A Fuzzy Set Approach for Assessing the Cost-effectiveness of a Safety Improvement Project

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ABSTRACT

Though there have been reports on the cost or benefit impacts of safety improvement projects, few studies have provided detailed information on the exact costs and benefits. This fact implies that a lot of difficulties still need to be overcome in assessing the exact costs and benefits for safety improvement projects in the workplace. Furthermore, some safety improvement projects might result in invisible or less-tangible benefits, which are hard to translate into crisp economic values. Establishing a fuzzy cost-effectiveness assessment methodology is therefore investigated in this study to quantify the economic worth of a safety project. Firstly, the possible costs and benefits associated with a safety improvement project are identified and classified. The contingent valuation method (CVM) is fuzzified by applying the fuzzy Delphi method to collect the less-tangible benefits represented by several linguistic terms. Finally, the fuzzy-valued return-on-investment (FROI) of the safety improvement project can be obtained. A real case is adopted for demonstrating the practicability of the proposed methodology.

Key words: safety improvement, cost-effectiveness, contingent valuation method, fuzzy Delphi method.

1. INTRODUCTION

Many enterprises have conducted numerous industrial safety projects, but have not analyzed the cost-effectiveness. This is due to some difficulties that still needed to be overcome in assessing the costs and benefits of a safety improvement project. On one hand, a safety engineer might not have enough knowledge and ability to analyze the cost-effectiveness of safety improvement projects. On the other hand, it remains very difficult to assess the monetary value of the less-tangible benefits associated with safety improvement in the factory. The less-tangible benefits include the enhancement of safety in the workplace or the decrease in work-related risk factors imposed upon the workers. These less-tangible benefits cannot be bought or sold in the marketplace, and therefore are considered as ‘non-market goods.’ Non-market goods cannot be easily presented in terms of crisp monetary values. However, an employer always wants to know whether or not a safety improvement project is a good value for money. This research was thus aimed at proposing a methodology for solving the above-mentioned problems.

Measuring the costs of safety improvement projects is usually easier than measuring the benefits because a lot of cost estimation methods have been suggested (Miller, 1995; Miller, 1997; Cagno, Caron, & Mancini, 2000). In addition, the necessary accounting data associated with the costs of safety

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improvement projects often are readily available within the manufacturing companies.

Many of the benefits of safety improvement projects, such as the increase of monthly outputs, the savings with reduced injury loss, and the savings with reduced asset loss, can be determined by collecting accounting data associated with related operations and accidents (Chhokar et al., 2005). However, it might take several years after the execution of safety improvement actions to completely perceive the benefits resulting from a safety improvement project. Furthermore, some benefits of safety projects are invisible or less tangible, as mentioned previously. These are much harder to quantify in specific currency amounts but should be recognized. Two of the less-tangible benefits particularly worth noting are increased employee commitment and improved corporate image, as suggested by Hendrick (2003). No method was provided in Hendrick’s study to quantify the less-tangible benefits in financial terms.

Fortunately, non-market goods have recently been valued with the contingent valuation method (CVM). The CVM was developed in the environmental field to assess the value of public goods such as environmental quality and natural resources (Cummings, Brookshire, & Schulze, 1986; Mitchell & Carson, 1989; Carson, 1991). This method was later also applied to value the changes in healthcare or safety condition (Johansson & Jonsson, 1991; Eckerlund, Johannesson, Johansson, Tambour, & Zethraeus, 1995; Choi, Lee, & Lee, 2001; Hanley, Ryan, & Wright, 2003). The CVM usually adopts surveys to find out the respondents’ willingness-to-pay (WTP) for improvements on specific conditions. The WTP survey is an appropriate measure in a situation where people want to acquire non-market goods (Choi et al., 2001).

Since the less-tangible benefits derived from a safety improvement project also have the characteristics of non-market goods, the application of the CVM is considered suitable for determining the economic value of the less-tangible benefits. For this reason, the CVM is applied to determine the monetary value of the less-tangible benefits in this study. However, it is difficult for the employees to express their WTP in crisp values. Therefore, WTP has to be fuzzified, and some linguistic terms can be provided for the employees to choose from. Subsequently, the fuzzy Delphi method is applied to aggregate the fuzzy WTPs. Finally, a formula is proposed to calculate the fuzzy-valued return-on-investment (FROI) of the safety improvement project. A practical case in a semiconductor fabrication plant is adopted to illustrate the viability of the proposed methodology.

2. METHODOLOGY

The first step of the cost-effectiveness analysis is to collect all cost data associated with the safety improvement project. Section 2.1 provides the descriptions of the five possible cost categories. After the safety improvement actions, all benefits resulting from the safety improvement project should be
assessed. Six possible benefit categories are listed and explained later in Section 2.2. If there are any less-tangible benefits derived from the improvement actions, the WTP questionnaire should be designed and used to evaluate the monetary value of the less-tangible benefits. A detailed guide for designing the WTP questionnaire is provided in Section 2.3. A systematic procedure based on the fuzzy Delphi method is proposed in Section 2.4 to obtain the fuzzy-valued WTP (FWTP). After obtaining the monetary values of the costs and benefits, both are used in analyzing the cost-effectiveness with the traditional business case model, as described in Section 2.5.

2.1 Cost Categories

The possible investment costs in conducting safety improvement projects in the workplace can be classified into five categories, which have been derived from a previous study (Wu, Chen, & Chen, 2006), as described below:

1. Risk identification fees: The expenditure on identifying the work-related risk factors in the workplace and on studying their impacts on the workers are included in risk identification fees.
2. Research and design fees: After risk identification, it is required to research and design improvement actions that will eliminate or reduce the work-related risk factors. All the activity costs incurred during researching and designing improvement actions are considered as research and design fees.
3. Administrative improvement costs: Administrative improvement means making changes in management systems, work processes, standard operation procedures, or other regulations in order to prevent workers from exposure to the work-related risk factors. These changes might also be accompanied with employee down time. All the costs resulting from the administrative improvement activities belong to the administrative improvement costs.
4. Hardware improvement costs: Hardware improvement costs include any capital investment in construction, equipments, tools, and other physical assets to eliminate or reduce the work-related risk factors. This kind of improvement might also be accompanied with employee down time. All the costs resulting from the hardware improvement activities are included in the hardware improvement costs.
5. Monthly overheads: Monthly overheads imply the monthly operating costs associated with maintenance following the improvement actions. The reduced productivity or sales derived from the improvement actions should also be considered as overheads.

2.2 Benefits Categories

The possible benefits after performing safety improvement projects in the workplace can be classified into six categories, which were derived from a previous study (Wu et al, 2006), as follows:
1. Increase of monthly outputs: Improved productivity resulting from the improvement actions brings about an increase in monthly outputs. The increase in outputs can be calculated as the increased quantity of the product per month multiplied by its gross margin.

2. Saving of monthly working time: The safety project might make the workers more efficient, which leads to the saving of working time. A time and motion study should be employed to confirm how much time is saved. The saving of working time can be calculated as the working hours saved per month multiplied by the corresponding average wage rate.

3. Saving of monthly operation costs: The operation costs might be reduced after the safety improvement actions. The saving of monthly operation costs can be determined by collecting the accounting data for several months.

4. Saving due to reduced injury loss (per month): The safety improvement actions might reduce accidents. If the improvements lead to fewer injury cases than before, then the saving due to reduced injury loss should be considered as a benefit.

5. Saving due to reduced asset loss (per month): In addition to injury loss, accidents are usually accompanied with asset loss such as work-in-process damage, materials damage, product damage, factory rebuilding or repair, equipment purchase or repair, and facility purchase or repair. If the safety improvement leads to fewer accidents than before, the saving due to reduced asset loss should be considered as a benefit.

6. Less tangible benefits (per year): Some benefits resulting from the safety project could not be included in the accounting system. These benefits are called less-tangible benefits, such as the reduction in health-related risk factors imposed upon the workers, increased employee commitment, and improved corporate image. The monetary values of these benefits can be estimated with the WTP questionnaire.

2.3 WTP Questionnaire Design

The less-tangible benefit evaluation questionnaire or the WTP questionnaire is aimed at collecting the workers’ willingness-to-pay for the improvement actions of a safety improvement project. In order to make each respondent understand the project, the first part of the WTP questionnaire summarizes what changes will take place after executing the project.

The second part of the WTP questionnaire comprises questions about the WTP for the less-tangible benefits accompanying the executed safety project. The mean WTP value of the sampled workers can be an estimator of the population mean, if the sample size is large enough.

2.4 Obtaining FWTP by the Fuzzy Delphi Method

In the traditional CVM approach, a WTP is given in crisp values, which is difficult if the target is very vague or the attitude of the employee is uncertain. Both
conditions might happen in assessing the cost-effectiveness of a safety improvement project. To tackle this problem, the fuzzy Delphi method is applied. The traditional Delphi method is one of the effective methods which enable forecasting by converging a possibility value through the feedback mechanism of the results of questionnaires, based on experts’ judgments (Cheng, Tsujimura, Gen, & Tozawa, 1995). For estimating a reliable WTP, the fuzzified Delphi method can be effectively used. The procedure is described as follows.

1. Request some representative employees to give their FWTPs in triangular fuzzy numbers \((a^{(i)}, b^{(i)}, c^{(i)})\), where \(i\) indicates the index attached to the representative employee and 1 indicates that this is the first phase of the evaluation process.

2. These responses from \(n\) representative employees form a sheaf \((a^{(i)}, b^{(i)}, c^{(i)})\), \(i = 1, 2, \ldots, n\). The mean of this TFN sheaf is then computed as \((a^{m}, b^{m}, c^{m})\).

3. For each representative employee, the divergence is computed as \((a^{m} - a^{(i)}), b^{m} - b^{(i)}, c^{m} - c^{(i)})\). This information is then sent to each individual representative employee.

4. Each representative employee now gives a new TFN \((a^{(i)}, b^{(i)}, c^{(i)})\) and the process, starting with phase 2, is repeated as in Step 2.

5. When the mean TFN becomes sufficiently stable, the process is stopped.

If the mean TFN that satisfies a given convergence criterion is found, this process is completed and the corresponding mean TFN becomes the FWTP estimate. The dissemblance index which exists between two fuzzy numbers (Kaufmann & Gupta, 1988) can be used as a criterion for the stable solution. Define the intervals of the confidence at presumption level \(\alpha\) of two fuzzy numbers \(\tilde{P}\) and \(\tilde{Q}\) as \(P_{\alpha} = [p_{L}^{(\alpha)}, p_{U}^{(\alpha)}]\) and \(Q_{\alpha} = [q_{L}^{(\alpha)}, q_{U}^{(\alpha)}]\), where \(p_{L}^{(\alpha)}\) and \(q_{L}^{(\alpha)}\) are their respective lower boundaries and \(p_{U}^{(\alpha)}\) and \(q_{U}^{(\alpha)}\) are their respective upper boundaries. The distance between \(\tilde{P}\) and \(\tilde{Q}\) is given by

\[
\delta(\tilde{P}, \tilde{Q}) = \int_{0}^{1} \delta(P_{\alpha}, Q_{\alpha}) d\alpha
= \frac{1}{2} (\beta_{2} - \beta_{1}) \int_{0}^{1} (|p_{L}^{(\alpha)} - q_{L}^{(\alpha)}| + |p_{U}^{(\alpha)} - q_{U}^{(\alpha)}|) d\alpha,
\]  (1)

where \(0 \leq \delta(\tilde{P}, \tilde{Q}) \leq 1\); \(\beta_{1}\) and \(\beta_{2}\) are given any convenient values in order to surround both \(P_{\alpha = 0}\) and \(Q_{\alpha = 0}\). It is also called the dissemblance index of \(\tilde{P}\) and \(\tilde{Q}\).

2.5 Obtaining FROI

The total cost (indicated with \(C\)) was defined as the initial investment of the safety improvement project. Assume that there are no other investment costs at the end of each year during the service life of the safety improvement project. The service life of the project (indicated with \(n\)) should be estimated first. The benefit every year (indicated with \(\tilde{B}_{t}\)) is suggested to happen at the end of the \(t\)-th year.
Therefore, the total benefit should be converted into the present value according to some given interest rate or discount rate (indicated with \( i \)). \( \tilde{B}_t \) is a fuzzy value because of the inclusion of FWTP. Then, the fuzzy net present worth (FNPW), \( \tilde{P} \), of the safety improvement project can be calculated using equation (2):

\[
\tilde{P} = \sum_{i=1}^{n} \frac{\tilde{B}_t}{(1+i)^t} - C .
\]  

(2)

The FROI of the project, \( \tilde{R} \), can be easily calculated by dividing \( \tilde{P} \) by \( C \), as shown in equation (3):

\[
\tilde{R} = \frac{\tilde{P}}{C} \cdot 100\% .
\]  

(3)

3. A PRACTICAL EXAMPLE

A practical safety improvement project was taken as an example for evaluating the practicability of the proposed methodology. The work-related risk factors in a 200-mm wafer fabrication in Taiwan were identified (Wu et al., 2006). These risk factors included unsuitable postures in manual material handling and very high load port of the process tools (Figure 1). The improvement actions of that project comprised delivering lectures about standard postures for handling wafers and reducing the height of the load port of the process tools. The purpose of the lectures was aimed at training operators to handle wafers with proper postures. The mechanism of the low position transportation arm was used to automatically reduce the height of the load port while loading/unloading a wafer batch. All these improvements were expected to reduce work fatigue and to enhance work safety for the wafer-handling workers.

![Figure 1. An example of improvement made in the safety project.](image)
3.1 Collecting the Costs

The costs of the above-mentioned project were collected from the historic accounting documents in that company. The main cost items of this project were outside consultant fees and equipment purchase. The total initial investment cost \( (C) \) was TWD 151,000,000. The service life of the project was estimated as 13 years.

3.2 Performing the WTP Survey

The less tangible benefits were evaluated with the WTP questionnaire. This questionnaire was designed for collecting operators’ willing-to-pay for the improvement actions in the project mentioned above. The payment card approach of CVM was adopted to elicit the operators’ subjective worth to reducing work fatigue and enhancing work safety after improvement. The questionnaire comprised three parts: the first part states the improvement actions conducted in the project, the second one asks about the WTP for the improvement, and the third one comprise questions about the socio-economic background of the workers. These questions were designed to collect the age, years of occupation, and monthly income of the respondent.

For the WTP questionnaire survey, 719 effective responses were obtained from 1000 operators in the wafer manufacturing factory. Eventually, the total amount of the operators’ FWTPs per year could be considered as the benefit at the end of each year during the service life of the project. The total amount of all workers’ FWTPs every year for reducing work fatigue could be estimated as \((22,710,792, 31,542,767, 35,643,326)\) TWD, which is a TFN, while the estimated total amount of all workers’ FWTPs every year for enhancing work safety was \((30,124,061, 35,027,978, 38,881,055)\) TWD, also a TFN. The fluctuation in the average FWTP for reducing work fatigue during the aggregation process is demonstrated in Figure 2. Note that the average FWTP converged to a constant value. The fluctuation in the dissemblance index of two successive values of the average FWTP is shown in Figure 3 \((\beta_2 - \beta_1 = 2)\). The convergence condition has been established as the dissemblance index < 1000.

![Figure 2](image_url)  
*Figure 2. Fluctuation in the average FWTP during the aggregation process.*
3.3 Determining the Benefits

Since there were no significant changes in the outputs, working time, operation cost, injury and assets loss by accidents before and after improvement, these benefit categories were assigned zero values. For the less tangible benefits, the estimated benefit per year were (52,834,853, 66,570,745, 74,524,381) TWD, which was the summation of the FWTPs for reducing work fatigue and for enhancing work safety.

3.4 FROI Calculation and Discussions

The discount rate was set to be 4% and the service life was 13 years. The FNPW of this project could be calculated as follows:

\[
\tilde{P} = \sum_{i=1}^{13} \frac{(52,834,853, 66570745, 74,524,381)}{(1+4\%)^i} - 151,000,000
\]

\[
= (376,462,837, 513,752,017, 593,174,225).
\]

Then, the FROI could be obtained as \((376,462,837, 513,752,017, 593,174,225) / 151,000,000 \times 100% = (249\%, 340\%, 393\%)\). The high FROI of this project demonstrated good economic efficacy for the safety improvement actions. But, it should be noted that the less-tangible benefits derived from the WTP responses are not actual economic benefits unless the workers really pay the money. In general real cases, the employers usually just want to understand whether the performed safety project is worth investing, instead of getting the money paid by the employees.

The proposed methodology requires comparing accident and injury information between the pre- and post-improvement periods. Unfortunately, most of the companies in Taiwan collect little information about accident and injury losses. Few compensation costs and days lost were reported and filed, consequently,
these data were not adequate to assess the real economic values resulting from safety improvement actions.

This study provided a time-saving and easy method to assess the economic benefits of less tangible benefits resulting from a safety improvement project. In the demonstrative example, only one month was required to conduct the WTP survey after the improvement actions. In addition, the FROI of the project can also be calculated easily. The estimated FROI can be also considered as an important index to support/criticize the cost-effectiveness of the executed project. The FROI could be defuzzified if necessary. For example, it can be defuzzified according to the centroid-of-area (COA) formula:

\[
D(\text{FROI}) = \frac{(249\% + 340\% \times 2 + 393\%)}{4} = 331\%.
\]

Nevertheless, a fuzzy-valued ROI preserves flexibility in judging the effectiveness of the project.

4. CONCLUSION

A fuzzy cost-effectiveness assessment methodology is proposed in this study to quantify the economic worth of a safety improvement project. Firstly, the possible costs and benefits associated with a safety improvement project should be collected. Then the CVM method is fuzzified by applying the fuzzy Delphi method to collect the less-tangible benefits represented by several linguistic terms. Finally, the FROI of the safety improvement project can be obtained. A real case is adopted to demonstrate the practicability of the proposed methodology. The proposed cost-effectiveness assessment methodology can not only be used to quantify the less-tangible benefits but can also be applied to judge the effectiveness of a safety improvement project. The FROI of the illustrative practical project was estimated to be 249\%\textasciitilde393\%, which demonstrated good economic efficacy for the safety improvement. The estimated FROI can be considered as an important index to support/criticize the economic value of the safety improvement project, and it is also helpful information for making safety investment decision in the future.

However, it would be hard to accurately assess the cost-effectiveness of a safety improvement project if the cost and benefit information has not been completely collected during the project. Moreover, the statement of the WTP questionnaire should be carefully and clearly described in order to prevent misunderstanding.

REFERENCES


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