



APPLICATION OF AHP METHOD FOR OPTIMAL SELECTION OF THE IT SYSTEM SUPPORTING BUSINESS OPERATIONS IN THE LOGISTICS ENTERPRISE

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ABSTRACT

The main objective of this paper is to solve the multi-criteria decision problem consisting in optimal selection of the best software for supporting logistics operations in an enterprise. Analytic Hierarchy Process (AHP) based procedure has been used in this paper which selects a decision alternative for the problem considered. As a result, a solution that satisfies the decision-maker has been determined.

The paper consists of three parts. The first one includes an overview of IT systems supporting the logistics management in a company. Then a theoretical background of the Analytic Hierarchy Process is presented as the basis for deliberations contained in the third part, which offers a way to solve the problem of IT system selection that can be used by any logistics company.

INTRODUCTION

Company management is based on continuous decision-making that in today's economic reality has become increasingly complex and multi-faceted. The time when the managers were guided mainly by experience and intuition is gone forever. Today, complex decisions require techniques to facilitate their analysis. In a situation where a decision-maker has to deal with a large number of decision alternatives, which must be evaluated against numerous criteria, the lack of methodical approach and relying on an intuitive selection only may result in serious negative consequences.

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This paper discusses a problem that can be classified as multi-criteria decision problem, consisting in the selection of IT system to support the logistics management in an enterprise. It should be emphasized that the selection of an appropriate IT system is a decision that requires considerable financial outlays, is fraught with high risk and generates long-term consequences for the company's operations. Therefore, this problem requires careful consideration of many aspects, and the decision should lead to obtaining the best solution not only for the present time, but also for the next few years of the company's operations. In order to select an optimal IT system, several criteria must be carefully analysed, e.g. functional range of the system, its performance, scalability, user's interface, price, implementation support, etc. Of course, this does not mean that all these factors are equally important and have equal influence on the choice of the final alternative.

Decision-makers are expected to make rational decisions. The alternatives that take into consideration the right relationship between positive and negative consequences are regarded as the rational choice¹. AHP (*Analytic Hierarchy Process*) is one of the methods for identifying the strength of these relationships through the evaluation of decision alternatives. It is a technique of *Multiple-Criteria Decision Analysis* (MCDA) and/or *Multiple-Criteria Decision-Making* (MCDM)².

The objective of this paper is to present AHP method as a useful tool for the selection of IT system to support the activities of a logistics enterprise. The decision on the purchase of IT system should be preceded by business and organizational analysis of an enterprise. As a result, feasibility study of the project should be conducted. This issue and others problems related to IT system implementation are not discussed in this article. These issues are widely discussed in literature (Jabłoński, Bartkiewicz 2006, Kisielnicki 2013, Majewski 2006, Szymonik 2006, Wrycza 2010). This study is based on the assumption that by analysing the number and complexity of requirements applying to such types of software, the final choice is usually limited to few manufacturers only. Following the pre-selection, in the final decision stage a decision-maker is usually left with 2 or 3 systems to choose, with very similar parameters, and then making the optimal choice is the hardest task. For this reason, a tool to support the final selection can be extremely useful.

Information systems of logistics enterprises can be supported by different types of IT systems. The next section discusses the categories of these systems. Each of the groups discussed has its own specific characteristics and plays an important role in supporting the logistics processes.

¹ Each decision involves some consequences that can be grouped into the following areas: consequences positively assessed through the benefits, consequences negatively assessed through the expenditures, consequences neutrally assessed, e.g. due to the lack of certainty as to the final results.

² An in-depth comparative analysis of 11 methods (including AHP) included in MCDM can be found in: Velasquez, Hester (2013).

CATEGORIES OF IT SYSTEMS TO SUPPORT LOGISTICS ENTERPRISE MANAGEMENT AND CRITERIA FOR THEIR SELECTION

For the purpose of the logistics IT support in an enterprise, the following types of systems are used (Majewski 2006):

- TPS (*Transaction Processing Systems*) - transactional systems to support recording of business events;
- MRP/ERP (*Manufacture Resource Planning / Enterprise Resource Planning*) - systems to support the management of the entire enterprise, including financial management;
- SCM (*Supply Chain Management*) - used for supply chain management;
- WMS (*Warehouse Management System*) - used for managing warehouse processes.

Transaction systems are oriented at recording business processes and creating documents that support this process. According to Kisielnicki (2013), it is estimated that they account for approx. 80% of IT infrastructure in enterprises. They are used at the lowest operating management level and play service-related role for other systems. Data obtained from these systems feeds "higher" generation systems, facilitating their operation. The examples of transactional systems are: records of suppliers and customers, sales, finance, payroll, etc.

The first integrated IT systems supporting logistics management are related to the materials management and operation of manufacturing processes. Material Requirements Planning (MRP I) system is based on a calculation of the actual demand for materials based on sales orders, bill of materials and inventory balances. Manufacture Resource Planning (MRP II) is the concept of production management based on its scheduling, which becomes the basis for determining the necessary resources and materials. IT system of this class, apart from the integration of production planning, purchasing and manufacturing, supports also the area of sales, finance and marketing of an enterprise (Jabłoński, Bartkiewicz 2006).

Next generation systems - of ERP class - are the modular software (*Enterprise Resource Planning - ERP I*) or the component software (*Relationship and Enterprise Resource Planning - ERP II*), i.e. are made up of independent but cooperating applications that support all business functions of the enterprise. ERP I provides the extension of MRP II concept with financial procedures (controlling, management accounting, cash flow account) and the solutions for process manufacturing and transport services. It focuses on the processing of transactions related to the operation and optimization of internal processes of the organization. In contrast, ERP II is extending this model by external cooperation (with suppliers, customers and other business partners), based on the services of Internet technologies and mobile solutions.

Creators of ERP systems are constantly expanding their functionality, bearing in mind the needs of users and changes in management techniques and new technologies. In the age of the Internet, with the extending logistics supply chains and increasing competition, it is not sufficient to streamline the internal business processes but the desired value in business consists in taking care of the quality of information flow between the trading partners (Szymonik 2006)). For this reason, the integration of ERP with other systems that are responsible for interaction with business environment be-

came widespread. They include SCM, CRM (*Customer Relationship Management*) and SRM (*Supplier Relationship Management*).

CRM system supports the company in building and effective management of relationships with the customers in order to maximize long-term mutual benefits. It supports and automates the sales process, marketing campaigns, telemarketing activities, customer service, business service, etc. (Kisielnicki 2013, Wrycza 2010). With knowledge gained from the results of numerous analyses that can be performed in that system, customer service is improved resulting in establishing beneficial relationships with the customers.

SRM software in a certain way reflects the capabilities of CRM; the difference is, however, that it influences and supports the management of relationships with the suppliers of raw materials and services. It enables the management of supplier database and activity relating to orders and deliveries. With automation of activities, it is possible to optimize inventory, analyse suppliers' performance, shorten delivery times.

In turn, SCM system provides support in the field of supply chain management. With this IT solution, it is possible to develop a model of the entire supply network and its limitations. This model becomes the basis for synchronizing the movement of materials between co-operators and helps the companies to adjust their operations (procurement, production, inventory and transportation) to the specific market demand (Szymonik 2006). SCM systems improve the inter-organizational processes by supporting the functions of planning and implementation of all activities in the supply chain, as well as of coordination and collaboration in the supply chain, in order to maximize profit at the lowest cost for the entire chain. However, to be able to use SCM system it is important to first improve business processes with ERP system. For this reason, SCM software can be described as a complementary solution to ERP.

Warehouse Management System (WMS) consists of specialized IT tools used for the management of warehouse processes. The main objective of this system is fast location of goods in the warehouse and control of stock turnover (Majewski 2006). The optimization algorithms in WMS systems are applied to increase the use of storage space, optimize the deployment of goods, reduce labour consumption of preparing the goods for release and enable to plan transport services, with the optimization of routes and shipments. WMS can operate autonomously as an application to organize and supervise the movement of goods in the warehouse and related information flows, or it can cooperate (be integrated) with the superior ERP system, which supports the management of the entire enterprise.

The decision to implement an IT system is a strategic decision, because the efficient management of information results in the increase in productivity and effectiveness, and thus is an important factor in increasing the competitiveness of an enterprise. The IT system that is tailored to the needs of an organization will not only improve the operational effectiveness of an enterprise, but it will also strengthen the company's business strategy. When choosing the system, it is important to pay attention to the following criteria, which are grouped into three main areas (Długosz 2009):

- **system provider** – their experience, references, number of implementations, the willingness to make the desired modification, implementation support and the scope of services and post-implementation assistance;

- **system features** - support for the company's strategy, openness, flexibility, efficiency, scalability, user-friendliness, innovation, price, use of modern methods and management concepts;
- **technical issues** - use of the latest methods and technology, availability of software in a SaaS model (*Software as a Service*) and open source, hardware platform and database required.

The presented classification of IT systems shows the trend that software developers create scalable and flexible applications that can be modified by the implementation of software that is tailored to the current situation of the company. With the increased needs, the system can be replaced or extended in the future. It clearly shows that the decision regarding the selection of IT system for the logistics company is not a one-off decision. Logistics IT system in an enterprise can be modelled according to the needs and capabilities of an organization, though the extension with new modules / components. For this reason, it is important to have a good tool to facilitate multi-criteria selection of the optimal IT system - like AHP. Its theoretical foundations are discussed in the next section.

AHP METHOD AS A TOOL FOR OPTIMAL DECISION-MAKING

The method of Analytic Hierarchy Process (AHP) was developed by Thomas L. Saaty in 1970s. It is an approach to solving multi-criteria decision-making problems which, after a comprehensive evaluation (of more than one criterion), leads to the final selection of the best solution to the analysed problem.

The procedure for the use of AHP method involves a set of activities that must be performed in several stages (Prusak, Stefanów 2014, Saaty 1990, Zeshui 2014).

Stage 1. **Construction of a decision-making model** - involves a description of the problem in the form of hierarchical structure. Figure 1 presents the simplest and basic form of hierarchical model. The primary objective is at the top of the hierarchy and the considered decision alternatives are at the bottom. The decision-making criteria constitute the intermediate levels in the model. If needed, the criteria can be further broken down (criteria branches) into sub-criteria or sub-subcriteria. The number of intermediate levels depends on the complexity of the problem, and the decision-making model adopted by a decision-maker.

Each model is based on the dominance hierarchy by which it is possible to assess the impact of the elements located at the lower level in the model on the elements at the next level above. The power of this impact is assessed at the second stage of the procedure by comparing the elements in pairs.

Stage 2. **Obtaining original information using the fundamental scale of pairwise comparisons.** Following series of pairwise comparisons, performed by a decision-maker in relation to the items located on each level of the hierarchical model and associated with an element located at a higher level, a comparison matrix is constructed.

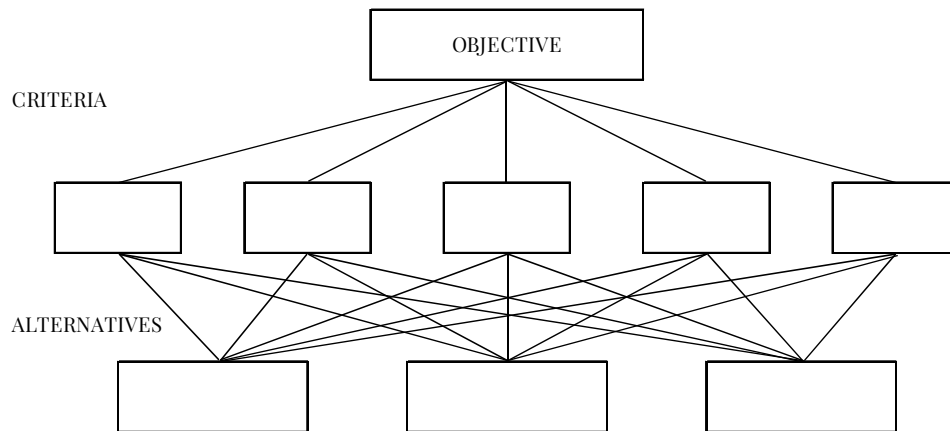


Fig. 1. Example of a three-level hierarchical model
Source: own study.

Each of the compared pairs of elements is evaluated verbally and assigned with rank in the form of numeric value. The scope of ranks assigned to verbal evaluations is shown in Table 1.

Table 1: Saaty’s fundamental scale of comparisons

Domination (rank)	Determination		Meaning
	Polish	English	
1	równoważny (tak samo preferowany)	<i>equal importance</i>	both elements have the same impact
3	nieznacznie preferowany	<i>moderate importance</i>	one element has slight advantage over the other
5	silnie preferowany	<i>strong importance</i>	strong advantage of one element over the other
7	bardzo silnie preferowany	<i>very strong or demonstrated importance</i>	very strong advantage of one element over the other
9	całkowicie preferowany	<i>extreme importance</i>	extreme (full) advantage of one element over the other
2, 4, 6, 8	wartości pośrednie	<i>in-between</i>	applied when the evaluation with a set of odd numbers is not possible

Source: own study based on Saaty Thomas L., Vargas Luis G., *Models, Methods, Concepts & Applications of the Analytic Hierarchy Process*. New York: Springer Science + Business Media, 2012. p. 6.

Defining the advantage of one component over the other is based on the so-called axiom of reciprocity (rank reversal). If the object (i) has higher weight attributed than (j), and following the transformation this relation has the number a_{ij} assigned, then to the reversal relationship, i.e. to the relation of the object (j) to the object (i), the value of $1/a_{ij}$ is assigned.

Through pairwise comparisons for all the decision alternatives separately for each criterion, the matrices $A^{(1)}, A^{(2)}, \dots, A^{(m)}$ are obtained. The general form of pairwise comparisons matrix, denoted by the symbol A , can be recorded as follows:

$$A = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix} = \begin{bmatrix} 1 & a_{12} & \cdots & a_{1n} \\ 1/a_{12} & 1 & \cdots & a_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ 1/a_{n1} & 1/a_{n2} & \cdots & 1 \end{bmatrix} \quad (1)$$

where: A - $n \times n$ matrix (n is the number of compared items).

When matrix is determined, the values of weighting factors, also referred to as priorities or weights, shall be established.

Step 3. Estimating the value of weighting factors. As a result of comparisons made, it is possible to determine mutual priorities (local and global weights) in relation to the criteria and decision alternatives. The values of weighting factors indicate the importance of criteria and sub-criteria for the evaluator, and at the same time reflect the contribution of each of them to the decision-making objective.

Estimating the value of weighting factors is mostly done with the use of:

- computer applications (e.g. Super Decisions, Expert Choice);
- matrix calculus;
- geometric mean;
- arithmetic mean.

Each of the above methods has its strengths and weaknesses. Due to the easiness of calculation in comparison to other methods, the procedure based on the arithmetic mean is the most widely used method of manual calculation in AHP. It provides the approximate values of the weighting factors, however, the values obtained in practical application are considered sufficient to support the decision-making process (Prusak, Stefanów 2014).

Two steps need to be followed in order to estimate the values of weighting factors using the arithmetic mean.

Step 1. The standardization of each data column in matrix. It is based on summing up of each column consisting of pairwise comparison matrix expressions (a_{ij}), and then each matrix element $a_{1i}, a_{2i}, a_{3i}, \dots, a_{ni}$ has to be divided by the amount that was previously calculated for the column.

Step 2. Calculating the arithmetic mean for each row of the standardized data enables to calculate the weighting factors known as priorities (\tilde{w}_i) of individual elements. These priorities take values from 0 to 1, and their sum is 1.

$$\tilde{w}_1 + \tilde{w}_2 + \dots + \tilde{w}_n = 1 \wedge \tilde{w}_i \geq 0 \quad (2)$$

Stage 4. **Aggregation of results and classification of decision alternatives.** In order to obtain the final results, the synthesis of object priority products against the criteria shall be performed. Local weights are obtained from pairwise comparisons matrices, and the global weights are calculated by multiplying the local weight of a given element by the weighing factor of the corresponding element located one level up in the hierarchy.

This step allows to determine the order of decision alternatives by their participation in the implementation of the primary goal.

Based on the procedure presented, the solution to multi-criteria decision-making problem which is the aim of this paper, was attempted.

DESCRIPTION OF THE PROBLEM AND ITS SOLUTION USING AHP METHOD

As it was indicated in the introduction of this study, AHP method was used for the final selection of IT system, when, after pre-selection of IT solutions, the decision-maker was left with three systems to choose from. Based on the criteria for system selection that are described in section 2, in the present case four key criteria were analysed:

- **functional range of the system** - compatibility of the functions offered with the requirements of the user, which is the result of the comparative analysis of user requirements and functional properties of the system at the level of all its functions (from elementary properties to the principal ones);
- **user interface** - easy to use, adaptable to individual preferences, in an appropriate language version (e.g. multilingual one for international companies) and properly extended functions of context assistance, which will provide the user with information without the need to refer to system documentation;
- **price** - great value for the effects expected and whether the costs of training, service, implementation support are included, and whether operating costs and future development of the system were considered;
- **implementation support** - a company offering software should have a strong position in the market and experience in numerous implementations; it should also provide the appropriate implementation assistance, maintenance service, software development and training - in other words, it should provide the users with a sense of security.

Therefore, the analysed the problem consists in the choice of one of three systems based on four criteria presented above. Hierarchical structure of this case is shown in Figure 2.

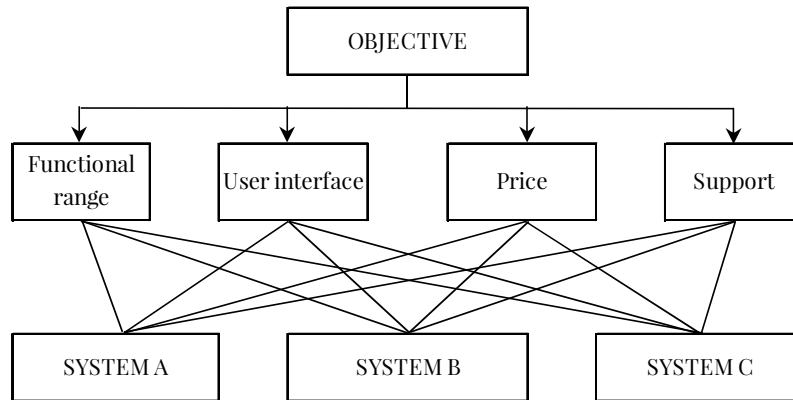


Fig. 2. The hierarchical structure of IT system selection
Source: own study

The decision-maker described their preferences through the series of pairwise comparisons. These values are shown in Table 2.

Table 2: Input data matrix

Criterion	Functional range	User interface	Price	Support
Functional range	1	7	4	5
User interface	1/7	1	1/5	1/7
Price	1/4	5	1	1
Support	1/5	7	1	1

Source: own study.

The data contained in Table 2 can also be represented as matrix:

$$A = \begin{bmatrix} 1 & 7 & 4 & 5 \\ 1/7 & 1 & 1/5 & 1/7 \\ 1/4 & 5 & 1 & 1 \\ 1/5 & 7 & 1 & 1 \end{bmatrix} \quad (3)$$

where: A - matrix containing the data of the described decision-making case

In order to evaluate the priorities, the arithmetic mean method was applied. This is the simplest and yet the most widely used method for determining the value of the weighting factors (priorities), which should be conducted in two steps:

- standardization of each data column,
- calculating the arithmetic mean for each row of the standardized data.

The resulting calculations made according the above diagram are included in Table 3. Their result is an estimate of the criteria weighting factors.

Table 3: Input matrix standardization and weighting factors for the criteria

Criterion	Functional range	User's interface	Price	Support	Weights	Weights [%]
Functional range	0.6278	0.3500	0.6452	0.7000	0.5807	58.07
User's interface	0.0897	0.0500	0.0323	0.0200	0.0480	4.80
Price	0.1570	0.2500	0.1613	0.1400	0.1771	17.71
Support	0.1256	0.3500	0.1613	0.1400	0.1942	19.42
of	1.0000	1.0000	1.0000	1.0000	1.0000	100.00

Source: own study.

The factors presented in Table 3 show the participation of a given criterion in achieving the objective, i.e. in the selection of best IT system for the enterprise. The results show that for the decision-maker the functional range of IT system is a decisive factor (0.5807) for system selection, and user interface is the least important factor (0.0480).

The next step is to check to what extent each compared criterion is met by System A, System B and C System, in other words, the system priority values should be determined. Table 4 shows the data obtained from the comparison of all three systems, taking account of the functional range of each system.

Table 4: Comparison of systems in terms of functional range

	System A	System B	System C
System A	1	$\frac{1}{4}$	5
System B	4	1	9
System C	$\frac{1}{5}$	$\frac{1}{9}$	1

Source: own study.

The systems were compared in pairs by the decision-maker, who indicated the following preferences for the functional range criterion of the assessed system:

- system A *vs* system B: $\frac{1}{4}$ - it means that the advantage of System B is little stronger than weak in terms of the assessed criterion of System A;
- system A *vs* system C: 5 - means that System A has a strong advantage over System C;
- system B *vs* system C: 9 - System B has an extreme advantage over System C.

In the manner presented above, the decision-maker compared the pairs of systems in terms of the subsequent three criteria. These data provide the basis for estimating the values of weighting factors using the arithmetic mean method. As a result of the calculations (they are not presented in the paper due to limited space), the following observations we made:

- in terms of functional range of the system, System B is the best (weight 0.7013);
- in terms of user's interface, System C is the best (weight 0.6080);
- in terms of price, System B is the best (weight 0.7644);
- in terms of implementation support, System C is the best (weight 0.4739).

To decide which IT system is best for the company in question, it is necessary to make a synthesis of the priority products of systems analysed against the criteria and relevant weighting factors of the criteria. To do this, local priorities must be calculated first and then the global (absolute) priorities³, as they illustrate the impact of a given criterion on the total (global) rating of the specific IT system. By summing up all global priorities obtained for each system, the final assessment of each IT system is made. Global priorities together with the synthetic results are shown in Table 5.

Table 5: Global priorities and synthetic results

	Functional range	User's interface	Price	Support	Total
Criteria weights	58.07%	4.80%	17.71%	19.42%	
System A	13.73%	1.31%	2.94%	5.13%	23.11%
System B	40.72%	0.58%	13.53%	5.08%	59.91%
System C	3.62%	2.92%	1.24%	9.20%	16.98%

Source: own study.

The data contained in Table 5 show the extent to which the various systems help to achieve the objective (to select the best IT system). In the present case, the most advantageous decision is to choose System B, because it got the highest overall rating of 59.91%. On the other hand, the least desirable option is System C (16.98%).

SUMMARY

When making the strategic decisions for the company regarding the selection of IT system, all reasonable steps should be taken to select an optimal option. The application of AHP method allows for quick solution to this complex decision-making problem, and the optimal solution is achieved by analysing all the assumed criteria. With the use of AHP method, it is easier to assess decision alternatives, both in terms of the values which are measurable (quantitative factors, e.g. software price) and immeasurable (qualitative factors, e.g. user interface) for the decision maker. The analysis and evaluation of quantitative criteria seems simpler, as it can be expressed with measurable economic values, however, the qualitative elements are difficult to estimate and depend on subjective preferences of a decision-maker. The method applied uses Saaty's scale, which is especially useful for the evaluation of such criteria.

The method of hierarchical analysis of the problem is a useful tool which helps to streamline and objectify the difficult decision-making process. The hierarchical model of system selection proposed in the paper can also be extended by additional elements (sub-

³ Global priorities show the participation of each alternative in achieving the overall objective (top of hierarchy) and local priorities show the importance of the given element towards the element located one level up in the AHP model. Local priorities are obtained from the pairwise comparisons matrix and global priorities are calculated by multiplying the local priority of a given item by the weighting factor of the corresponding element located one level up in the hierarchy,

criteria and sub-subcriteria), depending on the needs of a decision-maker, in the same way in which the variables are selected for the construction of econometric models.

This method can replace costly expert reports, which would be the basis for the selection of IT option. Another important issue is also the fact that the mathematical calculations indicating the optimal alternative eliminate the risk of manipulation in the process of decision-making. These calculations can be performed using appropriate computer program which significantly accelerates and facilitates the decision-making process.

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