A Bayesian networks approach to build human-machine-ergonomic risk assessment model for construction workers

Li Song
School of Economics & Management, Anhui University of Science & Technology, Anhui 232001, P R China
E-mail: lilysong23@163.com

Abstract. Effective safety management should pay much attention to harmony of human-machine ergonomic system. Bayesian Networks is a valuable tool to provide a robust probabilistic method of reasoning with uncertainty and is more suitable to represent complex dependencies among components and to include uncertainty in modeling. This paper build a BN risk model in order to analyze the extent to identify potential risk factors of human-machine-Ergonomic system, which can give reference to improve efficiency of safety management.

1. Introduction
With the rapid economic development and increase of construction projects, much more accidents have occurred in construction industry. Building construction is a dynamic process with complex safety factors and conditions[1, 2]. The main aims of safety management are maintaining excellence safety performance and facilitating improvement by creating a cycle of activities to eliminate or at least reduce injuries and damage to the environment[3, 4]. Building harmonious human-machine-environment relationship though efficient application of ergonomics has proved to be efficient way to maintain the health, safety and satisfaction of human [5, 6]. There are only a few studies on evaluating ergonomic risk so far. The purpose of this article is therefore to make an ergonomic risk assessment model by approach of Bayesian network in order to analyze the extent to identify potential risk factors.

2. Applications of BNs in human-machine ergonomic risk analysis

2.1. Bayesian Networks
A Bayesian Networks is a graphical representation of a joint probability distribution over a set of statistical variables for analyzing models involving uncertainty [7]. Owing to the capacity to represent such problems where uncertain variables are represented as vertices, Bayesian Networks is well suited to handling problems associated with high levels of complexity and uncertainty [8]. The structure of a Bayesian networks is made up of a directed acyclic graph (DAG) whose nodes represent variables. Arrows between variables represent direct causal dependencies on the basis of statistical analysis, process understanding or other types of associations. A conditional probability table (CPT) is used to describe the probability of each value of the child node, conditioned on every possible combination of values of its parent nodes. If a variable has no parents, it is described by a marginal probability distribution. The posterior probability distribution for a variable is calculated given new observations. A Bayesian network can be expressed $B = \langle G, \Theta \rangle$, $G$ represents a directed acyclic
graph, consisting of a variable node and an edge, $G=\{A_1, A_2, \cdots, A_n\}$. $B$ represents all of the convergent sets in $G$. When parent node of $A_i$ is given, and each parent node is independent of its non-child nodes, $G$ is a network topology. $\Theta$ represents a set of conditional probability distributions of nodes.

Assume Variable node-set is $<A_1, A_2, \cdots, A_n>$, when $A_1, A_2, \cdots, A_n$ are independent of each other, according to the chain rule, then

$$P=(A_1, A_2, \cdots, A_n)=\prod_{i=1}^{n} P(A_i|P_n(A_i))$$  \hspace{1cm} (1)

Assuming that prior probability is $P(A_i)$, The new information obtained by the survey is $P(B|A_i), i=1,2,\cdots,n$, then the posteriori probability is

$$P(A_i|B)=\frac{P(B|A_i)\cdot P(A_i)}{\sum_{i=1}^{n} P(B|A_i)\cdot P(A_i)}$$  \hspace{1cm} (2)

2.2. Human-Machine-Ergonomic risks factors

The number of variables of the BNs model depends on the purpose and scope of the study. Here we aim at modelling ergonomic risks. Construction sites are usually complex with various kinds of hazards owing to dynamic interaction between human, machine, ergonomic and management factors. We select human factors, machine factors, ergonomic and management factors as 1-level index, each 1-level has several sub-level indexes, shown in table 1.

| 1-level indexes | Human factors B1 | Machine factors B2 | Ergonomic factors B3 | Management factors B4 |
|-----------------|------------------|--------------------|----------------------|-----------------------|
| Professional qualifications C11 | facilities C21 | Site layout C31 | Recruitment & select C41 |
| Level of education C12 | electricity C22 | Lighting and temperature C32 | Work organization C42 |
| Work experience C13 | Equipment & vehicles C23 | Noise and vibration C33 | Training C43 |
| Safety protection C24 | Safety signals and signs. C34 | Safety administration C44 |
| Work space C35 | |

3. Build human-machine-ergonomic risks model based on BNs

Risk events are bayesian networks node variables. These nodes have two states: the event would occur (Y) or not (N). We get the prior probability value of the bottom nodes by way of survey, as shown in table 2.
Table 2. Prior probability value of the bottom nodes.

| HMER factor | Y   | N   | HMER factor | Y   | N   |
|-------------|-----|-----|-------------|-----|-----|
| C11         | 0.56| 0.44| C32         | 0.45| 0.55|
| C12         | 0.46| 0.54| C33         | 0.35| 0.65|
| C13         | 0.28| 0.72| C34         | 0.54| 0.46|
| C21         | 0.25| 0.75| C35         | 0.46| 0.54|
| C22         | 0.30| 0.70| C41         | 0.31| 0.79|
| C23         | 0.22| 0.78| C42         | 0.52| 0.48|
| C24         | 0.55| 0.45| C43         | 0.28| 0.72|
| C31         | 0.36| 0.64| C44         | 0.34| 0.66|

Based on the prior probability value of the bottom nodes and the conditional probability of the middle level node, we can calculate probability of ergonomic risk by writing the corresponding MATLAB code. Then we put related parameters of the nodes into bayesian networks, and obtained the posterior probability of each risk event node. Table 3 show posterior probabilities of 1-level ER factors. The order of the probability of 4 types of 1-level risk events is B3> B4> B1> B2. ergonomic factors have more risk than others, which means that much work should be done in fields of eliminating ergonomic unsafe factors.

Table 3. Posterior probability of 1-level factor risk and total risk.

| HMER factor | B1   | B2   | B3   | B4   | HMER  |
|-------------|------|------|------|------|-------|
|             | Y    |      |      |      |       |
|             | 0.6532| 0.3896| 0.7952| 0.7625| 0.6504|
|             | N    |      |      |      |       |
|             | 0.3468| 0.6104| 0.2048| 0.2375| 0.3498|

4. Conclusions
Bayesian networks provides a robust probabilistic method of reasoning with uncertainty and is more suitable to represent reliable basis for construction safety evaluation. In a construction system, safety performance depend on interaction between human, machine, environment and management. In this paper we have demonstrated in principle that BNs can be used for evaluating probability of ergonomic risks. We have also shown how such a model can be used for practice. The model succeeds in building a quantitative tier on top of the qualitative explanations of ergonomic risks. We do believe that such models can become a reliable tool for improving safety management.

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