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THE PROCEDURE FOR CALCULATING INPUT PARAMETERS IN THE PROCESS OF DETERMINING POTENTIAL RISK ZONES IN WAREHOUSES

Abstract: *Taking into account that fire safety in warehouses is a serious challenge and has not been sufficiently investigated, this paper aims to present a new methodological approach concerning the mentioned issue. The COPRAS MCDM method was implemented in the aforementioned approach to determine the weight coefficients based on the emission and thermal characteristics of the materials placed in the high-bay warehouse. The mentioned coefficients represent input data for calculations and simulations related to determining potential fire risk zones. The effectiveness of the proposed approach was verified by a numerical example.*
Keywords: *Fire, High-bay warehouse, MCDM, COPRAS method, Fire risk zones*

1. INTRODUCTION

Bearing in mind that fire poses a serious threat to the safety of people and property, whether residential, warehouse, or industrial, managing the risk of fire outbreaks is a major challenge in urban and rural areas. [1]. Fires in warehouses have a small share in the total number of fires compared to other locations where fires occur. However, in terms of the release of heat, the size of the area affected by the fire, the degree of damage to the building itself, and material damage, these fires in warehouses have significant consequences compared to fires in other types of buildings.

Warehouses, which represent an integral part of logistics, are often exposed to various improvements and corrections in the development phase, all with the aim of better performance, capacity, and efficiency of the warehouses themselves. The aforementioned improvements result in larger and higher warehouses, the use of automated systems for storage and retrieval of storage units (AS/RS systems), increased storage density, and placement of storage units at higher heights [2]. The improvements above have made warehouses efficient, but they have also led to potential hazards in fire protection.

The analysis and modeling of fires in storage facilities, as well as the assessment of the risk of accidents, is attracting more and more attention from both researchers and engineers who design these facilities and systems. Fires in such buildings are characterized as very intense due to the high content of combustible matter per unit area about the volume of the building. Depending on the type of warehouse and the fuel in the warehouse, in the event of a fire, smoke and toxic combustion products (containing carcinogenic substances) are emitted intensively, which contributes to harming the health of people inside the facility as well as air pollution.

The main goal of the research in this paper is the development of a procedure for determining the input parameters necessary for the process of determining the potential risk zone of fire occurrence in high-bay warehouses. Compared to existing methods and approaches in the field of safety and risk assessment in warehouses, this procedure enables the precise determination of input parameters in the form of weight coefficients that are obtained based on the characteristics of the stored material. By using the multi-criteria decision-making method, weight coefficients are obtained for each material that is stored and which represents input data in the process of determining the specified location in the high-bay warehouse.

2. MATERIALS AND METHODS

The procedure for determining input parameters consists of two parts (Fig. 1). The first part refers to the selection of parameters used in fire risk assessment methods, necessary to obtain weighting coefficients necessary for determining fire danger zones using multi-criteria decision procedures [3, 4]. The second part presents the COPRAS method, which was chosen as relevant for obtaining the weight coefficients necessary for further calculation, as in the paper [5].

2.1 Selection of Parameters for Multicriteria Analysis

The basic concept in the development of the procedure was to combine factors related to the emission of harmful substances due to the frequency of poisoning in fires, as well as aspects related to the process of burning materials in a fire. To implement the procedure, 7 key parameters were selected based on the available literature, which at the same time represents a limitation of the COPRAS method to the number of criteria that can be applied. The mentioned parameters represent the criteria in the multi-criteria analysis procedure, which are divided into two groups: criteria related to the impact on human health and the thermal characteristics of the stored materials.

To determine potential fire risk zones based on data from the available literature [6, 7], 7 different parameters were selected: CO concentration [mg/g], CO_2 concentration [mg/g], Smoke density [kg/m^3], Ignition temperature [^{o}C], Thermal conductivity [V/mK], Specific heat capacity [J/(kgK)] and calorific value

[MJ/kg]. By increasing the number of criteria within the COPRAS method, the quality and precision of the results obtained by the multi-criteria decision-making process are reduced [8].

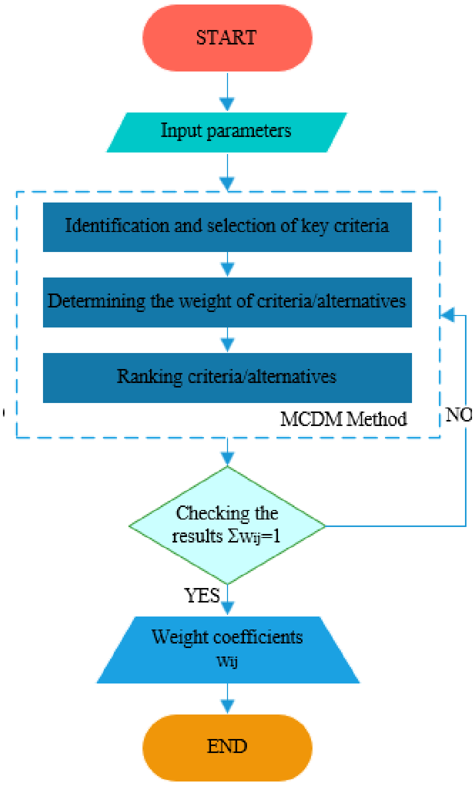

Fig. 1. Flowchart of the proposed procedure

2.2 Determination of Input Parameters Using the COPRAS Method

The COPRAS method is widely used in various fields. It was used for risk assessment in the construction industry, for the selection of the type of robotization in production, for the selection of mechanical processing of composite materials, for the selection of materials for solar panels, etc. In this paper, the COPRAS method was used to determine the weighting coefficients, which also represent input parameters for risk assessment in the case of a high-bay warehouse, as the authors presented in their paper [9]. The COPRAS method includes several steps:

- Step 1 - Creation of the initial decision matrix

In the first step, to create the initial decision-making matrix, 5 materials were selected to be stored: wood, cardboard, chipboard, PVC plastic, and rubber. These materials will represent alternatives in the process of multi-criteria decision-making using the COPRAS method in further steps. In a multi-criteria decision-making process, the criteria usually have different units of measure. In order to transform the performance of the considered alternatives, which represent the materials in the warehouse, into dimensionless values, the normalization procedure is used. For normalization in the COPRAS method, the following formula is used, which also represents the initial matrix containing the input data related to the *i-th* alternative and the *j-th* criterion:

$$X = \left[x_{ij}\right]_{m\times n} = \begin{bmatrix} x_{11} & \cdots & x_{1j} & \cdots & x_{1n} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ x_{21} & \cdots & x_{ij} & \cdots & x_{2n} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ x_{m1} & \cdots & x_{mj} & \cdots & x_{mn} \end{bmatrix}_{m\times n} \quad (1)$$

where alternatives are marked with $i=1, 2,...,m$, and criteria are marked with $j=1,2,...,n$.

- Step 2 - Normalization of the decision matrix

The normalization of the values of the elements of the decision matrix to remove the dimensionality is done by linear transformation with the mathematical form according to Eq. (2).

$$r_{ij} = \frac{x_{ij}}{\sum_{i=1}^{n} x_{ij}},\ i=1,...m,\ j=1,...n \quad (2)$$

where: k_{ij} - performance of the *i-th* alternative in relation to the *j-th* criterion; m - number of alternatives; n - number of criteria.

- Step 3 - Forming the weighted normalized decision matrix $V = \left[V_{ij}\right]_{m\times n}$

The weight vector indicating the preference level is denoted by the weight vector represented in Eq. (3).

$$w_j = \left[w_1 \dots w_n\right] \text{ where } \sum_{i=1}^{n}\left(w_1 \dots w_n\right) = 1 \quad (3)$$

The weight-normalized value of the decision matrix V_{ij} is calculated using the weight vector and the normalized decision matrix, using Eq. (4):

$$V_{ij} = w_j \times r_{ij},\ i=1,...m,\ j=1,...n \quad (4)$$

- Step 4 - Sum of the weighted normalized values of criteria V_{ij}

In this step, it is necessary to categorize the criteria into useful or useless criteria to maximize all those criteria that are useful and minimizing all those that are considered useless. To make it easier to calculate income S_{+i} (maximizing indices) and expenditure S_{-i} (minimizing indices), the decision matrix first places the income and then expenditure criteria, and S_{+i} and S_{-i} are calculated using expressions (5) and (6):

$$S_{+i} = \sum_{j=1}^{n} V_{ij} \,\Big|\, j \in j^{\max},\ i=1,...m \quad (5)$$

$$S_{-i} = \sum_{j=1}^{n} V_{ij} \,\Big|\, j \in j^{\min},\ i=1,...m \quad (6)$$

- Step 5 - Determining the relative importance (weight) of each alternative

Relative importance helps to compare different alternatives through a generalized metric. It can be calculated according to the following formula:

$$Q_i = S_{+i} + \frac{S_{-\min}\sum_{j=1}^{n} S_{-i}}{S_{-i}\sum_{j=1}^{n}\left(S_{-\min} / S_{-i}\right)},\ i=1,2,...m \quad (7)$$

where S_{-min} is the minimum value of S_{-i}.

• Step 6 - Ranking the alternatives

The considered alternatives are ranked in ascending order, according to the value of Q_i, and the best alternative is determined using the following formula:

$$U_i = \left[\frac{Q_i}{Q_{\max}} \right] \times 100\% \tag{8}$$

3. NUMERICAL EXAMPLE

In the numerical example shown in this section, the parameters of the high-bay warehouse related to dimensions and layout (see Fig. 2) given in the paper [9] were used. Based on the considerations given in Chapter 2, to obtain the most accurate data needed for further simulation, it was decided to select 5 types of solid materials (wood, cardboard, chipboard, PVC plastic, and rubber) as alternatives in the multi-criteria decision-making process, which will be the subject of further calculations.

Fig. 2. Layout of a high-bay warehouse with associated dimensions and materials (• wood, • cardboard, • chipboard, • PVC, and • rubber)

Material	CO [mg/g]	CO_2 [mg/g]	Smoke density [kg/m^3]	Ignition temperature [°C]	Thermal conductivity [W/mK]	Specific heat capacity [J/(kg K)]	Calorific value [MJ/kg]
Wood	6	1696	100	350	0.15	1360	14.4
Cardboard	0.1	1450	39.8	427	0.061	1400	13.5
Plywood	6	1774	400	150	0.13	2500	17
PVC	71	657	55.03	391	0.185	900	41
Rubber (tire)	600	1911	8000	315	1.85	1880	35

Table 1. Input parameters in the procedure of determining the weighting coefficients required for the simulation

Criterions	C1	C2	C3	C4	C5	C6	C7
Unit of measure	[mg/g]	[mg/g]	[kg/m^3]	[°C]	[W/mK]	[J/(kg K)]	[MJ/kg]
Goal	min	min	min	max	min	max	min
	Beneficial			Non-Beneficial			
Weights	0.2	0.2	0.2	0.1	0.1	0.1	0.1
A1	6	1696	100	350	14.4	1360	0.15
A2	0.1	1450	3.8	427	13.5	1400	0.061
A3	6	1774	400	150	17	2500	0.13
A4	71	657	55.03	391	41	900	0.185
A5	600	1911	8000	315	35	1880	1.85

Table 2. Decision matrix

The list of materials and the numerical values of the seven selected parameters are given in Table 1. The listed characteristics of materials related to combustion shown in the mentioned table represent criteria in the multi-criteria decision-making process and are taken from the literature [10, 11].

Table 2 presents the criteria in the order presented in section 2.1, of which C1, C2, and C3 are considered useful because they take into account the emission of harmful gases affecting human health, while the other criteria are C4, C5, C6, and C7 concerning combustion declared in the first case as useless.

Following all the steps provided by the COPRAS method (1-6) and based on equations (2-8), in step 6 the weights for each of the alternatives w_i and the corresponding ranking are obtained as shown in Table 3.

4. RESULTS

After the procedure was carried out, the individual results of each alternative for each criterion were obtained, which are shown in Fig. 3. Based on the obtained data from the table, it is seen that alternative A5, i.e. rubber has the highest weight coefficient.

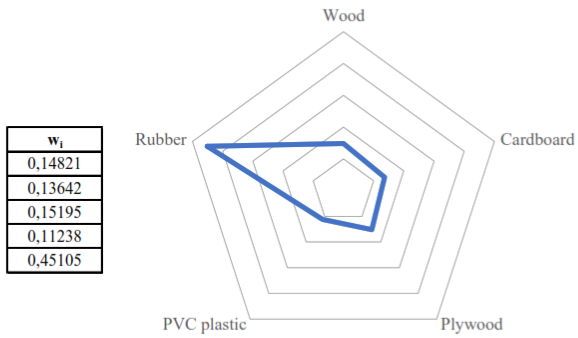

Fig. 3. Tabular and graphical representation of the results obtained using the procedure

5. FINAL REMARKS

Warehouses represent an important link in the supply chain. Warehouses that function efficiently allow the companies that own them to smoothly perform all the necessary operations within the warehouse itself. For the aforementioned reasons, a multi-criteria analysis using the COPRAS method was carried out in this paper, taking into account several criteria in the form of thermal characteristics of materials. The materials considered as alternatives in this procedure are wood, cardboard, plywood, PVC plastic, and rubber. The paper also shows that the COPRAS MCDM method is simple, easy to use, and can be applied to a wide range of decision alternatives. The relative weight coefficients obtained using the mentioned method will represent the input parameters for further simulations and mathematical models for fires in warehouses and storage systems. In future research, it is possible to compare the results of several multi-criteria methods and determine which of the methods provides more accurate data on the weight coefficients.

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