Source: Autors

4. Conclusion

The main goal of this model is to support business decision-making processes in supply chains related to the evaluation, ranking, and selection of suppliers with the best performance depending on the type of supply chain. The main purpose is to help the management identify, structure, and solve semi-structured and unstructured problems and to make a choice between different alternatives.

The research in this paper has included supplier evaluation and ranking, depending on which type of supply chain they belong to. Since one supplier can participate in several different types of supply chains, their ranking may be the same, better, or worse, depending on which supply chain they belong to. Information on how they are ranked in different types of supply chains can be of great importance to the company management, which, on the basis of this, can decide to replace supplier with another supplier in the supply chain where their ranking is the worst, or appropriately act in order to improve their performance, which would ultimately improve the supplier ranking and their performance.

Previous studies have dealt with supplier evaluation and ranking without taking into account the characteristics of different types of supply chains. The contribution of the paper lies in the development of a new supplier performance measurement model, so that their evaluation and ranking is done taking into account the priority of key performance indicators in different types of supply chains.

The DEA-AHP outputs included are incorporated into the decision-making support system, which the authors also developed in parallel with the presented model for evaluating suppliers in different types of supply chains, so that specific results of multi-criteria optimization of the proposed model are included in the system for improving business processes in e-supply chains.

As a decision-making support tool, managing supplier performance in supply chains is more than just reporting. It is an integrated set of processes, methodologies, metrics, and applications designed to manage supply chain performance. In this way, organizations translate strategies and goals into plans, monitor performance, analyze deviations between planned results and realized values, and take corrective actions in order to improve supplier performance in different types of supply chains.

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