Teknik Dergi, 2018 8537-8561, Paper 511

A Method for Determination of Accident Probability in the Construction Industry

Senem BİLİR[1]
G. Emre GÜRCANLI[2]

ABSTRACT

Safety issues within the construction industry have been an area of concern in almost every country. In this paper, an objective and quantitative accident probability calculation approach is proposed using 623 actual construction accidents that resulted in 681 casualties between the years 2000 and 2013. Of these accidents, the first five account for 84.1% of all fatalities and 85.4% of all injuries. In total, five construction jobs (excavation, reinforced concrete work, masonry, plastering and painting, and roof work) were the focus of the study, as they account for 70.8% of all occurrences. Probability values were calculated by using the Poisson distribution, in which accident rates and exposure values were used as distribution parameters. In an industry where accidents are recorded according to non-specific standards, it is very difficult to represent the probability of accidents within a known distribution model. The proposed approach in this paper provides an objective method to obtain probabilities by using the Poisson distribution for construction accidents.

Keywords: Construction safety, accident probability, exposure, man-hour values, Poisson distribution, risk assessment.

Abbreviations:

BLS: Bureau of Labor Statistics

CFOI: Census of Fatal Occupational Injuries

ILO: International Labour Organization

OSHA: Occupational Health and Safety Administration

SSI: Social Security Institution

Note:

- This paper has been received on December 07, 2017 and accepted for publication by the Editorial Board on May 16, 2018.
- Discussions on this paper will be accepted by September 30, 2018.

• DOI: 10.18400/tekderg.363613

1 Technical University of Istanbul, Dep. of Civil Engineering, İstanbul, Turkey - sbilir@itu.edu.tr
2 Technical University of Istanbul, Dep. of Civil Engineering, İstanbul, Turkey - gurcanlig@itu.edu.tr

1. INTRODUCTION

In many developing countries, the construction industry has a great influence on both the economy and also social policies. However, one of its most significant factors is the high number of fatalities that it suffers. These are due to the characteristics of the industry, such as its contingent forms of contracting, the difficulty in coordinating subcontractors and trade contractors, the existence of different types of jobs on a single site, an uneducated/untrained workforce, and the risks that arise from the content of the construction projects themselves [1].

Table 1. Incidence rates for fatal accidents in the construction industries of 17 countries [5].

Country	2008	2009	2010	2011	2012	2013	2014	2015	2016
Austria	11.7		8.7	5.3	11.3	10.9	6.1	4.1	7.2
Belgium		10	10.4	8.8	6.5	9.5			
Croatia		7.5	12.2	13.7	11.7	5.4		8.7	11.6
Bulgaria	19.4	12.7	15.2	11.9	7.3	13.1	13.9	12	13.6
Hong Kong. China		81	47	19	42	47	46	45	
Czech Republic		7.7	8.6	11.1	8.3	9.6	11.7	12.4	
Israel					24.8		23.1	24.8	
Poland	14.7	13.4	13	11.2	9.2		6.8	8.3	
Romania	32	24	32.1	16.4	14.3	12	14.9	10.3	11.8
Spain	10	9	8.5	8.6	6.6	6.2	8.2	7.7	5.1
Ukraine						14.5	17.6	20.3	
Norway		6.1	5	5.8	3.6	4.3			
Portugal						14.6	15.6		
Switzerland				7.9		24.6	23.8	1.7	
Turkey	36.4	35.3	32.1	29.8	13.2	27.4	22.1	6.8	13.4
United Kingdom		1.8	2.3	2.3		1.9		2	
United States		9.9	9.5	9.1	9.5	9.7	9.8		

F: Fatalities; I: Injuries. Ratios are one per 100,000 insured workers.

Occupational accidents also have a negative impact on the industry in terms of reduced productivity and lost working days. According to the Census of Fatal Occupational Injuries (CFOI) 2013 report, 828 fatalities occurred in the construction industry of the United States of America (the highest number of deaths among all industries), and this sector ranks fourth in terms of fatal accident rates per 100,000 full-time workers [2]. Accident statistics in developing countries reveal that implementation of laws and regulations, as well as prevention techniques, fall short in their attempts to mitigate or abate hazards on construction sites. The figures show that the majority of fatalities occurred on projects undertaken by small or medium sized enterprises. These companies do not implement adequate safety rules or management procedures, and the workers in those companies lack the training to carry out these practices [3,4].

As revealed in Table 1, the fatality rates of developing countries are higher than those of developed countries. The table compares the construction industries of seventeen countries [5].

Based on the Social Security Institution (SSI) data set for the years 2000 to 2016, the annual average number of employees is 18,840,449. 1,283,756 of these work in the construction industry [6]. The average share of the industry with regard total employment has reached 7.7% (see Table 2), and this represents a 20-year high [7].

Table 2. 2000 - 2016 Occupational accident statistics of the SSI [6].

Year	Employment of construction industry and its share (%) in total workforce	Total permanent disabilities due to occupational accidents	Permanent disabilities in construction industry and their share (%) in total	Total fatal accidents for all industries	Number of Fatal construction accidents and their share (%) in total
2000	761452 (3.5)	1818	399 (21.9)	1173	379 (32.3)
2001	681882 (3.2)	2183	517 (23.7)	1008	341 (33.8)
2002	713629 (3.3)	1820	439 (24.1)	872	319 (62.6)
2003	685902 (3.2)	1421	354 (24.9)	810	274 (32.8)
2004	752136 (3.8)	1693	345 (20.4)	841	263 (31.3)
2005	933498 (4.7)	1639	322 (19.6)	1072	290 (27.1)
2006	1185723 (5.8)	2267	425 (18.7)	1592	397 (24.9)
2007	1247970 (6)	1550	361 (23.3)	1043	359 (34.4)
2008	1238888 (5.8)	1452	373 (25.7)	865	297 (34.3)
2009	1227698 (5.8)	1668	282 (16.9)	1171	156 (13.3)
2010	1431000 (6.3)	1976	319 (16.1)	1434	475 (33.1)
2011	1581000 (7)	2093	405 (19.4)	1700	570 (33.5)
2012	1789487 (15)	2036	563 (27.7)	744	256 (34.4)
2013	1849942 (14.8)	1660	459 (27.7)	1360	521 (38.3)
2014	1875929 (14.2)	1421	404 (28.4)	1626	501 (30.8)
2015	1980630 (14.1)	3433	979 (28.5)	1252	473 (37.8)
2016	1887099 (13.7)	4447	1450 (32.6)	1405	496 (35.3)
Ave	1283756.8 (7.7)	2033.9	493.9 (23.5)	1174.6	374.5 (32.1)

The most striking fact that can be perceived from Table 2 is that over the period from 2000 to 2016, the average number of fatal occupational accidents is 1174; whereas in the Turkish construction industry the average number of fatal occupational accidents is 374 [6]. Although, the Turkish construction industry accounts for 7.7% of total employment, it accounts for 32.1% of fatal occupational accidents. Gurcanli and Mungen (2013) reported official figures that showed that there were 1700 fatal occupational accidents in Turkey in 2011, and that 570 of them occurred in the construction industry [8]. This means that approximately every one out of three occupational accident fatalities occur in the construction industry, and for this reason, it has a reputation for being the most dangerous industry in Turkey.

Current occupational health and safety legislation (Health and Safety Law No:6311 and related regulations) requires employers to implement safety measures as well as safety management systems in Turkey more strictly. However, the level of conscientiousness in the industry is unsatisfactory, and safety is perceived as an extra cost and unnecessary expenditure. For this reason, the industry has acquired a reputation of being one of the most hazardous when it is compared with other industrial branches. In recent years, huge construction projects have been implemented, improving the level of conscientiousness and the quality of safety promotion techniques. However, the subcontracting system and related problems such as the coordination and training of subcontractors still exist and the majority of the victims of fatal accidents are employees of these subcontractors.

Hazard analysis and applicable risk assessment methods are considered to be prominent elements of an effective safety system and on-site prevention practices. Each element of any risk assessment technique should be established by using experience, historical data and numerical methods. Common risk assessment techniques such as L Matrix and Fine Kinney depend on the personal opinions and experiences of the practitioners on-site. However, the professionals who apply risk assessment techniques have not often benefited from being trained by a scientific approach. Accident likelihood or accident probability is one of the fundamental parameters for risk assessment methods, and the knowledge of how to calculate or assess this parameter is an important issue.

This study proposes an objective probability calculation method which focuses on construction activities in conventional construction projects by using accident rates and worker exposure levels in order to implement easy and effective risk assessment specifically for construction sites. Moreover, the authors argue that the findings can be used by decision makers, safety experts, project planners and site engineers as well as academicians for safety-inherent project planning at all stages of a construction project, from pre-design to post-construction.

2. LITERATURE RESEARCH

Health and safety in the construction industry has been discussed in several studies, but it is still a hot topic due to the number of fatalities and the effects of new technologies and construction methods [9-21]. New hazards and risks require applicable risk assessment methodologies or the adaptation of older ones by changing/improving the elements within those methods. Accident probability is one of the most important parameters for evaluating the level of risk on construction sites. For instance, Van Nunen et al. (2016) argue that accident probability, and the possible loss in terms of decision making while resolving risks and uncertainties, could have adverse results [22]. Jocelyn et al. (2016) presented a quantitative risk estimation methodology using the probability parameter to prevent machinery-related accidents [23]. Wang et al. (2017) examined railway system safety and the concept of system risk using the catastrophe theory [24]. The authors used a fault tree in order to calculate the probability of dangerous phenomena in their study. In addition, there is a great deal of research that focuses on the determination of accident probability or likelihood in the construction industry. For instance, Brauer (1994) classified the likelihood parameters as: frequent, probable, occasional, remote, and improbable [25]. Lee and Halpin (2003) determined seven safety factors (including the experience of workers, skills, behavior, training, etc.) through consultation with 35 experts with an average of 24 years of work experience [26]. The three most critical safety factors were determined to be: education, supervision and preplanning, and by using these factors they estimated accident probabilities using a fuzzy logic-based analysis. Moreover, Jannadi ve Almishari (2003) calculated probability by conducting four pre-analyses [27]. The authors developed the RAM software for risk assessment. In order to designate accident probability with RAM, users were asked to define the tools and equipment, materials, and chemicals to be used in a given activity. In addition to these probability parameters, other problems can be encountered in the workplace, and users were asked to list the personal protective equipment provided to the employees. As a result of these questions, RAM was able to calculate the probabilities of accidents. Furthermore, Hallowell and Gambatese (2009) proposed an activity-based total risk quantification of concrete formwork in their research [28]. The authors utilized a risk quantification method that was proffered formerly by Jannadi and Almishari (2003) and Baradan and Usmen (2006) [9-27]. They accepted accident frequency as an accident probability parameter. Hallowell and Gambatese (2009) first decided on the frequency scale, and then set sub-activities of concrete formwork by using field observations [28]. In order to assign frequency values to the sub-activities involved in concrete formwork erection and striking, the opinions of 15 experts were taken using a 3-step Delphi method. The accident frequencies garnered from this data are shown in Table 3. Not only Hallowell and Gambatese (2009), but also Sun et al. (2008) have accepted accident frequency as representative of accident probability in their studies of risk estimation [29].

Mitropoulos and Namboodiri rejected the tradition of identifying risk as a function of probability and severity [30]. They developed a task demand assessment in order to calculate the risk of a given activity by using the risk factors involved in it. The resulting task demand scores provide insight into the likelihood of risk and the difficulty of the selected activities. The authors claimed that if the task demand factors increase, the likelihood of accident increase correspondingly.

On the other hand, after 2008 the U.S. Bureau of Labor Statistics (BLS) started to calculate fatal accident rates according to the working hours of full-time employees as shown in Equ.1 [31].

$$\text{Fatal Accident Rate} = (N / EH) * 200{,}000{,}000 \quad (1)$$

N: number of fatal accidents; EH: total working hours of all employees within the calendar year; 200,000,000: total working hours, which was obtained by assuming that 100,000 employees work 40 hours per week for 50 weeks. In accordance with this rate, the accident likelihoods within industries can be easily compared according to years, states, age groups, gender etc.

Table 3. Accident frequency scale of Hallowell and Gambatese (2009)

Man-hour per accident	Accident Frequency
> 100,000,000	1
10,000,000-100,000,000	2
1,000,000-10,000,000	3
100,000-1,000,000	4
10.000-100.000	5
1,000-10.000	6
100-1,000	7
10-100	8
1-10	9
0.1-1	10

If the literature is analyzed in detail, it can be seen that there are different risk assessment approaches (and/or calculations) that can be made according to different assumptions, and that this leads to a great variety of accident probability and likelihood definitions. The literature review for this study reveals that there is no strict definition of accident probability or likelihood, and that there are many gaps to fill for construction industry-specific risk assessment approaches and probability calculations.

3. METHODOLOGY

The construction industry is a project-based type of activity and each project is unique during its planning and construction phase. However, despite their differences, the main construction activities within each project are very similar – for example formwork, scaffolding, or roofing for residential building projects; or excavation, piling, and drainage for infrastructure projects. If construction activities are examined in detail, the similarities in their method of construction and the related safety risks may be observed. Therefore, an activity-based methodology was chosen for the calculation of probability parameters in this study. This was done to provide more generalized results. In the literature, there are many studies concerning construction safety [11, 21, 28, 32, 33, 34, 35] that use an activity-based approach. In this research, actual accident data was used in order to remove all subjectivity from the study. For this purpose, 623 expert witness reports from construction accidents (with a total of 681 casualties) that were submitted to the criminal and labor courts between 2000 and 2013 were analyzed (Figure 1). These expert witness reports were submitted for the construction accidents from all over the Turkey. The most common types of accidents, and the most prevalent activities in which these accidents occur, were identified. Within the scope of the study, instead of focusing on all construction activities, five main construction activities (excavation, reinforced concrete work, masonry, plastering and painting, and roof work) were analyzed due to their disproportionate share of accidents. These activities accounted for 482 of the total 681 cases (both fatal and non-fatal), a share of 70.8% [36].

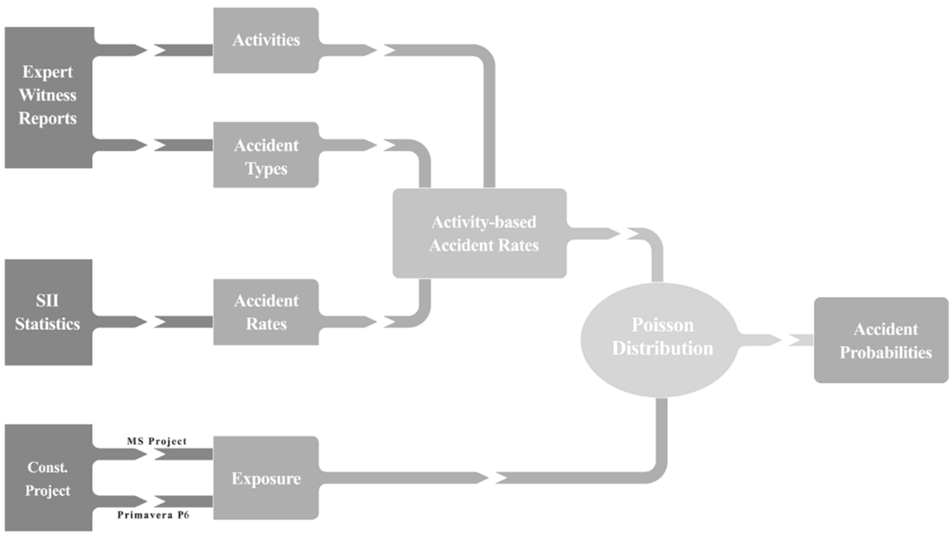

Figure 1. Graphical representation of the methodology

In addition, the "occupational accidents and diseases statistics" published between 2000 and 2013 by the SSI were examined and combined with the results obtained from the expert witness reports. From these analyses, activity-based and accident type-based accident frequencies were obtained as an outcome. The exposure values for construction activities (i.e. man hour values) were also taken from the work schedules and planning tables of twenty traditional construction projects.

Accident probabilities were calculated using the Poisson distribution model by taking into account accident rates and exposure values [37]. In the construction industry, where accidents are recorded according to a non-specific standard, it is very difficult to represent the probability of accidents within a known distribution model, but thanks to this approach, it was possible to provide an objective method to obtain accident probabilities using the Poisson distribution.

3.1. Determining Activity-Based Accident Rates

The accident rates were calculated using the data from the SSI accident statistics and expert witness reports in order to prevent subjectivity in this study. The first step is to focus on the most frequent accidents types obtained from these expert reports.

Most frequent accident types

In this study, occupational accidents between the years 2000 and 2013 were used. Although, legislative amendments were added after the year 2003 in order to comply with European Union standards, the utilization of new construction technologies and methods in huge projects have been carried out in Turkey since 2000. The time interval is therefore considered to be suitable for the purpose of this research study [38].

Table 4. Fatal and non-fatal construction accidents obtained from expert witness reports

Accident Type	Fatality	Fatality (%)	Injury	Injury (%)	Total	Total (%)
Fall from height	278	59.3	118	55.7	396	58.1
Struck by flying/falling object	42	9	23	10.8	65	9.5
Building/Structure collapse	30	6.4	21	9.9	51	7.5
Contact with electricity	28	6	11	5.2	39	5.7
Cave-ins	16	3.4	8	3.8	24	3.5
Other	15	3.2	9	4.2	24	3.5
Struck by a moving vehicle	14	3	1	0.5	15	2.2
Struck by moving part of a vehicle	12	2.6	6	2.8	18	2.6
Explosives Accidents	12	2.6	3	1.4	15	2.2
Equipment roll over accidents	11	2.3	1	0.5	12	1.8
Traffic Accidents	7	1.5	6	2.8	13	1.9
Hazards due to machine and tool usage	4	0.9	5	2.4	9	1.3
Total	469		212		681	

The classification of the accident types were the first step, and in this respect, both the OSHA (1971/97) and ILO (1998) accident classification databases were used [39,40]. Using the accident classification schemes in these databases, 12 accident types were identified as the most frequent. Following this, 623 expert witness reports were analyzed. These were based on the accident type classification, and 681 accident cases were obtained from these reports (Table 4).

In Table 4, the number of the most frequent accidents and their percentages are shown. Fall from height, struck by flying/falling object, building/structure collapse, contact with electricity and cave-ins appear as the five most frequent accidents. It can be also seen that these five accident types constitute a very significant share of the total, accounting for 84.1%

of fatalities and 85.4% of injuries. Although, there are several activities in any construction project, it is reasonable to determine the most critical activities based on the occurrence of accidents and then to concentrate only on these critical activities to reach more generalized results. Therefore, within the scope of this study the first five accident types and the most common construction activities were chosen.

Most hazardous activities

Gurcanli and Mungen (2013) analyzed 1,117 expert witness reports of construction accidents in Turkey between the years 1972 and 2008, and noted the activities of any casualty at the time of each accident [8]. However, further analyses were required in order to determine the accident types. For this reason, all expert witness reports were reviewed and the roles of the casualties at the time of each accident were obtained. This gave an insight leading to determination of the most hazardous construction activities.

Additionally, "Fall from height" which ranks first, and which accounts for 59.3% of fatalities, was examined in detail due to the possibility of its occurrence in many different activities on construction sites [41]. Similar attention was given to the other frequent accidents, and their sub-types (fall near the edge of a slab, fall into a hole and so on) were identified. Furthermore, this analysis revealed the activities of the casualties. As a result, the most hazardous construction areas were determined as being: excavation, reinforced concrete work, masonry, plastering and painting, and roof work.

Risk analysis of most hazardous activities

Risk analysis was needed to specify the risks of the five activities. The accident types that are given in Table 4 may not be observed in each of the five activities. For example, during roof works it is very unlikely to observe traffic accidents. Therefore, accident types were distributed to activities by considering the nature of the activity in Table 5. Assuming there are no safety measures on construction sites, the most common accidents were assigned to the most hazardous activities.

Accident concentration

Accident concentration is a term that has been generally used for presenting the intensity of traffic accidents encountered in states, provinces or zones [42,43,44]. However, in this study the term "accident concentration" was used for the number of accidents in each activity. Concentration values were needed in order to calculate the activity-based and accident type-based accident frequencies. Therefore, the 623 expert witness reports were examined again and accident concentrations were determined by taking into consideration the five selected construction activities and th

It can be said that the most hazardous risks of excavation work are cave-ins, being struck by a moving vehicle, being struck by flying/falling object, being struck by moving part of a vehicle, and traffic accidents (see Table 6). Figure 2 demonstrates the distribution of 9 different risks that exist in excavation work and also the accident concentration of each one.

Table 5. The most hazardous construction activities and their risks

Activity Number	Activity Name	Risk Number	Risk Code	Risks
1	Excavation	1	R05	Cave-ins
		2	R01	Fall from height
		3	R02	Struck by flying/falling object
		4	R03	Building/Structure collapse
		5	R04	Contact with electricity
		6	R07	Struck by a moving vehicle
		7	R10	Equipment roll over accidents
		8	R12	Traffic Accidents
		9	R11	Struck by moving part of a vehicle
2	Reinforced Concrete	1	R01	Fall from height
		2	R02	Struck by flying/falling object
		3	R06	Other
		4	R03	Building/Structure collapse
		5	R09	Hazards due to machine and tool usage
		6	R04	Contact with electricity
		7	R11	Struck by moving part of a vehicle
		8	R07	Struck by a moving vehicle
3	Masonry	1	R01	Fall from height
		2	R07	Struck by a moving vehicle
		3	R02	Struck by flying/falling object
		4	R06	Other
4	Plastering & Painting	1	R01	Fall from height
		2	R02	Struck by flying/falling object
		3	R06	Other
		4	R07	Struck by a moving vehicle
		5	R09	Hazards due to machine and tool usage
5	Roof Works	1	R01	Fall from height
		2	R02	Struck by flying/falling object
		3	R06	Other
		4	R07	Struck by a moving vehicle

Table 6. Accident concentration of excavation work

Activity Number	Activity	Risk Number	Risk Code	Risk Name	Number of Fatalities	Number of Injuries	Accident Concentration
1	Excavation	1	R05	Cave-ins	10	3	13
		2	R01	Fall from height	3	1	4
		3	R02	Struck by flying/falling object	5	5	10
		4	R03	Building/Structure collapse	2	1	3
		5	R04	Contact with electricity	3	1	4
		6	R07	Struck by a moving vehicle	8	3	11
		7	R10	Equipment roll over accidents	3	1	4
		8	R12	Traffic Accidents	2	4	6
		9	R11	Struck by moving part of a vehicle	7	1	8
				Total	43	20	63

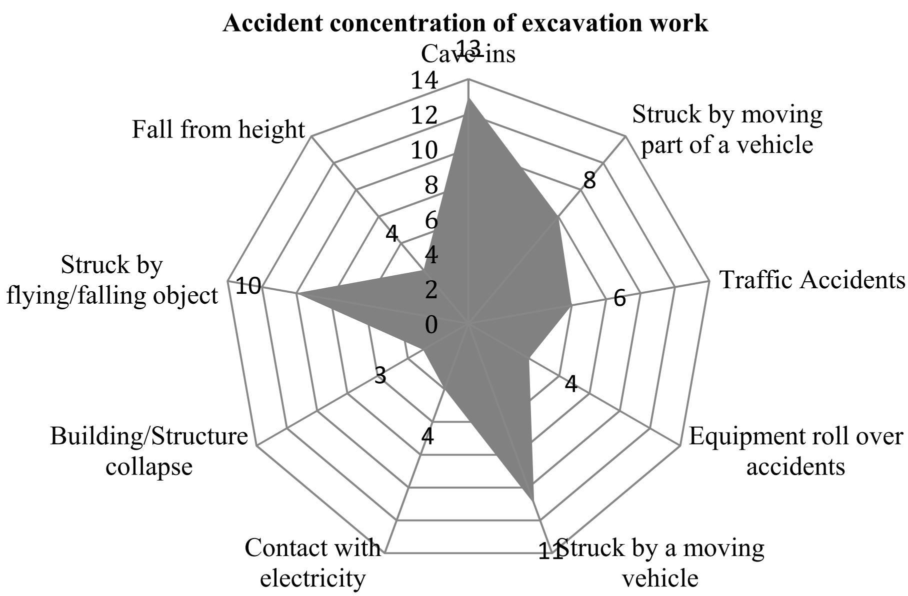

Figure 2. Accident concentration of excavation works

As previously mentioned, the number of victims of the five selected activities (excavation, reinforced concrete works, masonry, plastering and painting, and roof works) constitute 70.8% of all accidents (681) in the expert witness reports database (Table 7). Furthermore, this ratio is important for accident rate calculation of total occupational accidents in Turkey. Since it is impossible to investigate the expert witness reports of all occupational accidents, this ratio was used to estimate the number of accidents that fall within the scope of this work.

Table 7. Accident concentrations of determined construction activities

Activity Name	Number of fatalities	Number of injuries	Total number	Ratio of total number of accidents (%)
Excavation	43	20	63	9
Reinforced Concrete	110	34	144	21.1
Plastering&Painting	60	49	109	16
Masonry	62	27	89	13.1
Roof	65	12	77	11.3
Total	340	142	482	70.8

Accident rates

For the calculation of the Accident Rate parameter, the “Work Place and Employee Statistics” and the “Occupational Accident Statistics” archives of the Turkish SSI were analyzed. From these, construction industry employment data, the number of accidents resulting in permanent injuries and the number of fatal accidents were obtained for the years between 2000 and 2013.

Based on the SSI data, it could be assumed that construction workers work 45 h/wk (this is the maximum legal limit but it is often exceeded) and 50 wk/yr. While calculating the average accident rate for the 13 years under discussion, first the total working hour for the construction industry was calculated for each year. Since the accident concentration of the five selected construction activities constitutes 70.8% of all construction accidents according to the expert witness reports, 70.8% of SSI accidents data was calculated for each year. After dividing the number of accidents by the work volume, the accident rates for each year were obtained. An average of 13 years was used as the “accident rate” in the activity-based and accident type-based accident rate calculations. The average accident rate was found to be 2.26×10^{-7} accidents per 100,000 hours construction work for the five activities (Table 8).

The distribution of accidents among the five activities were utilized in order to obtain the activity-based and accident type-based accident rate values. Table 9 shows the fatalities, injuries and total accident numbers and ratios for the five activities.

Table 8. Accident rates of the construction industry of Turkey between 2000 and 2013

Year	Const. industry employment	Number of perm. disability	Number of fatality	Number of accident	70,8% of number of accidents	Weekly work hour (h)	Annual work (wk)	Annual work volume (man-hour / yr)	Accident rates for 5 jobs (annual number of accidents / total work volume)
2000	761,452	399	379	778	551	45	50	1,713,267,000	3.22E-07
2001	681,882	517	341	858	607	45	50	1,534,234,500	3.96E-07
2002	713,629	439	319	758	537	45	50	1,605,665,250	3.34E-07
2003	685,902	354	274	628	445	45	50	1,543,279,500	2.88E-07
2004	752,136	345	263	608	430	45	50	1,692,306,000	2.54E-07
2005	933,498	322	290	612	433	45	50	2,100,370,500	2.06E-07
2006	1,185,723	425	397	822	582	45	50	2,667,876,750	2.18E-07
2007	1,247,970	361	359	720	510	45	50	2,807,932,500	1.82E-07
2008	1,238,888	373	297	670	474	45	50	2,787,498,000	1.70E-07
2009	1,227,698	282	156	438	310	45	50	2,762,320,500	1.12E-07
2010	1,431,000	319	475	794	562	45	50	3,219,750,000	1.75E-07
2011	1,581,000	405	570	975	690	45	50	3,557,250,000	1.94E-07
2012	1,789,487	563	256	819	580	45	50	4,026,345,750	1.44E-07
2013	1,849,942	459	521	980	694	45	50	4,162,369,500	1.67E-07
Σ		5,563	4,897	10,46	7,406			Ave:	2.26E-07

Table 9. Distribution of accidents between five construction activities

Activity	Number of Fatalities	Ratio of Fatalities (%)	Number of Injuries	Ratio Of Injuries (%)	Total number of accidents	Ratio of Total Number of Accidents (%)
Excavation	43	12.6	20	14.1	63	13.1
Reinforced Concrete	110	32.4	34	23.9	144	29.9
Plastering &Painting	60	17.6	49	34.5	109	22.6
Masonry	62	18.2	27	19	89	18.5
Roof	65	19.1	12	8.5	77	16
Total	340	1	142	1	482	1

By examining the distribution (or share of each job) in Table 9, Table 10 can easily be worked out. First, the ratio of each activity across the total number of accidents is calculated (third column). It can be seen that the most hazardous activity is reinforced concrete work with a ratio of 0.229. The values for plastering and painting, masonry, roof work and excavation are 0.226, 0.185, 0.160 and 0.131 respectively. Secondly, the accident rates for the five construction activities are calculated and given in the fourth column. For instance, the activity-based accident rate for excavation work was found to be 2.95 x 10^{-8} (accident/work-hours). This accident rate was distributed across risk categories according to their ratios and the accident type-based rates for each risk category in excavation work were calculated in the last column. The accident rates of reinforced concrete work (6.747E-08), masonry (4.170E-08), plastering and painting (5.107E-08) and roof work (3.608E-08) were obtained using the same work outs. The accident probabilities can therefore be calculated with the help of these accident rates.

3.2. Calculating Activity-Based Exposures

In the literature, exposure values are either not included (i.e. in L Matrix) or are used as constant values for all risks [27, 45]. However, it is crucial to establish a conceptual framework for the exposure parameter, which is based on man-hour values extracted from the project schedule to eliminate subjectivity in risk assessment. Unfortunately, there are few studies in the literature suggesting that the exposure parameter can be obtained from the man-hour values for use in establishing a linkage between construction scheduling, planning and risk assessment [28,32]. For instance, Mitropoulos and Namboodiri (2011) suggest exposure as a percentage of the duration that a worker is exposed to the relevant hazard [30]. In addition, Gangolles et al. (2010) determined exposure as depending on drawings and the bill of quantities for 90 risk types [11].

Table 10. Accident rates of five construction activities

Activity Name	Average Accident Rate for 5 Activities	Ratio of Activity to Total Number of Accidents (%)	Accident Rate of Activity	Risk Number	Risk Code	Risk Name	Number of Accidents for Activity	Ratio of Accidents for Activity	Rate of Accidents for Activity
Excavation	2.26E-07	0.131	2.95E-08	1	R05	Cave-ins	13	0.206	6.09E-09
				2	R01	Fall from height	4	0.063	1.87E-09
				3	R02	Struck by flying/falling object	10	0.159	4.69E-09
				4	R03	Building/Structure collapse	3	0.048	1.41E-09
				5	R04	Contact with electricity	4	0.063	1.87E-09
				6	R07	Struck by a moving vehicle	11	0.175	5.15E-09
				7	R10	Equipment accidents (Roll over etc.)	4	0.063	1.87E-09
				8	R12	Traffic accidents	6	0.095	2.81E-09
				9	R11	Struck by moving part of a vehicle	8	0.127	3.75E-09
Reinforced Concrete	2.26E-07	0.299	6.75E-08	1	R01	Fall from height	90	0.625	4.217E-08
				2	R02	Struck by flying/falling object	20	0.139	9.371E-09
				3	R06	Other	6	0.042	2.811E-09
				4	R03	Building/Structure collapse	13	0.090	6.091E-09
				5	R09	Hazards due to machine and tool usage	1	0.007	4.686E-10
				6	R04	Contact with electricity	4	0.028	1.874E-09
				7	R11	Struck by moving part of a vehicle	8	0.056	3.749E-09
				8	R07	Struck by a moving vehicle	2	0.014	9.371E-10
Masonry	2.26E-07	0.185	4.17E-08	1	R01	Fall from height	49	0.551	2.296E-08
				2	R07	Struck by a moving vehicle	7	0.079	3.280E-09
				3	R02	Struck by flying/falling object	21	0.236	9.840E-09
				4	R06	Other	12	0.135	5.623E-09
Plastering & Painting	2.26E-07	0.226	5.11E-08	1	R01	Fall from height	83	0.761	3.889E-08
				2	R02	Struck by flying/falling object	14	0.128	6.560E-09
				3	R06	Other	6	0.055	2.811E-09
				4	R07	Struck by a moving vehicle	5	0.046	2.343E-09
				5	R09	Hazards due to machine and tool usage	1	0.009	4.686E-10
Roof Works	2.26E-07	0.160	3.61E-08	1	R01	Fall from height	59	0.766	2.765E-08
				2	R02	Struck by flying/falling object	9	0.117	4.217E-09
				3	R06	Other	4	0.052	1.874E-09
				4	R07	Struck by a moving vehicle	5	0.065	2.343E-09

While determining exposure values, the project schedules and planning tables of 20 traditional construction projects in the Istanbul province were examined. These project schedules and planning tables were analyzed in detail with the aid of Primavera P6 and MS Project software [46,47]. After ensuring the accuracy of the data, the exposure values of the five selected activities were determined for 20 construction projects. The exposure values were calculated as follows:

$$E_i = H \times N_i \quad (1)$$

where E_i denotes the exposure of the activity, H represents daily working hours and N_i corresponds to the number of workers involved in that activity. The daily working hours was taken to be nine hours (the same as the daily working hours of the SSI) and the number of workers were taken from the project planning tables. Since exposures were calculated on a daily basis, data regarding the total duration of the work is not required. Table 11 illustrates how the exposure values were calculated.

Table 11. Calculation of exposure for foundation excavation in Project 1

Sub-activity name	Activity type	Risk Code	Risk Name	Accident Rate	Duration of activity (day)	Daily working hour (h)	Number of worker	Exposure
Foundation Excavation	Excavation	R05	Cave-ins	6.09E-09	15	9	8	72
		R01	Fall from height	1.87E-09	15	9	8	72
		R02	Struck by flying/falling object	4.69E-09	15	9	8	72
		R03	Building/Structure collapse	1.41E-09	15	9	8	72
		R04	Contact with electricity	1.87E-09	15	9	8	72
		R07	Struck by a moving vehicle	5.15E-09	15	9	8	72
		R10	Equipment accidents (Roll over etc.)	1.87E-09	15	9	8	72
		R12	Traffic accidents	2.81E-09	15	9	8	72
		R11	Struck by moving part of a vehicle	3.75E-09	15	9	8	72

3.3. Calculating Activity-Based Accident Probabilities

Due to the characteristics of the construction industry, such as the uniqueness of each project, the difficulty to establish time series for accidents and their project-based character (as opposed to process-based), and so on, it is difficult to use the concept of "probability". Since the distribution of occurrences (or accidents) do not fit within probabilistic distributions, in many safety studies “accident likelihood” was often preferred and used instead of “accident probability” [12,32,33].

On the other hand, the utilization of “likelihood” has some disadvantages. For example, in an activity that has 1,000 man-hours work and accident frequency rate of 0.002 (accident/work-hours), the accident likelihood will be calculated as 2 (accident frequency x exposure). This means that in a 1,000 man-hours of work, 2 occupational accidents will take place. However, occupational accidents are random events, and it would be wrong to give an exact number of accidents for a given activity. Therefore, it is important that the accident occurrence rate of the construction industry is represented as a probability function.

For this study, the Poisson distribution model was used to calculate accident probability. The Poisson distribution is a discrete probability distribution that can be used to calculate the probability of a number of event occurrences for a specific time. In order to utilize the Poisson distribution for a data set, two prerequisites are required [48]:

(1) Events should have a known and constant occurrence rate

(2) Events should be independent

For the construction industry, occupational accidents are independent events. Moreover, the rates of occupational accident occurrences can be calculated using the calculation method proposed in this study. Therefore, the Poisson distribution may be selected as a suitable model for the expression of accident occurrence probabilities.

In the Poisson distribution, the probability of k times the occurrence of an event can be calculated from equation 2:

$$Pr(X = k) = \frac{\lambda^k e^{-\lambda}}{k!} \tag{2}$$

where λ= AR x E (Accident Rate x Exposure), and k: number of accidents. It is possible to determine the probability of the occurrence of an accident 0,1,2,…,n times by using the Poisson distribution. If the same example is used in the likelihood approach (an activity that has 1,000 man-hours of work and where the accident frequency rate is 0.002 accident/work-hours) and is expressed with the Poisson distribution, 0,1,2,…, the n times accident occurrence probability can be calculated as shown in Figure 3.

As shown in Figure 3, the probability of zero accidents is less than 0.15, the probability of 1 or 2 accidents are between 0.25 – 0.3 for an activity that has 1000 man-hours of work. The probability of 3 or 4 accidents in a single construction job is relatively high and cannot be ignored for further analyses. However, the probability of five or more accidents are quite low. Although the accident likelihood was calculated as being 2, the accident probabilities of 0, 1, 2, 3 and 4 accidents were considerably higher for the same example. For this reason, the accident probability as calculated by using the Poisson distribution, offers a broader perspective to implement risk assessments for safety professionals or on-site practitioners.

In the proposed accident probability approach, it was assumed that risk assessment will be performed during the planning stage. This allows a zero accident target to be set during the project duration. Therefore, the probability of having zero accidents was calculated and it was subtracted from 1 in order to calculate the total probability of accident occurrences (1 - P(X=0)).

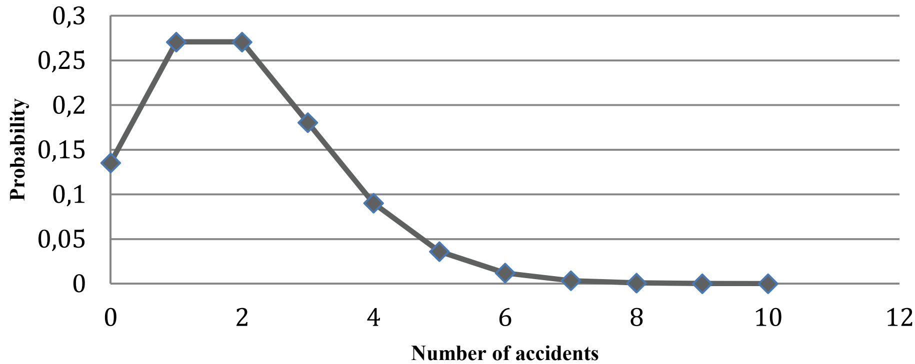

Figure 3. Accident probabilities in the Poisson distribution

Table 12. Accident probability calculation for foundation excavation activity in Project 1

Sub-activity name	Risk code	Risk name	Accident rate	Exposure	Accident Rate x Exposure	Accident probability	Accident probability x 1.000.000
						Σ	**2,13**
Foundation excavation	R05	Cave-ins	6.09E-09	72	4.40E-07	4.00E-07	0.44
	R01	Fall from height	1.87E-09	72	1.30E-07	1.00E-07	0.14
	R02	Struck by flying / falling object	4.69E-09	72	3.40E-07	3.00E-07	0.34
	R03	Building / Structure collapse	1.41E-09	72	1.00E-07	1.00E-07	0.1
	R04	Contact with electricity	1.87E-09	72	1.30E-07	1.00E-07	0.14
	R07	Struck by a moving vehicle	5.15E-09	72	3.70E-07	4.00E-07	0.37
	R10	Equipment roll over accidents	1.87E-09	72	1.30E-07	1.00E-07	0.14
	R12	Traffic Accidents	2.81E-09	72	2.00E-07	2.00E-07	0.2
	R11	Struck by moving part of a vehicle	3.75E-09	72	2.70E-07	3.00E-07	0.27

As an example, the calculation of accident probability of the foundation excavation work of Project 1 is given in Table 12. In Project 1, eight workers were assigned to foundation excavation, and with a 9-hour working day, the exposure value was calculated to be 72 man-hours. Similar calculations were made for the other construction activities and sub-activities. Since the resulting probabilities are relatively small, each probability value was multiplied by 1,000,000 in order for it to be more easily understood. The total accident probability of the foundation excavation of Project 1 was calculated to be 2.125, in other words this figure represents the total probability of all accidents which may occur during foundation excavation work. Similarly, the probabilities of any sub-activities in excavation, reinforced concrete work, masonry, plastering and painting and roof work can be calculated for a traditional construction project (see Table 12). This approach allows an easy way of calculating the total accident probability of a sub-activity (of any construction job) as well as providing a tool to highlight the most hazardous accident that may occur in a given activity.

4. RESULTS

If the flow of the method is similarly followed, probability calculation tables can be prepared and total accident probabilities can be found. As an example, there are eight different sub-work items in Project 1, and their probabilities are given in Table 13. There are 55 sub-activities in Project 1, but within the scope of this paper only the first 8 items are being given as examples. It can be seen that the total accident probability value in the first row (2.13) comes from the probability calculations depicted in Table 12. For all other sub-activities, similar calculations were made and are collected in this table.

Although some sub-activities belong to the same main activity, their probabilities were calculated differently due to their different exposure values (see Table 13). Decision makers and safety experts can use these probability values while preparing lists of project work items according to their significance. Additionally, these calculated probabilities can be used, together with accident severity, in any on-site risk assessment application.

It is also worth mentioning that the accident rates given here can be considered accurate because they were calculated using actual accident data from expert witness reports and SSI statistics. Likewise, the exposure values of the five selected activities were calculated on a daily basis from actual project planning tables using man-hour values. Hence, the probabilities were calculated using accident rates and exposures which are reliable and precise.

Since the calculation tables use man-hour values and a well established work breakdown structure of all construction jobs, the proposed methodology requires a continuous collaboration between planning departments and safety professionals. Information regarding scope changes, usage of free or total floats, changes in schedule or methods of construction should be immediately given to the safety experts. For instance, the assignment of more workers to a construction project to decrease the duration (in other words, a way of "crashing") will result in an increase of exposure. Since exposure is an indispensable parameter for accident probability calculations, such deviations should not alter the probability calculation approach. Using our Poisson distribution approach, accident probabilities are always expressed between 0 and 1 which eliminates the need for scaling, no matter the size of the exposure value.

Table 13. Total accident probability calculations for 8 sub-work items in Project 1

#	Sub-activity name	Activity name	Beginning	Ending	Exposure	Total Accident Probability
1	Foundation excavation	Excavation	8.05.06	24.05.06	72	**2.13**
2	Lean concrete	Reinforcement Concrete	25.05.06	26.05.06	27	1.82
3	Cement coating	Reinforcement Concrete	2.06.06	2.06.06	63	4.26
4	Foundation formwork	Reinforcement Concrete	9.06.06	9.06.06	81	5.47
5	Foundation reinforcement	Reinforcement Concrete	10.06.06	22.06.06	108	7.27
6	Foundation concrete	Reinforcement Concrete	23.06.06	24.06.06	72	4.85
7	Basement shear wall formwork	Reinforcement Concrete	28.06.06	3.07.06	81	5.47
8	Basement shear wall reinforcement	Reinforcement Concrete	4.07.06	8.07.06	90	6.07

The presented probability approach was applied across all sub-activities of the 20 construction projects and reasonable results were obtained in all cases. Thanks to this approach, hazardous sub-work items can be listed from the highest to the lowest accident probability on a daily basis. The primary purpose of this study is to suggest a new and objective approach to estimate the accident probability parameter for risk assessment within the construction industry. Therefore, actual accident values were analyzed several times to determine the most frequent accident types and the most hazardous work-items, as well as a risk analysis of the most hazardous activities and accident concentrations.

Following this, the accident rates for construction work items and certain accident types, such as fall from height; cave-ins and so on were calculated. Similarly, with sufficient past data, the overall probabilities of all sub-work items in a project can be calculated. The combination of a solid and consistent accident probability parameter that includes exposure as well as severity for any approach toward risk assessment will provide reliable risk scores for decision makers, safety professionals and construction managers to plan and manage projects by taking health and safety into account. It is hoped that safety experts, project planners, site engineers and academicians (for further research) can easily use the probability approach developed for this study. As previously mentioned, the majority of former approaches for the assessment of risks on construction sites determined "accident probability" through expert opinion. Calculating the probability of an accident without the need for personal experiences and opinions, in other words calculating it in an objective manner, is an important feature of this approach. In addition, project planners can compare the accident probabilities of different construction projects at the same time and manage their own resource planning (and/or resource levelling) according to results of these comparisons.

Supplementary to these contributions, it may be argued that, especially for practitioners on-site, using probability scores in advance may allow a greater focus on project scheduling, man-hour figures, amount of resources assigned for construction activities and budget limitations as well as on the workforce. Moreover, thanks to the risk analysis of the most hazardous activities prepared in this study, safety experts do not need to repeatedly analyze the activities with the highest risks for every project. Furthermore, safety professionals who wish to use the presented probability approach will only require the exposure values of their projects, and these figures can be easily adapted for any country that has sufficient past accident data and similar industry characteristics. It is thought that the proposed approach, in general, provides:

- Objective assessment of the past accident data,
- Utilization of man-hour values through the aid of the planning department to reach exposure values,
- Guidance on how to use real project schedules for risk estimation for safety professionals.

5. CONCLUSION

In this study 623 expert witness reports for accidents that occurred between 2000 and 2013 were analyzed in detail. Similarly, occupational accident statistics by the SSI were analyzed and accident concentrations for excavation, reinforced concrete work, masonry, plastering and painting and roof work were provided, and the most frequent accident types for these activities were obtained. Since, all data was obtained from real cases, this study accurately represents the accident rates and applicable probability values. Because the activities under examination are used in various construction works, the probability approach presented in this research study can be used for other construction projects. Accident probabilities were calculated using the Poisson distribution, and by adapting the accident probability values to risk assessment methods it is possible to provide more objective and realistic risk assessments.

In this study, the data which was used as a starting point to analyze accidents in the construction industry were taken from official statistics as well as expert witness reports submitted to the Turkish criminal and labor courts. Other countries can also use these accident rates in their own risk assessments or adapt the presented method to their countries' construction industry.

Acknowledgement

This work is supported by the Coordination of Scientific Research Projects of Istanbul Technical University (BAP-ITU) under the project no. 38168.

References

[1] Zou, P., X.,W., Sunindijo, R., Y., 2013. Skills for managing safety risk, implementing safety task, and developing positive safety climate in construction project. Automation in Construction, 34, 92-100.

[2] CFOI. Census of Fatal Occupational Injuries Report, 2013.<http://www.bls.gov/iif/oshcfoi1.htm> (retrieved 12.05.14).

[3] Loosemore, M., Andonakis, N., 2007. Barriers to implementing OHS reforms – the experience of small subcontractors in the Australian construction industry. International Journal of Project Management 25, 579–588.

[4] Yi, J.-s., Kim Y.-w., Kim K.-a., Koo B. 2012. A suggested color scheme for reducing perception-related accidents on construction work sites. Accident Analysis and Prevention, 48, 185-192.

[5] ILO. International Labour Organization, Statistics and Database, LABORSTA, Occupational Injuries. <http://www.ilo.org/ilostat/faces/home/statisticaldata/data_by_subject?_adf.ctrl-state=vchypfgka_4&_afrLoop=598083992046714> (retrieved 06.04.2014)

[6] SSI. Social Security Institution Occupational Accidents Statistics Report, 2012. 10.12.2013. Retrieved from http://www.isteguvenlik.tc/SGK2012IsKazaIstatistik.pdf (in Turkish).

[7] Gurcanli E., Bilir S., Sevim M., 2015. Activity Based Risk Assessment And Safety Cost Estimation For Residential Building Construction Projects. Safety Science, 2015, 80, 1–12, DOI: 10.1016/j.ssci.2015.07.002.

[8] Gurcanli G.E., Mungen U., 2013. Analysis of construction accidents in turkey and responsible parties. National Industrial Health, 51 (6), 581-595.

[9] Baradan, S., and Usmen, M. A. 2006. Comparative injury and fatality risk analysis of building trades. J. Constr. Eng. Manage., 132(5), 533–539.

[10] Gnoni, M. G., Saleh, J. H., 2017. Near-miss management systems and observability-in-depth: Handling safety incidents and accident precursors in light of safety principles. Safety Science, 91, 154-167.

[11] Gangolells, M., Casals, M., Forcada, N., Roca, X. and Fuertes, A. 2010. Mitigating construction safety risks using prevention through design. Journal of Safety Research, Vol. 41, 107-122.

[12] Gurcanli G.E., Mungen U., 2009. An occupational safety risk analysis method at construction sites using fuzzy sets. International J. of Industrial Ergonomics 39(2), 371-387.

[13] Hallowell, M. 2011. Risk-Based Framework for Safety Investment in Construction Organizations. J. Constr. Eng. Manage., 137(8), 592–599.

[14] Irumba R., 2014. Spatial analysis of construction accidents in Kampala, Uganda. Safety Science. 64. 109-120.

[15] Park, C. S., Kim, H. J., 2012. A framework for construction safety management and visualization system. Automation in Construction 33, 95–103.

[16] Raviv, R., Fishbain, B., Shapira, A., 2017a. Analyzing risk factors in crane-related near-miss and accident reports. Safety Science, 91, 192-205.

[17] Raviv, R., Fishbain, B., Shapira, A., 2017b. AHP-based analysis of the risk potential of safety incidents: Case study of cranes in the construction industry. Safety Science, 91, 298-309.

[18] Zhang, S., Sulankivi, K., Kiviniemi, M., Romo, I., Eastman, C. M., Teizer, J., 2015. BIM-based fall hazard identification and prevention in construction safety planning. Safety Science, 72, 31-45.

[19] Zwetsloot, G.I.H.M., Kines, P., Wybo, J.L., Ruotsala, R., Drupsteen, L., Bezemer, R. A., 2017. Zero Accident Vision based strategies in organisations: Innovative perspectives. Safety Science, 91, 260-268.

[20] Tozer, K , Celik, T , Gurcanli, G . (2018). Classification of Construction Accidents in Northern Cyprus. Teknik Dergi, 29 (2), 8295-8316. DOI: 10.18400/tekderg.325546

[21] Baradan, S , Akboga, O , Cetinkaya, U , Usmen, M . (2016). Ege Bölgesindeki İnşaat İş Kazalarının Sıklık ve Çapraz Tablolama Analizleri. Teknik Dergi, 27 (1), 7345-7370.

[22] Van Nunen, K., Reniers, G., Ponnet, K., Cozzani, V., 2016. Major accident prevention decision-making: A large-scale survey-based analysis. Safety Science, 88, 242-250.

[23] Jocelyn, S., Chinniah, Y., Ouali, M., S., 2016. Contribution of dynamic experience feedback to the quantitative estimation of risks for preventing accidents: A proposed methodology for machinery safety. Safety Science, 88, 64-75.

[24] Wang, Y., Weidmann, U., A., Wang, W., 2017. Using catastrophe theory to describe railway system safety and discuss system risk concept. Safety Science, 91, 269-285.

[25] Brauer, R. L. 1994. Risk management and assessment. Safety and health for engineers, Van Nostrand Reinhold, New York, 543–572.

[26] Lee, S., and Halpin, D. 2003. Predictive tool for estimating accident risk. J. Constr. Eng. Manage., 129(4), 431–436.

[27] Jannadi, O., and Almishari, S. 2003. Risk assessment in construction. J. Constr. Eng. Manage., 129(5), 492–500.

[28] Hallowell, M. and Gambatese, J. 2009. Activity-Based Safety Risk Quantification for Concrete Formwork Construction. J. Constr. Eng. Manage., 135(10), 990–998.

[29] Sun, Y., Fang, D., Wang, S., Dai, M., and Lv, X. 2008. Safety risk identification and assessment for Beijing Olympic venues construction."J. Manage. Eng., 24(1), 40–47.

[30] Mitropoulos, P., Namboodiri M., 2011. New method for measuring the safety risk of construction activities: task demand assessment. J. of Constr. Eng and Manage., 137(1), 30-38.

[31] BLS. Bureau of Labor Statistics. 2013. <http://www.bls.gov/iif/#data> (retrieved 25.06.13).

[32] Casanovas, M. M., Armengou,J., Ramos, G. 2014. Occupational risk ındex for assessment of risk in construction work by activity. Journal of Construction Engineering and Management,Vol. 140, pp.04013035-1-04013035-9.

[33] Woodruff, J. M. 2005. Consequence and likelihood in risk estimation: A matter of balance in UK health and safety risk assessment practice. Safety Science, 43(5), 345-353.

[34] Birgönül, M. T., & Dikmen, İ. (1996). İnşaat projelerinin risk yönetimi. İMO teknik Dergi, 7(4), 1305-1326.

[35] Erginel, N., & TOPTANCI, Ş. (2017). Is Kazası Verilerinin Olasılık Dağılımları İle Modellenmesi. Mühendislik Bilimleri ve Tasarım Dergisi, 5(SI), 201-212.

[36] Bilir, S. (2015). An Activity Based Occupational Safety Risk Assessment Method Integated to The Project Schedule In Construction Projects. (Doctoral dissertation, Institude of Science and Technology).

[37] Bilir, S., & Gurcanli, G. E. (2016). A Method to Calculate the Accident Probabilities in Construction Industry Using a Poisson Distribution Model. In Advances in Safety Management and Human Factors (pp. 513-523). Springer, Cham.

[38] OSHA. 1971/97. Recording and reporting occupational injuries and illness. Regulations, Part 1904, Occupational Safety and Health Administration, U.S. Departmant of Labor, Washington, D.C.

[39] ILO. 1998. Meeting of Experts on Labour Statistics. Report MELSOI/1998/1, Geneva. Ingstad, O. and Bodsberg, L., 1989. CRIOP: A Scenario - Method for Evaluation of the Offshore Control Centre. SINTEF, Report No. STF75 A89028, Trondheim.

[40] Zhang, S., Teizer, J., Lee, J. K., Eastman, C. M., Venugopal, M., 2013. Building information modelling (BIM) and safety: automatic safety checking of construction models and schedules. Automation in Construction, 29,183-195.

[41] Borsos, A, Cafiso, S., D'Agostino, C., Miletics, D., 2016. Comparison of Italian and Hungarian black spot ranking. Transportation Research Procedia, 14, 2148 – 2157.

[42] Cafisoa, S.,Di Silvestroa, G., Di Guardoa, G., 2012. Application of Highway Safety Manual to Italian divided multilane highways. Procedia - Social and Behavioral Sciences 53, 911 – 920.

[43] Van Geelen, H., Volckaert, A., Sarrazin, R., Janssens, I., 2016. Evolutionary approach of accident concentration zones. Transportation Research Procedia, 14, 3332 – 3341.

[44] Fine, W. T., & Kinney, W. D. 1971. Mathematical evaluation for controlling hazards. Journal of Safety Research, 3(4), 157−166.

[45] Primavera P6 Software, 2013. <http://www.oracle.com/us/products/applications/primavera/p6-professional-project-management/overview/index.html> (retrieved 04.02.13).

[46] MS Project, 2013. <https://products.office.com/en/project/project-and-portfolio-management-software> (retrieved 07.01.13).

[47] Kjellen, U., Preventation of accidents through experience feedback. London.GBR: CRC Press, 2000.

[48] Statistics – The Poisson Distribution. 02.07.2015. Retrieved from <https://www.umass.edu/wsp/resources/poisson/>