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DETERMINATION OF CUSTOMER REQUIREMENT FOR WELDING FUMES INDEX DEVELOPMENT IN AUTOMOTIVE INDUSTRIES BY USING QFD APPROACH

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ABSTRACT

This paper discussed on the determination of customer requirement for the development of a welding fumes index by using Quality Function Deployment (QFD) approach. Welding fumes index is developed with the objective to enhance the welding workplace safety and health. Index simplifies complex health-hazard issues of welding fumes to be comprehended easily by the employees and administration. Likert scale questionnaires on the welder desire to know the various welding fumes health effects that exist in their workplace were distributed among welders of an automotive assembly industry in the state of Pahang, Malaysia. A pilot test of the QFD questionnaire were done (n=11) and Cronbach Alpha's analysis is 0.967 which indicates a high level of internal consistency of the questionnaire scale. In the actual sampling (n=32), the results of the questionnaires show that all the customer requirements (irritant effect, sensitiser effects, respiratory system effect, systemic toxin effect, reproductive toxins effect, carcinogen effect, mixture effect) were equally important to the welders. The relationship between the customer (welder) requirement and technical characteristic were established whereby important technical characteristics were shortlisted (personal sampling 23.0%, multi chemical analysis 20.8%, exposure limit 19.7%, health questionnaire 17.6% and lung function test 14.7%). Development of welding fumes indices according to employees demand will increase the knowledge and awareness on occupational safety and health among employees (welders).

***Keywords*: Welding fumes; welding health effect; Quality Function Deployment (QFD).**

INTRODUCTION

Hundreds of millions of people throughout the world are working under circumstances that foster ill health or unsafe. It is estimated that yearly over two million people worldwide die of occupational injuries and work-related diseases. In fact more people die from diseases caused by work than are killed in industrial accidents (Hassim and Hurme, 2010). There are two main acts in Malaysia for occupational and safety; the Factories and Machinery Act (Act 139) (Malaysia, 2010a) and the Malaysian Occupational Safety and Health Act (Act 514) (Malaysia, 2010b). Department of Occupational Safety and Health (DOSH) is the only government agency responsible for administrating, managing and enforcing legislation pertaining occupational safety and health in Malaysia.

An effective approach to health and safety at work needs a suitable risk assessment phase. However, less attention has been paid in this phase of the practice, using non appropriate tools and methodologies which are either too complex to manage or too simple and subjective, thus not suitable for recognizing hazards and reduce the corresponding risks (Fera and Macchiaroli, 2010). Difficulty exists in measuring the two quantities in which risk assessment is concerned with which is the potential loss and the probability of occurrence. The chance of error in measuring these two quantities is large. Risk with a large potential loss and a low probability of occurring is often treated differently from one with a low potential loss and a high likelihood of occurring. In theory, both are of nearly equal priority, but in practice it can be very difficult to manage. A risk assessment would be simpler if transform into a single metric which could embody all of the important information (Kirch, 2008). Thus, transformation of risk assessment into an environmental index form would be the best alternative solution.

Although there is a wide breadth of hazards that exist in welding operations, only 2% of Occupational Safety and Health Association (OSHA) general industry citations addressing on this matter (Asfahl, 2004). Welding is a common industrial process. A hazard that has both acute and long-term chronic effects is welding fume/ particulate matters. Fumes are solid particles that originate from welding consumables, the base metal and any coatings present on the base metal. In welding, the intense heat of the arc or flame vaporizes the base metal and/or electrode coating. This vaporized metal condenses into tiny particles called fumes that can be inhaled. The thermal effects can cause agglomeration of the particles into particle chains and clusters that can be deposited in the human respiratory tract (Ashby, 2002, Fiore, 2006, Ravert, 2006). Most of the particles in welding fumes are less than 1µm in diameter when produced, but they appear to grow in size with time due to agglomeration (Isaxon et al., 2009).

LITERATURE REVIEW

Occupational Safety and Health in Malaysia

Malaysia is a developing nation and the manufacturing sector is the major contributor to the Malaysian economy with the number of 1,023,072 people engaged in the manufacturing sector in November 2012 (Department of Statistic, 2013). Welding is a common industrial process in the manufacturing sector that has both acute and long term chronic hazards mainly from the inhalable welding fumes. Currently in Malaysia, according to Occupational Safety and Health Act (1994), Under the Use and Standard of Exposure of Chemical Hazardous to Health (USECHH), chemical health risk assessment (CHRA) need to be carried out by an assessor appointed by the employer (Malaysia, 2000). A chemical health risk assessment report is produced by the assessor which includes potential risk, nature of hazard to health, method and procedure in the use of chemical, degree of exposure and control measures. Chemical health risk assessment in welding workplace is essential in order to ensure the minimum level of exposure is maintained as required by the prevailing standards. However, the important information provided by the assessor especially the degree of exposure has usually been kept by safety and health officer and company management. In terms of health effects, the employees should be notified on the degree of exposure in their workplace. A good safety and health practise can be improved if the chemical exposure were well understood by the employees. Thus, there is an urgent need to develop an index as a ranking tool to simplify complex health-hazard issues of welding fumes to be comprehended easily by the employees.

Occupational Safety and Health Assessment

Occupational safety and health assessment in exposure of chemical hazardous to health had attracted attention of the researchers all over the world. However, assessment related to human health aspects is very limited. The employees are the most affected personal by exposure of chemical hazardous to health. However, in general, risk is evaluated in terms of its consequences with respect to project performance and rarely in terms of human suffering (Badri et al., 2011). Smallwood (2004) confirmed that quality, planning and costs are the parameters given the greatest consideration. Instead of developing a risk assessment method focused on project performance, planning and cost, this study will try using a new and different approach by focusing on human health aspect. This study highlight that employees should know what type of health risk they faced. By using the QFD approach, this study will ask the employees what health risk should the index portray based on Niosh Pocket Guide of Hazardous Health Effect (NIOSH, 2010). Development of welding fumes indices according to employees demand hopefully will increase the knowledge and awareness on occupational safety and health among employees.

In welding processes, there is a very limited risk assessment model that had been developed. Karkoszka and Sokovic (2012) developed the integrated risk estimation in welding process using qualitative methods of assigning probability of occurrence, significance and risk involve in aspect of occupational and safety. However, this model did not consider the quantitative data on chemical exposure. Thus, there is still gap in developing a suitable risk assessment method relating welding fume exposure with health risk of welder in quantitative manners.

NIOSH (1998a) had highlighted research needs to pursue a means of indexing exposure by job type or process by taking into account the intensity of the welding job and work practices. However, welders are not a homogeneous group, the potential adverse effect of welding fume exposures are oftentimes difficult to evaluate. Differences exist in wader populations, such as industrial setting, types of ventilation, type of welding processes and materials used (Antonini et al., 2006). Indexing exposure by job type or process is almost impossible to implement. However, indexing exposure according to the location would be benefited as ranking tools between different location and assist the comparison with the same scale before and after the implementation of any exposure control. The index value should relate proportionally with health symptoms of the welders. Kirch (2008) also agreed risk assessment would be simpler if a single metric could embody all of the information in the measurement. The main idea of the development of the welding fumes index by the authors can be referred to Hariri et al., (2012a) and Hariri et al., (2012b).

Hewitt (2001), highlighted the challenges for developing countries in strategies for risk assessment and control in welding. Developing countries are increasingly being drawn within the global economy in which transfer of technologies such as welding from developing economies into those which do not have similar infrastructures in terms of health and safety may be disastrous. Uncritical adoption of new welding technologies by developing countries potentates future health problems. This was also supported by Baram (2009). Hence, there is an urgent need to develop an index that can interpret the welding chemical exposure in welding processes into a simpler form to be comprehended easily by the employees. In such conditions, welding fumes index for welders is seen as the positive efforts in developing tools to rank, highlight and give awareness to the welder when dealing with their daily welding jobs.

Environmental index

The purpose of an environmental index is to summarize a large volume of information and represent it as a single ordinal number that is easy to understand. Environmental index is used to describe the quality or health of a specific environmental system such as air, water, soil and sediments (Sadiq et al., 2010). The index is a single number aggregated mathematically from two to more environmental indicators, where an indicator is a single quantity derived from one pollutant variable (Ott, 1978) . An index is constructed from several indicators weighted together to describe the total impact on certain aspect of the broader state of the environment. The aggregation process simplifies the complexity of the issues at hand and forms the link between the scientific community, the public and decision makers because index communicate the state of the environment in terms that the public can comprehend easily (Sofuoglu and Moschandreas, 2003).

From a regulatory compliance perspective, threshold levels of parameters are established in the context of possible adverse human health impacts. These threshold values can be standardised, guidelines, self imposed limits or best practice. As a result, it is useful to relate the index to some sort of acceptability measure. Development of environmental index involves following four basic steps; 1:Selection of relevant factors and parameters, 2:Transformation of selected parameters into sub index, 3:Derivation of weights and 4: Aggregation of sub index to determine the value model using a specific model (Sadiq et al., 2010).

In selecting appropriate and relevant parameters, the overall index must first have a specific goal or objective. Practically it is impossible to include every single parameters related to the index. Therefore, few representative measurable parameters are selected for practical and cost effective purpose. After the selection of relevant factors and parameters, they are converted into a sub index on a dimension less scale using transformation function such as linear, segmented linear, non-linear system in varying degrees. Therefore, the weights are assigned based on their importance and possible impact on an environmental system investigated. The last step in developing index is to combine all sub indexes using an aggregation model that describes the overall condition of environmental systems. Some of the information is lost during this process, however the loss of information should not lead to the results being misinterpreted, otherwise the usefulness of the index will decline (Sadiq et al., 2010, Ott, 1978).

Quality Function Deployment

Quality Function Deployment (QFD) is a well known customer-oriented methodology for planning quality and controlling the product development processes from the conceptual design to manufacturing operations in response to the voice of the customer (Akao, 1990). QFD involves two main aspects; customer requirement and design specifications. Customer requirement is usually expressed in qualitative characteristic terms collected through questionnaires (e.g. Want to be notified on respiratory effect, neurotoxins effect and carcinogenicity effect). Design specifications are the conversion of customer needs to measurable characteristics (welding fume concentration, analysis metal elements exists in welding fumes and metal element threshold limit). House of Quality (How) is the main construct of QFD. HoQ is a matrix that provides an efficient means of relating customer requirement and design specifications. The matrix consists of several sections or sub matrices joined together in various ways, each containing information related to the others as shown in Figure 1 (Cohen, 1995).

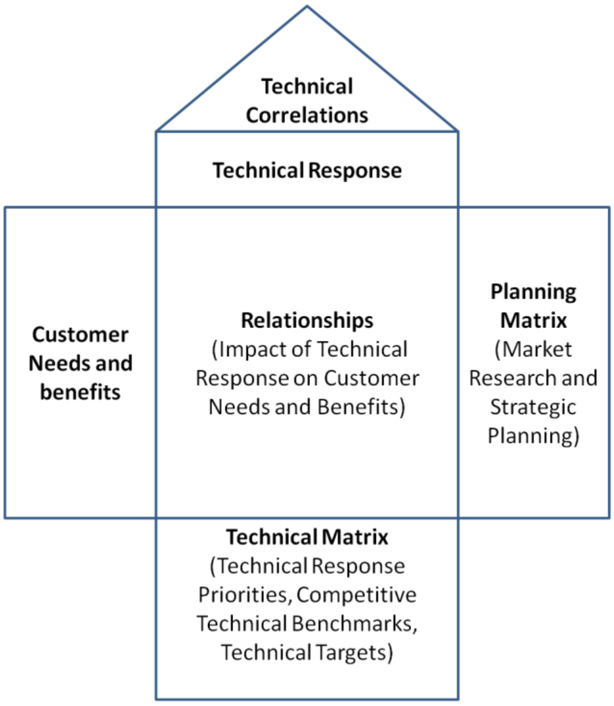

Figure 1. House of Quality (HoQ)

QFD are mainly applied for manufacturing purposes and there is a very limited study on application of QFD into the safety health and purpose. Francisque et al., (2011) used QFD approach to identify and prioritize the factors to reconcile the actual risk with perceived risk of drinking water by considering customer complaints about water safety. The author concludes that the customer requirement for water safety can be satisfied by improving the highest impact characteristics to the level expected by the customer. Leman et al., (2010) used QFD approach in designing industrial air pollution monitoring system for safety and health enhancement of toxic gases due to welding processes. The system was developed according to the employee's requirement collected through questionnaire and successfully fulfils the criteria required by the customer. Both of this study had successfully integrated QFD in the safety and health area and proved the flexibility and reliability of QFD approach.

METHODOLOGY

A pilot case study (n=11) was conducted in the automotive industry in Pahang. Welders were asked to answer a self-admistrated questionnaire on their desire to know the health effect that exists in their workplace. A 5- points Likert scale was used in the questionnaires (1: really do not want to know, 2: do not want to know, 3: not sure, 4: want to know, 5: really want to know). These questionnaires were then collected and analysed by using QFD method. The internal consistencies of the scale used in the pilot case study were analysed by Cochran Alpha for reliability. Based on the pilot case study, improvement was made to the questionnaire and actual case study (n=32) were carried out on all welders in the same industries.

Customer Requirement

Customer requirements are the list of basic demands that play a major role in QFD approach. In this case, the customers are the welders in this automotive industry. To shortlist the customer requirement on health effects during welding processes, data on health effect of metal fumes were collected from Pocket Guide on Chemical Hazard (NIOSH, 2010) and OSHA Welding Health Hazard Report (OSHA, 1996). There are 7 categories of health effect associated with welding fumes which is; irritants, sensitizers, respiratory effect, systemic toxins, neurotoxins, reproductive toxins and carcinogen.

One more element to consider in this study is the mixture effect of the metal fume exposure. Apart from the health impacts of the individual metal element, mixture hazard between these metal elements are also need to be considered. Mixture hazard can be initially quantified using Hazard Index (HI) approach by summing the concentration of the individual mixture component after they have been scaled for toxic potency relative to each other (Nims, 1999, Nordberg et al., 2007, Mumtaz, 2010). If the HI value exceeds 1, further analysis should be taken. From these 8 major health effects of welding fumes, welder were asked through questionnaire on what type of health effects that they desire to know exists in their welding workplace.

Technical Requirement

On the technical characteristic to met these customer requirements, a total of 9 technical requirements was considered as follow; personal sampling, area sampling, direct reading sampling, multi chemical analysis, blood/tissue test, chest x-ray, exposure limit, health questionnaire and lung function test. The technical requirement was shortlisted according to the Guidelines on Monitoring of Airborne Contaminant for Chemical Hazardous to Health (DOSH, 2005) and NIOSH Publication No. 2005-110: Specific Medical Test or Examinations Published in the Literature for OSHA-Regulated Substance (NIOSH, 2004). However blood/tissue test and chest x-ray were omitted due to limitation in cost and practicality.

RESULTS AND DISCUSSION

QFD involves two main aspects; customer requirement and technical characteristics. Customer requirement is usually expressed in qualitative characteristic terms collected through questionnaires (desire to know the health effect that exists in the workplace; irritants, sensitizers, respiratory system, systemic toxins, neurotoxins, reproductive toxins, carcinogen and mixture hazard). Technical characteristics are the conversion of customer needs to measure characteristics. Technical characteristics considered in this study were personal sampling, area sampling, direct reading sampling, multi chemical analysis, exposure limits, health questionnaire and lung function test. House of Quality (HoQ) which is the main construct of a QFD, is a matrix that provides an efficient means of relating customer requirement with technical characteristic.

The relationships between customer requirement and technical characteristics were weighted according to numerical values (0,1,3,9) in ascending order from none to strong intensity of relationships. The roof of the hook is used to identify the correlation and the relationship between technical characteristics. The importance each of the customer requirements were obtained using a questionnaire distributed to the welders.

In the pilot case study done in January 2012, From overall 20 persons involved in the welding assembly line, only 11 questionnaires were returned back. It was found that all customer requirements score mean criteria value between 3.64 and 4.09 (3.41 to 4.20 : want to know) which represent that all customer requirements were equally important to the welders. The Cochran alpha’s analysis resulted in 0.967 which indicates a high level of internal consistency of our scale with this specific sample. However, the percentage of welders answering ‘not sure’ in the questionnaire were high. 30%-40% of the welders answer ‘not sure’ for systemic toxins, neurotoxins, reproductive toxins, carcinogen and mixture effect. This is mainly caused by the technical terms that difficult to be understood by the welders. Thus, improvement was made to make the question more easily to be understood. To avoid the social desirability bias, only 4 scales were used in the actual study ; 1: really do not want to know, 2: do not want to know, 3: want to know, 4: really want to know (Matell and Jacoby, 1972, Worcester and Burns, 1975, Garland, 1991).

The actual case study was carried out in January 2013. Number of welders had increased to 32 and all the welders answered the self admistrated questionnaire. It was found that all customer requirements score mean criteria value between 3.31 and 3.41 (3.25 to 4.00: really want to know) which represent that all customer requirements were equally important to the welders. Table 1 shows the HoQ for the actual case study. It is sapparent that the highest degree of technical importance is the personal sampling (23.0%), multi chemical analysis (20.8%), exposure limits (19.7%), health questionnaire (17.6%) and lung function test (14.7%).

CONCLUSION

The development of welding fumes index by taking into consideration the voice of the welders would benefit the developer and at the same time capable to fulfil the requirement of the customer. The pilot and actual case study carried out in one of the automotive industries has showed the realibility of QFD approach in relating the customer requirement with the technical characteristics, thus giving a more clearer picture on how to further developed the welding fumes index based on the shortlisted technical characteristics. Future works will consider several case studies and larger respondents to determine the important parameters and technical characteristics for the development of welding fumes index.

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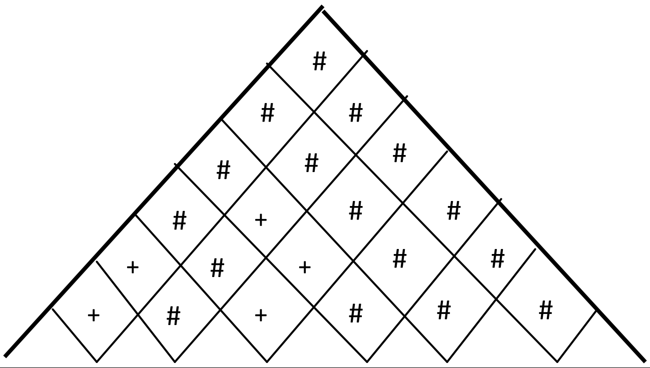
Table 1. House of Quality (HoQ) for actual case study

Relationship

: strong positive

+ : strong



	DEMANDED QUALITY	Importance	Personal Sampling	Area Sampling	Direct Reading	Multi Chemical Analysis	Exposure Limit	Health Questionnaire	Lung Function Test	TOTAL
			TECHNICAL CHARACTERISTIC							
CUSTOMER REQUIREMENTS	Irritants effect	3.41	0	0	0	0	0	9	0	9
			0	0	0	0	0	30.69	0	
	Sensitizer effect	3.41	9	0	0	3	0	9	9	30
			30.69	0	0	10.23	0	30.69	30.69	
	Respiratory system effect	3.38	9	1	1	9	9	9	9	47
			30.42	3.38	3.38	30.42	30.42	30.42	30.42	
	Systemic toxin effect	3.34	9	1	1	9	9	9	9	47
			30.06	3.34	3.34	30.06	30.06	30.06	30.06	
	Neurotoxins effect	3.34	9	1	1	9	9	3	1	33
			30.06	3.34	3.34	30.06	30.06	10.02	3.34	
	Reproductive toxins effect	3.31	9	1	1	9	9	3	0	32
			29.79	3.31	3.31	29.79	29.79	9.93	0	
	Carcinogen effect	3.38	9	1	1	9	9	3	3	35
			30.42	3.38	3.38	30.42	30.42	10.14	10.14	
	Mixture effect	3.41	9	1	1	9	9	3	9	41
			30.69	3.41	3.41	30.69	30.69	10.23	30.69	
Technical Importance			212.1	20.2	20.2	191.7	181.4	162.2	135.3	923.1
Percent Importance (%)			23.0	2.2	2.2	20.8	19.7	17.6	14.7	100

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