WAREHOUSE RISK ASSESSMENT USING INTERVAL VALUED INTUITIONISTIC FUZZY AHP

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ABSTRACT

Warehouses are essential components of a supply chain management system. Any malfunction in warehouses may have an important effect on the subsequent operations of a firm. For example, an accident that occurs in a warehouse can damage the operations of the company as well as the health of the employees. In this paper, critical operations at a warehouse are considered in terms of occupational health and safety. The originality of the paper is that the proposed approach provides a new perspective on warehouse risk assessment. It is the first time a method involving interval valued intuitionistic fuzzy Analytical Hierarchy Process (IVIF-AHP) and a new risk assessment table is utilized to evaluate and categorize the risks in warehouses. As a result of the proposed risk assessment method, hazards in warehouses are categorized as insignificant, marginal, or catastrophic.

Keywords: Warehouse risk management; risk assessment; risk analysis; interval valued intuitionistic fuzzy sets; Analytical Hierarchy Process

1. Introduction

Warehouses are crucial components of a supply chain management system, and efficiently functioning warehouses enable companies to carry out their operations smoothly. Since any malfunction in warehouses may influence the subsequent operations of a firm, an accident that occurs in the warehouse can damage the operations of the company as well as the health of the employees. Thus, it is important to identify hazards in a warehouse and the risks associated with them in order to be able to prevent potential accidents in warehouses. A risk is defined as a combination of the probability of occurrence of an undesired situation and the severity of that situation. Risk assessment consists of an analysis and evaluation process of the risks associated with hazards in operations, and should be done systematically. The main objective in the risk assessment process is to rank the risky

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factors in the operations in order to provide risk elimination or reduction by applying protective measures from the most important risk to the least important risk. The first step of a risk assessment is hazard identification. The following steps in the assessment are risk identification, risk analysis, determination of precautions, and risk review, respectively. The determination of precautions is performed based on the risk magnitude obtained from the risk analysis step. In general, risk analysis methods use categorical scales and these scales are inadequate for the evaluation. For instance, let us assume that probability of occurrence and severity are 3 and 4 for Case A, 3 and 5 for Case B, and 4 and 4 Case C, respectively. If we use an L-type risk analysis method, risk magnitudes of these cases are obtained as 12, 15, and 16, respectively. Based on the risk evaluation procedure of an L-type matrix method, these results are categorized as high, very high and very high, respectively. Sometimes, a mere one point increase on any parameter may change the category of the risk. Furthermore, there are some gaps in the risk magnitude scale of the conventional methods since they use categorical data. For instance, in an L-Type risk matrix, the scores such as 5, 7, 11, 13, 14, [17, 19], [21, 24] are not obtained by producing any probability of occurrence or severity of occurrence. Therefore, in some cases, the sensitivity of the conventional methods to small changes can be pointless. In the scope of this study, a new approach is proposed in order to overcome this deficiency.

In this study, after a wide literature review hazards in a warehouse are identified and grouped together to form a hierarchy. Then, interval valued intuitionistic fuzzy Analytical Hierarchy Process (IVIF-AHP) is utilized to obtain the weights of risks based on probability of occurrence and the severity in the warehouse. Then, these weights are used to assess risks in warehouse operations. In this study, since the evaluation process is based on the expert's judgments and the collected data for the risk severity and probability of occurrence are in linguistic form, fuzzy logic is required for the calculation of risk magnitudes. Intuitionistic fuzzy sets are preferred because of their ability to better represent the expert's opinions by using both membership and non-membership values. The preventive measures that should be taken first, the operations that should be stopped immediately and the processes that should be monitored are determined according to the results of the analysis. The originality of the paper is that the proposed approach presents a new perspective to risk evaluation in terms of occupational health and safety, and it is the first time an IVIF-AHP is applied to a risk evaluation procedure.

2. Literature review

There have been several studies related to hazards in warehouses throughout the literature. Forklift accidents were examined by Larsson and Rechnitzer (1994) and Saric et al. (2013). In these studies, it was emphasized that a foot run over by a loaded forklift is a lot more dangerous than expected. It can cause severe trauma and fractures. Moreover, since they operate in confined spaces and make maneuvers within narrow aisles, forklifts can be dangerous for the pedestrians nearby. One of the most common forklift accidents involves a forklift striking a pedestrian and possibly leading to severe trauma or death. Some other forklift accidents include falling from/by forklift, collisions, overturns, and sudden stops (Larsson & Rechnitzer, 1994; Saric et al., 2013).

Ren (2012) investigated logistics warehouse fire risk by using the Analytic Hierarchy Process. In the evaluation process, warehouse fire risk was examined under the four categories of warehouse building, goods, management, and environment. Tyldesley et al. (2004) analyzed the benefits of fire compartmentation in chemical warehouses. Moreover, the cost-effectiveness of fire compartmentation with respect to other fire protection measures was emphasized. Markert (1998) evaluated the mitigation of the consequences of fires in chemical warehouses. In the study, the performances of four fire testing methods were compared to evaluate the toxicity of fire products. Moreover, the impact of the release of unburned pesticides and their pyrolysis products on human health was assessed. Qin et al. (2016) examined the feasibility of natural smoke extraction in warehouse buildings whereas Miles and Cox (1996) utilized a computational fluid dynamics model in order to assess hazards related to warehouse fires.

Basahel (2015) examined work-related musculoskeletal disorders (MSDs) in warehouse workers. In the study, lifting and pulling activities in supermarket warehouses was analyzed by using Rapid Upper Limb Assessment and a pain self-report chart to reveal the relation between these activities and lower back, shoulder and lower arm pain. Furthermore, the heart rates of workers were continuously recorded to assess the physiological stresses of the activity postures. It was concluded that lifting activity significantly affects low back pain. Bouloiz et al. (2013) proposed a system dynamics model to show causal interdependencies among technical, organizational and human related safety factors. A behavioral analysis of safety conditions in a chemical storage unit was conducted by examining different scenarios through VENSIM software in order to enhance the safety of the system.

3. Method

In this section, a new approach is proposed to the literature in order to eliminate or reduce the magnitude of any risk in warehouses. The steps of the procedure are as follows:

Phase 1. Planning. In the scope of this phase, the following activities are executed.
Step 1.1. Construction of a risk assessment team. Since most of the systems are complex, a risk assessment team whose members have technical expertise or extensive knowledge on the activities at the corresponding working environment has to be constructed. Furthermore, the team should consist of members who are familiar with risk analysis methods.
Step 1.2. Definition of data collection procedure. In this step, plans are made about how to gather information and measure information output on a work environment and tasks are allocated to the team members.
Step 1.3. Definition of hazard sources. Potential sources of harm or hazardous situations are identified. In this respect, all potential sources of danger including human related, hardware or machine related problems, and systematic errors should be inspected in the hazard identification process.
Step 1.4. Definition of potential risks. One attempts to foresee all risks that are a possibility from any potential source.

Phase 2. Analysis. In this phase, the risk magnitude is obtained based on the probability of occurrence and the severity.
Step 2.1. Determining probability and severity weights. The main purpose of this step is to predict the probability of an undesired event causing the risks identified above. For this, the past statistics or expert views have been widely used in the literature. In particular, expert views are preferred when past statistics are not available. However, expert preferences are not precise and they include uncertainty and vagueness. Hence,

in this study, the probability and severity of the undesired events are obtained by using IVIF-AHP. The steps of IVIF-AHP are as follows (Wu et al., 2013):
Step 2.1.1. Pairwise comparisons of hazards with respect to probability and severity are obtained by using the linguistic terms given in Table 1 and these linguistic terms are converted their corresponding interval valued intuitionistic fuzzy numbers.
Step 2.1.2. From this pairwise comparison, score judgment matrix, $\tilde{s}_{ij}$, is obtained by using Equation 1.

$$\tilde{s}_{ij} = \tilde{\mu}_{ij} - \tilde{\vartheta}_{ij} = [\mu_{ij}^L - \vartheta_{ij}^U, \mu_{ij}^U - \vartheta_{ij}^L], \text{ for all i, j=1, 2, . . . , n} \tag{1}$$

Step 2.1.3. Then, interval multiplicative matrix, $\tilde{A}$, is obtained by using Equation 2.

$$\tilde{A} = 10^{\tilde{S}} \tag{2}$$

Step 2.1.4. The priority vector of interval multiplicative matrix is calculated as follows:

$$\widetilde{w}_i = \frac{\sum_{j=1}^n \tilde{a}_{ij}}{\sum_{i=1}^n \sum_{j=1}^n \tilde{a}_{ij}} = \left[\frac{\sum_{j=1}^n \tilde{a}_{ij}^-}{\sum_{i=1}^n \sum_{j=1}^n \tilde{a}_{ij}^+}, \frac{\sum_{j=1}^n \tilde{a}_{ij}^+}{\sum_{i=1}^n \sum_{j=1}^n \tilde{a}_{ij}^-}\right] \tag{3}$$

Step 2.1.5. As $\widetilde{w}_i$ ($i \in$ N) are interval numbers, comparison of each $\widetilde{w}_i$ with others is made and possibility degree matrix, $P = (p_{ij})_{nxn}$, is constructed by using Equation 4.

Let $a = [a^-, a^+]$ and $b = [b^-, b^+]$ be interval numbers. The possibility degree of $a \geq b$ is as follows:

$$p(a \geq b) = \frac{\min\{L_a + L_b, \max(a^+ - b^-, 0)\}}{L_a + L_b} \tag{4}$$

where $L_a = a^+ - a^-$ and $L_b = b^+ - b^-$.

Step 2.1.6. Prioritization of $P = (p_{ij})_{nxn}$ by using Equation 5 to obtain weights and rank.

$$w_i = \frac{1}{n}\left[\sum_{j=1}^n p_{ij} + \frac{n}{2} - 1\right] \tag{5}$$

Table 1
Linguistic scale for evaluation

Linguistic Terms	$[\mu_L, \mu_U]$	$[v_L, v_U]$
VH	[0.6, 0.8]	[0, 0.2]
H	[0.45, 0.65]	[0.15, 0.35]
E	[0.3, 0.5]	[0.3, 0.5]
L	[0.15, 0.35]	[0.45, 0.65]
VL	[0, 0.2]	[0.6, 0.8]

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Step 2.2. Determination of risk category. To determine the risk category, the chart given in Table 2 is utilized based on the values obtained in Step 2.1.

Table 2
Risk assessment matrix

	Severity ratio for a risk: W_{RS}				
Likelihood ratio for a risk: W_{RP}	$W_{RS} \geq 0.08$	$0.08 > W_{RS} \geq 0.06$	$0.06 > W_{RS} \geq 0.04$	$0.04 > W_{RS} \geq 0.02$	$0.02 > W_{RS} \geq 0$
$0.08 \leq W_{RP}$	Category I	Category I	Category I	Category II	Category III
$0.06 \leq W_{RP} < 0.08$	Category I	Category I	Category II	Category II	Category III
$0.04 \leq W_{RP} < 0.06$	Category I	Category II	Category II	Category III	Category III
$0.02 \leq W_{RP} < 0.04$	Category II	Category II	Category III	Category III	Category III
$0.0 \leq W_{RP} < 0.02$	Category III	Category III	Category III	Category III	Category III

The interpretations of the categories given in Table 2 are as follows:
Category III: Insignificant. The risk may occur but it is not possible for it to result in any damage or injury.
Category II: Marginal. The risk has a great potential to constitute a threat to injury or to result in a failure of the system.
Category I: Catastrophic. The risk is quite high and has a great potential to cause serious damage or failure of the system.

Phase 3. Risk evaluation and reduction. In this step, risk reduction, validation analysis, and an audit are conducted. Based on the risk magnitude, a set of control measurements are utilized in order to provide risk reduction. For the control measurements, one of the following strategies is preferred:

i. Elimination of the hazard: The hazard source is omitted from the system in order to remove the hazard from the workplace. In order to achieve this, the process type should be changed. It is difficult to execute this strategy.

ii. Substitution of the hazard: In this strategy, the substitute of the current process which includes less risk is preferred.

iii. Hazard control: This strategy includes engineering applications, managerial applications, and personal protective equipment sub-strategies and these strategies are applied to reduce the current risk.

4. Analysis

In the literature, some of the potential hazards in warehouse operations are identified as failure to conduct conveyor belt maintenance, vehicle exhaust fumes, not providing personal protective equipment to employees, falls from a height, slip and trips, undetermined forklift road lines, use of forklifts by employees without a driver's license, potential explosion due to recharging of forklift truck batteries, overloading the forklift, and improper loading / unloading postures and movements of employees (Larsson & Rechnitzer, 1994; Saric et al., 2013; Example risk assessment for a warehouse, 2007; Basahel, 2015). Hazards in a warehouse are classified in Table 3, and then, the pairwise comparisons of these hazards are performed.

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Table 3
Classification of hazards for warehouses

H1	**Physical and Chemical Hazards**
H11	Lighting
H12	Air Circulation (for vehicle exhaust fumes)
H13	Loud sounds
H14	Temperature
H15	Chemical materials
H2	**Mechanical Hazards**
H21	Failure to conduct conveyor belt maintenance
H22	Failure to conduct forklift maintenance (refueling and periodic maintenance)
H23	Overloading the forklift
H24	Recharging of forklift truck batteries – potential explosion by release of hydrogen, spillage of acid
H3	**Workplace Hazards**
H31	Falls from a height (Working height)
H32	Wet floors (Slips, trips, and falls)
H33	Undetermined forklift / pedestrian road lines
H34	Accidents caused by docks
H35	Improperly stored materials
H4	**Human Related Hazards**
H41	Not providing personal protective equipment to employees
H42	Use of forklifts by employees without driver's license
H43	Stretching the body by lifting heavy objects
H44	Not following safety procedures for picking up, putting down and stacking loads
H45	Not following safety procedures for speed limits of forklift

Pairwise comparisons, obtained in the linguistic form for the hazards in warehouse, and corresponding consistency ratios are provided in Tables 4-13. Consistency ratios of the pairwise comparison matrices are calculated as in the classical AHP method by using the crisp numbers corresponding to these linguistic terms.

Table 4
Pairwise comparison of main hazards for probability

Hazards	**H1**	**H2**	**H3**	**H4**
H1	E	VH	H	L
H2	VL	E	L	VL
H3	L	H	E	L
H4	H	VH	H	E
CR	0.074			

Table 5
Pairwise comparison of main hazards for severity

Hazards	**H1**	**H2**	**H3**	**H4**
H1	E	VL	L	VL
H2	VH	E	E	VL
H3	H	E	E	VL
H4	VH	VH	VH	E
CR	0.100			

Table 6
Pairwise comparison of sub-hazards of H1 for probability

H1	**H11**	**H12**	**H13**	**H14**	**H15**
H11	E	L	L	H	VL
H12	H	E	H	VH	L
H13	H	L	E	H	L
H14	L	VL	L	E	VL
H15	VH	H	H	VH	E
CR	0.072				

Table 7
Pairwise comparison of sub-hazards of H1 for severity

H1	**H11**	**H12**	**H13**	**H14**	**H15**
H11	E	L	L	H	VL
H12	H	E	H	VH	L
H13	H	L	E	H	L
H14	L	VL	L	E	VL
H15	VH	H	H	VH	E
CR	0.072				

Table 8
Pairwise comparison of sub-hazards of H2 for probability

H2	**H21**	**H22**	**H23**	**H24**
H21	E	L	VL	H
H22	H	E	L	H
H23	VH	H	E	VH
H24	L	L	VL	E
CR	0.076			

Table 9
Pairwise comparison of sub-hazards of H2 for severity

H2	**H21**	**H22**	**H23**	**H24**
H21	E	L	H	VL
H22	H	E	H	L
H23	L	L	E	VL
H24	VH	H	VH	E
CR	0.076			

Table 10
Pairwise comparison of sub-hazards of H3 for probability

H3	**H31**	**H32**	**H33**	**H34**	**H35**
H31	E	L	VL	VL	L
H32	H	E	L	VL	H
H33	VH	H	E	L	H
H34	VH	VH	H	E	VH
H35	H	L	L	VL	E
CR	0.081				

Table 11
Pairwise comparison of sub-hazards of H3 for severity

H3	**H31**	**H32**	**H33**	**H34**	**H35**
H31	E	VH	H	VH	L
H32	VL	E	L	L	VL
H33	L	H	E	H	L
H34	VL	H	L	E	VL
H35	H	VH	H	VH	E
CR	0.081				

Table 12
Pairwise comparison of sub-hazards of H4 for probability

H4	**H41**	**H42**	**H43**	**H44**	**H45**
H41	E	H	L	VL	L
H42	L	E	VL	VL	L
H43	H	VH	E	L	H
H44	VH	VH	H	E	H
H45	H	H	L	L	E
CR	0.072				

Table 13
Pairwise comparison of sub-hazards of H4 for severity

H4	**H41**	**H42**	**H43**	**H44**	**H45**
H41	E	H	VH	VH	H
H42	L	E	H	VH	H
H43	VL	L	E	H	L
H44	VL	VL	L	E	L
H45	L	L	H	H	E
CR	0.072				

The probability weights and severity weights of these hazards are given in Tables 14 and 15. Then, a risk assessment is made by using Table 2 and categories of hazards are provided in Table 16.

Table 14
Probability Weights

H1	0.295	**H2**	0.161	**H3**	0.230	**H4**	0.314
H11	0.051	**H21**	0.036	**H31**	0.031	**H41**	0.054
H12	0.070	**H22**	0.043	**H32**	0.045	**H42**	0.042
H13	0.059	**H23**	0.054	**H33**	0.054	**H43**	0.074
H14	0.039	**H24**	0.028	**H34**	0.061	**H44**	0.081
H15	0.076			**H35**	0.039	**H45**	0.063

Table 15
Severity Weights

H1	0.158	**H2**	0.270	**H3**	0.231	**H4**	0.341
H11	0.027	**H21**	0.061	**H31**	0.057	**H41**	0.088
H12	0.037	**H22**	0.072	**H32**	0.031	**H42**	0.080
H13	0.032	**H23**	0.047	**H33**	0.046	**H43**	0.059
H14	0.021	**H24**	0.091	**H34**	0.038	**H44**	0.046
H15	0.041			**H35**	0.059	**H45**	0.068

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Table 16
Results of risk assessment in warehouses

H1	**Physical and Chemical Hazards**	
H11	Lighting	Category III
H12	Air Circulation	Category II
H13	Loud sounds	Category III
H14	Temperature	Category III
H15	Chemical materials	Category II
H2	**Mechanical Hazards**	
H21	Failure to conduct conveyor belt maintenance	Category II
H22	Failure to conduct forklift maintenance (Refueling and periodic maintenance)	Category II
H23	Overloading the forklift	Category II
H24	Recharging of forklift truck batteries – potential explosion by release of hydrogen, spillage of acid	Category II
H3	**Workplace Hazards**	
H31	Falls from a height (Working height)	Category III
H32	Wet floors (Slips, trips, and falls)	Category III
H33	Undetermined forklift / pedestrian road lines	Category II
H34	Accidents caused by docks	Category II
H35	Improperly stored materials	Category III
H4	**Human Related Hazards**	
H41	Not providing personal protective equipment to employees	Category I
H42	Use of forklifts by employees without driver's licence	Category I
H43	Stretching the body by lifting heavy objects	Category II
H44	Not following safety procedures for picking up, putting down and stacking loads	Category I
H45	Not following safety procedures for speed limits of forklift	Category I

As a result of the proposed assessment, the most critical hazards are identified as H41, not providing personal protective equipment to employees; H42, use of forklifts by employees without driver's license; H44, not following safety procedures for picking up, putting down and stacking loads; and H45, not following safety procedures for speed limits of forklift. Since these hazards are identified as catastrophic, operations or activities involving these hazards must be terminated immediately until these hazards are eliminated. Marginal hazards in warehouses are identified as H12, air circulation; H15, chemical materials; H21, failure to conduct conveyor belt maintenance; H22, failure to conduct forklift maintenance; H23, overloading the forklift; H24, recharging of forklift truck batteries – potential explosion by release of hydrogen, spillage of acid; H33, undetermined forklift / pedestrian road lines; H34, accidents caused by docks; and H43, stretching the body by lifting heavy objects. Since these hazards have a great potential to

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constitute a threat in a warehouse, even if activities involving these hazards are not terminated, they must be constantly monitored. The rest of the hazards are identified as insignificant, indicating that they can be neglected.

5. Conclusions

Warehouses are significant components of a supply chain management system. Efficiently functioning warehouses facilitate the ability of companies to carry out their operations smoothly. An accident occurring in a warehouse can damage both the health of the employees and the operations of the company. Therefore, identification of potential hazards in a warehouse and classification of these hazards are required to be able to take necessary actions.

In this paper, a new approach in which hazards are categorized based on probability and severity weights calculated through IVIF-AHP is proposed. The advantages of the proposed method can be explained as follows:

(I) It includes an expert inference system to obtain risk magnitude. As distinct from the matrix type risk assessment method, this method presents robust and sufficient results for a safety specialist.
(II) The risk matrix utilized to obtain the risk magnitudes presents a sensitive and adequate scale.
(III) The results obtained from the analysis are more comprehensive than the conventional methods.

In a work environment, some activities might be dependent on each other and the obtained risk magnitude for these activities can be affected by these interdependencies. Therefore, in future research, the proposed method can be extended to evaluate the interdependencies among the risks in a work environment.

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