Computers & Industrial Engineering 100 (2016) 88–109

Contents lists available at ScienceDirect

Computers & Industrial Engineering

journal homepage: www.elsevier.com/locate/caie

Axiomatic Design for Lean-oriented Occupational Health and Safety systems: An application in shipbuilding industry

Ferhat Babur, Emre Cevikcan, M. Bulent Durmusoglu *

Istanbul Technical University, Department of Industrial Engineering, 34367 Istanbul, Turkey

ARTICLE INFO

Article history:
Received 25 May 2015
Received in revised form 2 May 2016
Accepted 13 August 2016
Available online 17 August 2016

Keywords:
Occupational Health and Safety
Axiomatic Design
Lean
Roadmap

ABSTRACT

The use of facilities provided by industrialization and technological developments has led to increase in occupational diseases and accidents in workplaces. A sheer success in Occupational Health and Safety (OHS) is possible when safety activities for employees, production and business are considered synchronously. OHS systems, where scientific research oriented technological advances applied, are required to be designed with the aim of preventing OHS related problems and their effects in sustainable manner. In this study, a systematic approach is proposed for design of Lean-oriented OHS systems by using Axiomatic Design principles. A holistic roadmap is obtained as the output of the study for the application of OHS system to a production system. The proposed OHS system design is applied to a real life shipyard system from shipbuilding industry and its feasibility is demonstrated.

1. Introduction

The number of occupational diseases and accidents has increased in parallel with the improvement in industry. A number of people died or maimed due to occupational diseases or accidents, 98% of which could be prevented (Heinrich, Peterson, & Roos, 1980). According to the International Labour Organization (ILO), more than 337 million accidents occur on the job annually and result in (together with occupational diseases) more than 2.3 million deaths annually (Url-1). Loss of labour about OHS constitutes 4% of the total gross national product all over the world (ILO, 2011). In addition, for every 300 near-miss events without injury, there are 29 minor to moderate injuries and 1 major injury or fatality (Heinrich, 1931; Taylor, Easter, & Hegney, 2004). That being the case, including multi-disciplinary and preventive activities for occupational diseases and accidents, OHS is of great importance in industrial environments (Alli, 2008).

Both World Health Organization (WHO) and ILO define OHS as follows (ILO Encyclopaedia of Occupational Health and Safety): "Occupational health should aim at: the promotion and maintenance of the highest degree of physical, mental and social well-being of workers in all occupations; the prevention amongst workers of departures from health caused by their working conditions; the protection of workers in their employment from risks resulting from factors adverse to health; the placing and maintenance of the worker in an occupational environment adapted to his physiological and psychological capabilities; and, to summarize, the adaptation of work to man and of each man to his job."

OHS has been handled in numerous scientific studies in addition to practical applications (Barlas, 2012a; Barlas, 2012b; Ferjencik, 2011; Shikdar & Sawaqed, 2003). The major part of OHS literature is related with ergonomics (Bentley & Tappin, 2010; Neumann, Marianne, & Jorgen, 2009; Shikdar & Sawaqed, 2004), psychology (Quick & Tetrick, 2003; Warr, 2002) and work environment (McClain, 1995). Meanwhile, some OHS approaches addressing physical hazards such as noise, vibration and dust (Aluclu, Dalgic, & Toprak, 2008; Hermanus, 2007), chemical hazards such as heavy metals and gases (Garrigou, Baldi, & Le Frious, 2011) and biological hazards such as bacteria and viruses (Piccoli, Assini, & Gambaro, 2001) are proposed. In addition, causing occupational accidents disorderliness in working environment can be regarded as a hazard in terms of OHS. Therefore, 5S, which maintains order and cleanliness in shop floor, constitutes a basis for continuous improvement as well as OHS activities (Hirano, 2009).

Risk analysis and evaluation is a critical process which includes (i) the determination of hazards inside and outside the workplace, (ii) the determination of their potential harms to employees, workplace and environment, (iii) the assessment of risk and (iv) taking pro-active measures against them. Therefore, risk concept has been handled in many scientific studies (Dekker, Cilliers, & Hofmeyr, 2011; Hopkins, 2011; Maiti, 2010). Moreover, some sector oriented

* Corresponding author.
E-mail addresses: ferhatbabur@gmail.com (F. Babur), cevikcan@itu.edu.tr (E. Cevikcan), durmusoglum@itu.edu.tr (M.B. Durmusoglu).

http://dx.doi.org/10.1016/j.cie.2016.08.007
0360-8352/

studies on healthcare (Cagliano, Grimaldi, & Rafele, 2011), electric industry (Liggett, 2009), wood processing industry (Holcroft & Punnett, 2009) and maintenance processes (Lind, Nenonen, & Kivisto-Rahnasto, 2008) were conducted.

On the other hand, a systematic design domain cannot be obtained without scientific rules. Systematic approach has a facilitating effect on the stages of understanding, learning, developing and applying product and service design.

Axiomatic Design (AD) theory, proposed by Suh (1990), exposes the objective of the design evidently by determining FRs and constraints during design process. In addition, AD involves a systematic flow and decomposition process.

Two axioms, namely independence axiom and information axiom are used in AD (Suh, 1990). Independence axiom (Durmusoglu & Kulak, 2008; Kim, Suh, & Kim, 1991; Kulak, Durmusoglu, & Tufekci, 2005) aims at determining the roadmap which should be followed during the design process. Information axiom (Kulak, Durmusoglu, & Kahraman, 2005) has the goal of determining the most appropriate design alternative with respect to FRs. Kulak, Cebi, and Kahraman (2010) provide a comprehensive review on AD applications.

Many AD applications in designing product (Cha & Cho, 1999; Lee, Seo, & Park, 2003), manufacturing system (Cochran, Eversheim, Kubin, & Sesterhenn, 2000; Nakao, Kobayashi, Hamada, Totsuka, & Yamada, 2007; Suh, Cochran, & Paulo, 1998), software (Yi & Park, 2005) and decision support system (Coelho & Mourão, 2007; Jang, Yang, Song, Yeun, & Do, 2002) exist in the literature. Since both lean thinking (Womack & Jones, 1996) and manufacturing support AD start with "What we want to achieve in terms of customer point of view?" logic, it will be meaningful to give some information about lean manufacturing.

Lean manufacturing is originated by Toyota Production System and classifies all activities as either value-adding or non-value-adding (i.e. wastes). Value-adding activities transform materials and information into products and services that customers want. However, non-value-adding activities do not directly contribute to create products and services despite they consume resources. Companies applying lean manufacturing tools ultimately want to meet customer demands with fewer resources and less waste. Succeeding a cultural as well as people oriented transformation, lean manufacturers use many process-improvement tools to achieve and sustain effectiveness, flexibility, and profitability (Baysan, Cevikcan, & Satoglu, 2013).

The expected results of lean manufacturing, namely shorter lead times, reduction in inventory, space requirement and machine breakdowns as well as improvement in delivery performance and cost management provide competitive advantage to lean companies (Monden, 1993). Moreover, health and safety hazards can actually be decreased by lean manufacturing because it mixes previously separated exposures and this affects additively and cumulatively (Anvari, Zulkifli, & Yusuff, 2011; Gnoni, Andriulo, Maggio, & Nardone, 2013). The intensification of work leads both to higher plant productivity and to greater adverse ergonomic and stress-related health effects for workers. Some attempts have been made to address the relationship between Lean Manufacturing and OHS (Anvari et al., 2011; Brown and O'Rourke, 2007; Gnoni et al., 2013; Longoni, Pagell, Johnston, & Veltri, 2013). However, these studies do not demonstrate how to apply lean tools to an OHS System in detail.

Since the proposed OHS system design is applied to a real life shipyard, it will be meaningful to mention OHS related standards and guidance studies for shipbuilding industry. For example, in a recent study, Occupational Safety and Health Administration (OSHA) provides a shipyard industry specific booklet with the code of OSHA 2268-10R (OSHA, 2014) including OHS standards for shipyard employment (Title 29 CFR Part 1915). The booklet also discusses the importance of regular employee training for employee awareness and the elements of a safety and health program that can be used by employers. In the booklet, it is stated that hazards not covered by shipyard industry standards may be covered by General Industry standards contained in 29 CFR Part 1910. In parallel, OSHA proposed some shipyard industry specialized guides for particular standards in related topics such as safe lighting practices (OSHA, 2013b), ventilation (OSHA, 2013c), hot work on hollow or enclosed structures (OSHA, 2013d), working alone in shipyards (OSHA, 2013e), fire watch safety during hot work (OSHA, 2012a), eye protection against radiant energy (OSHA, 2012b), aerial lift fall protection over water (OSHA, 2011), safe work practices for shipbreaking (OSHA, 2010). In addition, OSHA industry guide (Savage, 2014) is designed to assist employers in shipyard employment in complying with standards that have special requirements such as written programs, inspections, competent persons, training and recordkeeping requirements that are applicable to shipyard employment.

Furthermore, some other institutions such as ILO (1974), Oil Companies International Marine Forum (OCIMF) (2003), Workplace Safety and Health Council (2009), Washington State Legislature (2014) and Ingalls Shipbuilding (2015) also attempt to make standards and guidance studies for OHS in shipyard industry.

The consideration of a large body of literature has revealed that there is no published study which includes the following features synchronously.

- providing AD for OHS system under lean production principles,
- integrating Standard Risk Model with Kinney Risk Assessment Method for OHS system,
- including an application-based feasibility analysis in a real life shipyard system.

In this context, this paper has the originality of developing a road map by using the independence axiom, the first axiom of AD, for the design of lean OHS system effectively to address this research gap. The road map provides a decomposition of broad design objectives into smaller supporting objectives that are then linked to specific design parameters (DPs) for framing OHS systems. In addition, this study is believed to add value to industry in terms of effectively raising control of OHS activities, since it indicates a detailed application of some related lean tools (5S, visual production performance tracking and task assignment boards, Kaizen, A3 thinking, Yokoten, Oobeya (Hoppmann, Rebentisch, Dombrowski, & ve Zahn, 2011) and work standardization) to OHS system.

The remainder of this paper is organized as follows: The basic concept of AD principles is introduced in Section 2. An AD oriented methodology for OHS system design is presented in Section 3. The application of the proposed methodology is given in Section 4. Conclusions are provided in Section 5.

2. Axiomatic Design

Design is an interplay between *what* we want to achieve and *how* we want to achieve it (Suh, 2001). Often designers believe that the precise description of "what we want to achieve" is a difficult task. Many designers deliberately leave their design goals implicit rather than explicit and then start working on design solutions even before they have clearly defined their goals. They measure their success by comparing their design with the implicit design goals that they had in mind, which may or may not be what the customer would want. They spend a great deal of time improving and iterating the design until the design solution and "what they