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An integrated quality function deployment and capital budgeting methodology for occupational safety and health as a systems thinking approach: The case of the construction industry

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ABSTRACT

In this paper, an integrated methodology for Quality Function Deployment (QFD) and a 0–1 knapsack model is proposed for occupational safety and health as a systems thinking approach. The House of Quality (HoQ) in QFD methodology is a systematic tool to consider the inter-relationships between two factors. In this paper, three HoQs are used to consider the interrelationships between tasks and hazards, hazards and events, and events and preventive/protective measures. The final priority weights of events are defined by considering their project-specific preliminary weights, probability of occurrence, and effects on the victim and the company. The priority weights of the preventive/protective measures obtained in the last HoQ are fed into a 0–1 knapsack model for the investment decision. Then, the selected preventive/protective measures can be adapted to the task design. The proposed step-by-step methodology can be applied to any stage of a project to design the workplace for occupational safety and health, and continuous improvement for safety is endorsed by the closed loop characteristic of the integrated methodology.

1. Introduction

Although there are several definitions for a system, one definition is that “a system is a set of interacting units or elements that form an integrated whole intended to perform some function” (Skyttner, 2005; Larsson et al., 2010). Systems thinking is the study of closed loop interactions among the elements of a system (Goh et al., 2010). Safety in general, and occupational safety in particular, has been attributed to the system, and should be considered in a holistic manner. Several causal accident models have been defined in the literature, and systems thinking has been generally used to explore the causality of a lack of safety in these systems (Goh et al., 2010; Larsson et al., 2010; Leveson, 2011).

In this paper, we propose a systems thinking approach for safety by tracing the relationships between tasks performed by a worker, the hazard inherent while performing the task, the events that can arise from the hazard, and finally the preventive/protective measures that serve as feedback to the task design such that a closed loop is obtained for continuous review of the interactions and continuous improvement of the system. The proposed approach does not intend to create a direct causal loop diagram, but to show how specific tasks can relate to specific hazards, which in turn relate to specific events, and finally what preventive/protective measures can be introduced against the events, so that tasks can be performed in a safer environment with the selected preventive/protective measures. For illustration of the pairwise relationships between the aforementioned parameters, the HoQ tool of QFD methodology is proposed to be used, and the most effective preventive/protective measures found in the last HoQ are evaluated by capital budgeting methodology. Then, the tasks can be performed in an environment with the preventive/protective measures selected using capital budgeting methodology. The systems thinking approach proposed in this paper can guide a more careful selection of tasks as a result of tracing the inter-relationships among the parameters, such that the tasks with a high probability of leading to events that cause damage to people and the company may even be omitted or a task design supported by preventive/protective measures can be performed in a safer environment. Moreover, the proposed methodology is extended to involve different players in the whole system in a country, where the feedback from different companies is reflected in country-wide databases for different industries.

QFD is a systematic technique to translate customer needs (CN) into the technical characteristics (TC) of a product or service. QFD methodology has been applied in different functional fields, such as product development, quality management, customer needs analysis, product design, planning, concurrent engineering, decision making, management, team work, timing, and costing, and in different industries, such as transportation and communication, electronics and electrical utilities, software systems, manufacturing, services, education and research, and construction (Chan and

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Table 1
Literature review of QFD in safety.

Reference	Sector	Uncertainty consideration/Method	HoQ	Integration with other methods	Application
Moores (2006)	Healthcare-Diagnostic with radiology	No	HoQ: Between radiation safety requirements by customers and technical/service requirements	No	Application with experts
Liu and Tsai (2012)	Construction	Yes/Fuzzy risk assessment	HoQ_1: Between construction items and hazard types; HoQ_2: Between hazard types and hazard causes	Analytic Network Process (ANP) for calculating the weights, Failure Mode and Effect Analysis (FMEA) for calculating the risk priority number	Empirical case
Braglia et al. (2007)	No specific sector	No	HoQ_1: Between severity and causes of failure; HoQ_2: Between causes of failure and engineering solutions	FMEA, cost analysis	Case study taken from the literature

Wu, 2002). Some papers have illustrated the applicability of QFD methodology in the construction industry. Abdul-Rahman et al. (1999) analyzed a low-cost housing project using QFD with respect to reliability, cost, and delivery. Abdul-Rahman et al. (1999) developed a concurrent engineering methodology for designing/building projects as an extension of the so-called Design Function Deployment (DFD) methodology. Armacost et al. (1994) used QFD to integrate the customer requirements for a manufactured exterior structural wall panel in an industrialized housing project. Cariaga et al. (2007) used QFD as a part of value analysis for evaluating design alternatives in the construction industry. Dikmen et al. (2005) proposed to adapt the methodology to marketing strategy of a construction company for a large housing complex project, and evaluated the results for long-term strategic decisions. Eldin and Hikle (2003) implemented QFD for the conceptual design of a large classroom for college students. Huovila and Seren (1998) applied QFD as a part of a concurrent engineering practice for rapid construction projects. Kamara et al. (1999, 2000), and Kamara and Anumba (2000) proposed a client requirements processing model in the construction industry as a part of the so-called concurrent life-cycle design. Lee and Arditi (2006) proposed to evaluate the total quality performance of design/build firms using QFD methodology. Mallon and Mulligan (1993) addressed the relationship of QFD with other quality tools, such as total quality management, and illustrated the applicability of QFD for a renovation project for a hypothetical personal computer workroom facility. Pheng and Yeap (2001) analyzed the benefits and applicability of QFD methodology in design/build projects. Syed et al. (2003) adapted QFD for civil engineering capital project planning.

The integration of QFD with other techniques, such as linear programming, has also appeared in the literature (Karsak, 2004; Lin et al., 2008; Yamashina et al., 2002; Park and Kim, 1998; Halog et al., 2001; Kahraman et al., 2006). However, the application of QFD in safety science has been relatively rare.

In this paper, we propose an integrated QFD methodology, and a scheduling and capital budgeting methodology to systematically prepare an action plan for occupational safety and health, and apply the proposed methodology to a hypothetical construction project. We believe that QFD is appropriate for safety management because it is possible to assign weighted importance scores to risks in a step-by-step manner starting from the tasks performed by considering the relationship of each parameter with other parameters, so that the parameters, for example, the hazards, that are more frequently related to other parameters, for example, tasks, will be assigned more weight. The QFD part of the methodology includes three HoQs. In HoQ_1, the tasks and hazards are inter-related; in HoQ_2, the hazards and events are interrelated; and in HoQ_3, the events and preventive/protective measures are inter-related. In HoQ_3, the final priority weights of events are obtained by considering their preliminary priority weights obtained from HoQ_2, the probability of occurrence, physical effects on the victim, and economic effects on the company. Finally, the priority weights of preventive/protective measures obtained from HoQ_3 are evaluated using a scheduling and capital budgeting methodology for the investment of preventive/protective measures. Because occupational safety and health is a national issue, a group-based methodology is also proposed to incorporate different views into the methodology and statistical information.

The paper is organized in the following manner. In Section 2, a literature review of QFD in safety is given. In Section 3, the details of the integrated methodology for the three-step HoQ and 0–1 knapsack model are given. In Section 4, the proposed integrated methodology is applied to a hypothetical construction project, and in Section 5, the methodology is applied to a hypothetical application in a Small and Medium Enterprise (SME). In Section 6, the limitations of the methodology are discussed briefly, and a dynamic group-based fuzzy QFD methodology is proposed. Finally, in Section 7, conclusions and potentials for future research are discussed.

2. Literature review of QFD in safety and reliability

Table 1 provides the papers that apply QFD in safety and reliability.

As illustrated in Table 1, QFD application in safety and reliability has been relatively limited. Braglia et al. (2007) proposed a QFD approach to reliability by tracing the relationship between the severity and causes of failure in one HoQ, and the relationship between causes of failure and engineering solutions in another HoQ. In the first HoQ, they determined a severity score, and multiplied the score by the probability and non-detectability to calculate the Risk Priority Number (RPN). As a result of the second HoQ, they also performed a cost analysis. Although the approach proposed in this paper is similar to the approach by Braglia et al. (2007), the approach in this paper uses a more detailed risk assessment and capital budgeting analysis.

3. The integrated methodology of the three-step HoQ and 0–1 knapsack model

The integrated methodology for the three-step HoQ and 0–1 knapsack model is outlined in Fig. 1. The basic assumption of the methodology is that there is an additive and linear relationship between the task and hazards, hazards and events, and events and preventive/protective measures. For example, the importance of hazard is determined by the weighted average of the relationship scores with each task, where the weights are the importance weights of the tasks. The methodology is based on QFD

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