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IDENTIFYING FACTORS INFLUENCING FALLS FROM HEIGHTS

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Abstract: *We set out to identify the factors that influence falls from height, in order to obtain relevant information regarding the existence of causal relationships between the components of the work system (executor, workload, means of production and the work environment) and the risk due to the fall from the height. The methodology applied to fulfill the objective of this stage included: online research and documentation, rigorous evaluation and critical analysis of the selected articles in order to identify and centralize the factors that influence the risk of falling from height. The results of the analysis highlighted the fact that the main factors in the occurrence of accidents are the workers through "behaviors and attitudes"; the configuration of the workplace and last but not least personal protective equipment, due to non-use, inappropriate use, or use in a damaged state.*

Keywords: *occupational health and safety, danger of falling, fall injuries*

During work at height (for example, on a roof, scaffolding, etc.), workers in various sectors of activity often face the danger of falling, as they may lose contact with the surface on which they are standing and may fall and suffer various injuries.

According to the Romanian law (file 123 "Work at height" from H.G. 355/2007 on workers' health surveillance amended and supplemented by H.G. no. 1169 / 2011), "work at height" means the activity carried out at a minimum of 2 m measured from the surface under the worker's feet to the natural reference base (soil) or any other artificial reference base, base from which there is no danger of falling into the void".

Falls that occur during activities carried out at height generally have multiple causes. Under the concept of multiple causes, the factors combine randomly, causing accidents. The extent to which the safety of workers working at height is compromised is determined by the action of existing risk factors at the workplace, which can be amplified by a number of influences (such as planning and training, materials and equipment, supervision, project management, workplace safety culture). Assigning a single specific cause to an accident or incident is rarely accurate and is often considered a misguided approach because it fails to identify the real causes. The general objective of identifying the factors that generate falls from height is to provide clues on how to create better accident prevention programs, by improving the control and training procedures, by better defining responsibilities and planning surveillance activities.

By analyzing existing statistics at European level and those presented in 2013 by the Association of Utility Mountaineering in Industry (IRATA) [7], on accidents caused by falling from a height, as a result of activities carried out "on the rope" (using techniques utilitarian mountaineering), on scaffolding, on the roof, it was found that they are present in most sectors of activity. Using as an indicator the value of the accident incidence rate for a given population (100,000 workers), the data presented by IRATA [7] for the countries of the European Union, in 2012, place the construction sector (1,989 accidents) in the top of work accidents due to falls from height, followed by manufacturing (1,630 accidents), agriculture, forestry, fishing (1,413 accidents) and mining (1,356 accidents).

Analysis of existing data in the literature found that most accidents at work due to falls from a height occur in construction [5], [8], [9] - during activities on scaffolding, pillars and stairs, for the assembly of prefabricated parts, for the lifting of formwork, for demolition, for maintenance and rehabilitation of buildings, for works in crane cabins located at high altitude, for works in forklift and elevator cabins located at high heights in warehouses , for activities performed at ground level near an uncovered ditch / pit; for works in wells and sewers, etc.

Types of risks

When working at height, there is both the risk of falling due to the difference in level between the workplace and the ground, and the risk of falling due to the specific workload to be performed, which can lead to either death or injury. bodily ailments or health conditions. The severity of the injuries is determined by the impact speed of the person, it depends both on the height of the fall, the nature of the impact surface, and the part of the body that hits the surface.

However, data from the literature have shown that serious or fatal injuries can result not only from the impact of the body from a great height on a solid surface, but also from:

- the impact caused by a fall from a low height, through a fragile surface;
- impact with the head forward from a low height.

In the case of working at height, the following types of risks have been identified:

- the risk of falling predominantly after a fall from a height;
- risk of falling followed by:
- swinging the body and hitting obstacles ("pendulum effect");
- stopping the fall due to the requests sent by the belt to the body;
- suspension of the body of the worker who is hanging from the fall arrest equipment and the time spent in this position;
- the risk associated with personal fall protection equipment due to the fact that PPE:
- PPE is not installed properly [5];
- PPE prevents the free movement of the body;
- prevents the placement of other components of the PPE;
- the risk of falling as a result of:
- insufficient adhesion of the footwear;
- dizziness;
- blindness (due to shiny objects);
- lack of visibility;

- hypothermic shock or sunstroke;
- rapid drop in temperature;
- specific risk related to the type / workload:
- mechanical (sharp edges, sharp tools, falling objects, etc.);
- thermal (sparks, free flame, etc.);
- chemical;
- electric;
- risk due to weather conditions: wind, rain or ice over the walkways, etc .;

Whether it is a fall of 2 m [9] or a height of more than 2 m [8], [9], this is generally not without consequences; the severity and nature of the injury ranging from bruising, sprains and fractures of the upper and lower limbs, fractures of the ribs, head trauma, damage to internal organs, to death [5], [9]. As a result of these injuries, work accidents due to falls from a height can be classified [10] into:

- ➢ accident that causes temporary incapacity for work (ITM) - accident that causes temporary incapacity for work for at least 3 consecutive calendar days, confirmed by a medical certificate or, as the case may be, by other medical documents, according to the legal provisions;
- ➢ accident that causes disability (INV) - accident that causes disability confirmed by a decision to classify a degree of disability, issued by the medical authorities in law;
- ➢ fatal accident (D) - accident resulting in the death of the injured party, confirmed immediately or after a period of time, based on a forensic act.

Due to the major contribution of accidents due to falls from heights to accident statistics across Europe, studies have been conducted over time in different countries to identify the factors that cause falls from a height and to find optimal solutions. reduction of accidents at work.

Although the studies analyzed led to a good understanding of the size and pattern of accidents, the link between the various factors identified was limited to the influence of individual factors and the workplace on the occurrence of accidents due to falls from heights. Taking into account that accidents due to falls from heights occurred in different sectors of activity (construction, agriculture, chemical and steel industry, extractive industry, etc.), while working, or while traveling to or from work , it can be considered that not only the configuration of the workplace and the level difference of more than 2 m are a source of danger, but also the cumulative action of physical, mechanical, chemical hazards present in the work environment, as well as their synergistic action, at which can be added to the action of other workers.

In order to identify all the risk factors that over time have caused work accidents due to falling from a height, the research was based on their study:

- taking into account the different configurations of the workplace - the area in which the danger of falling has occurred - such as during: work on scaffolding [11], [12], [13], on pillars and stairs, on roofs [11], [14], during the lifting of the formwork [15], the periodic inspection and maintenance of the installations [15], the demolition [15], the maintenance and rehabilitation works of the buildings [14], the works in crane cabins located at high altitude, during ground level activities near an uncovered ditch / pit [16], as well as on roof works [15], [17], [13], etc.

- for several occupations, such as masons, carpenters, tinsmiths, plumbers, electricians, construction workers, carpenters, painters, other employees;
- considering the size of the companies in which they were produced: companies with more than 100 employees, companies with less than 10 employees.

In order to obtain relevant information on the existence of causal relationships between the configuration of the workplace and the risk caused by falls from heights, we performed a formal analysis starting from the components of the work system (performer, workload, means of production and work environment). thing).

Components of the work system and risk factors

Identified in various studies, the risk factors that caused the falls from a height were grouped into:

1. ***Risk factors specific to the executor*** (the worker involved in the execution of a task), generated by:

- behavior and attitudes: through reluctance to take safety measures, lack of a culture of security ("It won't happen to me") [15]; attention / vigilance, work disorder, decision to continue work after identifying a dangerous situation, decision to continue work without personal protective equipment [18], [16], [19], [20]], the decision to continue working without insurance, the decision to act regardless of the conditions of the working environment [18], jokes, communication skills [21], the use of inappropriate protective equipment [15], the removal of the safety device, adopting an unsafe position or position, choosing improper anchorage points [17], using damaged personal protective equipment [17], improper use of personal protective equipment [5], [17], distraction, ignorance and negligence of workers [22]], reckless operation, incorrect position during workload [11], inadequate risk assessment, improper marking of openings, incorrect assembly scaffolding or lack of parapets, non-compliance with safety and health rules [17], etc .;
- state of health: through hearing disorders, chronic or acute pathologies, mental disorders [18], alcohol consumption [18], medication consumption, weakness, fatigue [21], [18], traumas suffered, etc .;
- lack of experience [11] (inability to work on stairs, scaffolding, roofing, etc.);
- training and education: through language and cultural problems [22], lack of experience [22], lack of training, [23], lack of education in the field of health and safety at work [11], insufficient training [22], problems communication [22], lack of qualification [15], lack of awareness of fall protection;
- moral: by putting pressure on performance; feeling vulnerable; the relationship with the boss and the other workers; material interest.

2. ***Risk factors specific to the workload,*** generated by:

- lack of knowledge of working technologies and methods [11], inadequate working standards, lack of supervision [11], failure to provide personal protective equipment, limited access to resources, etc...;
- oversizing the requirements imposed on the executor; the pace of the work;

3. ***Risk factors specific to the means of production*** [15], [13] which may be generated by:

- the presence of equipment or objects with high temperatures, sharp, sharp, rough objects, the use of defective, overloaded equipment, the presence of

unprotected explosive materials, the use of non-insulated power tools [18];
- improper storage of materials [21], presence of chemicals, etc.

4. ***Risk factors specific to the work environment*** [15], generated by inadequate working conditions such as:

– inadequate lighting;
– surrounding activities, such as falling objects, heavy machinery traffic;
– work surface (wet, slippery, damaged, fragile surfaces, etc.);
– the presence of unprotected edges and openings [23], [14];
– defective stairs and scaffolding [23];
– adverse external conditions (ice / snow, adverse temperatures, rain (21), sun, noise) [17].

Given the significant variations in organizational methods, practices and work tasks in construction, the diagram in Figure 1.1 illustrates the share of macro-variables that determine the occurrence of falls from heights. By analyzing the diagram, it can be seen that the main factors in the accidents are the workers through "behavior and attitude" (approx. 13%), the configuration of the workplace (approx. 12%) and last but not least personal protective equipment (approx. 13%), due to non-use, improper use, or deteriorated use, up to 100% due to the work environment, age of workers, health, training and education, construction materials, company size, etc.).

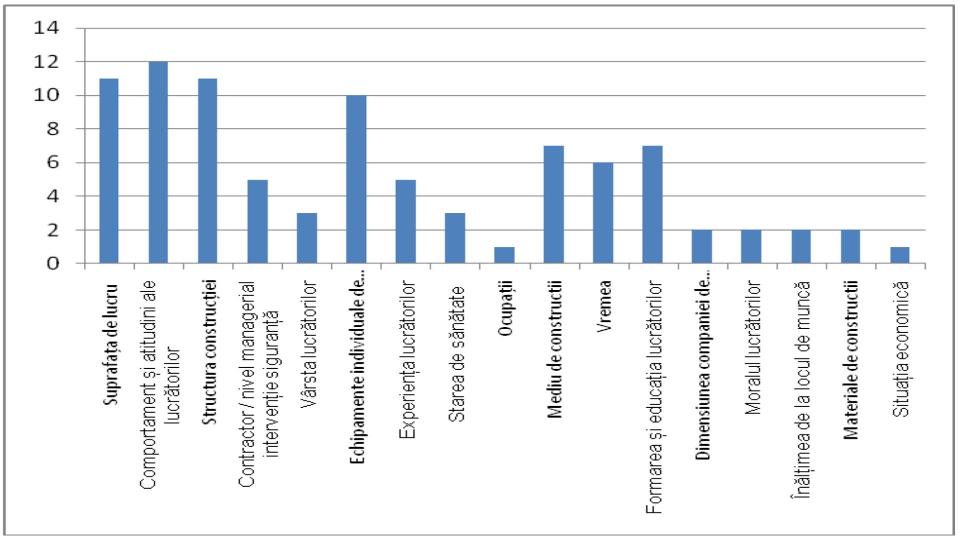

Figure 1 - The weight of the macro variables that determine the occurrence of falls from height

Often, the action of these risk factors can be accelerated by the result of the influences from the design of works, project management, activities that take place nearby, culture in the field of security and risk management, customer requirements, economic climate in which the activity takes place, etc.

Other factors identified such as contractors / managerial safety, health and the workplace environment also constantly contribute to the risk of falling, and factors such as age, experience of workers and occupations are also frequently discussed, but their impact on the risk of falling from a height is somewhat modest.

Because "behavioral and attitude of workers" is one of the most common causes in most studies, it can be said that this is one of the factors that directly contribute to the risk of falling from a height, over time compared to other variables.

At national level, the establishment of measures to promote the improvement of occupational safety and health of workers is regulated by Law no. 319/2006 - Law on safety and health at work (transposing at national level Framework Directive 89/391 / EEC). The law establishes the main obligations of employers with regard to ensuring the safety and protection of workers' health; occupational risk prevention; informing and training workers, including the protective equipment to be used.

Considered as the last protection measure to be applied when it has been established that following the use of other protection measures or reorganization of the workplace, the risk has not been eliminated, the personal protective equipment (hereinafter abbreviated PPE) is “any equipment carried or held by the worker to protect him from one or more risks which could endanger his safety and health at work, as well as any additional elements or accessories designed for this purpose. "[24]

As for personal protective equipment against falling from a height, it does not consist of a single component, but of a set of components, which are removably or non-removably connected, thus forming a system designed to protect the user against falls from height.

Construction industry has one of the highest accident and fatality rates among other major industries, with more than 60,000 fatal accidents each year worldwide. Falling from height is one of the leading causes of fatalities and injuries in construction. Passive protection devices (e.g., safety net) have been used to minimize the impact of falling from height for ages, while proactive warning systems appear recently to alert the workers when they are at risks of falling. To provide appropriate warnings to the worker but not to distract them due to the false alarm, the falling risk needs to be carefully evaluated. Hainan Chen and Xiaowei Luoa published in 2016 a material titled „Severity Prediction Models of Falling Risk for Workers at Height” [25] where the authors introduced algorithms for falling risk prediction and evaluated their performance. Injuries records during 2005 to 2015 were extracted from the OSHA database and 1161 intact falling-related record were used in this study. K-Modes, RBF network and Decision Trees are chosen to build three risk prediction models, and the performance of those three proposed models were evaluated using the OSHA injuries record data. The results indicate that the DT-based falling risk prediction model has the best performance of 75% and the top three critical factors of falling event’s severity are distance from the ground, worker’s occupation and the source of the falling. The delivered severity prediction model provides the foundation of more accurate real time risk evaluation for workers at height. Their research is based on on the OSHA inspection data, and focuses on the fall accidences in the construction industry which the SIC Major Group codes include 15, 16, and 17. All the data since Jan. 01 1984 with specified 15 parameters have been obtained, which the EventType is fall, and any record which has none or blank value of parameters are filtered out, and finally there are 1166 intact records for this research. The authors used Clustering Algorithm and Decision Tree Learning Algorithm to filter and interpret the data.

First, the importance of the parameters has been analyzed. Based on the Gini importance theory [26] and the mRMR algorithm [27], the importance of the parameters is calculated and the results are illustrated in Figure 1. Gini importance and mRMR are two classic features selection algorithms. These two algorithms can calculate the importance of features for classification, in which the larger importance value, the more influence for the classification.

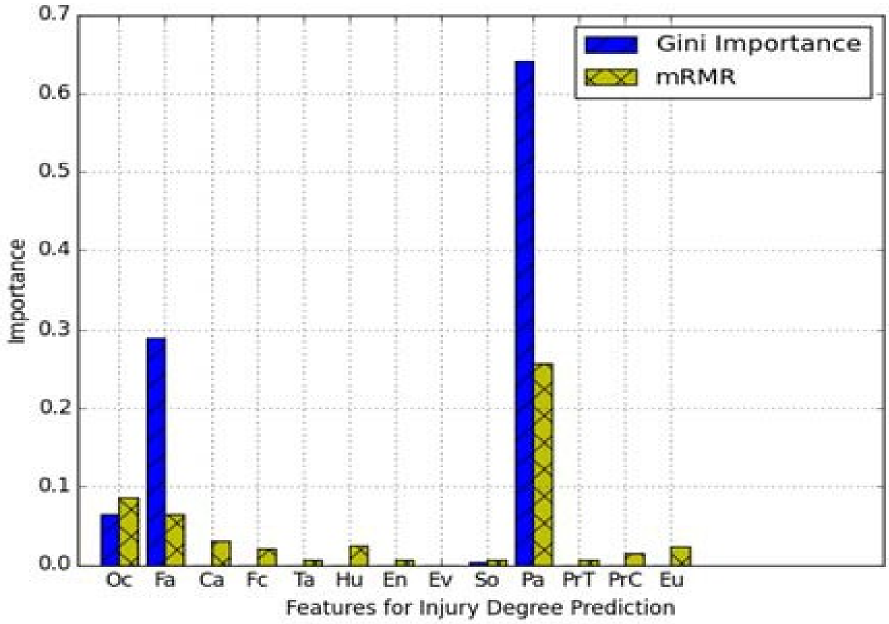

Figure 2 - Features Importance Analysis for Injury Degree Prediction

As the illustrated results, the Occupation, FallDist and PartBody are the most 3 important parameters both in Gini importance analysis and the mRMR algorithm. For EventType parameter, it shows that the importance is 0 in the all situations. It is because that in this research the fall accidents are focused on, all the EventType values are fall. If just considering the injury degree, it shows that Occupation, FallDist, SourceInjury, and PartBody, the 4 parameters contribute most to the classification.

Based on the OSHA data, one fall accident is an abstract record described by 15 features. According to the analysis in section 3.1, PartBody, FallDist, Occupation, and SourceInjury are the top 4 important features for classifying the data set into different injury degrees. The accuracy of the three types of classification algorithms has illustrated in Figure 2.

For the k-Modes algorithm, the value of the Degree feature is the label of the records and the k-Modes output.

The value of the most relative features composed of the feature vectors and the input of k-Modes algorithm. Through learning the relation rules, the k-Modes algorithm predicts the injury degree according to the feature vectors. The k-Modes algorithm can generally achieve 0.62 accuracy.

RBF network also employed the most relative 4 features as the input vector, and the output is the degree of injury. Although generally RBF network is a good kind of ANN algorithm for classification, in this research, it can only achieve up to 0.49 accuracy for injury degree prediction.

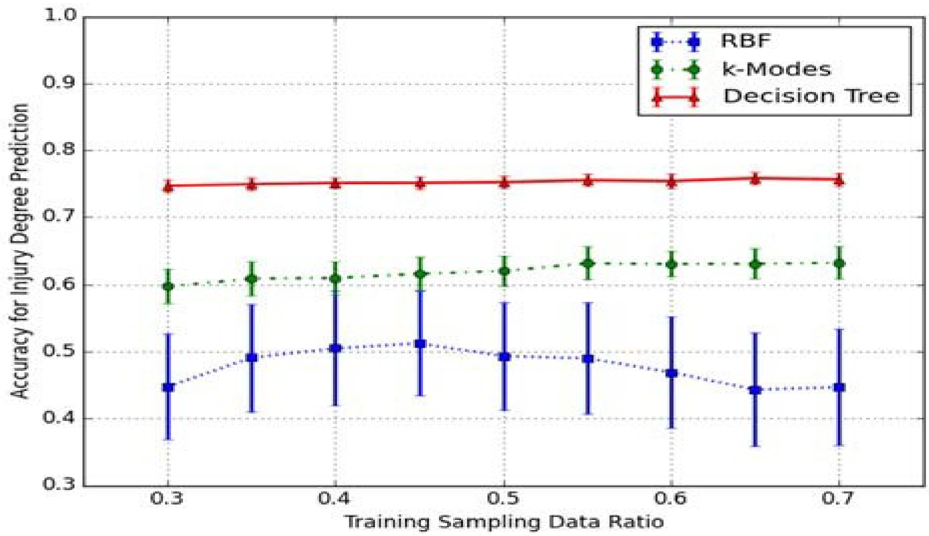

Figure 3 - Training Data Ratio VS. Prediction Accuracy for Injury Degree

Decision Tree algorithm based on the Gini importance theory to process the data vector. Based on the analysis in section 3.1, the top four important features were selected. Therefore the feature vectors can achieve the maximal Gini importance. Its accuracy for injury degree classification is around 0.75.

In order to investigate fall injury proactive protection for construction industry workers, this research studied the OSHA data. Two parameter analysis methods: Gini importance analysis and mRMR algorithm were employed to analyze the importance of the data features, and 3 kinds of data mining algorithms DT, k-Modes, and RBF network were applied to classify and predict the degree of the injury. By comparing the accuracy of the 3 kinds of algorithms, the DT algorithm definitely has the best performance for the injury prediction. According to the importance analysis, the injured part of the body (PartBody), fall down distance (FallDist), worker's occupation (Occupations) and the source of the injury (SourceInjury) are the top 4 important parameters for injury degree prediction.

Summary and conclusions

In conclusion, to a certain degree, the fall accidents in construction can be predicted, and the data mining algorithm, especially Decision Tree algorithm can do further contributions for fall injury proactive protection. In addition, according to the importance analysis and prediction comparison, just depending on the objective features of the construction company or construction workers to predict the construction injuries is definitely a reluctant method. In order to offer proactive protection, monitoring the position and posture of a worker, which can be relative to the FallDist and PartBOdy features, in real time is significant.

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