A New Personnel Hazard Assessment Approach for Construction Sites

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Introduction

Frequent work site inspections are essential to maintaining safe conditions on construction sites. These should be conducted by competent persons and should include inspections of the work site, equipment, and all materials to be used in performance of the job. On the other hand, the safety professionals and inspectors should have to know the points where they will focus on in the risk assessment process. Hence, the hazard assessment should be done before risk evaluation. Moreover, the hazard assessment generally is not performed numerically and this field study aims at proposing a new safety scoring methodology specifically applicable for construction site inspections and presenting numerical expression for the hazardous conditions. It is important noting that many safety assessment techniques or approaches have been widely used, but often fall short in their ability to score construction sites according to the occupational safety legislation. Not only for the construction industry, but also in other industries, classical safety checklists used by inspectors based on the boolean expressions such as safe/unsafe or safety conditions satisfied/unsatisfied. In this study an innovative checklist that allows inspectors to score each safety condition between 1 and 10, 1 for the best and 10 for the worst condition was established. The checklist is prepared according to the nine leading causes of fatalities in the Turkish construction industry and the weight of the each item is determined using Analytic Hierarchy Process involving matrices that produce a ranking through Pair-Wise Comparison voting of competing safety conditions to be satisfied. From the experience of the experts, it is essential to identify the most significant safety measures to be taken for each cause of accident to reduce the potential hazard on construction site. Among all the safety measures, some are considered more important than the others. This identification process highly depends on the past experience and subjective judgements of the experts. On the other hand, safety experts in this study determined the severity scores again ranking from 1 to 10 for each type of accident. Hazard level matrix was formed for the construction site by multiplying these two quantities. The new approach was implemented at a tunnelling and underground construction site by regular on site inspections and the results are discussed for implementation of an effective occupational safety system and improvement of the accident prevention. The approach proposed is an effective tool for the inspectors to score the construction sites by taking into account the compliance with the safety legislation and assess the hazards according to the leading causes of fatalities in the Turkish construction industry.

Determination of the weights of safety measures by pair wise comparisons and derivation of safety scores and finding the first variable Safety Level

In the first step in the field study all the safety measures for each accident cause weighted by experts. From the experience of the experts, it is essential to identify the most significant safety measures to be taken for each cause of accident to reduce the potential hazard on construction site. Among all the safety measures, some are considered more important than the others. Therefore, improvement on these more important safety measures has stronger influence reducing hazard regarding that type of accident. This identification process highly depends on the past experience and subjective judgements of the experts, moreover it is a complicated task. In this research, the pair wise comparison method is utilized. Pair wise comparison starts with comparing the relative importance, or importance ratio, of two selected items. If n items are associated with en weights, w1, w2, ...wn, the relative importance, aij, considering the ith item and the jth item is obtained as;

$$a_{ij} = \frac{w_i}{w_j} \qquad \text{(Eq.1)}$$

The pair wise ratios satisfy

$$\begin{bmatrix} a_{11} & & a_{1n} \\ a_{21} & & a_{2n} \\ . & & . \\ . & & . \\ . & & . \\ a_{n1} & & a_{nn} \end{bmatrix} \begin{bmatrix} w_1 \\ w_2 \\ . \\ . \\ . \\ w_n \end{bmatrix} = n \begin{bmatrix} w_1 \\ w_2 \\ . \\ . \\ . \\ w_n \end{bmatrix} \qquad \text{(Eq.2)}$$

Since an item is equally important as itself, the value of a diagonal element in the matrix is 1 ($a_{ii}=1$), and values of the elements in the upper triangle of the matrix are the reciprocal values of the elements in the lower triangle of this matrix, only n(n – 1)/2 times of comparisons are needed. For ease of explanation, this equation is described as

$Aw = nw$ or $(A - nI)w = 0$ (Eq. 3)

where I is a nxn identify matrix. From this equation, it is apparent that n is an eigenvalue of A, and w is an eigenvector for eigenvalue n. In general case, it cannot be given the precise values of w1/w2 but only estimates of them. The estimation errors result in inconsistency of the data in the pair wise ratio matrix. Saaty introduced a consistency index, CI, as a measure to evaluate the deviation from consistency of the pair wise ratios. CI is calculated by

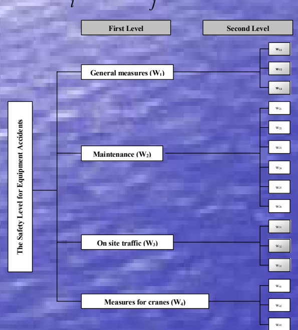
$CI = (\lambda max - n)/(n - 1)$ (Eq. 4)

where lmax is the maximum eigenvalue of A considering estimation errors. When values of the elements of a reciprocal matrix are generated randomly, the consistency index for this matrix is shown as RI. The ratio of CI to RI for the same order matrices is called the consistency ratio (CR). A pair wise ratio matrix with consistency ratio less that 0.10 is considered as a good one to calculate the weights of the items. When identifying the importance measures of safety measures to be taken for each accident cause (to eliminate potential hazard), experts are asked to specify how a particular need is more important than another one. On the other hand, for falls from height, contact with electricity and heavy equipment accidents, there are two hierarchical levels to assess the safety level. For example, the safety measures to prevent equipment accidents are sub grouped as "general measures", "maintenance", "on site traffic" and "measures for cranes". In analytical hierarchy process, these subgroups are regarded as first level, the measure under these four groups are the second level. The AHP structure used for equipment accidents are shown as in Figure 1.

Using the checklist is shown in the figures, safety analyst evaluates the safety requirements and mentioned before, the analyst do not check whether the requirement satisfied or not, however, he/she gives points between the scale of 1 to 10 and these points multiplied by the importance measures (relative weight) of each requirement. This point is also important, because it is a new approach for construction safety checklists, by considering the relative weights of each safety measure, and the system does not regard all the safety measures to be equal. Instead, system works according to the relative weights, or relative importance, derived from the pair wise comparison analysis performed by experts. Of course, all the safety requirements are necessary and lack of any safety condition may lead to serious injuries, however, from the experience of the safety professionals in Turkey, for example, it can be obviously said that, falls from roof edge, much higher than, fall caused by scaffolding collapse. On the other hand, the checklist proposed needs to be developed; regarding safety management items those must be satisfied to establish an effective safety system in the site.

If there are two levels Safety Score=

$$\sum_{i}^{n} \left(W_i \cdot \sum_{j}^{k_i} w_{ij} . s_{ij}\right)$$



Weights		Safety measures for equipment accidents	Safety score for each item given by experts (s)										Relative Point
W1=0.26	w11=0.10	Are all flagmen equipped with proper flags, sign paddles, or lights?	**1**	2	3	4	5	6	7	8	9	10	0,03
	w12=0.47	How is the wearing of the flagmen? Are wearings proper (red or orange warning garments) or for working at night, are reflectorized wearing garments satisfactory?	1	2	3	4	5	6	7	8	**9**	10	1,09
	w13=0.43	What is the qualifications of the operators? Have they got operator licence and to what extent are these kinds of licences, training certificates recorded and revised?	1	2	3	4	5	6	7	8	**9**	10	1,02
W2=0.44	w21=0.10	Are rated load capacities, recommended operating speeds, and special hazard warnings posted on all equipment and visible from operator's station?	1	2	3	4	**5**	6	7	8	9	10	0,22
	w22=0.45	Are the safety measures satisfactory so that bulldozer and scraper blades, dump bodies, etc., fully lowered or blocked when being repaired or not in use?	1	2	3	4	5	6	7	8	9	**10**	2,00
	w23=0.45	To what extent do these vehicles have a proper service brake system, emergency brake system, and parking brake system in operable condition? Are routine daily inspections and recording system for this point satisfactory?	1	2	3	4	**5**	6	7	8	9	10	1,00
W3=0.04	w31=0.43	To what extent are motor vehicles which operate within an off highway job site that is closed to public traffic being operated according to the requirements of the standards?	1	2	3	**4**	5	6	7	8	9	10	0,07
	w32=0.04	Are parking brakes set on for all parked equipment, and are necessary measures taken when equipments parked on an incline? (i.e are wheels chocked for all equipments)	1	2	3	4	5	6	7	8	**9**	10	0,01
	w33=0.26	To what extent are all vehicles equipped with proper and satisfactory audible warning device that is in operable condition at the operator's station and do all vehicles with an obstructed view to the rear have a back up alarm or are they always used with an observer? (i.e To what extent are proper conditions satisfied for all earthmoving or compacting equipment with obstructed rear view)	1	2	3	4	5	6	**7**	8	9	10	0,07
	w34=0.04	To what extent is all equipment used in site clearing operations equipped with proper rollover protection? (To what extent are all rubber tired, self-propelled scrapers, rubber-tired front end loaders, wheel type agricultural and industrial tractors, crawler tractors, crawler type loaders, and motor graders (with or without attachment) equipped with proper rollover protective structures?)	1	2	3	4	5	**6**	7	8	9	10	0,01
	w35=0.11	To what extent the workers are prevented to enter the working area of the equipments? Are the warning signs or safety bands (strips) for caution settled properly?	1	2	3	4	**5**	6	7	8	9	10	0,02
	w36=0.09	a. What is the condition of the roads and passing ways of the site b. What is the traffic safety measures and traffic organization of the construction site to prevent traffic accidents?	1	2	3	4	**5**	6	7	8	9	10	0,02
	w37=0.04	To what extent are the preventive measures satisfactory against roll overs while equipments (excavators for example) are working on a inclined surface? Do the proper warning signs or guardrails exist to prevent roll overs into the excavated locations?	1	2	3	4	5	6	7	8	9	**10**	0,01
W4=0.26	w41=0.68	What are the conditions of the footings or ground for mobile or static cranes? Are proper measures taken to prevent fall overs?	1	2	3	4	5	6	7	8	**9**	10	1,60
	w42=0.20	To what extent are workers or third person prevented to enter the moving radius of the cranes? Are there any safety bands or warning signs near the cranes?	1	2	3	4	**5**	6	7	8	9	10	0,26
	w43=0.12	To what extent are manufacture's specifications and limitations applicable to the operation of any and all cranes and derricks complied with? Are the balancing of the crane systems satisfactory to prevent falling of loads carried by them?	1	2	3	4	5	6	7	8	9	**10**	0,30
													Total Safety Score = 7.74

Definition of accident severity (AS) variable and finding semi-qualitative values for it

Moreover, from the field research, the data for accident severity is also derived. Since the lack of hospital records or another kind of information, the severity of each type of accident determined, again, by incorporation of insufficient historical data and subjective judgement. Criteria provided herein address the consequences of accidents to humans: on site and worker/operator. Environmental or financial consequences of the accidents are not cited here. In qualitative or semi-quantitative risk analysis methods, likelihood and severity (consequence) of the accidents are considered. On the other hand, in the presented hazard assessment approach, current safety level is used instead of likelihood. Morever, the severity definitions should be put on an applicable basis for the industry. In the literature, for severity rankings 4 to 7 scales are defined and in this study 5 scaled ranking is chosen. By the aid of the literature research the terms for describing accident severity are suggested to be defined as in Table 1 and experts were asked to give a score between 1 and 100 to assess the severity of an accident. They may not give exact number and give score between categories, for example 42, 63, 75 etc. These values can easily managed using fuzzy set definitions as explained in later sections. For each type of occupational accident they gave scores using their experience and subjective judgment. The characteristics of the experts should be mentioned here to point the importance of their opinions. All of them are civil engineers, their field is occupational safety in construction and they experienced and witnessed many accidents on construction sites.

Table 1. Categories and Definitions for Accident Severity

Scale (0–100)	Ranking	Consequence	Definition
0	1,2	Catastrophic	Fatalities occur highly frequently, serious injury. Also includes the possibility of multiple fatalities in close succession due to the incident, e.g. Explosion
	3,4	Severe	Fatalities occur frequently, major injury. Leading to permanent partial disablement or unfitness for work or tedrimental to performance of work over extended period, such as long term absence.
	5,6,7	Medium	Minor to major injury but occasional fatality. Detrimental to the performance of present work such as curtailment of activities or some days absence to recover fully, maximum one week
	8,9	Minor	Minor injury, not detrimental to individual employability or to the performance of present work.
100	10	Negligible	No serious injury or damage to health

Table 2. Accident severity values given by the experts

		Experts					
		1	2	3	4	5	Ave.
1	Fall from height	10	5	20	15	30	16
2	Contact with electricity	25	50	65	20	5	33
3	Accident by falling object	30	10	65	35	35	35
4	Heavy equipment accidents	35	30	75	30	45	43
5	Traffic accident on site	35	80	85	50	5	51
6	Building or Structure Collapse	5	60	65	15	5	30
7	Cave-ins	20	20	35	0	10	17
8	Fire or Explosion	40	40	62.5	10	10	32,5
9	Material bouncing to face or other parts of the body	70	25	87,5	65	45	58,5
10	Other causes of accidents	80	40	65	70	65	64

If there is only one level Safety Score=

$$\sum_{i}^{k} w_i . s_i$$

Weights	Safety measures for traffic accidents on site	Safety score for each item given by experts (s)										Relative Point
w1=0.15	To what extent the on-way system or turning points to minimise reversing provided?	1	2	**3**	4	5	6	7	8	9	10	0,45
w2=0.03	How is the wearing of the flagmen? Are wearings proper (red or orange warning garments) or for working at night are reflectorized wearing garments satisfactory? 1926.201(a)(4)	1	2	3	4	5	6	7	8	9	**10**	0,33
w3=0.03	To what extent are all vehicles which are left unattended at night, adjacent to a highway in normal use or a construction site where work is in progress, equipped with lights, reflectors, or barricades to identify the location of the equipment? 1926.600(a)(1)	1	2	3	4	5	**6**	7	8	9	10	0,20
w4=0.03	Are parking brakes set on for all parked motor vehicle, and are necessary measures taken when vehicles parked on an incline? (for example, are wheels chocked for all equipments) 1926.600(a)(3)(ii)	1	2	3	4	5	6	7	8	**9**	10	0,27
w5=0.34	To what extent are motor vehicles which operate within an off highway job site that is closed to public traffic being operated according to the requirements of this standard? 1926.601	1	2	3	4	5	6	**7**	8	9	10	2,38
w6=0.11	Do all vehicles with an obstructed view to the rear have a back up alarm or are always used with a observer? 1926.601(b)(4)	1	2	**3**	4	5	6	7	8	9	10	0,33
w7=0.04	To what extent separate pedestrian, vehicle access point and routes around the site provided?	1	2	**3**	4	5	6	7	8	9	10	0,12
w8=0.22	To what extent are vehicles in use inspected at the beginning of each shift to assure that all parts, equipment, and accessories affecting safety operation are free of defects? 1926.601(b)(14)	1	2	**3**	4	5	6	7	8	9	10	0,67
w9=0.03	To what extent traffic or warning signs are satisfactory?	1	2	3	**4**	5	6	7	8	9	10	0,13
												Total Safety Score = 4.89

Construction of the Hazard Level Matrix

Hazard level matrix was formed for the construction site by multiplying these two quantities. In the last table, the matrix is shown. It is different from the conventional used 5x5 matrix for risk assessment. The transition zones between two categories are taken into account in this approach and instead of likelihood, the safety level variable is used. The safety level also point outs the possibility of an accident on a site. By implementation of this approach, a safety professional on a construction site can easily assess the hazard level of an accident type and manage the negative situations by the aid of the checklist. He/she can easily detect the deficiencies that lower the safety level score down from the checklist and he can develope counter measures against them. In this poster presentation we can only show the checklist for two types of accidents, however the checklist covers the 9 leading cause of the accidents in the construction site. The approach was implemented in a construction company and safety inspections were performed weekly. The hazard levels derived shed light on the later implementation of the safety management items which are harmonized with OHSAS 18001.

For instance the safety level for equipment accidents was found as 7.74 and its accident severity is 43 (4.3 in a 1 to 10 scale). The Hazard Level is 33.3. Its in the hazardous region, however very close to the slightly hazardous category. If we focus on the checklist it is obvious which points increases the hazard level. If all the requirements are satisfied the safety level will be 10 while hazard level 43. The level is still in the slightly hazardous region. Although the risk level can be lowered down to zero risk region in the risk analysis, in hazard assessment concept you can only point out the best and the worst conditions. In this case, the best condition for equipment accidents a score lowered down to 43 and its corresponding expression slightly hazardous. However, by the aid of the approach presented, safety professionals will become aware of the hazardous conditions for each type of accident.

Accident Severity Ranking		Safety Level for a certain type of an accident									
		Poor			Inadequate		Average		Adequate		Safe
		1	2	3	4	5	6	7	8	9	10
Catastrophic	1	1	2	3	4	5	6	7	8	9	10
	2	2	4	6	8	10	12	14	16	18	20
Severe	3	3	6	9	12	15	18	21	24	27	30
	4	4	8	12	16	20	24	28	32	36	40
Medium	5	5	10	15	20	25	30	35	40	45	50
	6	6	12	18	24	30	36	42	48	54	60
	7	7	14	21	28	35	42	49	56	63	70
Minor	8	8	16	24	32	40	48	56	64	72	80
	9	9	18	27	36	45	54	63	72	81	90
Negligible	10	10	20	30	40	50	60	70	80	90	100

LEGEND	Extremely Hazardous	Hazardous	Slightly Hazardous	Safe	No Hazardous Conditions Exist

Conclusion

The advantage authors argue that, the flexible structure of the proposed checklist has advantages for the safety proffessionals. The proposed model and the checklist itself give a more flexible structure for combining the qualitative as well as quantitative information. The attributed weights for each safety items derived from the AHP process have advantages for the safety professional. In every construction site, the safety engineers, site manager, safety expert and other employees that join the decision making process in project management should perform pair wise comparisons of the safety measures, because of the fact that the unique characteristics of each construction site. Moreover, the safety team in the company may repeat this process at the beginning of each important project phase. The importance of the safety items (weights) may be changed according to the construction work, qualifications of the personnel, techniques and materials used. For every construction sites with different characteristics, the safety items may have different importance and the method proposed is flexible to manage these peculiarities. After detection of the hazard level, the risk assessment may be performed by using the variables Accident Likelihood and Consequent Severity or by other approaches like fuzzy logic as the authors implemented in many cases. The ranking of the hazardous situations before the risk assessment may bring some advantages for the assessors to focus on the selected items and by the aid of the approach presented, safety professionals will become aware of the hazardous conditions for each type of accident during the project.

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