APPLICATION OF FAHP AND FTOPSIS METHOD FOR DETERMINING THE IMPORTANCE OF MODERN INFORMATION TECHNOLOGIES IN WAREHOUSE PROCESSES

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Abstract

Contemporary business conditions identify warehousing as a key component of supply chain (SC) efficiency It can appear in all stages of SC implementation, from the supply of raw materials to the delivery of finished products to customers. The warehouse is a place of transformation of goods flows in which numerous processes are carried out. The efficiency of the storage process implementation greatly impacts the performance of the entire SC. Numerous benefits can be realized by influencing the processes that require the most resources. One of those processes is order-picking. The order-picking process can be influenced on three levels: technical-technological, organizational, and managerial. While existing literature has extensively examined technical and technological aspects, there remains a notable gap in understanding the holistic impact of modern pick-assist technologies on warehouse management. In this paper, improvement at the management level will be considered by introducing modern technologies such as pick by light, pick by voice, pick by vision- augmented reality, and others. This paper is dedicated to the selection of modern pick-assist technologies to increase warehouse productivity. The technology selection is based on defined criteria. The Fuzzy Analytic Hierarchy Process (FAHP) method will be used to determine the weights of the criteria, while the Fuzzy Technique for Order Preference by Similarity to Ideal Solution (FTOPSIS) method will be used to determine the rank. The results of the research are expected to provide practical guidelines for the selection and implementation of modern pick-assist technologies in warehouses, aiming to improve the efficiency of order picking and overall productivity.

Keywords: Warehouse, order-picking, pick-assist technologies selection, FAHP, FTOPSIS

1. INTRODUCTION

The distribution warehouse within SC represents the link between the industry and the customers. As such, it must meet certain conditions. Prioritizing maintaining the appropriate degree of customer satisfaction is important, but the warehouse's productivity should also increase. Increasing productivity can be achieved by improving storage processes. The greatest effects will be achieved by influencing complex processes that consume the most time and cost. As such, the order-picking process stands out. Order picking is a process that is carried out in warehouses of piece goods and includes all activities that follow the separation of the required assortment of goods according to type and quantity to fulfill customer's requirements- accurately and on time. The impact on the order-picking process can be implemented from three aspects: technical-technological, organizational, and managerial. In this paper, the emphasis is placed on the management aspect, that is, on the technologies for guiding the picker through the warehouse [1, 2].

In the paper, a warehouse case study that uses RFID technology for the process of guiding the picker through the warehouse was observed. According to the current demands of the customers, the application of the mentioned technology does not give the expected results in terms of the speed of realization of the customer's order, thus productivity. The goal of this paper is the selection of pick-assist technologies for the management of pickers to increase the productivity of the entire warehouse.

The problem of selecting pick-assist technologies has been addressed in other papers; however, it has not been comprehensively observed. The contribution of this paper is reflected in the fact that it systematically analyses the problem of lack of productivity and proposes technologies aimed at increasing it. In addition, the technology comparison was performed based on a wide set of criteria that corresponded to the observed problem.

The FAHP method was used to determine the weight of the criteria. The method was selected due to a certain number of qualitative criteria, as well as the structure of the problem itself. The FTOPSIS method was used to obtain the final ranking. The reason for its application is the clear differentiation of the considered alternatives according to the defined criteria.

Following a brief explanation of the research's purpose and goal in the introduction, the second chapter explains the problem and provides a summary of relevant studies in the field of selection pick-assist technology. Furthermore, the criteria that will be used to compare the alternatives are supplied along with the alternatives that will be examined. A hybrid multi-criteria decision-making (MCDM) approach for selecting the dominant alternative is discussed in the third chapter. The fourth chapter summarizes the applied model's final results. The conclusion provides a discussion of research findings and suggestions for further investigation.

2. PROBLEM DESCRIPTION AND LITERATURE REVIEW

With the progressive development of the Internet and information communication technologies (ICT), in the SC, a new sales channel has developed: e-commerce, with which customers have complex requirements for products and services. Therefore, the structure of customer orders changes. Orders have fewer lines, the quantity of products decreases, and the number of requested deliveries increases. This creates certain challenges for storage operations [2, 3]. There is a need to adapt the warehouse system to new requirements. The goal of the management is to increase the productivity of the warehouse while meeting the demands of the customers. An increase in the number of orders requires a change in the organizational or management aspect of the order, which will be discussed in more detail in this paper. An increased number of pickings of different products reduces productivity and increases the level of errors, which have a negative impact on storage operations. Following the observation, RFID technology is being applied for the management of pickers, which in the past period corresponded to the characteristics of the task.

Considering the changes in these characteristics in SC, it is necessary to find an adequate replacement for RFID technology, which would compensate for its shortcomings and thus increase the productivity of the warehouse. Pick-by-voice, pick-by-vision, and pick-by-light appear as potentially applicable technologies. To compare these technologies, it is necessary to select criteria based on which they will be evaluated. The criteria are selected based on the characteristics of the observed case study. Baechler et al. [1] compared paper and paperless technologies for managing pickers. The technologies were compared based on the time of realization of the order, the number of errors, and the complexity of the task. In his master thesis, Zavaleta [2] compares several pick-assist technologies, among which are pick-by-voice, pick-by-vision, and pick-by-light. The comparison was made based on economic, quantitative, and social parameters. The AHP method was used for selection. Zapata et al. [3] did a comparative analysis of the paper with pick-by-voice, pick-by-vision, and pick-by-light technologies. The selection was made based on costs and technological characteristics. Neural networks were used for selection. Baumann [4], in his master thesis, compares several pick-assist technologies. The selection was made based on the number of wrongly picked units per order, the speed of order picking, etc.

2.1 Modern information technologies as the key to the efficiency of warehouse processes

In this paper, the following technologies are proposed that support the order-picking process: pick-by-voice, pick-by-vision, pick-by-light, and RFID. All the mentioned technologies are integrated with a warehouse management system (WMS) that ensures information updates in real time.

Pick-by-voice (A1) is a technology that uses audio and voice signals to support the picking process, i.e., information is transmitted to pickers via headphones [5]. Pickers are given information about the product's location and quantity, and after completing the task, they confirm the end of the operation by voice [6, 7]. This process is repeated until all articles are picked from the order, and then a new order is started. This technology requires short training of employees, ensures high productivity and flexibility of the system, enables the realization of multiple operations at the same time, etc.

Pick-by-vision (A2) uses augmented reality technology to support the picking process. Pickers wear a device in the form of special glasses that display virtual information in the real world. During the picking, the device displays all necessary information to the picker, including the location and quantity of the articles [8]. This technology enables the realization of multiple operations at the same time, requires complex employee training, ensures high productivity, etc.

Pick-by-light (A3) is a technology that, by emitting light signals on rack cells, provides information to the picker from which location he should pick the articles. On the shelves, there are buttons with light signals and screens that show the requested number of articles. After picking the articles, the employee confirms the completed task by pressing the button, which turns off the light signal [5, 9]. Pick-by-light technology requires simple training and provides satisfactory productivity, while from the aspect of implementation, it is complex and does not support the realization of multiple operations simultaneously.

RFID (A4) is a technology that enables contactless reading and wireless data transfer from tags. The basic components of this system are tags, readers, and central software. The employee uses a reader to scan the tags of exceptional articles and confirm the completed task. Information from the tags is transmitted to the central software via radio waves [5]. This technology is simple to implement, requires employee training, and is characterized by low productivity and the inability to perform multiple operations simultaneously.

2.2 Criteria for the evaluation of pick-assist technology

The evaluation of the proposed pick-assist technology was carried out concerning efficiency and technological criteria [10-13]:

- **Efficiency criteria**: Productivity (C1) – refers to the measure of efficiency and effectiveness in the performance of picking activities, determined through the number of retrieval units per hour. Investment costs (C2) – includes the total costs of acquiring hardware, software, and system infrastructure. Operating costs (C3) – includes the costs that an organization incurs during its day-to-day operations to maintain and manage its operations. The ability to improve system performance (C4) – refers to the ability of technology to improve a system to achieve better results or provide better performance than the current state. Reliability (C5) – refers to the measure of security and consistency in system operation.
- **Technological criteria:** The possibility of performing dual operations (C6) – the possibility of realizing additional activities in addition to picking. The complexity of implementation (C7) –refers to the assessment of how quickly and realistically it is feasible to integrate and apply a certain technology into the existing system. Training course (C8) – is the process of providing employees with specific skills, knowledge, and competencies to increase their efficiency, productivity, and ability to perform their tasks appropriately. Flexibility (C9) – it represents the ability of technology to adapt to different requests and changes in the environment.

3. HYBRID MCDM MODEL

A hybrid multi-criteria decision-making (MCDM) model that combines the Fuzzy Analytic Hierarchy Process (FAHP) [14] and Fuzzy Technique for Order Performance by Similarity to Ideal Solution (FTOPSIS) [15] methods is used in this paper to solve the problem of ranking and selection of pick-assist technology. Using fuzzy logic enables us to effectively model uncertainty and vagueness in real-world data, providing flexibility and tolerance to errors in analysis and decision-making. This technique allows for more inclusive and precise interpretation of linguistic terms and complex situations, enhancing decision-making processes across various domains. In the paper, both the FAHP and FTOPSIS methods were utilized: FAHP was employed for evaluating criteria due to its suitability for their pairwise comparison, while FTOPSIS was used for ranking alternatives, as it determines their proximity to potentially optimal and worst solutions. The implementation process of each method involved defining the criteria hierarchy, selecting an expert team, gathering and analyzing data, as well as interpreting the results. The methodology for integrating the results into the final ranking of alternatives included combining the evaluations obtained from FAHP with the distances of alternatives calculated using FTOPSIS. The steps of the model application are as follows.

Step 1. Define the problem structure and pair-wise comparisons – The problem needs to be structured hierarchically following the FAHP method. For the pair-wise comparison procedure in the AHP method, Satie's scale (1-9) is used. Pairwise comparisons need to be performed for all sub-criteria and criteria relative to the higher level of the hierarchy. Table 1 provides linguistic scale and corresponding triangular fuzzy numbers to be used for assessment.

Table 1 Linguistic evaluations for comparing criteria/alternatives

Linguistic scale	Fuzzy numbers	Linguistic scale	Fuzzy numbers
Absolutely preferable/better (AP/B)	(8,9,10)	Moderately preferable/better (MP/B)	(3,4,5)
Very preferable/better (VP/B)	(7,8,9)	Remotely preferable/better (RP/B)	(2,3,4)
Strongly preferable/better (SP/B)	(6,7,8)	Barely preferable/better (BP/B)	(1,2,3)
Pretty preferable/better (PP/B)	(5,6,7)	Equally important/good (EI/G)	(1,1,2)
Quite preferable/better (QP/B)	(4,5,6)		

Step 2 - Defining the fuzzy matrix $\tilde{E}$

In this step, the fuzzy matrix used in the FAHP method for pairwise comparisons is defined. The matrix is formed for each set of criteria/subcriteria being compared to each other.

$$\tilde{E} = \begin{bmatrix} \tilde{a}_{11} & \cdots & \tilde{a}_{in} \\ \vdots & \ddots & \vdots \\ \tilde{a}_{n1} & \cdots & \tilde{a}_{nn} \end{bmatrix} \quad (1)$$

Step 3. Determining the relative weight of the criteria – For this paper, the "Logarithmic Fuzzy Preference Programming" (LFPP) method developed by Wang and Chin [16] was chosen to calculate the relative weight of the criteria. Each triangular fuzzy number is defined as follows: $\tilde{a}_{ij} = (l_{ij}, m_{ij}, u_{ij})$. The LFPP method is based on the calculation of the logarithmic function of the fuzzy number, as follows:

$$\ln \tilde{a}_{ij} \approx (\ln l_{ij}, \ln m_{ij}, \ln u_{ij})\,; i,j = 1, \dots, n \quad (2)$$

n – number of criteria

$$Min\,J = (1-\lambda)^2 + M \times \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} (\delta_{ij}^2 + \eta_{ij}^2), \quad (3)$$

$$s.t. \begin{cases} x_i - x_j - \lambda \ln(m_{ij}/l_{ij}) + \delta_{ij} \geq \ln l_{ij}, i = 1, \dots, n-1; j = i+1, \dots, n \\ -x_i + x_j - \lambda \ln(u_{ij}/m_{ij}) + \eta_{ij} \geq -\ln u_{ij}, i = 1, \dots, n-1; j = i+1, \dots, n \\ \lambda, x_i \geq 0, i = 1, \dots, n \\ \delta_{ij}, \eta_{ij} \geq 0, i = 1, \dots, n-1; j = i+1, \dots, n \end{cases} \quad (4)$$

Where is: $\boldsymbol{x_i^*(i = 1, \dots, n)}$ – optimal solution; $\boldsymbol{M = 10^3}$ – very large constant.

Step 4. Determination of weight criteria – The crisp normalized priority vector of the matrix $\widetilde{A} = (\tilde{a}_{ij})_{n\times m}$ can be obtained as:

$$W_i^* = \frac{exp(x_i^*)}{\sum_{j=1}^{n} exp(x_j^*)}, i = 1, \dots n, \tag{5}$$

Step 5. Normalization of the fuzzy matrix – Determination of normalized fuzzy matrix as follows:

$$\tilde{R}_{kj} = \left[\begin{pmatrix} \tilde{r}_{11} & \cdots & \tilde{r}_{1o} \\ \vdots & \ddots & \vdots \\ \tilde{r}_{p1} & \cdots & \tilde{r}_{po} \end{pmatrix}\right] \tag{6}$$

Where $\tilde{\boldsymbol{r}}_{\boldsymbol{kj}} = (\boldsymbol{l}_{\boldsymbol{kj}}, \boldsymbol{m}_{\boldsymbol{kj}}, \boldsymbol{u}_{\boldsymbol{kj}})$ is the assessment of alternatives $\boldsymbol{k}\,(\boldsymbol{i} = \boldsymbol{1}, \dots, \boldsymbol{p})$ with respect to criteria $\boldsymbol{j}\,(\boldsymbol{j} = \boldsymbol{1}, \dots, \boldsymbol{o})$ according to the scale from Table 5; p – total number of alternatives; o – total number of criteria; l_{kj}, m_{kj}, u_{kj} – lower, middle, and upper bounds of the fuzzy number, respectively.

Step 6. Weighted normalized fuzzy decision matrix – After normalization, by multiplying the matrix with the relative weight of the criteria (w_j) obtained by the FAHP method, a weighted fuzzy matrix is obtained and its mathematical notation is as follows:

$$\tilde{V}_{kj} = \left[\begin{pmatrix} \tilde{v}_{11} & \cdots & \tilde{v}_{1o} \\ \vdots & \ddots & \vdots \\ \tilde{v}_{p1} & \cdots & \tilde{v}_{po} \end{pmatrix}\right] \tag{7}$$

Step 7. Determining the distance – For each alternative determine the distance of the alternative from the Fuzzy Positive Ideal Solution and Fuzzy Negative Ideal Solution according to the FTOPSIS method. The ideal solution in the TOPSIS method maximizes beneficial criteria and minimizes costs, while the anti-ideal solution does the opposite by minimizing beneficial criteria and maximizing costs.

$$d_k^* = \sum_{j=1}^{n} d(\tilde{v}_{kj}, v_j^*), d_k^- = \sum_{j=1}^{n} d(\tilde{v}_{kj}, v_j^-), \tag{8}$$

Step 8. Ranking of alternatives – Finally, the final value of the alternatives according to the criteria is determined by calculating the CC_i coefficient as follows:

$$CC_k = \frac{d_k^-}{d_k^- + d_k^*}, \forall k = 1, \dots, p, \tag{9}$$

4. RESULTS OF MODEL APPLICATION

The process of evaluation and selection of the most suitable alternative was carried out using the hybrid MCDM model. Below is a numerical example that was solved by the presented model. Experts from the field of logistics provided their linguistic assessments for evaluating criteria and alternatives, which were then transformed by **Table1**. These transformed linguistic assessments served as inputs to the model, representing the expert knowledge encoded in a form suitable for the MCDM model. After applying the FAHP method the weights of the strict criteria are given in **Table 2**. Linguistic evaluations of alternatives according to criteria are given in **Table 2**. The evaluations used in the framework of the FTOPSIS method are defined on the same fuzzy sets as in the FAHP method.

The criteria obtained by the FAHP method in combination with the evaluations of the alternatives (**Table 1**) represent the input data for the FTOPSIS method. The final ranking of the alternatives obtained by the TOPSIS method is shown in **Table 3**. The obtained results show that the best ranked is A1, and the worst ranked is A4. A2 is in second place, while A3 is in third place.

Table 2 Evaluation of alternatives by criteria

	A1	A2	A3	A4	Wj
C1	VB	PB	QB	RB	0.405
C2	AB	BB	MB	SB	0.135
C3	PB	BB	VB	MB	0.045
C4	VB	PB	QB	RB	0.010
C5	PB	RB	MB	SB	0.005
C6	VB	VB	MB	MB	0.296
C7	AB	QB	RB	SB	0.076
C8	VB	RB	SB	QB	0.024
C9	AB	VB	QB	VB	0.004

Table 3 Rank of pick-assist technology obtained by FTOPSIS method

CC_k	Rank
0.963	1
0.562	2
0.334	3
0.232	4

5. CONCLUSION

The productivity of warehouses largely depends on the realization of their processes. Increasing the productivity of the dominant storage processes contributes to increasing the productivity of the warehouse itself as well as the entire SC. In the era of automation, digitization, and robotization, various ways of improving storage operations are available. One of those ways is the introduction of modern pick-assist technologies in order picking [1-3]. Order picking is a crucial part of a distribution warehouse and provides numerous possibilities to improve its processes. According to the sophisticated structure of the order-picking method, this paper has focused on the management aspect of account selection. There are numerous technologies for guiding order pickers through the warehouse: RFID, pick-by-voice, pick-by-light, pick-by-vision, and others. The mentioned technologies differ according to the possibilities of their applications. Based on that and analyzing the case study, it is necessary to select the most suitable one.

This paper examines a case study of a distribution warehouse, which has reduced productivity due to inefficient implementation of customer requests. The analyzed warehouse uses RFID technology and plans to replace it with one of the new pick-assist technologies. In the paper, three alternatives were considered, which were evaluated based on nine criteria. A hybrid method consisting of FAHP and FTOPSIS methods was used for decision-making. The FAHP was used to obtain the weight of the selected criteria, and the FTOPSIS method was used to obtain the final ranking. The most favorable solution was obtained with pick-by-voice technology. This technology also has the best rating according to the most important criteria. This investigation provides the foundation for comparing pick-assist technologies. In addition, the evaluation was done for a real-life case study, that is, to solve the problem in the warehouse. The disadvantage is reflected in the fact that the solution cannot be accepted as universal, but for every other task, it must be evaluated following the specific task. The contribution of this paper lies in providing guidelines for selecting pick-assist technology based on real criteria for a typical warehouse. The development of this paper can be directed towards the inclusion of a wider set of criteria or the application of other MCDM methods.

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