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Building a Model Using Bayesian Network for Assessment of Posterior Probabilities of Falling From Height at Workplaces

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ABSTRACT

Background: Falls from height are one of the main causes of fatal occupational injuries. The objective of this study was to present a model for estimating occurrence probability of falling from height.
Methods: In order to make a list of factors affecting falls, we used four expert group's judgment, literature review and an available database. Then the validity and reliability of designed questionnaire were determined and Bayesian networks were built. The built network, nodes and curves were quantified. For network sensitivity analysis, four types of analysis carried out.
Results: A Bayesian network for assessment of posterior probabilities of falling from height proposed. The presented Bayesian network model shows the interrelationships among 37 causes affecting the falling from height and can calculate its posterior probabilities. The most important factors affecting falling were Non-compliance with safety instructions for work at height (0.127), Lack of safety equipment for work at height (0.094) and Lack of safety instructions for work at height (0.071) respectively.
Conclusion: The proposed Bayesian network used to determine how different causes could affect the falling from height at work. The findings of this study can be used to decide on the falling accident prevention programs.

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Introduction

Falls from height in the workplace (such as falls from ladders, scaffolds) is a major cause of fatal occupational injuries.[1] Falling is a serious hazard in many industries. Workers who work at height are at risk offalls from heights, with fatal consequences. Many workers are exposed to falls from heights, surfaces and walkways. These falls can result in serious injury or death.[2] As noted by NIOSH, "exposure to fall hazards is a nearly constant aspect of employment".[3] Kines study showed that falls from heights were the most common accidents resulting in lost-time injuries in Netherlands.[1] In the Netherlands, 28% of the reported incidents, are falls from height.[4] In addition, occupational fall accidents remain a significant cause of injuries and fatalities among the American workforce.[3] Occupation fall accidents continue to pose a significant burden to U.S. industry, both in terms of human suffering and economic losses. According to The U.S. Bureau of Labor Statistics, a total of 835 fatal falls were recorded (15% of jobrelated deaths), and fall accidents accounted for more than 30% of all non-fatal injuries involving days away from work.[3]

The survey of occupational accidents database of Iran Ministry of labor and social affair reveals that falls from heights accounted for 31.14% of occupationally related accidents. In addition, 41.05% of occupational fatality accidents are falling from height and 11.61% of falling from height is fatality accidents. This statistics show that consequence severity of this type accident is very high.

As such, the accident statistics presented above may remain unchanged unless control measures are taken to minimize the occurrence of these accidents.[3] The prevention of fall from heights is, therefore, of interest not only for workers and employers, but also for the society, governments, health and safety professionals, and insurance companies. So falling from height accident prevention and control is an important problem that should be solved in workplaces, the significant solution is falling risk assessment. Risk assessment is the important means how to prevent and control falling from height accidents. Its purpose is to improve the working at height safety and the level of safety management, prevent and control of accidents.[2]

In addition, risk assessment is recognized as an integral part of successful health and safety management. The effective management of safety and health will depend to suitable and proper risk assessment and use the results of this assessment effectively.[4]

Many of the studies on occupational falls from height are statistical in nature, which seems to be inadequate sources in attempting to understand the underlying processes of an accident and to plan for managing this accident[1]. In addition, several studies have been performed examining the causes of injuries and deaths from falls,[4] such as those from the NIOSH Fatal Accident Circumstances and Epidemiology (FACE) reports,[5] OSHA report on falls from elevated platforms[6], the study of McCann for deaths in construction related to personnel lifts[7] and the study of HSE for falls from height in various industrial sectors.[8] Many researchers have focused specifically on identifying the reasons behind accidents and on developing safety systems and information technologies have been implemented as a preemptive measure of potential accidents. Recently, safety concerns related to psychology, industrial hygiene, ergonomics, systems engineering and sociology have been studied.[9] Shi, et al. built the index system for risk of falling by AHP-Fuzzy comprehensive evaluation method. The results showed that the safety conditions are consistent with engineering applications.[10] Aneziris, et al. presented logical models for quantifying the probability of fall from ladders, roofs, scaffolds, holes in ground, moveable platforms and nonmoving vehicles and in addition the probability of the consequences of such falls like death, permanent injury and nonpermanent injury.[4]

The objective of this article is presentation a model for estimating of falling from height occurrence probability. We purpose Bayesian theorem.

Materials and Methods

Determination of falling from height causes

In order to make a list of factors affecting falls from height accidents we used four expert groups (total 50 subjects) judgment (Table 1). At this phase, two criteria for the selection of experts have used include having at least a bachelor's degree and having at least two years of experience.

By phone, email, face to face or a combination of them, the purpose of the study was explained to the experts. After examining the views of experts, the literature review and survey database, 31 factors (causes) were identified for falling from height.

Determine the validity and reliability of questionnaire of falls from height accidentscauses

First, the face and content validity of the questionnaire must be determined.

Table 1: Various groups of experts

Groups	Areas of expertise	Degree (number)		Total
		Bachelor	Masters and PhD	
1	Experts working in various industries	10	6	16
2	Occupational health and safety professionals studying at universities	-	10	10
3	Labor inspectors	11	3	14
4	Safety experts from the Center for Justice	6	4	10
Total		27	23	50

Since one of the purposes of this study was designing a questionnaire specifically for the causes of accidents related to falls from a height, the content validity was used because it is more valid than apparent validity. Therefore, Lawshemodel was used.[11] After creating a list of factors affecting falls from height by experts, review of the literature and database, in order to determine the validity and reliability of the questionnaire, the 44 experts were used. After determining the questionnaire CVR (Content Validity Rate) and CVI (Content Validity Index), 37 of the 42 primary causes of the falling remained (Table 2). To determine the questionnaire reliability the experts were asked to score the causes of the accident, according to its importance from 1 to 5 (1 lowest and 5 the highest importance). This was repeated after two weeks. Data from these two phaseswere entered into the SPSS 17 software and Cronbach's alpha was calculated to determine the internal consistency of the questionnaire and the Spearman test was used to determine the external (repeatability) correlation that were 0.840 and 0.836 respectively.

Building Bayesian networks

The occurrence of any incident and its consequences is affected by different factors, some of which interact with each other and both are affected by or affect. Knowing this and the complexity of relationships between factors and incidents, using only a literature review was would not give the complete picture of the factors. Therefore, the judgment of experts and occupational accidents database of Iran Ministry of Labor And Social Affair to prepare these factors (causes) were used. However, interviews with experts, literature review and the review of existing databases, leading to a large number of factors affecting the incidents, but information about causes and processes within the system were not identified. So the 10 labor inspectors or experts with at least 5 years' experience were asked to determine the various levels of accidents causes in Table 3. In this table, expert starts with determining the causes which directly affect the before level and continues to achieve a desirable level of details. In the fourth column of Table 2, the factors influencing previously factor have been identified. After providing an appropriate level of details within the network, the Bayesian network using Uninet software was developed.

Network quantification

In this research for quantifying the network, the judgment of experts and occupational accidents database of Iran Ministry of Labor and Social Affair were used. For quantification of the curves can use the mentioned sources, too. The experts were asked to score the causes of the accident, according to its importance from 1 to 9 (1 lowest and 9 the highest importance). Then data were entered into the Super Decision software and using this software a weight was obtained for each of causes to quantify the network nodes.In addition, to quantify some of the nodes that had sufficient data (including age, education, time of accident, marital status), database was used. This step results are shown in the fifth column of Table 2. Quantification curves means determination of rank correlation (conditional) or formulas for curves on the network.

Table 2: Factors affecting falls from height and their weights

Source	No.	Variables	Affected by	Weight
Literature review, Experts judgment and database	V1	Non-compliance with safety instructions for work at height	V3, V7, V8, V21, V26	0.127239
	V2	Lack of safety equipment for work at height	V4, V7	0.094838
	V3	Lack of safety instructions or guidelines inappropriate for work at height	N/A	0.071574
	V4	Non-compliance with legal requirements	V3, V7, V8, V21	0.065478
	V5	Lack of personal protective equipment	N/A	0.064399
	V6	Non-embedded safety scaffold or work platform securely	V1, V4, V7, V10	0.062479
	V7	Lack of audit, inspection or monitoring by the employer	N/A	0.050528
	V8	Lack of effective training	V37	0.050195
	V9	Do not use personal protective equipment	V5, V7, V8, , V21, V23	0.046237
	V10	Working with the rate of unsafe or working in the rush	N/A	0.045908
	V11	Snow or rain	N/A	0.042446
	V12	Negligence and carelessness of worker at work	V8, V10, V18	0.043138
	V13	Slip workplace	V7, V11	0.033868
	V14	Too much work and More than usual	N/A	0.030659
	V15	Horseplay	V8	0.030009
	V16	Lack of physical competence for work performed by the worker	V20	0.013023
	V17	Using unsafe equipment at work	V1, V2, V7, V8	0.009924
	V18	Excessive fatigue of worker	V14	0.006755
	V19	Windy conditions	N/A	0.008801
	V20	Workers sickness	N/A	0.005106
	V21	Safety requirements are not being developed as part of the working tasks	N/A	0.00146
	V22	Lack of safety management systems in the workplace for obtaining work permits	N/A	0.002625
	V23	Hot or cold weather	N/A	0.006688
	V24	The lack of a program to investigate the accident occurred	N/A	0.007761
	V25	Work without permission	V7, V22	0.007402
	V26	Lack of reward and punishment system in relation to safety at work	N/A	0.009101
	V27	Lack of warning systems	N/A	0.008242
	V28	Not identify hazards, assessment and control them	N/A	0.005064
	V29	Age group	N/A	0.00151
	V30	Education	N/A	0.000914
	V31	Marital Status	N/A	0.003962
	V32	Day of week	N/A	0.00745
	V33	Time of occurrence	N/A	0.006767
	V34	Accident experience	N/A	0.009318
	V35	Activity sector	N/A	0.007339
	V36	Work experience	N/A	0.009599
	V37	Month of occurrence	N/A	0.006518

To determine the correlation between causes, the SPSS 17 software and Spearman's test were used. Using Uninet software, probabilistic nodes and function nodes were mapped. Probabilistic nodes are the nodes that their distributions were obtained using existing data or expert judgment. Function nodes are the nodes that are considered as functions of their parent nodes. Their distributions were obtained using the marginal distribution of parent nodes.

To determine the likelihood of a falling accident from height the following formula was used.

$$P(H|E) = \sum \frac{P(E|H)*P(H)}{P(E|H)*P(H)+P(E|\sim H)*P(\sim H)}$$

Where:

- P(HlE) is posterior probability of falling accident
- P(H) is prior probability of falling accident
- P(ElH) is prior probability of falling accident according a known cause
- P(~H) = 1-P(H)
- P(El~H) = 1- P(ElH)

Sensitivity Analysis

Model sensitivity analysis generally involves analyzing the changes in the model output when changes are made to the input. With models based on the BBN approach the input consists of the graphical structure of the network (that is to say nodes and arcs) and its quantification (which means the distributions for nodes and the rank correlations for arcs). The input parameters for a BBN model are therefore: [12]

- the factors (nodes) included into the network
- the arcs/influences between factors
- the weights assigned to nodes
- the correlations assigned to arcs

In the current study, each of the four types of sensitivity analysis carried out. For each type of input, several changes are made which lead to several sensitivity analysis cases. The changes are made in the basic Bayesian network presented. The results for the probabilities and the standard deviation in the sensitivity analysis cases were compared with the results for the probabilities and the standard deviation obtained using the basic Bayesian network (Table 3 and Table 4).

Ethical considerations

There are no ethical considerations to declare.

Results

Among the 37 contributing factors to the falling from height (which is specified by experts judgment), non-compliance with safety instructions for work at height (0.127239), lack of safety equipment for work at height (0. 0.127239) and lack of safety instructions or guidelines inappropriate for work at height (0.071574) gained the highest weight respectively. In addition, factors non-compliance with safety instructions for work at height and do not use personal protective equipment (affected by 5 factors) were influenced by most factors (Table 2). In sensitivity analysis after nodes and arcs elimination or their quantities reduction, the case output and standard deviation changed (Tables 3, 4).

Table 3: Sensitivity analysis using nodes weight reduction and nodes elimination

Nodes weight reduction				
Node	**Basic node weight**	**Case node weight**	**Case output**	**Case output STD**
V1	0.126854	0.006854	0.822737	0.620031
V6	0.0633223	0.000323	0.840865	0.626962
V3	0.073646	0.000646	0.837930	0.625959
V2	0.095958	0.000958	0.831199	0.624635
Nodes elimination				
Eliminated node	**Basic node weight**	**Case output**	**Case output STD**	
V32	0.008592	0.840396	0.626486	
V8	0.048452	0.828972	0.608690	
V1	0.126854	0.776067	0.558443	
	Basic case output: 0.858180		Basic case STD: 0.630211	

Table 4: Sensitivity analysis using arcs correlation reduction and arcs elimination

Arcs correlation reduction				
Arcs	**Basic arc correlation**	**Case arc correlation**	**Case output**	**Case output STD**
V10 → V12	0.645	0.005	0.857441	0.625441
V2 → V17	0.764	0.004	0.858410	0.621938
V3 → V4	0.827	0.007	0.858282	0.622349
V2 → V17 V3 → V4			0.858513	0.613528
Arcs elimination				
Arcs	**Basic arc correlation**	**Case output**	**Case output STD**	
V8 → V1	0.436	0.858236	0.623630	
V2 → V17	0.764	0.858411	0.622004	
V3 → V4	0.827	0.858284	0.622174	
V2 → V17 V3 → V4		0.858515	0.613856	
	Basic case output: 0.858180		Basic case STD: 0.630211	

Discussion

Among the 37 factors that were identified by experts, reviewed the literature and database, the Non-compliance with safety instructions for work at height factor (0.130326) had the highest weight. It could be the influence of various factors on this factor (5 factors influence on these factors). One reason for the "Not identify hazards, assessment and control them factor" (0.0.005064) had a low weight could be that from the experts viewpoints. Lack of safety equipment for work at height and Lack of safety instructions or guidelines inappropriate for work at height could be because of lack of employer and regulator supervision or because of lack of employees and supervisors safety awareness. The improvement actions in these 3 main falling causes are training, supervision and auditing because these auditing and training are affected many factors such as Non-compliance with safety instructions for work at height and Non-compliance with legal requirements factors.

The sensitivity studies were designed to check how the model output changes when small adjustments are made to the model input. For this particular model, one should bear in mind that there are two steps when creating the model and each step has different input parameters. For the first step, the input parameters are the nodes and the arcs between them, while the input parameters for the second step are the quantities for nodes and correlations for arcs. Whenwechanged theinputof thenetwork, its output and standard deviation was changed. The greatest changes occurred with the removal of the nodes. As seen in the Tables 3, 4, the built network is very sensitive to input changes.

In this paper, a model is proposed to predict the accident injury probability. The risk model developed is formulated in terms of risk indicating variables using Bayesian Networks for falling from height. The networks are developed by combining expert judgment, literature review and database. The developed model is precise in its predictive ability (Tables 3, 4). The risk indicating variables are selected taking into consideration falling causes such as age, time of occurrence, Non-compliance with safety instructions for work at height etc. When injured workers are involved in the injury accidents are classified by their injury severity this model may also be thought of as accident risk model being relevant for risk informed decision making in the context of accident management. The current study presented a BN model to show the interrelationship between causes affecting the falling from height accident and calculate its risk. The BN used to determine how different causes could affect the falling from height at work. The BN model is a multivariate probabilistic model, which represents a set of variables and the dependencies that exist among them. The model permitted us to make Bayesian inference, which means that it was possible to estimate the falling accident and its consequence probability and risk. The BN model offers flexible methods of reasoning based on the probabilities throughout the network in accordance with the laws of probability theory.

Successful accident prevention relies largely on knowledge about the causes of accidents. In any accident control activity, particularly in occupational accidents, correctly identifying high-risk groups and factors influencing accidents is the key to success interventions.[13-16] The findings identified in this study can be used to decide on the accident prevention programs. In order to prevent or reduce the number of occupational accidents, the components causing occupational accidents should be identified via analysis, assessments, necessary measures should be taken, and audits should be used to see if the measures are implemented effectively or not. What is important here is the continuous implementation of measures and auditing. The success of preventing occupational accidents depends on this process. Accidents may be decreased if a safety culture is constituted and shared with employees.[17,18]

Conclusion

The results of this research indicate that Bayesian networks are very useful in explaining the causes of falls. By identifying the dependency relationships between different variables, Bayesian networks offer a broad-based perspective on the circumstances surrounding work performed at a height that will enable us to define a preventative strategy that reflects a particular reality. Bayesian networks represent a statistical tool of huge potential in investigating the causes of accidents in the workplace. As an expert system, Bayesian networks allow us to build a knowledge base that progressively grows with the inclusion of new data.[19-21]

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Competing interests

There is no conflict of interest to declare.

References

1. Kines P. Case studies of occupational falls from heights: Cognition and behavior in context. *J Safety Res* 2003;34:263-271.
2. Hsiao H, Timothy J,Nancy A. Research and practice for fall injury control in the workplace. 2010 International Conference on Fall Prevention and Protection; 2010 May 19-20; Morgantown: National Institute for occupational safety and health;2011.
3. Thurmon E, Lockhart G. Kinetic learning in occupational fall prevention training. 2010 International Conference on Fall Prevention and Protection;2010 May 19-20; Morgantown: National Institute for occupational safety and health;2011.
4. Aneziris ON, Papazoglou IA, Baksteen H, Mud M, Ale BJ, Bellamy LJ, et al. Quantified risk assessment for fall from height. *Safety Sci* 2008;46:198-220.
5. National Institute for occupational safety and health. Worker death by falls. Cincinnati: US department of Health and Human Services;2000. Report NO: 2000-116.
6. Occupational safety and health safety and health administration. Selected occupational fatalities related to vehicle – mounted elevating and rotating work platforms as found in reports of OSHA fatality/catastrophe investigations. U.S. Department of Labor Occupational Safety and Health Administration;1991.
7. McCann M. Deaths in construction related to personnel lifts, 1992–1999. *J Safety Res* 2003;34:507-514.

8. Health & Safety Executive. Fall from Height – Prevention and risk control effectiveness. Berkshire: Bomel limited;2003. Research report: 116.
9. Pérez K, Novoa AM, Santamariña-Rubio E, Narvaez Y, Arrufat V, Borrell C, et al. Incidence trends of traumatic spinal cord injury and traumatic brain injury in Spain, 2000–2009. *Accid Anal Prev* 2012;46:37-44.
10. Shi S, Jiang M, Liu Y, Li R. Risk assessment on falling from height based on AHP-fuzzy. *Procedia Eng* 2012;45:112–118.
11. Lawshe CH. A quantitative approach to content validity. *Pers Psychol* 1975;28:563-575.
12. Hanea D, Ale B. Risk of human fatality in building fires: A decision tool using Bayesian networks. *Fire Safety J* 2009;44:704-710.
13. Macedo AC, Silva IL. Analysis of occupational accidents in Portugal between 1992 and 2001. *Safety Sci* 2005;43:269-286.
14. Jeong BY. Characteristics of occupational accidents in the manufacturing industry of South Korea. *Int J Ind Ergonom* 1997;20:301-306.
15. Unsar S, Sut N. General assessment of the occupational accidents that occurred in Turkey between the years 2000 and 2005. *Safety Sci* 2009;47:614-619.
16. Chi CF, Yang CC, Chen ZL. In-depth accident analysis of electrical fatalities in the construction industry. *Int J Ind Ergonom* 2009;39:635-644.
17. Liao CW, Perng YH. Data mining for occupational injuries in the Taiwan construction industry. *Safety Sci* 2008;46:1091-1102.
18. Lin YH, Chen CY, Luo JL. Gender and age distribution of occupational fatalities in Taiwan. *Accid Anal Prev* 2008;40:1604-1610.
19. Cheng CW, Leu SS, Cheng YM, Wu TC, Lin CC. Applying data mining techniques to explore factors contributing to occupational injuries in Taiwan's construction industry. *Accid Anal Prev* 2012;48:214-222.
20. Groves WA, Kecojevic VJ, Komljenovic D. Analysis of fatalities and injuries involving mining equipment. *J Safety Res* 2007;38:461-470.
21. Martin JE, Rivas T, Matias JM, Taboada J, Arguelles A. A Bayesian network analysis of workplace accidents caused by falls from a height. *Safety Sci* 2009;47:206-214.