AN APPROACH TO DEFINE CONSTRUCTION PRACTICE FROM CONSTRUCTION IMAGES

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In the construction industry, safety is an important, but often neglected, factor. Due to its nature construction is one of the most hazardous industries and so identifying safe construction practices becomes very important. Nowadays, the use of construction images has become very popular. As information sources, images/pictures recorded of the construction process provide significant information relating to the safe construction practice. However, there are a number of problems related to using images to determine if the construction practices being used are safe or unsafe because of uncertain or inexact information collected by looking at that image. To deal with the uncertain information from construction images, it is proposed to use a database of images alongside their characteristics and an assessment [made by direct assessment on-site] of their safety. The framework proposed for this is described. It is initially based on Bayes' Theorem. From 20 construction images as an example, the result revealed that eight images demonstrate safe construction practices, whereas 12 images demonstrate unsafe construction practices. In conclusion, proposed approach demonstrates how it is possible, using on-site images, to define construction practice as safe or unsafe.

Keywords: Bayes' theorem, construction images; construction practices.

INTRODUCTION TO CONSTRUCTION SAFETY

All over the world, safety has always been a major issue in many industries. Construction is one of the most hazardous industries due to its nature. In Western Australia, during the period 1988-89 to 2004-05, the number of work related fatalities in the Construction Industry represent 15% of the total work related fatalities (State of the Work Environment 2005:8). In United Kingdom, the construction industry accounts for one third of all work fatalities (HSC, 2003). Another report from United States also gives a number of construction fatalities that is nearly one-fifth of all industrial fatalities in 2000 (BLS, 2001). This safety issues at construction sites have gained industry-wide attention.

The large number of accident occurrences has raised the awareness of the need for a system to manage construction safety. Accidents arise from different causes. Kartam (1997) stated that accident causes can generally be classified as physical incidents posing hazardous situations, and behavioral incidents caused by unsafe acts. Toole (2002) stated that construction accidents are associated with unsafe conditions and this implies a deficient management of safety. Unsafe conditions, such as an improper attitude of personnel and a hazardous project environment, are often not detected

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before an accident occurs. A preliminary literature review also revealed that there is very little research that has focused on assessment of accident potential before fact (Lee and Halpin, 2003:431).

Based on this, it can be proposed that there is a need to detect unsafe conditions before an accident occurs. To do this it is necessary for safety hazard recognition to be undertaken before and during construction.

PROBLEM STATEMENT AND RESEARCH OBJECTIVE

Accident statistics have played an important role in measuring safety performance. However, accident statistics are based on actual accident data and the compilation of post accident information. Ex post facto data provides factual data that are not necessary helpful in predicting accidents or assessing accident risk. Lack of accidents does not mean there is no risk of an accident; rather, there is a need to estimate the risk level of accidents based on current safety practices (Lee and Halpin, 2003:431).

Learning from mistakes and successes is and always has been an important aspect of safety work. Efforts to improve safety on construction sites can take many forms. While safety hazard mitigation measures have traditionally been implemented solely by the builder during the construction phase, many believe that additional actions can and should be taken earlier in the project, during the planning and design phases (Hacker *et al*, 2005:32).

Construction information in the form of images of the construction, are increasingly being used as a source of information in the study and control of construction practices. In particular, the images have been used for sometime to provide information concerning the construction methods used, progress, damage, and the condition of the site.

The objective of this research is to combine the use construction images with the desire to promote safe construction practices. This research is a part of ongoing research that is to develop a construction image database and a method of image analysis that can be used to assess, monitor and control safe construction practices on construction sites.

THE PROPOSED APPROACH

A safety practices encountered on construction sites are as varied as the sites themselves (Lee and Halpin, 2003:431). However, this research is designed to investigate how observation from records (as images) of current construction practice can be used to identify safe construction practices. This research has collected digital photographic image data of construction sites, and those data were stored. The images were taken from a wide range of construction sites in Western Australia, Indonesia, United Kingdom, and Egypt. The distance between the photographer and the object of photograph was varied so as to produce two main types of images, the whole activity image type and the detailed image type.

A small pilot survey was conducted using input from a few construction practitioners in Indonesia. These practitioners were shown a number of construction images and asked questions about their safety. For example, they were asked about construction practices in the image and whether they consider it safe or not using the image in figure 1. Some of the practitioners said that the practice was safe, the others said not safe. They disagreed on their assessments of the same image. When asked about the reason for their judgment, they said that based on their previous experiences some of them had had accidents using similar practice, while the others said they did not have accidents. The next question was to determine if they were aware explicit or written safety regulations related to certain activities before and during construction phase; the answer again varied. Some of the practitioners said that they had never seen that kind of regulation, the others said that they know about the regulation but ignored it and they had done the activity based on their experience from their previous work, another practitioners said they do know the regulation and follow it but with modification, and the last group of practitioners said they strict with the regulation.

Figure 1: An example image

In theory, construction practitioners should determine the construction practices that they intend to use by following a path of reasoning. It is not sufficient if these decisions are only based on knowledge gained from retained subjective personal experience. It should be based on well-founded experience and written regulation, and so everyone who plans working method will follow the same guidelines.

The Occupational Safety and Health Administration guideline, which is available from their website http://www.osha.gov have been adapted to construct the proposed guideline, which is a safety checklist. This safety checklist has been used to make an assessment of safe construction practice of collected image data. The checklist was completed for every image. The safety 'score' (safe or unsafe) given by the practitioners interviewed varied was also recorded. To incorporate the range of assessments of safety a mathematical analysis has also been developed to make a reliable prediction of safe construction practices. The analysis is used Bayes' Theorem, which can deal with inexact reasoning.

The framework used for identifying methods of assessing the degree of confidence of safe construction practices is shown in figure 2.

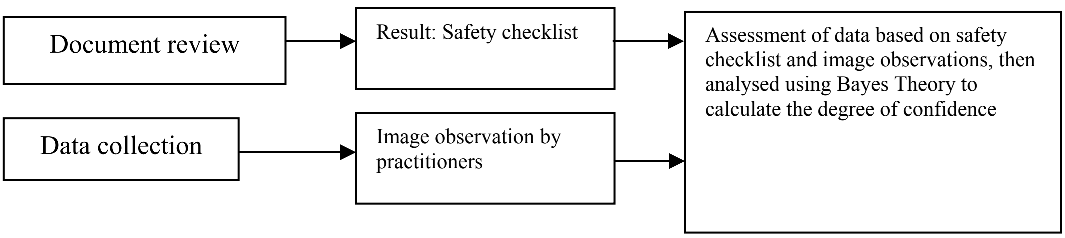

Figure 2: A Framework for assessing the degree of confidence of safe construction practices

The assessment method has been developed using observations of one particular construction operation (scaffolding) as a trial to demonstrate how such a predictive tool can be used to assess and predict the effectiveness of safety practices. Once demonstrated as an effective assessment method the resulting method can be used as reference for installing safe construction practice before work begins.

CONCEPT OF BAYES' THEOREM

In order to make a predictive expert system in areas such as safety, the method of analysis must be able to incorporate that are true or false. For example, given an image in figure 3:

Figure 3: Construction accident image

An event may be: "The machine was rolled from its place"

And the proposition is: "The machine was unstable"

Given that A is a proposition, the conditional probability *P(A / B)* can be interpreted as the *degree of belief* that A is true, given B (Giarratano and Riley, 1998). For the purposes of this research, the term "degree of belief" could be better expressed as "degree of confidence". This type of *hypothesis* is used for some proposition whose truth or falseness is not known for sure on the basis of some *evidence*. A conditional probability is then referred to as the *likelihood or degree of confidence,* as in *P(H/E)*, which expresses the likelihood of a hypothesis, H, being true based on some evidence, E.

$$P(H/E) = \frac{P(E/H)P(H)}{P(E)} \qquad (1)$$

(Giarratano and Riley, 1998)

This equation (1) is known as Bayes' Theorem formula

Where:

P(H/E) is a degree of confidence of hypothesis (H) given evidence (E), e.g. degree of confidence that the machine was unstable given evidence that the machine was rolled from its place.

P(E/H) is a degree of confidence of hypothesis (H) that can cause evidence (E), e.g. degree of confidence that the machine was rolled from its place because of the machine was unstable.

P(H) is a probability of hypothesis (H), e.g. probability of the machine was unstable

P(E) is a probability of evidence (E), e.g. probability of the machine was rolled from its place

In a real world, the more general and realistic situation is based on uncertain hypotheses and uncertain evidences. For the general case, assume that the degree of confidence in the complete evidence, E, is dependent on the partial evidence, e, by $P(E/e)$. Referring to figure 3, it can be stated that the evidence (E) is unstable machine, and the partial evidence (e) is the machine was placed on the weak soil. Thus, because the machine was placed on the weak soil then the machine was unstable. The complete evidence is the total evidence, which represents all possible evidence, and hypotheses, which comprise E. The partial evidence, e, is the portion of E that known. If all partial evidence known, then E = e and $P(E/e) = P(E)$.

More complex situation arises if there is compound evidence. Compound evidence consists of multiple pieces of evidence and expressed formally:

IF E1,E2,… and EN then H

For the example, using figure 3 above, the state can be expressed that:

E1 is unstable condition, E2 is unbalanced load, and H is rolling machine

Then the logic statement can be expressed the example formally:

"IF the machine was unstable AND has unbalanced load THEN the machine was rolled from its place"

So equation (1) become equation (2) as follow:

$$P(H/E_1 \cap E_2 \cap ...E_N) = \frac{P(E_1 \cap E_2 \cap ....E_N / H)P(H)}{P(E_1 \cap E_2 \cap ...E_N / H)P(H) + P(E_1 \cap E_2 \cap ...E_N / H')P(H')}$$

Where symbols are as before, and

P(H/E1∩E2∩…EN) is a degree of confidence of hypothesis (H) given compound evidences E1,E2,…EN.

P(E1∩E2∩…EN/H) is a degree of confidence of hypothesis (H) that can cause evidences E1,E2,…EN.

P(E1∩E2∩…EN/H') is a degree of confidence of hypothesis complement (H') that can cause evidences E1,E2,…EN.

P(H) is a probability of hypothesis (H)

P(H') is a probability of hypothesis complement (H').

In this research, a term hypothesis is refers to the degree of confidence that construction practice is being observed is safe. The term evidence is refers to safe attribute of one particular construction operation, and the partial evidence is refers to safe sub attribute, as a part of safe attribute, of one particular construction operation.

SAFE ACCESS SCAFFOLD ATTRIBUTES

In this demonstration, the attributes are limited exclusively to those applicable to access scaffolding on construction sites. For identification of access scaffold attributes, the information provided by Occupational Safety and Health Administration was adapted and modified. There are six attributes for supported access scaffold. The attributes are: (a) base section, (b) support structure, (c) access and ladders, (d) fall protection, (e) platform and walkways, and (f) electrical hazards. These six attributes were specified to minimize the risk of a worker falling, material falling or structural faults. Every attribute has sub attributes that provide clear explanation of safe access scaffold. Simple checklist items (see table 1) derived from these attributes and sub attributes are the best tools for gauging scaffold safety and as such can be viewed as decision aids. Table 1 provides the attributes and sub attributes for safe access scaffold. The entire sub attributes description refers to safe practice based on OSHA regulation, so that if the answer is “yes”, its means “safe”.

Assessment of safe construction practice – Bayes’ theorem-based analysis

Assessment of safe construction practice is stated using terms such as ‘safe’, ‘most likely safe’, ‘most likely unsafe’, and ‘unsafe’, and need to be translated into mathematical terms. The assessment was done by observed each image and give a score for a particular action based on safety checklist. For example, refer to attribute 1 (base section), the observation focused at the part of the image which has base section. Then, based on safety checklist the score for the construction practice for base section was given.

Table 1: The attributes and sub attributes for safe access scaffold

Attributes	Sub Attributes
1.Base section	1. The supported scaffold should be set on a stable object, such as base plates, mud sills, other adequate firm foundation 2. The supported scaffold should be plumbed and braced to prevent swaying and displacement
2.Support structure	1. The supported scaffold and scaffold components should be capable to support their own weight and at least four times maximum intended load without failure 2. Frames and panels are connected by cross, horisontal, or diagonal braces, to secure vertical members laterally 3. Cross braces is in such length as will automatically keep the scaffold plumb, level, and square 4. Brace connections are secure to prevent dislodging 5. Frames and panels are joined together vertically by coupling or stacking pins or equivalent means 6. Frames and panels are locked together to prevent uplift
3.Access and ladders	1. The hook-on and attachable ladder is specifically designed for use with the type of scaffold on which they are used 2. Stairway-ladders must have slip-resistant treads on all step and landings
4.Fall protection	1. Fall protections which are consists of either personal fall-arrest system or guardrail system should be provided on any scaffold ten feet or more above a lower level 2. Guardrail are installed along all open sides and ends of platforms 3. The top edge height of toprails on supported scaffold should be between 36 and 45 inches 4. If midrails are used, they should be installed at a height approximately midway between the top edge of the guardrail system and the platform surface
5.Platform and walkways	1. Each platform should be fully planked between the front uprights and the guardrail supports 2. The gaps between adjacent planks or between platforms and uprights are not greater than one inch 3. There is no more than a 14-inch gap between the scaffold platform and the structure being worked on 4. The toeboard should be installed along the edge of platform those more than ten feet above the lower level and have at least 3.5 inches high from the top edge 5. Ramps and walkways which is six feet and more above lower level should have guardrails
6.Electrical hazard	1. The scaffold and their conductive materials, such as building materials, paint roller extensions, scaffold components, that may be handled on them should not closer than ten feet to the power line, or scaffolds may be closer to overhead power lines than ten feet but they do has either de-energised the lines (grounded) or relocated the lines or installed protective coverings to prevent accidental contact with the lines

(Source: www.osha.gov)

In this analysis safe construction practice has been given a score of 100% and unsafe construction practice has score of 0%, so the term 'most likely safe' has a score of 66.67% and the term 'most likely unsafe' has score of 33.33%. By scoring the safe sub attributes *(e)* based on safety degree of confidence, then the degree of confidence of each attribute *P(E/e)* based on hypothesis *(H)* can be determined. Because all of the partial evidence were known then degree of confidence of attribute *(E)* based on hypothesis *(H)* was referred to *P(E/H)*.

Example 1:

See figure 4(c). Suppose the rule stated that: "The supported scaffolds set on a stable object (attribute 1= E_1, sub attribute 1 = e_1)". The information revealed by visual observation of figure 4(c) suggests that the scaffolds were set on a stable object. It can be seen from figure 4(c) that the scaffolds were has base plate on the ground, and so the degree of confidence to say that was safe was 100%. Likewise, for sub attribute 2 (e_2), the information revealed by visual observation of figure 4(c) suggests that the scaffold were plumbed and braced, and so the degree of confidence to say that was safe was 100%. From this, the degree of confidence of evidence (E_1) given two partial evidences (e_1,e_2) = *P(E/e)* = 100% = 1.00

The probability of hypothesis *P(H)* was determined based on the number of events of hypothesis divided by the number of sample space, which is referred to the number of total events of sub attributes. The total events of sub attributes could be varied based on the detailed information from the images. If the entire sub attributes could be recognized from the image, then the number of sample space would be 65.

Example 2:

The other information can be revealed from figure 4(c) were that image only shown base section (attribute 1) with two sub attributes and support structure (attribute 2) with six attributes. The numbers of total evidence were eight. From this total evidence, seven evidences have three possible events, so 21 events; one evidence has four possible events; the hypothesis has four possible events as well. And so, the total events become 29. P(H) was determined as four divided by 29, and so *P(H)* = 0.138

The probability of complement of hypothesis *(H')* was determined by subtracted the probability of hypothesis *(H)* from 100%. Likewise to determine degree of confidence of evidence given H complements. After the entire variable for equation (2) have determined, then the degree of confidence of hypothesis *(H)* given compounded evidence *(E_1,E_2,..E_N)* can be calculated. All of the assessment process was stored in MS Excel spreadsheet

Example 3:

- Calculate P(E/H):

$P(E_1/H)$ = 100% (as shown from example 1).

For attribute 2 (E_2): e_1= 100%, e_2= 66.67%, e_3= 100%, e_4= 66.67%, e_5= 100%, e_6= 100%, and so $P(E_2/H) = (\Sigma e_1,..e_6)/6$ = 89%

$P(E_1 \cap E_2/H) = P(E_1) * P(E_2)$ = 100% * 89% = 89% = 0.890 (as shown in table 2 column A)

- Calculate P(H)

To calculate P(H), shown from example 2. P(H) = 0.138 (as shown in table 2 column B)

- Calculate P(E/H')

P(E1/H') = 1 – P(E1/H) = 1 – 100% = 0%; P(E2/H') = 1 – P(E2/H) = 1 – 89% = 11%

$P(E_1 \cap E_2/H')$ = 0% * 11% = 0% = 0.000 (as shown in table 2 column C)

- Calculate P(H')

P(H') = 1 – P(H) = 1 – 0.138 = 0.863 (as shown in table 2 column D)

- Calculate $P(H/E_{comb})$

Refer to equation 2, so to simplify $P(H/E_{comb})$ = (A*B)/(A*B+C*D)

$P(H/E_{comb})$ = (0.890*0.138)/(0.890*0.138+0.000*0.863) = 1.000 (as shown in table 2 column E)

Interpretation and use of the results

In order to "calibrate" the proposed approach, 20 images of construction practice were used. These 20 construction images were processed to compute the degree of confidence that safe construction practices were being used. The calculation was undertaken using MS Excel spreadsheets using equation 2 (as shown at example 3), and the result of that process was shown in table 2. The results can be used to assess the probability of the image showing a safe site. For example referring to table 2, row 8 gives details of image number 8 (as shown in figure 4(c)). The result can be stated as "safe construction practice" if the score of P(E/H) > 0.00. If the score closer with 100% it means that the construction practice is safer.

By using this table, it can be seen that from 20 sample images that eight images defined as safe construction practice, and four images as the example shown at figure 4, and 12 images defined as unsafe construction practice, and four images as the example shown at figure 5. Tables such as this can be utilized to check safety of construction practice being used on site when the database (table) is extended to cover all attributes of safety characteristic. More significantly with a larger database it will be possible to extend the investigation to case-based reasoning that takes into account the situation where some values of safety characteristic cannot be determined from the image or where multiple results are available for the same characteristic values.

Table 2. Degree of confidence of safe construction practice

Image #	P(E│H)	P(H)	P(E│H')	P(H')	P(H│E_{comb})
	A	B	C	D	E=(AB)/(AB+CD)
1	0.640	0.077	0.000	0.923	1.000
2	0.000	0.073	0.000	0.927	0.000
3	0.000	0.085	0.000	0.915	0.000
4	0.000	0.080	0.219	0.920	0.000
5	0.350	0.073	0.000	0.927	1.000
6	0.465	0.080	0.000	0.920	1.000
7	0.527	0.073	0.000	0.927	1.000
8	0.890	0.138	0.000	0.862	1.000
9	0.000	0.125	0.000	0.875	0.000
10	0.000	0.077	0.000	0.923	0.000
11	0.000	0.077	0.000	0.923	0.000
12	0.000	0.080	0.000	0.920	0.000
13	0.000	0.085	0.098	0.915	0.000
14	0.000	0.077	0.000	0.923	0.000
15	0.000	0.085	0.000	0.915	0.000
16	0.867	0.073	0.000	0.927	1.000
17	0.596	0.077	0.000	0.923	1.000
18	0.236	0.069	0.000	0.931	1.000
19	0.000	0.077	0.000	0.923	0.000
20	0.000	0.073	0.000	0.927	0.000

Referring to equation (2) Where symbols are as before, and

$P(H/E_1 \cap E_2 \cap \ldots E_N) = P(H/E_{comb})$ is a degree of confidence of hypothesis (H) given compound evidences $E_1, E_2, \ldots E_N$. e.g. degree of confidence that the construction practice is safe given evidence which are base section and support structure, has score of 1.000

$P(E_1 \cap E_2 \cap \ldots E_N/H) = P(E/H)$ is a degree of confidence of hypothesis (H) that can cause evidences $E_1, E_2, \ldots E_N$. e.g. degree of confidence of the construction practice is safe that can cause safe base section and safe support structure, has score of 0.890

$P(E_1 \cap E_2 \cap \ldots E_N/H') = P(E/H')$ is a degree of confidence of hypothesis complement (H') that can cause evidences $E_1, E_2, \ldots E_N$. e.g. degree of confidence of the construction practice whether they are unsafe, or most likely unsafe, or most likely safe can cause safe base section and safe support structure, has score of 0.000

P(H) is a probability of hypothesis (H), e.g. the probability of safe construction practice, has score of 0.138

P(H') is a probability of hypothesis complement (H'), e.g. the probability of whether unsafe, or most likely unsafe, or most likely safe construction practice, has score of 0.862

(a) (b) (c) (d)

Figure 4: Safe construction practice images

(a) (b) (c) (d)

Figure 5: Unsafe construction practice images

The benefits of this proposed approach are:

- The safety checklist is simple and can used to quick on-site safety assessment.
- The calculation is using MS Excel spreadsheet, so the degree of confidence of current safety practice can be calculate quickly.
- The result from the calculation can be used to predict the safe construction practice. If the result revealed that the degree of confidence of current safety practice is 0 then that practice refers to unsafe practice. So, the safety hazards can be detected and the accident occurrence can be avoided.

CONCLUSION

Preliminary literature review revealed that accidents arise from different causes. Accident causes can generally be classified as physical incidents posing hazardous situations, and behavioral incidents caused by unsafe acts. Several root causes of the construction accident are associated with unsafe condition that implies a deficient management of safety. Unsafe condition, which is hazardous project environment and improper attitude of human, do not detect before an accident occurs. Furthermore, preliminary literature review also revealed that there is very little research has been focused on assessment of accident potential before fact. Thus, the needs to detect unsafe condition before an accident occur become very important.

This research has presented preliminary work to investigate safe construction practice using construction images. Information from construction images usually uncertain, thus the Bayes' Theorem was used to define the construction practice based on the degree of belief. An example demonstrates how it is possible, using this proposed approach, to identify construction practice and to detect the unsafe condition before an accident occurs. Future work will focus on developing an image database to provide safe construction practice.

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