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DEVELOPMENT OF AN ARTIFICIAL INTELLIGENCE-BASED PROGRAM FOR ENSURING WORKPLACE SAFETY AND ANALYZING SLIP, TRIP, AND FALL RISKS IN WAREHOUSES

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Abstract: Artificial intelligence (AI), designed to enable machines to perform tasks requiring human cognition, is widely used across many fields. Expert systems (ESs), a subset of AI, solve complex problems via expert knowledge. This study focuses on mitigating prevalent and complex slip, trip, and fall (STF) incidents by developing a program called WaSaEx, based on an AI-supported ES. WaSaEx, designed for offline use by occupational safety specialists, offers risk analysis, cost estimation, and training planning for occupational health and safety (OHS). Developed via Python and CLIPS, WaSaEx is ES-based, distinct from other OHS programs. This study introduces the WaSaEx program and evaluates its capability for risk analysis and preventive measures, specifically for reporting STF risks in storage areas. The program uses an L-type (5x5) matrix method to assess risks based on user responses, providing risk scores and preventive measures for each factor. It also systematically accounts for the interaction of risk factors that may lead to accidents. Consequently, WaSaEx offers a cost-effective, knowledge-based solution to enable swift and accurate risk analysis. This methodology delivers validated preventive measures and substantially reduces residual risks, thus fostering improved safety in storage environments. WaSaEx is pivotal in advancing workplace safety standards through its expert framework.

Keywords: Artificial intelligence, Expert systems, Occupational safety, Risk analysis, Slip, Trip and fall

Güvenli İş Yerlerinin Sağlanması İçin Yapay Zekâ Tabanlı Bir Program Geliştirilmesi Ve Depolama Sektöründe Kayma, Tökezleme Ve Düşme Risklerinin Analizi

Oz: Yapay zekâ (AI), insan bilişi gerektiren görevleri yerine getirebilecek makineler geliştirmek için tasarlanmış olup, birçok alanda yaygın olarak kullanılmaktadır. Yapay zekânın bir alt dalı olan uzman sistemler (ESs), uzman bilgisi kullanarak karmaşık sorunları çözmektedir. Bu çalışma, yaygın ve karmaşık mekanizmalara sahip kayma, tökezleme ve düşme (STF) kazalarını azaltmayı amaçlayan, AI destekli bir ES olan WaSaEx programının geliştirilmesine odaklanmaktadır. WaSaEx, iş güvenliği uzmanları tarafından çevrimdışı olarak kullanılmak üzere tasarlanmış olup, iş sağlığı ve güvenliği (OHS) için risk analizi, maliyet hesaplama ve eğitim planlama gibi işlevler sunmaktadır. Python ve CLIPS kullanılarak geliştirilen WaSaEx, OHS alanında kullanılan diğer programlardan ES tabanlı olmasıyla ayrılmaktadır. Bu çalışma, WaSaEx programını tanıtarak, depolama alanlarındaki STF risklerini raporlama açısından risk analizi ve önleyici tedbirler konusundaki yetkinliğini değerlendirmektedir. Program, kullanıcı yanıtlarına dayalı olarak riskleri değerlendirmek için L-tipi (5x5) matris yöntemi kullanmakta, her bir faktör için risk skorları ve uygun önleyici tedbirler sunmaktadır. Ayrıca, depolama alanlarında kazalara yol açabilecek risk faktörlerinin etkileşimi sistematik olarak analize dahil edilmektedir. Sonuç olarak, WaSaEx, hızlı ve doğru risk analizi yapılmasını hedefleyen, maliyet etkin ve bilgi tabanlı bir çözüm sunmaktadır. Bu yöntem,

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doğrulanmış önleyici tedbirler sağlamanın yanı sıra artık riskleri önemli ölçüde azaltarak depolama ortamlarında güvenliğin artırılmasına katkıda bulunmaktadır. Uzman bir çerçeveye sahip olan WaSaEx, iş yeri güvenliği standartlarının geliştirilmesinde önemli bir rol oynamaktadır.

Anahtar Kelimeler: Yapay zekâ, Uzman sistemler, İş güvenliği, Risk analizi, Kayma, Tökezleme ve düşme

1. INTRODUCTION

The discipline of occupational safety, which emerged due to tragic workplace accidents throughout human history (Stellman et al., 2021), has gained increasing importance because of the dynamic nature of modern workplaces (Rasmussen and Svedung, 2000). Additionally, since simple, linear causes can no longer explain workplace accidents and are instead the result of "technological, psychological, organizational, environmental, and temporary measures," systematic efforts are required to create safe workplaces (Hollnagel, 2012). In this context, continuous risk assessments, which are critical for ensuring safe workplaces, are highly important (Pawłowska, 2010). A key step in risk assessment is risk analysis, which identifies potential accidents, their likelihood, and the consequences they may bring, followed by determining preventive measures to mitigate these risks (Stamatelatos et al., 2011).

Warehouses, which have evolved into work hubs in response to the demands of modern work environments and pose a range of risks to employee safety, have become increasingly hazardous and complex (Durdevic et al., 2022; Richards, 2018). Among the leading causes of accidents and injuries in warehouses are slips, trips, and falls (STFs), which must be thoroughly analyzed to determine necessary preventive measures (Richards, 2018). STF incidents result from interactions between the foot and the ground (Larue et al., 2021). However, these incidents are influenced by a combination of environmental, personal (Larue et al., 2021), physical, ergonomic, and psychosocial factors (e.g., stress and fatigue) (Rubel et al., 2021), time pressure, actions taken to save time, design errors in the workplace (Bentley et al., 2005), high population density in work areas (Haslam and Filingeri, 2018), surface friction coefficients, and the inclination of work surfaces (Dong et al., 2021), all of which interact in complex ways (Motorcu and Murat, 2021a).

STF incidents, which are widespread (Popovic et al., 2023), are often perceived as minor or insignificant by society (Leclercq et al., 2021); however, they are serious causes of fatalities and injuries (Bentley et al., 2006) and are globally accepted as important (Nenonen, 2013; Alawad et al., 2020). Unlike other types of accidents, STF incidents occur at higher-than-average rates (Yoon and Lockhart, 2006), involve high costs (Liberty Mutual Insurance, 2021; Chang et al., 2016), result in lost workdays (Kong et al., 2013), and cause substantial economic losses due to disruptions in production or service schedules (Alawad et al., 2020). Motorcu and Murat (2021a) noted that STF incidents, which result in high accident rates globally, are also the leading cause of workplace accidents in Türkiye and are responsible for a significant proportion of fatal accidents. Therefore, these accidents pose serious occupational safety risks that must not be ignored in creating safe workplaces. Owing to the considerable impact of STF-related risks, they continue to be the focus of numerous studies in the international literature (Li et al., 2019).

For this reason, explaining the causes of STF accidents can be challenging in some cases (Leclercq et al., 2021; Larue et al., 2021). Nevertheless, low-cost measures can largely prevent them (Rubel et al., 2021). Identifying and eliminating STF hazards in advance can greatly reduce the occurrence of these accidents (Chen et al., 2020), and using information technologies in this process can further increase the effectiveness of safety measures (Chen et al., 2023).

In recent years, AI-supported systems have been widely used to address problems requiring expert knowledge and experience (Pac et al., 2021). AI plays a major role in creating safe workplaces by enabling a proactive approach (Sattari et al., 2021), helping manage safety in dynamic workplaces, and determining the correct preventive measures to eliminate hazards (Murat et al., 2022). Consequently, AI-supported systems can produce fast, successful results while reducing human error and identifying factors that human experts may overlook (Motorcu and Murat, 2021b). Artificial intelligence includes many techniques and methods, such as ES. ESs are computer programs developed to solve complex problems by utilizing the reasoning and experience of individuals specialized in a particular field (Gupta and Nagpal, 2020).

A literature review revealed that ESs, including occupational safety, are widely used across different fields. Dashti and Dashti (2020) developed an ES that can diagnose spinal disorders with results similar to those of specialists. Urrea and Mignogna (2020) designed an ES for the early diagnosis of hypertension, type 2 diabetes, and metabolic syndrome, allowing for the timely detection of these diseases. Pac et al. (2021) utilized data mining techniques to develop an ES for making effective decisions in pediatric patient diagnoses via hospital databases. In another study, Teke (2022) developed an ES capable of calculating the risk percentage for coronary artery disease (CAD) and offering personalized treatment recommendations. Sarı et al. (2023) created the Exbolt System, an ES that allows for the selection of the correct bolt in a shorter time by automating bolt selection. Additionally, Teke (2024) developed an ES to assess green suppliers, successfully evaluating their environmental friendliness with high performance.

Several ES applications have been developed in occupational safety. Başak et al. (2008) proposed a risk management module for preventing uncrewed aerial vehicle (UAV) accidents. Azadeh et al. (2008) designed an ES to assess petroleum refineries' health, safety, environment, and ergonomics. Lilić et al. (2010) developed a hybrid method using neural networks and ES to increase safety in the mining industry. Meciarova (2011) proposed an ES that identifies and eliminates risks associated with workers' exposure to cutting fluids. Baron et al. (2012) also designed an ES for risk identification and analysis. A notable example is a study by Amiri et al. (2017), which used fuzzy logic to identify the root causes of accidents through risk analysis. Another ES application using the Monte Carlo method was developed to assess fire risks in buildings, including the probability of fire occurrence, evacuation of people, and structural integrity calculations (Tofilo et al., 2013). Furthermore, Suryono et al. (2019) developed a real-time ES that analyzes air pollution data and determines air quality.

Studies predicting accidents have also been a focal point in the literature. Berisha et al. (2012) developed a fuzzy-based ES to predict accidents in construction and refractory industries. Qiu et al. (2018) calculated the probability of accidents under uncertainty via an ES. In another notable study by Taçgın and Sağır (2020), an ES was developed to identify the causes of accidents. Han et al. (2022) designed an ES to evaluate dam safety levels via risk calculations.

In the field of ergonomics, Pavlovic-Veselinovic et al. (2016) developed an ES that recommends preventive measures for musculoskeletal disorders (MSDs). Similarly, Mohan et al. (2020) created an ES that evaluates manual handling tasks via the NIOSH equation and provides recommendations for safe lifting. Abdul Aziz et al. (2022) developed an ES to assess ergonomic risk factors, which can also be used in training programs. Rostamy and Ghatara (2023) designed an ES to measure the financial impact of health, safety, and environmental actions on firms' financial performance.

These studies demonstrate that ESs are highly effective in risk assessment, providing accurate preventive measures that reduce human error and detect overlooked risks. The application of ESs in occupational safety has proven beneficial for creating safer workplaces (Murat et al., 2022). However, despite extensive use in various fields and ergonomic-focused studies on STFs, no ES application has been developed specifically for analyzing and preventing STF risks in the storage sector. Given that STF incidents are the leading cause of accidents in storage areas, an ES-based solution that targets these risks would significantly increase workplace safety. This study addresses this gap by developing WaSaEx, which uses an AI-based ES to conduct risk analysis and propose preventive measures for warehouse STF risk. In this study, a program called WaSaEx was developed using AI-based ES to ensure workplace safety. WaSaEx is designed to be used offline in businesses and institutions to perform tasks such as risk analysis, calculating occupational health and safety (OHS) costs, and planning OHS training. This study has two main objectives: first, to introduce the structure, algorithm, and flow diagram of the ES used in the WaSaEx program; second, to evaluate the program's capacity, usability, and effectiveness by analyzing STF risks in general storage areas and reporting preventive measures through its risk analysis function.

2. DEVELOPMENT OF THE PROGRAM

This study aims to provide the multidisciplinary knowledge and experience required for ensuring workplace safety through AI-supported ES. As part of a Ph.D. thesis, the first version of a program named WaSaEx was developed to assist in the creation of safe workplaces by enabling even novice users to perform accurate and comprehensive risk analyses with the support of an ES. The program analyzes risks based on user responses to questions posed via a user-friendly interface, accounting for the interactions between different risks. The analysis results are presented via a validated L-type (5x5) risk matrix, which assigns risk priority scores and reports preventive measures to the user. Ongoing development efforts are focused on integrating the Failure Modes and Effects Analysis (FMEA) method to enhance the program's risk assessment capabilities.

In summary, the program streamlines the labor-intensive and knowledge-heavy risk analysis process by leveraging technological capabilities to deliver high-accuracy results in a shorter time frame. This approach allows for systematic consideration of all risks, contributing to creating safer workplaces

2.1. Structure of the Expert System and Flow Diagram

The WaSaEx program operates in four phases: (i) user login, (ii) risk identification, (iii) risk analysis, and (iv) reporting, as illustrated in Figure 1. The flowchart outlines the program's logical workflow, starting with user authentication, where users either login or register to access the system. The process then moves to the risk identification phase, where the program poses questions to gather general and detailed information about potential risks. Based on the collected answers, the risk analysis phase evaluates the identified risks by asserting probabilities and severities, calculating the Risk Priority Number (RPN), and suggesting necessary precautions. Finally, the reporting phase consolidates the analysis into a report that can be viewed, printed, or saved for future reference. Each phase is seamlessly connected, ensuring a user-friendly experience. All the phases were developed using Python, which was chosen for its extensive library support, flexibility, and speed. The ES component of the program was implemented using CLIPS, a freeware expert system language provided by NASA. The graphical user interface (GUI) was designed via Qt Designer (Figure 2), with support from the PyQt5 library in Python to enable seamless integration.

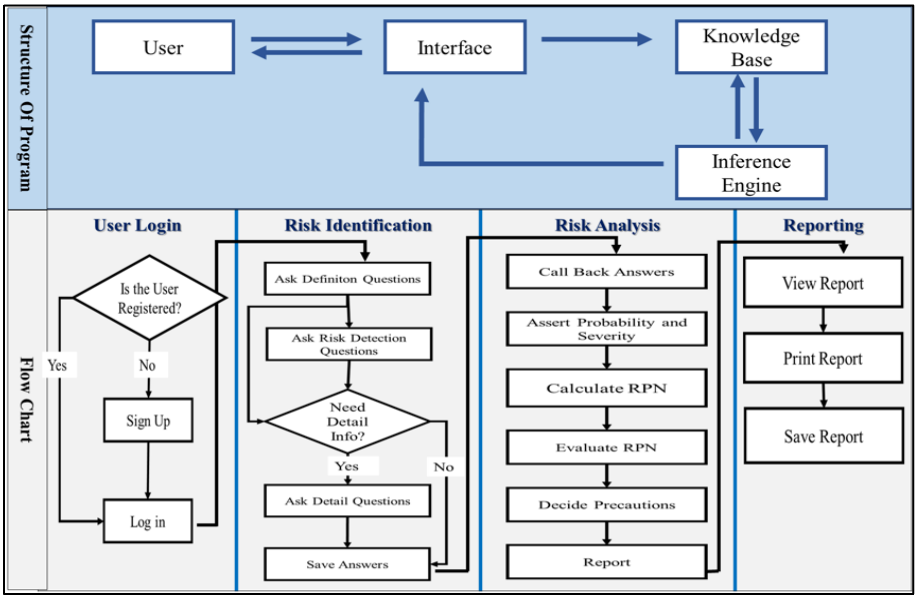


Figure 1:
Structure and flowchart of WaSaEx

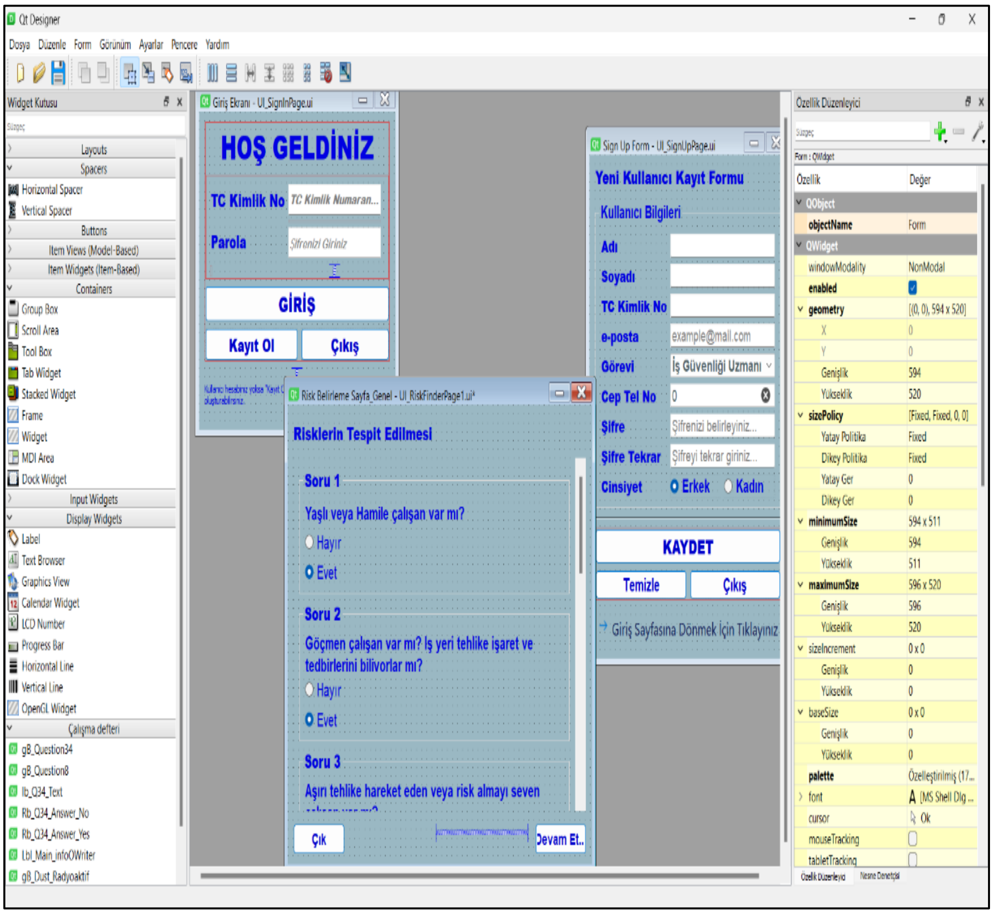


Figure 2:
Design of windows with a Qt Designer

In expert systems, rules are structured as IF (Conditions) and THEN (Results) statements, as shown in Figure 3. a. In CLIPS, the rules are similarly designed and transferred to the Python environment (Figure 3. b). The development process began with creating the user interface via the Qt Designer package. The program includes nine widget windows and one main window for user login and registration, questions, report viewing, and program information (Figure 4). These windows were converted into Python code via PyQt5 and integrated into the development environment. The program's questions are embedded with signal-slot features to prompt additional questions if needed.

```
IF
Q-9 = YES
THEN
ASK (Q-85 AND Q-86 AND Q-87)

IF
(Q-85 AND Q-86 AND Q-87) = YES
THEN
ASSERT (PROBOLITY (P) AND   SEVERITY (S))

IF
((Q-85 AND Q-87) = YES) OR
((Q-85 AND Q-86) = YES) OR
((Q-86 AND Q- 87) = YES) OR
THEN
ASSERT (PROBOLITY (P) AND   SEVERITY (S))

IF
(Q-85 OR Q-86 OR Q-87) = YES
THEN
ASSERT (PROBOLITY (P) AND   SEVERITY (S))
ELSE
ASSERT (PROBOLITY (P) AND   SEVERITY (S))
```

a.

```
kural15_26 = """
   (defrule Soru 15-26
          (declare (salience 895))
          (koridor ?koridor1)
          (yukKapasite ?yukKapasite1)
          (istifKapasite ?istifKapasite1)
   =>
           (if (and (eq ?yukKapasite1 biliniyor) (eq ?istifKapasite1
uygun))
          then
          (assert (severity (name risk30.1) (number 1)))
          (assert (probolity(name olasılık30.1)(number 1)))
          else
          (if (and (eq ?yukKapasite1 biliniyor) (eq ?istifKapasite1
uygunDegil))
           then
          (assert (severity (name risk30.1) (number 2)))
          (assert (probolity(name olasılık30.1)(number 2.5)))
          else
          (if (and (eq ?yukKapasite1 bilinmiyor) (eq ?istifKapasite1
uygunDegil))
           then
           (assert (severity (name risk30.1) (number 2.5)))
          (assert (probolity(name olasılık30.1)(number 2.5))))))
          (if (eq ?koridor1 gorunur)
           then
          (assert (severity (name risk30.2) (number 1)))
          (assert (probolity(name olasılık30.2)(number 1)))
           else
           (assert (severity (name risk30.2) (number 2)))
           (assert (probolity(name olasılık30.2)(number 2)))))"""
env.build(kural15_26)
```

b.

Figure 3:
a. *CLIPS code structure **b.** CLIPS codes embedded in python*

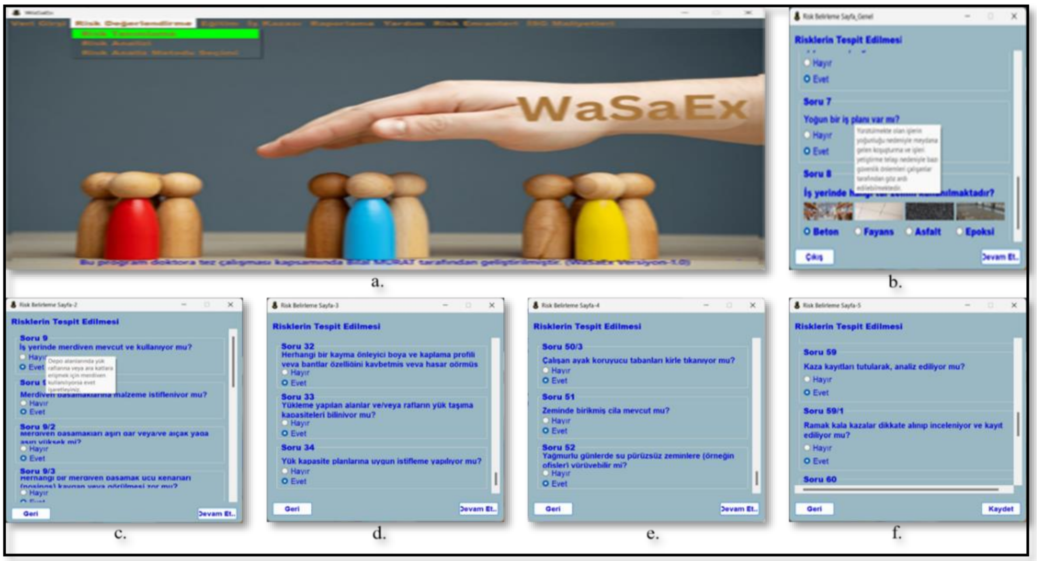


Figure 4:
a. *Main window **b.** First question window **c.** Second question window*
d. *Third question window **e.** Fourth question window **f.** Fifth question window*

To ensure that users do not skip questions and that response time is reduced, all the questions are preset to "Evet" (Yes) by default. User responses are recorded via the clipspy library in Python, as shown in Figure 5, with facts assigned based on the answers given in each question window. After all the questions are answered, the system consolidates the facts and performs risk analysis via CLIPS code embedded in the Python environment (Figure 3. b). Once complete, the facts are combined into a single dataset for the risk analysis phase. At this stage, the risk priority scores (RPSs) are calculated via the CLIPS environment in Python.

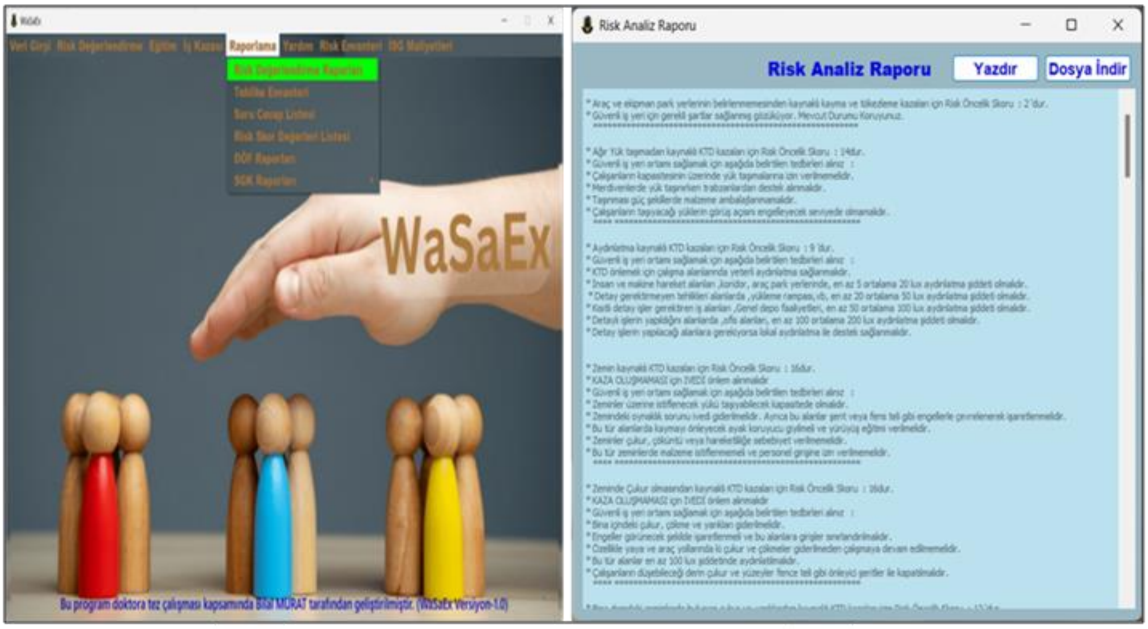
```
if question10_answer == "Evet":
   env.assert_string("(rampa mevcut)")
else:
   env.assert_string("(rampa mevcutDegil)")

if question9_1_answer == "Evet":
   siddet.assert_fact(name=clips.Symbol('risk60.1'), number=4)
   olasilik.assert_fact(name=clips.Symbol('olasılık60.1'), number=4)

elif question9_1_answer == "Hayır":
   siddet.assert_fact(name=clips.Symbol('risk60.1'), number=3)
   olasilik.assert_fact(name=clips.Symbol('olasılık60.1'), number=3)
```

Figure 5:
Asserting CLIPS facts in a Python environment

The calculated RPS values are evaluated via an L-type (5x5) risk matrix, and appropriate preventive measures are recommended based on the severity of the risk. These measures are provided to the user in a ".txt" file, which can be viewed and saved through the reporting module on the main window (Figure 6). A user registration feature was added to enable multiple users to access the program. The SQLite database library was used to manage user registrations and logins.



a. b.

Figure 6:
***a.** Report module **b.** Report screen*

2.2. Creating the Risk Inventory

The process begins with information gathering to form the knowledge base that shapes the WaSaEx program. The risk inventory was created based on studies in the literature (Allahverdi, 2002). The storage sector, which is highly frequent and poses significant risks to worker safety, was selected as the field of study (Durdevic et al., 2022; Richards, 2018). Warehouses, which have evolved from traditional storage spaces into production centers, now carry increased occupational risks, especially STF incidents (Richards, 2018). Both national and international studies have shown that STF accidents are the leading causes of workplace fatalities and injuries (Motorcu and Murat, 2021a).

Table 1. Knowledge inventory for workplace accidents, risk factors, and solution suggestions

Accident Type	Cause of Accident	Risk Level	Accident	Hazard Source	Solution Suggestion
STF accidents caused by carrying heavy loads	Carrying excessively heavy loads	1	Slip	Handling	Employees should not be allowed to carry loads beyond their capacity. Support should be taken from railings when carrying loads on stairs.
		2	Trip	Handling	Materials should not be packaged in shapes that are difficult to carry. Loads carried by employees should not obstruct their field of vision.
STF accidents caused by poor lighting	Lack of proper lighting	1	Slip	Lighting	The lighting intensity in human and machine movement areas (corridors, parking areas) should be at least 5 lux, with an average of 20 lux.
		2	Trip	Lighting	In areas with nondetailed hazards (e.g., loading ramps), lighting intensity should be at least 20 lux, with an average of 50 lux. Areas requiring limited detailed tasks (e.g., general warehouse activities) should have at least 50 lux lighting, with an average of 100 lux. In areas where detailed work is performed (e.g., office spaces), lighting should be at least 100 lux, with an average of 200 lux. Sufficient lighting should be provided in work areas to prevent STF. Additional local lighting should be provided where detailed tasks are performed if necessary.
STF accidents caused by unstable flooring	Unstable or loose flooring	1	Slip	Flooring	Floors must be able to support the load stacked on them.
		2	Trip	Flooring	The issue of unstable flooring must be resolved immediately. These areas should be marked with barriers such as tape or fence wires. Anti-slip footwear should be worn, and walking training should be provided in such areas. Floors should not have pits, depressions, or movements. Materials should not be stacked in these areas, and personnel should not be allowed entry.
STF accidents caused by floor pits	Pits, depressions, or cracks in indoor floors	1	Trip	Flooring	Pits, depressions, and cracks in indoor floors should be repaired.
		2	Slip	Flooring	Obstacles should be marked, and access to these areas should be restricted. Work should not continue on pedestrian and vehicle paths with pits or depressions until they are repaired. These areas should be illuminated with at least 100 lux intensity. Deep pits and surfaces where employees could fall should be covered with preventive barriers such as fence wires.

The program aims to analyze these frequent and hazardous STF accidents in the storage sector, using risk scores to recommend preventive measures. In total, 49 types of workplace accidents and 53 different risk factors contributing to STF incidents were identified for the storage sector. To address these risks, 187 preventive measures have been proposed. All the data were compiled into a knowledge inventory in Excel, as shown in Table 1. Updates and additions to the inventory were made when new scenarios arose.

To create a comprehensive risk inventory for each workplace, 87 questions were prepared and added to the knowledge base. These questions were categorized as follows: (i) 10 questions regarding workplace characteristics and vulnerable workers, (ii) 45 questions for identifying risk factors, and (iii) 32 questions for further elaborating on identified risk factors. These questions were linked to the relevant risks, ensuring the workplace was analyzed comprehensively and the interactions between different risks were considered.

The risk inventory was developed, excluding intelligent storage systems, cold storage, and specialized warehouses. It aims to identify potential hazards that could be overlooked or difficult to detect by considering the interactions between all risk factors and hazards.

2.3. Risk Analysis and Reporting in the Expert System

The expert system's risk assessment module allows for the identification of risks and the execution of risk analyses. The main window includes two tabs: "Risk Belirleme" (Risk Identification) and "Risk Analizi" (Risk Analysis) (Figure 5. a). Upon selecting the "Risk Belirleme" (Risk Identification) tab, users are presented with the predefined questions stored in the knowledge inventory. Users are expected to answer these questions, but if they skip a question or choose the default answer, they can proceed without additional input. To enhance clarity, the questions are supplemented with images (Figure 5. b), and additional explanations appear when users hover the mouse over the question (Figure 5. b). These principles are applied throughout the five question windows, where users' responses help create the risk inventory.

Once all the questions are answered, the "Risk Analizi" (Risk Analysis) tab (Figure 5. a) is selected, triggering the RPS calculation and evaluation in the background, which leads to the determination of preventive measures. The recommended preventive actions are saved as a ".txt" file and can be viewed, printed, or saved by the user through the reporting module (Figure 7).

2.4. Methodology for Risk Analysis

The expert system collects user responses and uses them to activate the ES mechanism for performing risk analysis. When the "Risk Analizi" (Risk Analysis) tab (Figure 4. a) is selected, the program initiates a series of steps and calculations in the background. The risk inventory (Table 1) includes the total risk factors contributing to each warehouse accident. These risk factors are divided into four groups based on their interactions and relationships, as visualized in Figure 7.

- Group 1: Risks that operate independently, without influencing or being influenced by other risk factors.
- Group 2: Risks that depend on additional information or context to determine their scores, requiring further exploration to finalize their impact
- Group 3: Risks that, when identified, escalate the probability and severity of other interconnected risks, amplifying their effects
- Group 4: Risks that emerge solely due to the interactions and combined effects of other risk factors

Figure 7 illustrates the interplay among various groups within a dynamic framework, emphasizing the interrelationships between risk factors. The diagram demonstrates how user-provided responses initiate the calculation of risk scores by navigating through these interconnected factors, culminating in a thorough risk analysis.

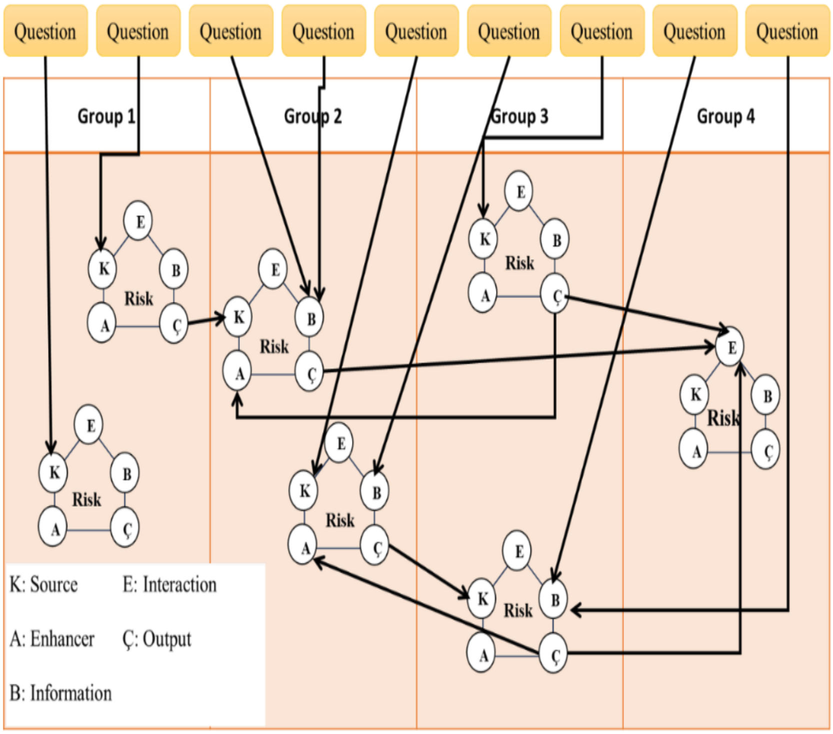


Figure 7:
Diagram of risk interactions

Workplace accidents result from the interaction of multiple risk factors rather than simple, linear causes. Therefore, to fully understand the root causes of accidents, the system must be analyzed holistically, considering "technological, psychological, organizational, environmental, and temporary" factors (Hollnagel, 2012). To capture these interactions, each risk factor is represented by five elements (Source (K), Enhancer (A), Information (B), Output (Ç), and Interaction (E)), as shown in the pentagonal nodes of Figure 8 (Hollnagel, 2012). The representation of risk factors enables the creation of interaction diagrams, which reveal how risks develop, the conditions required for their occurrence, and the elements that influence their probability and severity.

Interaction diagrams aid in calculating risk scores by systematically correlating risk factors through Equation (1). In this equation, (n) represents the total number of factors influencing risk, while (r) denotes the various combinations of these factors based on their potential coexistence in real-world scenarios. Combinations considered improbable in practice are excluded from the analysis. The viable combinations are then examined using the interaction diagram (Figure 7) and the decision tables shown in Table 2, which facilitate the assignment of heuristic probability and severity values. These values are systematically recorded in the fact list.

$$\mathrm{r} \leq \mathrm{n}, \mathrm{r} = \mathrm{n}, \mathrm{r} = \mathrm{n} - 1, \dots, \mathrm{r} = \mathrm{n} - \mathrm{n}; C(n,r) = \frac{n!}{r!\,(n-r)!} \tag{1}$$

Table 2. Probability and severity decision table

Questions	Rules															
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
Does wetness Continue?	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No	No
Is there a cleaning plan for possible spills and leaks?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	No	No	No
Is there excessive detergent residue left after cleaning?	Yes	Yes	Yes	No	No	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Yes
How much detergent residue is there?	little	Middle	High	-	-	little	Middle	High	little	Middle	High	-		little	Middle	High
Probability	**3**	**3.5**	**4**	**3**	**3**	**3**	**3.5**	**3.5**	**3.5**	**4**	**5**	**3.5**	**3**	**3**	**3.5**	**4**
Severity	**3.5**	**3.5**	**3.5**	**3**	**3**	**3**	**3**	**3.5**	**3.5**	**4**	**4**	**3**	**3**	**3.5**	**4**	**4**

Once all probability and severity values are assigned, Equation 2 calculates the risk priority score (RPS). The resulting scores are evaluated via Table 3, and preventive measures are recommended based on the magnitude of the identified hazards.

$$Risk\ Priority\ Scores\ (RPS)\ =\ Probability\ (P)\ \times\ Severity\ (S) \qquad (2)$$

In this way, safety measures for preventing each STF incident in warehouses are identified, and the most appropriate measures are determined based on the severity of the risk. The final step involves reporting these measures to the user, allowing for the reduction of risks to acceptable levels.

Table 3. L-type (5X5) matrix evaluation table

Probability / Severity	**Insignificant (1)**	**Minor (2)**	**Significant (3)**	**Major (4)**	**Severe (5)**
Rare (1)	Very Low (1)	Low (2)	Low (3)	Low (4)	Low (5)
Unlikely (2)	Low (2)	Low (4)	Low (6)	Medium (8)	Medium (10)
Moderate (3)	Low (3)	Low (6)	Medium (9)	Medium (12)	High (15)
Likely (4)	Low (4)	Medium (8)	Medium (12)	High (16)	High (20)
Almost Certain (5)	Low (5)	Medium (10)	High (15)	High (20)	Very High (25)

3. EVALUATION OF THE EXPERT SYSTEM-BASED RISK ANALYSIS IN THE WaSaEx PROGRAM (VERSION 1)

As a multidisciplinary field, occupational safety requires high expert knowledge to eliminate risks. With the transformation of warehouses into more complex environments and the increasing number of STF incidents, ensuring safety in these facilities necessitates in-depth expert knowledge. The challenge of providing continuous access to human experts, who are costly and only sometimes available, makes it difficult to establish a safe working environment.

3.1. Main Contributions of the WaSaEx Program to Risk Analysis

Creating safe workplaces requires expert knowledge in multiple fields. The WaSaEx program analyzes the workplace holistically and provides validated preventive measures by asking users simple, easy-to-answer questions. In addition, the program's development in Python allows for the future incorporation of machine learning, natural language processing, and other capabilities.

The main contributions of the developed program are as follows:

- **User-friendly Interface:** The program provides a user-friendly interface by enabling interaction with the expert system through a visual interface.
- **Comprehensive risk identification**: All risk factors and hazards present in storage areas are comprehensively identified.
- **Risk interaction consideration:** The program identifies risks that could be overlooked by considering the interaction of risk factors.
- **Minimized human error:** The systematic questioning process reduces the possibility of human error, thus minimizing the influence of user mistakes.
- **Holistic Approach to Risk Analysis:** The program guides the risk analysis team through a holistic examination of the entire workplace, considering all aspects systematically.
- **Realistic RPS Calculation:** By accounting for the interactions of risk factors, the program calculates risk priority scores (RPSs) that more closely reflect real-world conditions.
- **Time and knowledge savings:** The program provides significant time savings by integrating expert knowledge from various fields, reducing the time needed for research and investigation.
- **Cost and Time Efficiency:** The program focuses on preventive measures that address root causes, ensuring cost and time efficiency while mitigating risks.
- **Ease of Use for Novice Users:** The program is designed to be easy to use, even for novice users, allowing them to perform a complete risk analysis with all necessary technical information.
- **Reporting Functionality:** The program generates reports in text format, allowing occupational safety experts to use the results for further analysis.

3.2. Evaluation of Occupational Safety Results

The risk of STF incidents in warehouses is heightened because of 49 different accident types, each resulting from combinations of 53 risk factors. Furthermore, 16 of these risk factors arise directly from the interaction of other risks, making occupational safety management more complex. These risk factors stem from nine primary hazard sources:

- Personal characteristics
- Flooring
- Material handling
- Building design

- Environmental factors
- Managerial and administrative measures
- Personal protective equipment
- Lighting
- Training

The risk inventory created for STF incidents in storage areas reveals that these accidents often result from complex interactions between multiple risk factors (Motorcu and Murat, 2021a). Therefore, expert knowledge is needed to accurately identify and prevent these hazards (Leclercq et al., 2021; Larue et al., 2021). Therefore, expert knowledge is needed to accurately identify and prevent these hazards (Leclercq et al., 2021; Larue et al., 2021). Moreover, STF accidents are not caused by simple, linear interactions between risk factors; instead, they arise from the cumulative effects of multiple factors (Leclercq et al., 2021). To create safe storage areas, STF risk analysis should be conducted with a comprehensive, system-wide approach to achieve high-accuracy results (Newaz et al., 2023). Otherwise, important risks may be overlooked, as revealed by the interaction diagrams, which identified the persistence of 16 risk factors. Given the high frequency of STF incidents in warehouses (49 in total) (Yoon and Lockhart, 2006; Motorcu and Murat, 2021a), it is critical to conduct accurate risk analyses and implement validated preventive measures. Despite the complexity of STF mechanisms, analyses have revealed that STF risks can be mitigated with relatively simple precautions (Rubel et al., 2021). As a result, this study concluded that low-cost preventive measures can eliminate the risk factors for a significant portion of workplace accidents in storage areas.

4. APPLICATION OF THE WaSaEx (VERSION 1) PROGRAM FOR ANALYSIS OF STF RISKS IN THE STORAGE SECTOR

Upon launching the WaSaEx program, the user is greeted with a login page. After entering their username and password, they can access the program’s main window. If the user is not registered, they can create a new account by clicking the "Kayıt Ol" (Register) button. Once logged in, the user is presented with the main window, as shown in Figure 5. a. They can initiate the risk analysis by selecting the "Risk Tanımlama" (Risk Identification) submodule under the main "Risk Değerlendirme" (Risk Assessment) module.

In this section, the user is guided through five different windows containing sets of questions. By clicking "İleri" (Next), the user proceeds to the following question, and by clicking "Geri" (Back), they return to the previous question. The first question window identifies the general characteristics of the workplace and its employees. The user can change the default answer if needed, and additional information about the question is provided when the user hovers over it. All the questions are designed to be easily answered, with default answers preselected to streamline the process. Supplemental questions appear below the main question if additional information is required based on the user’s response.

After all the questions are answered, the user saves their responses by clicking the "Kaydet" (Save) button, which triggers probability and severity value assignments. The second step in the risk analysis involves running the "Risk Analizi" (Risk Analysis) submodule. This module identifies risk factors based on the user's responses, assesses the interaction between these risks, and consolidates the probability and severity values. The risk priority scores (RPSs) are then calculated, and the results are evaluated via the L-type (5x5) matrix. The preventive measures are written in a .txt file and accessed through the reporting module.

The report containing the risk analysis results can be viewed in the "Risk Değerlendirme Raporları" (Risk Assessment Reports) submodule under the "Raporlama" (Reporting) module (Figure 7). Users can print or download the report via the "Yazdır" (Print) or "İndir" (Download) buttons.

If a risk analysis needs to be performed for a different workplace, the program must be run from the beginning to the end. Otherwise, the previous responses are used for the subsequent analysis.

5. CONCLUSION

With advancements in information technology, AI applications for solving complex problems are becoming more widespread. ESs, which utilize the knowledge and experience of human experts to solve challenging and complex problems, have also become increasingly common. This study developed an ES-based program called WaSaEx to identify and analyze the leading cause of warehouse accidents—slip, trip, and fall (STF) incidents—and recommend appropriate preventive measures.

Through knowledge engineering, a risk inventory was created that identifies the factors contributing to STF incidents in warehouses. Additionally, the system provides a holistic analysis by evaluating the interactions between all risk factors. The user is guided through the process with simple, easy-to-answer questions, and the data collected from the responses are used to perform risk analysis via an L-type (5x5) matrix. The resulting RPS values generate a report recommending validated preventive measures. Consequently, the system allows users to conduct risk analyses swiftly and accurately, ensuring the recommendations are practical and aligned with validated preventive measures. Importantly, it offers a holistic approach to risk assessment by thoroughly evaluating all relevant factors, effectively minimizing residual risk values. This capability empowers users to make informed decisions, ultimately enhancing workplace safety.

In the future, AI applications are expected to play a more prominent role in occupational safety, with the potential for integrating advanced analysis methods, risk inventories, and accident prediction models. By utilizing such systems, workplaces can further enhance their safety measures. Consequently, conducting field tests and comparative analyses with different risk assessment methods will be crucial for enriching the available tools. WaSaEx (Version 1) continues to develop and improve the program's algorithms and flow diagrams. Additional modules are being added to enhance the system's capabilities and expand its scope, ensuring it can better support businesses and institutions performing offline risk analyses and planning OHS activities.

CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest regarding the publication of this article.

AUTHOR CONTRIBUTION

Bilal MURAT: led the knowledge engineering process, conducted the literature review, and was responsible for designing, coding, and developing the program. Additionally, contributed to the drafting of the manuscript.

Ali Riza MOTORCU: contributed to drafting sections of the manuscript, editing the work, and approving the final version.

Yunus KAYIR: contributed to drafting sections of the manuscript, editing the work, and approving the final version.

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