APPROACH TECHNIQUE OF SPECIFYING A PROPER AUTONOMOUS CART TYPE FOR ITS SERVICE IN THE LOGISTICS CENTER

ONDREJ STOPKA[1]

Abstract

Basically, relocation, protection, warehousing and management of materials and products throughout the logistics chain (manufacturing, warehousing, distribution, consumption and disposal) are referred to as cargo handling. Cargo handling includes a variety of manual, semi-automated and automated devices, processes and systems supporting the manufacture and logistics, and helps with the efficient cargo flow across the logistics chain. This research study designs an approach technique (procedure) to specify a proper type of the autonomous cart as a part of handling devices for its service activities within the area of opted logistics center applying an adequate multiple-criteria analysis method. Introductory parts of the paper summarize relevant literature review regarding research topic, methods and procedures important to compile the draft technique, identify all the relevant criteria used for the given purpose as well as define variants of autonomous carts taken into consideration in order to calculate the final outcome. The most important chapter specifies the approach technique design itself including application of method to calculate the criteria weights as well as use of the multiple-criteria analysis method, specifically the Weighted-Sum Approach, in order to define the variant ranking.

Keywords: Logistics service, logistics center, handling device, autonomous cart, multiple-criteria analysis

1. Introduction

Goods handling devices are considered the mechanical devices utilized within the carriage, warehousing, reloading, control, marking and securing the raw material, semi-products, final products, spare parts, returned and recycled goods throughout all the processes of manufacturing, in-house transport, distribution, supply activities, storage, consumption and disposal within the whole logistics chain. Various kinds of handling devices can be classified into several main categories [1, 2]:

- transportation device,
- positioning device,
- specialized reloading device (horizontal, vertical, combined),

[1] Institute of Technology and Business in Ceske Budejovice, Faculty of Technology, Department of Transport and Logistics, Okruzni 517/10, 370 01 Ceske Budejovice, Czech Republic, e-mail:stopka@mail.vstecb.cz

- loading unit formation device,
- warehousing device.

Particularly, transportation device is used to relocate goods from one place to another (for example, among workplaces, loading ramps as well as warehousing sites, etc.), whilst positioning and specialized reloading device is used to handle with goods at an individual point. The most important subcategories of transportation devices include cranes, conveyors and industrial trucks. Goods can be carried manually applying no device as well [3].

In relation to the term of "Industry 4.0" [4], a procedure for implementing transportation autonomous carts for carriage of materials on different types of pallets from point A to point B within logistics facilities (mainly manufacturing and assembly premises, warehouse and distribution facilities) is being initiated in various manufacturing, assembly and light-logistics companies in order to increase the efficiency of in-house handling activities [5-8].

Autonomous goods handling device [9, 10] is referred to as autonomous or self-driving technology for material handling and transportation equipment. This technology can be used to transform manually operated material handling equipment like push carts, pallet trucks, forklifts etc. into robotic equipment supervised by autonomous warehouse/manufacturing system. This technology has been used to develop autonomous carts especially for distribution centers so far [11, 12].

Procedure of goods flow in the area of automated logistics center is vividly depicted in the following figure (Fig. 1).

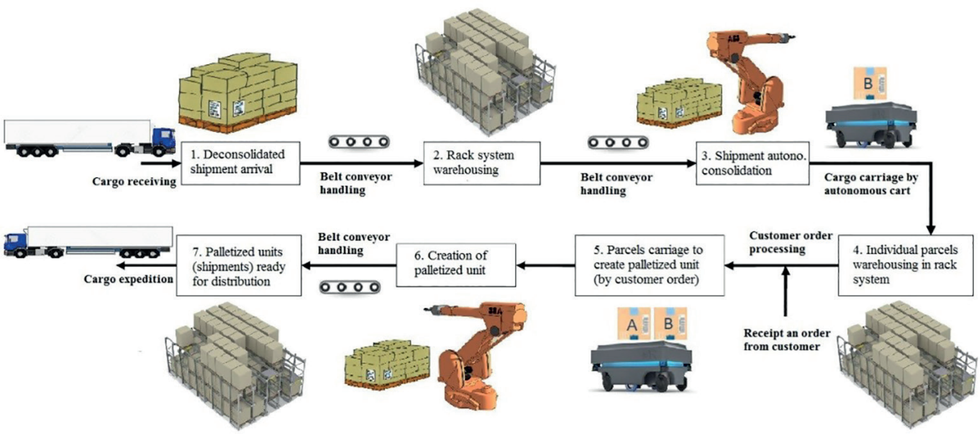

Fig. 1. Goods flow in the area of automated logistics center. Source: The authors

2. Data and methods used for approach technique compilation

Specification of a proper type of handling device for its service in the logistics center when implementing multiple-criteria evaluation of variants (selecting the proper handling device) may be deemed the decision-making matter [13, 14].

To solve a decision-making matter regarding specification of a handling device, several techniques of multiple-criteria analysis can be implemented [15-19]. Group of variants must be known, and subsequently, the specific one is to be identified [20].

Basically, a process in terms of multiple-criteria evaluation of variants (variant rankings determination) covers four adjacent parts [21-23]:

a. criteria and variants selection;
b. weights of criteria calculation;
c. continuous assessment of variants and intermediate calculations;
d. proper variant identification (variant ranking determination).

2.1 Techniques for weights of criteria calculation

Techniques to calculate the weights of criteria are diversified depending on the information having on the importance of criteria [22-24]:

- no information (e.g. Entropy technique);
- ordinal information (e.g. Fuller triangle technique, ranking technique);
- cardinal information (e.g. Saaty technique, scoring technique).

2.2 Techniques for the proper variant identification

Techniques for the proper variant identification, taking into consideration multiple-criteria analysis [25-27], are split depending on the information on an importance among the pairs of criteria; these techniques are, as follows:

- maximizing criteria relevance;
- minimizing criteria relevance;
- depending on the preferential relationship.

Individual techniques to identify the proper variant (or to determine the variant rankings) involve [25, 28]:

- ranking / scoring technique;
- Topsis technique;
- Oreste technique;
- Weighted-Sum Approach;
- Analytic Hierarchy Process;
- etc.

3. Obtained results – the approach technique design

This chapter covers a particular application of techniques of the multiple-criteria analysis to compile the approach technique for specifying a proper handling device (see chapter 2).

3.1 Criteria and variants selection

In order to specify a proper handling device for its service in the logistics center, six criteria ($C_1 - C_6$), as follows, are taken into account:

- C_1 – lift height [m];
- C_2 – battery life [hours];
- C_3 – payload capacity [kg];
- C_4 – driving speed [m/s];
- C_5 – GPS navigation [-];
- C_6 – handling device price [€].

In regard to selection of group of variants (autonomous carts – V_j), advanced (innovative) autonomous handling device, for its service in opted logistics center, manufactured by various producers are to be considered. Six autonomous carts [28, 29], as follows, are taken into account for further calculations (see Table 1):

- V_1 – autonomous cart 1;
- V_2 – autonomous cart 2;
- V_3 – autonomous cart 3;
- V_4 – autonomous cart 4;
- V_5 – autonomous cart 5;
- V_6 – autonomous cart 6.

Table 1. Assignment of criteria and their values to individual variants. Source: The authors

Criteria (C_j) / Variant (V_j)	lift height [m]	battery life [hours]	payload [kg]	driving speed [m/s]	GPS [-]	price [€]
autonomous cart 1	4	8	1 500	9	1	80 000
autonomous cart 2	1.9	9	1 200	2	0	118 000
autonomous cart 3	0.5	5	1 000	1	1	69 950
autonomous cart 4	1.2	5	1 200	3	1	60 000
autonomous cart 5	4	8	1 200	6	0	120 000
autonomous cart 6	0.5	15	500	2	1	45 000

3.2 Weights of criteria calculation

To calculate the weights of each criterion, the ranking technique was applied – from the most important criterion to the least important.

The procedure of this technique is, as follows [26, 30]:

a) numbering the individual criteria:

$$\frac{\begin{matrix} criterion & C \\ criterion\ index & j \end{matrix}}{\begin{matrix} i.e. & C_1,\ldots C_6 \end{matrix}}$$

b) determining the ranking of criteria: 1 to 6

c) see Table 2 – assigning the points to individual criteria ($C_1, C_2, \ldots, C_n$), i.e. 1 to 6 points so that the most important criterion gets the maximum value of points (i.e. weights v, v – 1, ..., 2, 1) and calculating the weights of criteria itself (w_j – the normalized weight of individual criteria C_j with the weight of v_j), by the equation (Eq. 1) [26, 27]:

$$w_j = \frac{v_j}{1+2+\cdots+n} = \frac{v_j}{\frac{n(n+1)}{2}}, \mathrm{j} = 1,2, \ldots, n, \ [\text{-}] \tag{1}$$

Table 2. Calculating the weights of individual criteria. Source: The authors

Criterion	j	Ranking	v_j	w_j	
C_1 – lift height	1	6	1	1/21	0.05
C_2 – battery life	2	1	6	6/21	0.29
C_3 – payload	3	2	5	5/21	0.24
C_4 – driving speed	4	4	3	3/21	0.14
C_5 – GPS	5	3	4	4/21	0.19
C_6 – price	6	5	2	2/21	0.10
Σ	-	-	21	1	1

d) checking the correctness: $n(n+1)/2 = 6*7/2 = 21$ [-].

3.3 Intermediate calculations and variant ranking determination

Variant ranking calculation is performed by the Weighted-Sum Approach [26, 29, 30], thus the compromise variant of the handling device is identified. In regard to the multiple-criteria evaluation of the variants, we can assign each value of the criterion C_j its usefulness, i.e. we can create the utility function u_j, which for the variant V_i acquires the values of (see Eq. 2):

$$u_j(V_i) = u_{ij}; \mathrm{i} = 1,2, \ldots, m; j = 1,2, \ldots, n, \ [\text{-}] \tag{2}$$

The scope of this function is the interval between the best and the worst value of the relevant criterion. The range of function values is the interval of ⟨0,1⟩.

The procedure of this technique is, as follows [27, 30]:

a) to add the values of weights and the nature of each criterion into the table 1;

b) see Table 3 – conversion (change) of the price criterion from the minimization to a maximization character (improvement over the worst-case criteria value);

Table 3. Conversion of the price criterion. Source: The authors

Price (minimization character)	Price (maximization character)
80 000 €	40 000 €
118 000 €	2 000 €
69 950 €	50 050 €
60 000 €	60 000 €
120 000 €	0 €
45 000 €	75 000 €

c) to find the ideal variant h_j for each criterion and write the value of 1 into the cell where this variant was (see Table 4);

d) to find the basal variant d_j for each criterion and write the value of 0 into the cell where this variant was (see Table 4);

e) see Table 4 – to calculate the partial utility function u_{ij} of the value y_{ij}, while the relationship is, as follows (Eq. 3):

$$u_{ij} = \frac{y_{ij}-d_j}{h_j-d_j};\ \mathrm{i} = 1,2, \dots, m; j = 1,2, \dots, n,\ [-] \tag{3}$$

f) see Table 4 – for each variant, we calculate the aggregate utility function $u(V_i)$, using the normalized weight of individual criteria w_j, by the relationship (Eq. 4):

$$u(V_i) = \sum_{j=1}^{n} w_j u_{ij},\ [-] \tag{4}$$

g) see Table 4 – subsequently, we sort the variants by the values of $u(V_i)$. The highest value of this indicator represents the best possible variant.

Table 4. Variant ranking calculation. Source: The authors

Criteria (C_j) / Variant (V_j)		C_1	C_2	C_3	C_4	C_5	C_6	$u(V_i)$	Ranking
V_1		1	0.3	1	1	1	0.75	0.7796	1.
V_2		0.466	0.4	0.7	0.125	0	0	0.3237	6.
V_3		0	0	0.5	0	1	0.825	0.3925	5.
V_4		0.23	0	0.7	0.25	1	0.895	0.4935	3.
V_5		1	0.3	0.7	0.625	0	0.475	0.4376	4.
V_6		0	1	0	0.125	1	1	0.5975	2.
Criterion weight (w_j)		0.05	0.29	0.24	0.14	0.19	0.10		
Criterion nature		max	max	max	max	max	max		
h_j	ideal	4	15	1500	9	1	75000		
d_j	basal	0.5	5	500	1	0	0		

Following the realized calculations above, the variant no. 1 was specified to be the proper autonomous cart type (automatic guided handling device unit) for its service in the opted logistics center.

4. Conclusion

Over the past decade, a rapid growth of various information technologies is noticeable and it has reached the grade when robotic equipment begins to gradually substitute humans in military industry, logistics, production, entertainment and households in terms of domestic services. Robotic equipment and autonomous driving systems have been approaching our surroundings and in the end, they will substitute humans step by step.

Based on those statements, it is more than clear that we have to place emphasis on specifying the appropriate and innovative handling device for working throughout the entire logistics chains. As confirmed by this research study, in terms of decision-making while identifying the proper device for handling, several techniques of multiple-criteria analysis may be implemented. Particularly, the ranking technique, to determine the weights of criteria, and Weighted-Sum Approach, to define the variant ranking, when considering a variety of variant options, appear to be more than useful tools.

Specifically for the purpose of this study, two mentioned techniques were used in regard to draft of the approach technique to specify a proper autonomous cart (as one kind of the automatic guided handling device unit) for its service in opted logistics center. Those techniques, and others, could certainly be applied to research problems of analogous decision-making topics.

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