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Determination of Accident and Injury Probabilities reflecting Causal Relationship between Product Defect, Accident and Injury

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Abstract. This study determines probabilities for a risk assessment based on a Bayesian network that reflects the causal relationship that affects risk, and also presents cases where this method is applied. For risk assessment, product factors, accidents and injuries are used to design the causal network structure, then conclude the probability of each hierarchy and conditional probability.

Keywords: Causal Relationship, Product Defect, Accident, Injury, Risk Assessment.

1 Introduction

In general, product risk is determined by the likely accidents during product usage and the degree of harm posed by such accidents (European Commission, 2010). Product accidents occur based on probabilities caused by product defects or accident-influencing factors. Once an accident occurs, it can cause injury to the body and damages to property. Given this, there is a causal relation between the accident-influencing factors and accidents, as well as between accidents and injuries. To assess product risk, such a causal relation needs to be reflected onto the assessment.

This study determines probabilities for a product risk assessment model using such causal relation and applies it to a case. In particular, the study presents an assessment method based on a Bayesian Network probabilistic model that shows causal relation. The study uses product accident-related information to structure networks with product defect factors and determine product risk based on conditional probability and the severity of injuries.

2 Background

At present various product risk assessment methods are being used for product safety management. EU uses RAPEX to announce weekly investigation data on products including those with severe risk in each country. Applicable products are manufactured products excluding food and drug items and medical devices. The system is used to limit the sale and usage of products that pose severe risk to the

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health and safety of consumers. EU also has an RAG (Risk Assessment Guideline) (European Commission, 2010; Product Safety Enforcement Forum of Europe, 2011).

Japan assess risk using the R-Map method. The R-Map method determines the risk by using a rich data base on accident cases, calculating the severity of the harm and its frequency, and inputting them in a matrix (Ministry of Economy, 2011).

ASEAN (Association of Southeast Asian Nations) legislated RAG in 2011 through the JSC EEE (Joint Sectoral Committee on Electrical and Electronic Equipment) (JSC EEE, 2012). This is based on the AHEEERR (ASEAN Harmonized Electrical and Electronic Equipment Regulatory Regime) legislated in 2005 and consists of a fitness assessment system and risk level determination process for electric and electronic products.

3 Determination of Probabilities

Let the random variable that represents the product defect factor be F_i and set F_i as the factors presented in the safety standards. Product defect factors are selected by referencing the product's harm factors, requirements in the safety criteria and details from the product accident investigation. Product harm factor is already defined as a product characteristics factor (European Commission, 2012).

Now $\mathrm{P}(F_i)$ represents the probability of factor i not meeting safety standards. $\mathrm{P}(F_i)$ is the upper most probability of the network concluded from the data of product safety investigation. If there is insufficient data from safety investigations, they can be estimated from the quality warranty documents of the company where actual accidents are reported.

Let N be the accumulated number of products in operation for that model, and that $\mathrm{N}(F_i)$ represent the number of cases where factor i falls short of safety standards. Then $\mathrm{P}(F_i) = \mathrm{N}(F_i)/\mathrm{N}$ can be used to calculate the product defect probability. However, as in the case with new models, if there are insufficient accident data, product defect probability should be estimated based on the scenarios concluded from product risk analysis.

Now, let A_j be the random variable of accident j, $\mathrm{j} = 1, \dots, \mathrm{J}$ occurring. And let $P(A_j|F_i)$ be the probability of accident j occurring under condition factor i, then the conditional probability $P(A_j|F_i)$ represents the probability of accident j occurring due to product defect factor i. $P(A_j|F_i)$ can be concluded from accident history data. If there is insufficient accident history data, then a subjective estimation must be made by an expert.

When an evaluator is subjectively estimating, the value of product defect factors affecting accidents must be set from very low(1) to very high(5) for input. The input value should be added depending on whether there is a product defect factor for each accident type, the weight for usage environment factor U is multiplied to calculate the Factor Accident Index (FAI).

$\mathrm{P}(\mathrm{A_j}|\mathrm{F_i})$ is calculated as the probability of an accident occurring under FAI and in this paper it is estimated by applying an exponential function. An exponential function is generally used to the probability density function of accident occurrence and can be expressed as in formula (1).

$$f(x) = \begin{matrix} \lambda e^{-\lambda x}, & x \geq 0 \\ 0, & x < 0 \end{matrix}$$

$$F(x) = \int_0^x \lambda e^{-\lambda x}\, dx = 1 - e^{-\lambda x} \quad (1)$$

Through existing case analyses, for a minimum FAI an accident occurrence probability of approximately 20% is assumed. For maximum FAI, a probability of about 70% to set the mediating variable in $f(x)$ as λ=0.05. Therefore, the conditional probability $P(A_j|F_i)$ is calculated as in formula (2), using the accumulated exponential distribution function corresponding to the FAI for each condition. For reference, when λ=0.05 changes in the accident occurrence probability and accumulated exponential distribution in accordance with changes in FAI are shown in Figure 1.

$$P(A_j|F_i) = F(FAI) \quad (2)$$

x	f(x)	F(x)
0	0.05000	0.00000
1	0.04756	0.04877
2	0.04524	0.09516
3	0.04304	0.13929
4	0.04094	0.18127
5	0.03894	0.22120
…	…	…
20	0.01839	0.63212

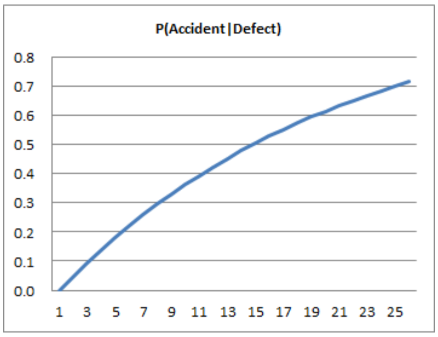

Fig. 1. Changes in the accident occurrence probability and accumulated exponential distribution in accordance with FAI values

The probability of an accident caused by product defect factors is calculated as follows. The occurrence probability of accidents A_j, $j = 1, \ldots, J$ can be calculated as in formula (3).

$$P(A_j) = \sum_{(i \in I)} \sum_{(F_i = T,F)} P(A_j, F_1, \ldots, F_I), j = 1, \ldots, J$$
$$= \sum_{(i \in I)} \sum_{(F_i = T,F)} P(A_j|F_1, \ldots, F_I)\, P(F_1, \ldots, F_I), j = 1, \ldots, J \quad (3)$$

The injury composes the nodes from injuries caused by accidents. Let I_k, $k = 1, \ldots, K$ be the random variable of injury degree k occurring and $P(I_k|A_j)$ be the occurrence probability of injury k occurring under condition j to calculate the injury probability caused by an accident. $P(I_k|A_j)$ uses the value calculated from accident-related data. If there is no accident history data, an expert's subjective estimation is used as in the accident hierarchy. That is, the value for the injury effect scale which is the degree of accidents affecting the occurrence of an injury, is input from very low (1) to very high (5). The input value becomes the injury occurrence likelihood score. Using this score, the Accident Injury Index (AII) is calculated. AII is a concept that corresponds the score of the likelihood of an injury occurring to the injury occurrence probability. It is presumed to correspond linearly to the score for the likelihood of injury occurrence. It is set to have very low to be 0.1, medium to be 0.5, and very high to be 0.9. Next, for each injury, the AII value is used to calculate conditional probability for accident occurrence $P(I_k|A_j)$.

Now, let's assume the AII of accident A_j causing injury I_k be A_{kj}, $j = 1, \ldots, J$, $k = 1, \ldots, K$. then the conditional probability of injury occurring I_k against total accidents, which is $P(I_k|A)$ can be calculated as in formula (4).

$$
\begin{aligned}
P(I_k|A) &= \sum_{j \in True} P(I_k|A_j), \forall k = 1, \ldots, K \\
&= \sum_{j \in True} P(I_k|A_j) \sum_{p=1}^{j-1} A\, I_{(j-p)k} + \sum_{p=1}^{j-2} \sum_{q=1}^{j-p-1} AI_{(j-p)}\, AI_{(j-q)} \\
&\quad - \prod_{r=1}^{j-1} AI_{(j-r)})\, AI_{jk}, \forall k = 1, \ldots, K
\end{aligned}
\tag{4}
$$

For example, the conditional probability of accident A_1, A_2, A_3 causing injury I_k which is conditional probability $P(I_k|A)$ is as seen in formula (5). That is, using each occurrence of accident as an independent axis, corresponding AII values to the probability of injury occurrence are made so that their sum becomes 1 within the entire space.

$$
\begin{aligned}
P(I_k|A)_{j \in \{1,2,3\}} &= \sum_{j=1}^{3} P(I_k|A) \\
&= AI_{1k} + (1 - AI_{1k})AI_{2k} + (1 - AI_{1k} - (1 - AI_{1k})\, AI_{2k})\, AI_{3k} \\
&= AI_{1k} + (1 - AI_{1k})AI_{2k} + (1 - AI_{1k} - AI_{2k} + AI_{1k}AI_{2k})\, AI_{3k}
\end{aligned}
\tag{5}
$$

Then the probability for injury I_k, $k = 1, \ldots, K$ in the injury hierarchy which is $P(I_k)$ can be calculated as in formula (6).

$$
\begin{aligned}
P(I_k) &= \sum_{(j \in J)} \sum_{(A_j = T,F)} P(A_1, \ldots, A_J),\ k = 1, \ldots, K \\
&= \textstyle\sum_{(j \in J)} \sum_{(A_j = T,F)} P(I_k|A_1, \ldots, A_J)\, P(A_1, \ldots, A_J), k = 1, \ldots, K
\end{aligned}
\tag{6}
$$

4 Product Risk

Based on the probability and severity of injuries that may occur during the usage of a product, the product's risk is determined. Assume that due to accident A_j , injury I_k occurred. And assume the severity of injury I_k is $S(I_k)$. Then in the PI (Probability and Impact) matrix in Figure 2, the risk corresponding to $P(I_k)$ and $S(I_k)$ which is (J_k), $j = 1, \dots, J$, $k = 1, \dots, K$ can be calculated.

The severity of injury is categorized into five grades of none, negligible, marginal, serious and fatal. All types of injuries such as contusions, lacerations, fractures, suffocation and many others that affect the human body are all included in the term injury.

8	>0.5	A	M	S	S	S
7	>0.1	A	L	S	S	S
6	>0.01	A	L	S	S	S
5	>0.001	A	A	M	S	S
4	>0.0001	A	A	L	M	S
3	>0.00001	A	A	A	L	M
2	>0.000001	A	A	A	A	L
1	<0.000001	A	A	A	A	A
Injury probability		none	negligible	marginal	serious	fatal
	Injury severity	0	I	II	III	IV

Fig. 2. Probabiliy Impact Matrix for risk assessment

Final product risk is determined as the maximum risk that appears on the PI matrix based on injury probability and injury severity (Formula (7)). If there are multiple injuries for product categories, the injury risk with the largest value is determined as the final risk.

$$Risk = Max_{j=1,\dots,J} Max_{k=1,\dots,K} (R_{jk}) \tag{7}$$

5 Conclusion

This study designed a causal network structure and determined probabilities for product risk assessment that reflects causal relation that may affect product risk. Network structure consists of the factor hierarchy, accident hierarchy, injury hierarchy and result hierarchy. Using quality assurance data and accident history records, the network structure of each hierarchy is designed and the hierarchy probability and conditional probability are concluded. The factor hierarchy consists of product defect factors and usage environment factors, while product defect factors were set based on safety standards. Usage environment factors consist of user, usage time and usage venue. Finally, based on the probability of injury and severity of injury, PI matrix was referenced to determine risk.

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