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AHP method application in selection of appropriate material handling equipment in selected industrial enterprise

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Abstract

The paper deals with handling equipment that can be used to transport/handle the final products in a selected industrial enterprise. The suitable handling equipment listed in the short-listwereselected by the authors of the paper based on the entry requirements and conditions of the enterprise and trends in material/final product handling towards increasing automation, enhancing productivity and maximizing safety. The Analytic Hierarchy Process method was used to support decision making on the appropriate handling equipment and specific calculations were carried out in the Expert Choice program. The Analytic Hierarchy Process as a tool of exact decision-making methods increases the objectivity of decision in general as well as the quality of suitable handling equipment selection in a particular industrial enterprise. One of the conditions of the enterprise for the equipment selection was the use of Intelligent/Smart solutions in the process of finished goods handling from the manufacturing area to warehouse.

Keywords Material handling · Automatic guided vehicle · Autonomous mobile robot · Analytic hierarchy process · Decision-making process

1 Introduction

Material handling is a vital element of the supply chainswhich involves a variety of operations including the movement, storage, protection and control of materials and products throughout the processes of manufacturing and distribution. Having efficient material handling systems is of great importance to these industries for maintaining and facilitating a continuous flow of materials through the workplace and guaranteeing that required materials are available when needed [1].

The internal transport system consists of the following basic elements: transported material, transport and handling units, transport vehicles and handling facilities, personnel and system of organization and management of the transport processes in the enterprise [2].

In response to the global technology shift, the worldwide competition and the demands of product variety, a large percentage of traditional manufacturing is undergoing organizational transformation and technology investment that make factories smarter and more efficient. The paradigm shift in technology has already started transforming public/private manufacturing and logistic industries including warehousing, automotive, etc. [3].

Intelligent/smart technology in industry and logistics is a relatively new concept that entered the market in the last few years. The impact of new trends on the logistics market in Slovakia is evident [4]. Enterprises are competing in the search for innovation in the logistics market, and thus

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technologies are developing at a dizzying space [5]. Smart Connected System Logistics is formed by implementation of intelligent/smart technologies, ideas, and concepts into logistics processes. Smart Connected System Logistics is basically Intelligent Connected Products (e.g. Automated Guided Vehicles, automated storage equipment, etc.) organized through the cloud, while the cloud-based solution is also access to information from other data factory sources such as system planning and management, external logistics etc. [6].

There are many types of special equipment that have been designed to reduce labour costs and/or increase space utilization. Storage and retrieval equipment can reduce labour costs by [7]:

- Allowing many pieces to be on the pick face, which increases pick density and so reduces travel per pick, which means more picks per person-hour.
- Facilitating efficient picking and/or restocking by making the product easier to handle (for example, by presenting it at a convenient height and orientation).
- Moving product from receiving to storage; or from storage to shipping.

Storage equipment can increase space utilization by [7]:

- Partitioning space into sub-regions (bays, shelves) that can be loaded with similarly sized pieces. This enables denser packing and helps make material-handling processes uniform.
- Making it possible to store product high, where, up to about 30 feet (10 meters), space is relatively inexpensive (above this height, the building requires additional structural elements).

Material handling systems can always be improved but rarely eliminated. In most operations, material handling can account for 30–75% of an item's total production cost. Moreover, in a typical manufacturing company, material handling accounts for 25% of employees, 55% of all factory space, and 87% of the production time. Streamlining material handling systems can greatly reduce costs across all fields [8]. Analytic Hierarchy Process method, well known as AHP, was created by American professor of mathematics acting at the University of Pittsburgh [9]. AHP was developed as a practical tool for supporting decision making with it application in several areas form individual human problems to global conflicts. It represents a basic theory of subjective measurement and is a tool for assigning weights to compare certain criteria or alternatives. AHP provides a model for decision-making, ranking, and prioritizing problems that is flexible and allowing to manage and formulate the hierarchy model according to certain situation [10].

AHP is performed by a special and consequently mathematical method, which divides the main problem into smaller and more detailed elements. The AHP method introduced by Saaty [11] is a procedure to divide a complex problem into a number of deciding factors and integrate the relative dominance of the factors with the solution alternatives to find the optimal one. It consists of following steps [12]:

Step 1 Structuring a problem as a decision hierarchy of independent decision elements
Step 2 Collecting information about the decision elements
Step 3 Comparing the decision elements pair wise according to their levels of influence with respect to the scale shown in the Table 1. The comparison results are presented in a square matrix B = $[\alpha_{ij}]_{n\times n}$, where "n" is the number of factors, and α_{ii}= 1,α_{ji}= 1/α_{ij},$\alpha_{ij} \neq 0$
Step 4 Relative weights of the factors are calculated by eigenvector of the matrix with the eigenvalue (λ *max*) closest to the number (n) of factors. Since comparison performed in AHP are subjective, judgment errors are inevitable and have to be detected through calculating a consistency index (CI) of the AHP matrix given by

$$\mathrm{CI} = \frac{(\lambda \max - n)}{n - 1} \tag{1}$$

The consistency ratio (CR) is given by

$$\mathrm{CR} = \frac{\mathrm{CI}}{\mathrm{RI}} \tag{2}$$

where, RI is random consistency index shown in the Table 2. Modification of the comparisons is needed when CR > 10%.

2 Automated guided vehicles and autonomous mobile robots

Material handling is of extreme importance to logistics and manufacturing industries as it accounts for a large percentage of the operation. In the manufacturing sector, the

Table 1 Saaty's 1–9 scale of pair wise comparison [12]

Intensity of importance	Definition
1	Equal importance
3	Moderate importance
5	Strong importance
7	Very strong importance
9	Extreme importance
2,4,6,8	Intermediate values

Table 2 Average random consistency index [12]

Size of matrix	1	2	3	4	5	6	7	8	9	10
RI	0	0	0,58	0,9	1,12	1,24	1,32	1,41	1,45	1,49

time spent on material/product handling and transportation can be as much as the time used on the value-added processes. Banks et al. [13] claimed that the time of material handling is about 85% of total manufacturing time. For the mentioned reason, the ability to analyse and evaluate material handling systems is essential for decision makers to improve material flow management and optimize manufacturing and distribution operations [1].

One of the core components in the manufacturing industry are the logistic systems. Automated Guided Vehicles (AGV) are widely used to transport goods and materials to different parts of a factory and are considered to be one of the most efficient and suitable options. AGV systems must be able to handle different situations, such as a change in layout, and operate in a dynamic environment. These challenges require smart decision-making inside a factory environment [14].

AGVs are a mature technology that can safely transport payloads ranging from several Kg to multiple tonnes, essentially acting as semi-rigid distributed conveyer belts covering large areas. Their navigation technology is evolving. Today multiple options are available ranging from the low-cost wire or magnetic tape guidance to the increasingly popular laser guidance. However, all requires following rigid guide points, thus requiring some degree of infrastructure modification and extended onsite installation [15].

Autonomous mobile robots (AMR) are radically different although AMR will ultimately enable automation to largely keep the flexibility and versatility of human-operated vehicles [15]. AMRs use computer-based vision systems to navigate through their environment. According to Datta and Banerji [16], “the advantage of this type of robot is that existing manufacturing environment does not have to be altered or modified as in the case of conventional automatic guided vehicles where permanent cable layouts or makers are required for navigation.” This type of robot is free to roam and perform tasks anywhere in the facility. The mentioned is a clear advantage over AGVs [8].

The difference between AGVs and AMRs are as following [17]:

- AMR’s are different from AGV in their level of autonomy.
- Automated systems are designed to perform a set of repetitive tasks by following pre-defined instructions with minimal or no human intervention.
- Autonomous systems, on the other hand, are not only able to perform defined tasks automatically but also have the intelligence to make independent decisions in ‘never-seen-before’ scenarios.
- AGVs follow fixed routes, usually along wire guidance, laser guidance or magnets embedded in the floor like trains. They are typically pre-programmed to follow a set of rules and have very little on-board intelligence.
- AMRs are robots so they have on-board computing and logic. AMRs navigate via maps that its software constructs on-site based on a walk through or via preloaded facility drawings like a car with a GPS. When it is given start and end locations, it generates the most direct path based on the map. They can dynamically respond to their operating environment to navigate around obstacles like pallets, people or forklifts, finding alternative routes to perform tasks and move loads.

This autonomous operation makes an AMR far more flexible than an AVG giving businesses the agility and flexibility they need for Industry 4.0. The main differences between AGV and AMR related to certain criteria are summarized in the Table 3.

One of the paper authors has previously published in articles the application of the AHP method in the area of human resources management, namely in the assessment of employees based on competencies in the article “Competencies of Managers as part of the Intellectual Capital in Industrial Enterprises”, as well as in the area of reverse logistics, article “Application of AHP in the process of sustainable packaging in the company”. Based on the research of published articles in various databases, several authors use the AHP method to support multi-criteria decision making in logistics, examples in Selection of Logistics Outsourcing Service Providers, reverse logistics service provider selection, An AHP-based framework for logistics operations in distribution centres and etc. On the basis of mentioned and the evaluation of the advantages and disadvantages of the AHP method, the method was chosen as suitable for its use in the area of logistics.

3 Application of AHP method in solving the specific issue

As mentioned above, the paper presents a multicriteria decision making model for supporting the decision on the appropriate handling equipment with finished goods based

Table 3 The difference between AGVs and AMR [18]

	AGV	AMR
Navigation	Infrastructure: wire guidance, reflective markers, Radio frequency ID, etc.	Trackless navigation. All sensing is done on-board. Senses the environment in a live fashion
Obstacles	Obstacles stop an AGV	Goes around obstacles and finds what the best path is according to its internal map
Flexibility	New tracks and infrastructure to be installed	Easily be remapped and taught new destinations and goals
Expandability	Possible to add new tracks and new units to it	Everything is managed on a fleet software package
Charging	Docking Station	Docking Station

on AHP method. In the process of suitable handling equipment selection, a number of criteria and requirements enter the decision-making stage, what make the process a multi-criterion problem. The Analytic Hierarchy Process supported by the Expert Choice program was chosen for solving the given problem from the wide range of methods of multi-criteria evaluation of the required level of qualification requirements. The algorithm for the individual steps of the AHP method application in the selection process is shown in Fig. 1.

Selected industrial enterprise is an enterprise which deals with the production of tires. At present, the transport/handling of the final products in the company is realized by forklifts. The enterprise disposes by the following types of forklifts:

- forklifts with clamp attachment,
- forklifts used for handling with specialized metal column pallet.

The application of the AHP method in selection of suitable handling equipment in enterprise was conditional to the following entry requirements:

1. Enterprise plans to increase the production volume.
2. Based on the previous requirement, it is necessary to ensure optimization and improvement of post-production handling processes.
3. Application of Smart solutions.
4. Consolidation of warehouse management in the expedition warehouse.

The fulfilment of the abovementioned requirements could be achieved through the use of several technologies. Based on the current situation in the enterprise and input requirements, the following handling equipment were proposed as solution variants:

- forklifts (currently used handling equipment in the enterprise)

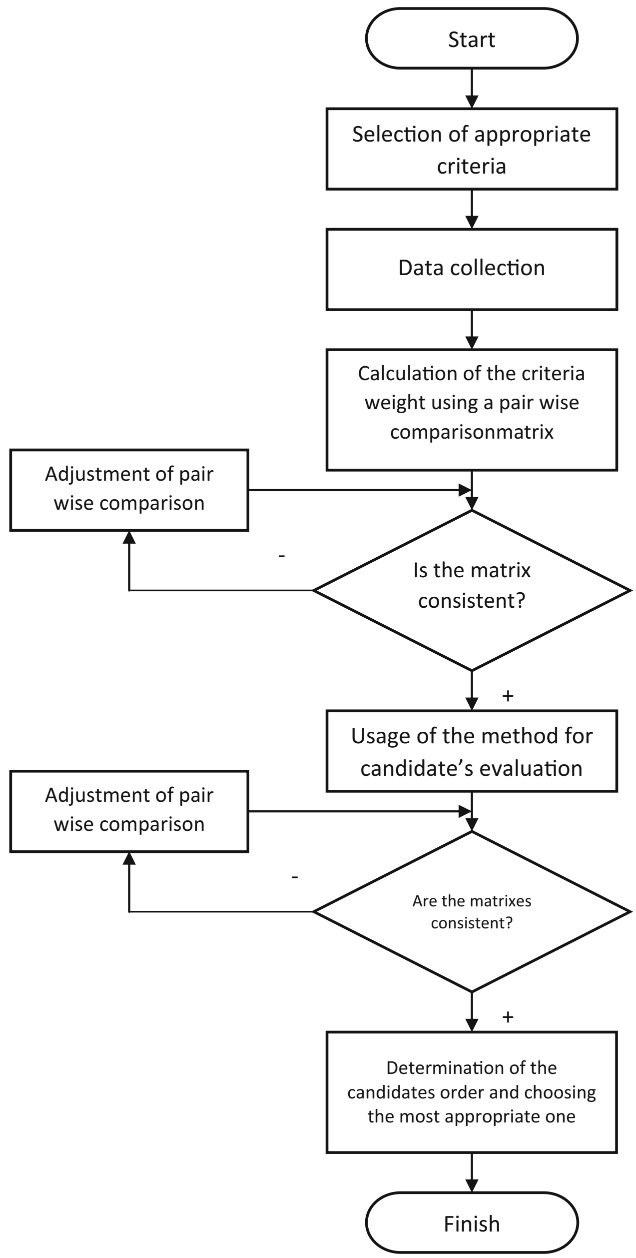

Fig. 1 Algorithm of AHP method application (authors of the paperown elaboration, 2019)

- AGV (the enterprise considered the implementation of AGV as one of the possible solutions to solve the current state)
- AMR (the solution was proposed by the authors of the paper based on input requirements of the enterprise and the nature of the device as smart solutions, its advantages and disadvantages compared to other solution variants)

The precondition for applying the method was to create a hierarchical structure of the problem based on the AHP method, which consists of the following steps:

Ad 1) To define the goal of the decision problem.
Ad 2) To identify the possible solutions variants of the problem.
Ad 3) To determine the criteria for evaluation of the solution variants.
Ad 4) To establish the relationships among the goal, variants a criteria and to compile the hierarchical structure

Ad 1) Definition of the decision problem goal As a goal of the decision was set "to determine the appropriate technology of handling equipment in post-production processes, based on the requirements of the enterprise". The goal is tied to addressing issues related to increasing production and efficiency of logistics in the enterprise.

Ad 2) Determination of possible solutions variants of the problem Solution variants represent technologies—specifically the handling equipment that have been selected in the short list. From a practical point of view, technologies/equipment unrealizable in the conditions of the enterprise have been eliminated from the decision-making process. The short list consists of 3 abovementioned Technologies: forklifts, AGV forklifts and AMR.

Ad 3) Determination of the criteria for evaluation of the solution variants The criteria were defined on the basis of enterprise requirements and generally applicable criteria used for investment decisions. The following criteria were included in the evaluation model:

1. *The amount of investment* the amount of estimated funds for the purchase and implementation of the proposed/selected solution.
2. *Flexibility* the ability of given solution to adapt to change of production concept/layout; the suitability for repetitive/non-repetitive jobs.
3. Return on investment.
4. *Number of employees* a solution that would contribute to reduce the number and utilization of employees.
5. Repair and maintenance intensity.
6. *Safety* safety/reliability of the operation (elimination of danger threatening the life and health of employees, elimination of human factor mistakes affecting the safety, etc.)
7. *Implementation intensity* time and technical intensity.

Ad 4) Creation of the hierarchical structure The result of the previous steps was the creation of a hierarchical structure, the Fig. 2.

The Expert Choice program was applied to solve the given problem. The procedure was as following:

(A) Determination and writing the goal, criteria and variants of the problem.
(B) Assignment of weight to individual criteria by pairing comparison of the criteria.
(C) Evaluation of the variants based on the pair comparison of the individual criteria.
(D) The resulting (synthetic) evaluation of individual variants.

(A) Determination and writing the goal, criteria and variants of the problem

The procedure is detailed described above, in the steps of creating the hierarchical structure (steps Ad 1)–Ad 4)).

(B) Weight assignment to individual criteria

Based on the evaluation of individual projects, a pair wise comparison matrix of criteria was created. In the pair wise comparison matrix, the criteria are compared on the basis of the rating scale. The EC software calculated the weight of the individual criteria on the basis of the pair comparison (Fig. 3). The most important criteria are the amount of investment, return of investment, safety and reliability of operation. In addition to evaluation of the individual criteria significance, the consistency value which value must be lower than 0.1 is displayed. In this case, the consistency value is 0.04. The logical consistency in the pairwise comparison was preserved.

The EC software displays decimal numbers by using rows, not the points as it is usual in English and the software does not display decimal numbers in the form of 0.XXX but it only displays the numbers following the decimal comma, i.e. without displaying a number zero.

(C) Evaluation of the variants according to individual criteria

Alternatives are evaluated in the same way as criteria. The result is pairwise comparison matrix of alternatives according to individual criteria from C1 to C7.

The Fig. 4 shows the evaluation of the variants significance according to the C1 criterion and at the same time it shows also the order of variants based on the obtained values, in ascending order, created by the EC software. The Fig. 4 subsequently shows a verified consistency with the

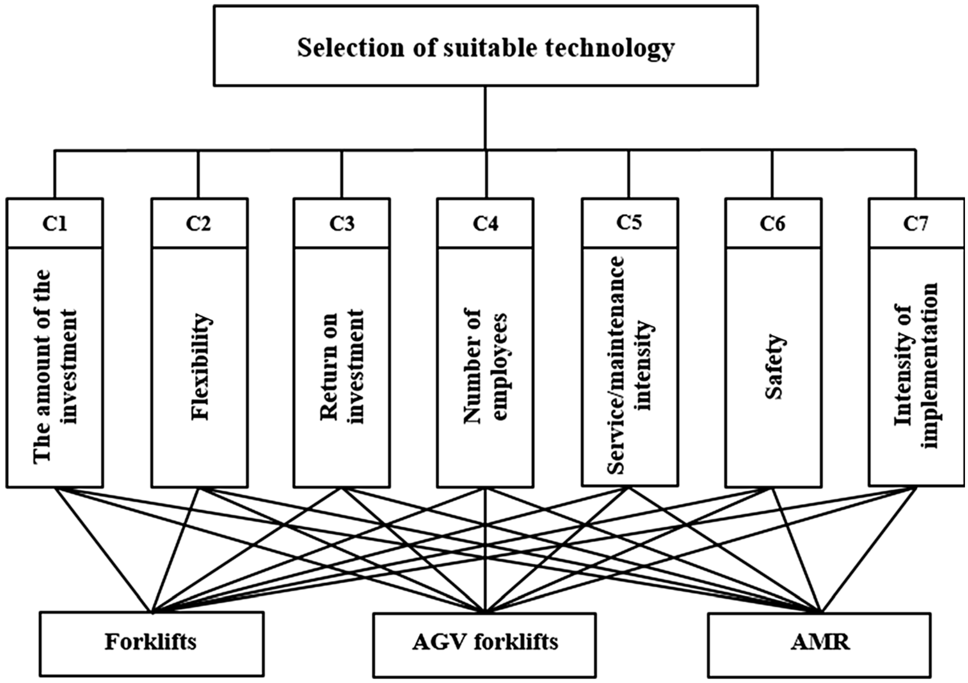

Fig. 2 Hierarchical structure for decision process (authors of the paper own elaboration, 2019)

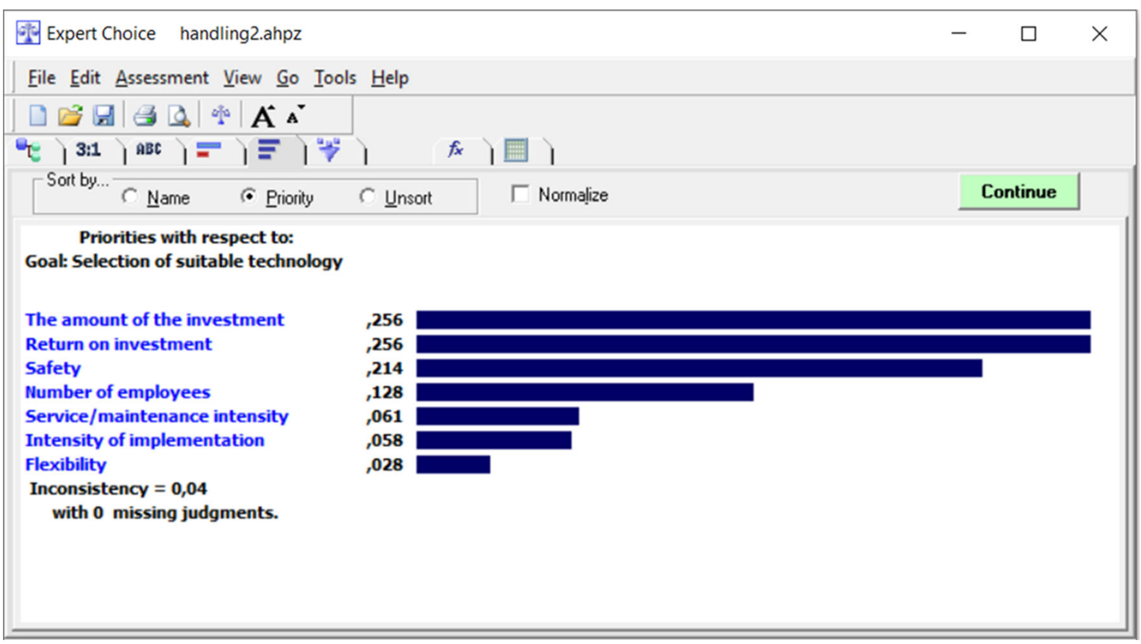

Fig. 3 The evaluation of criteria significance and consistency analysis (authors of the paper own elaboration in software Expert Choice, 2019)

value 0.00, which indicates that the logical consistency in the pairwise comparison was preserved.

The output from the EC software is the Fig. 5, which describes the order of individual handling equipment variants. The order of technologies is based on the values calculated by the EC program.

(D) The evaluation of the optimal solution variant, respectively the order of individual technologies (handling equipment)

The result of the decision-making process, based on criteria and input conditions in the enterprise, was the fact that the optimal solution variant is AMR. It is necessary to note that the order of individual handling equipment would be different under the specific conditions in other

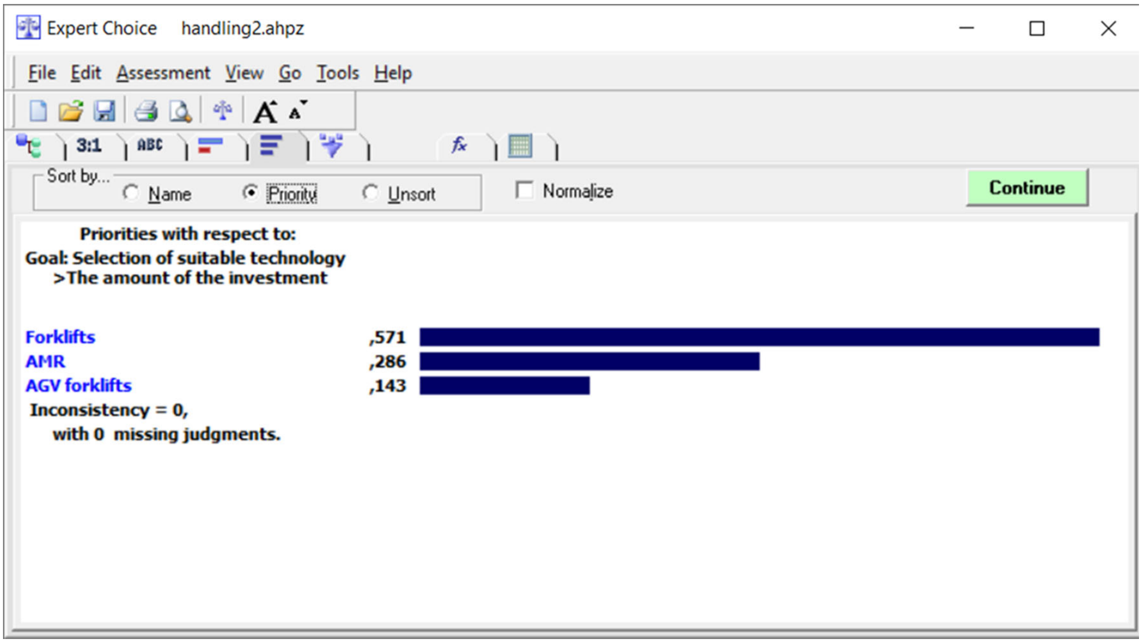

Fig. 4 Evaluation of the variants significance according to the C1 criterion (authors of the paper own elaboration in software Expert Choice, 2019)

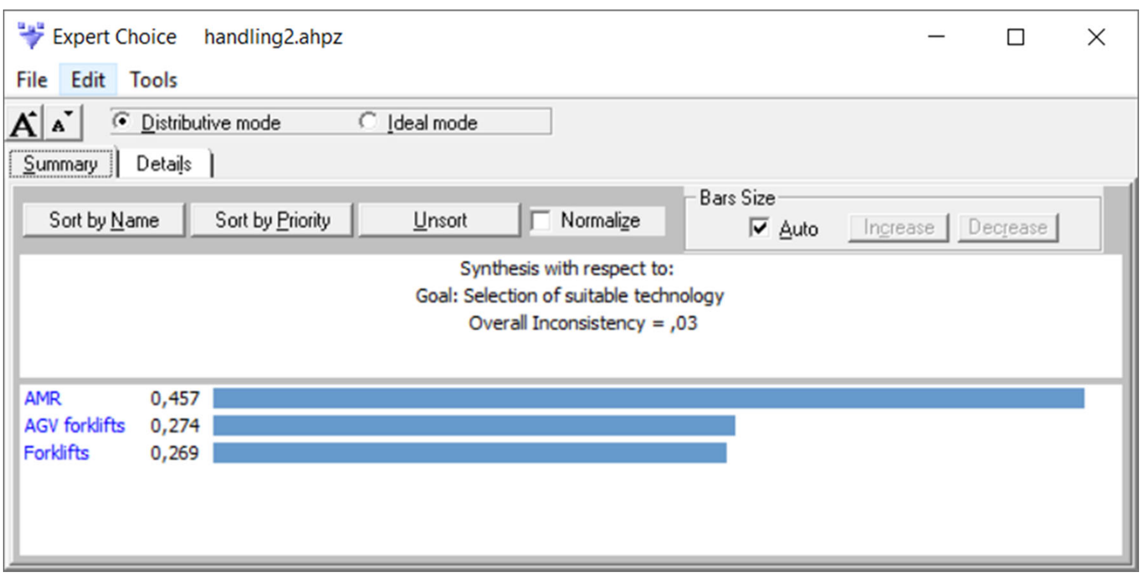

Fig. 5 The resultant evaluation of the technologies significance (authors of the paper own elaboration in software Expert Choice, 2019)

enterprises. Factors which would affect decision on the suitability of individual handling equipment are several: size of the enterprise, financial strength of the enterprise, production volume, character of the production/product, experience with the use of smart technologies, effort to engage/not engage the human resources, etc.

4 Conclusion

In general, several authors declare that material handling is an expensive non-value adding activity can account for 30–75% of a product's manufacturing cost. A typical manufacturing company dedicates 25% of its employees, 55% of its factory space, and 87% of its production time to material handling [8, 19].

Implementation of smart/intelligent solutions to the area of Logistics would help to improve for example through put time, lead time, and work in progress. However, in selection of smart technology, it is necessary to take into account the amount of investment needed to purchase and implement specific technology into practice, as well as ROI. Other factors that influence the selection of appropriate technology are specific input conditions in the enterprise, size of the enterprise, production volume, and financial strength of the enterprise and etc. Based on the abovementioned and study of various articles, the authors of the paper included AGV and AMR technologies to the short list of smart solutions. Both of the technologies could also be integrated to existing MES, WMS and other line management systems.

When comparing AGV and AMR Technologies: the cost of implementation (AGV costs averaging $ 125,000 per AGV, and AMR costs $ 60,000 per two AMR on average), suitability for repetitive and non-repetitive jobs, implementation complexity, and etc., the AMR technology could be considered as material handling solution for the future.

By applying AHP method to decision making process on appropriate handling equipment based on the determinate criteria and input condition of the enterprise, the AMR technology was selected and confirmed as the most appropriate technology to handle/transport final products under conditions of the selected enterprise.

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