Journal of Cleaner Production xxx (2015) 1–10

Contents lists available at ScienceDirect

Journal of Cleaner Production

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

A fuzzy-based assessment procedure for a clothing factory with waste-prevention consideration

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ARTICLE INFO

Article history:
Received 29 January 2015
Received in revised form
30 June 2015
Accepted 30 June 2015
Available online xxx

Keywords:
Waste prevention
Process improvement
Fuzzy-based assessment procedure
Clothing factory
Clothing production network

ABSTRACT

Production facilities, especially factories, should have long-term aspirations to be environmental responsible through adequate waste prevention and management processes. In this paper, we consider the case study of a clothing factory in China with significant labor-intensive operations. The factory's layout, process design, and materials management are aspects that can address the prevention and elimination of unnecessary transportation, processing waste, waiting time, inefficient work methods, inventory, and overproduction. This paper develops a fuzzy-based assessment procedure to consider waste prevention and management in the clothing industry. Here, the factory is modeled as a production unit using a fuzzy multistate network with labor-intensive operations. Using reliability analysis, we determine the probability of demand satisfaction to indicate whether the factory's waste prevention actions are effective. Further, we also show that the established fuzzy-based assessment procedure can consider both pessimistic and optimistic scenarios. Thus, this procedure is extremely useful to a production manager who seeks a comprehensive status of a clothing factory with a focus on consistent improvement.

1. Introduction

Waste prevention and management are long-term aspirations for a factory wanting to be environmentally responsible (Mickwitz et al., 2008; Lin et al., 2012). Moreover, by considering waste prevention, a factory can prevent and eliminate inefficient work and improve production processes. At a factory, waste prevention includes the prevention and elimination of unnecessary transportation, processing waste, waiting time, inefficient work methods, inventory, overproduction, and product defects (Stevenson, 2013). To prevent and eliminate the abovementioned waste, a factory has to expend efforts on factory layout, process design, and materials management. However, it is difficult to evaluate how effective factory performance achieves the goal of waste reduction. In addition, satisfying orders from customers is always the primary goal for any factory. Hence, an assessment procedure should be established to evaluate the possibility of meeting demand satisfaction while simultaneously considering waste-prevention goals.

In considering waste prevention, the primary target of this paper is to establish a fuzzy-based assessment procedure that provides reliability analysis in a clothing factory setting. Reliability is a performance indicator defined as the possibility of customer demand satisfaction. From the perspective of the clothing industry, it is traditionally considered as a precise handicraft profession (Black and Schroer, 1993; Black and Chen, 1994). The clothing industry involves a large number of manual operations and is therefore considered labor-intensive. In order to be competitive in the global environment, the clothing industry is forced to focus on waste prevention with robust labor-intensive operations (Allwood et al., 2008). Robust, labor-intensive operations also mean reliable demand satisfaction in the clothing production process. Despite the fact that automated or semi-automated factories can eliminate labor-intensive processes, human beings continue to play an important role in clothing production. However, in the clothing factory, it is difficult to quantify the human efforts by using a conventional assessment procedure (Ding et al., 2008; Chen and Lin, 2009; Chen, 2012). The conventional assessment procedure measures the ability of a machine or a workstation according to the machine's specifications (i.e., design capacity). It is difficult to determine the abilities of employees because such workers do not have design "specifications." Hence, a new assessment procedure

Abbreviations: AOA, activity-on-arc; CPN, Clothing production network; NPN, non-labor-intensive production network; WIP, work-in-process.

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http://dx.doi.org/10.1016/j.jclepro.2015.06.144
0959-6526/

that enables a quantitative performance evaluation (i.e., the reliability analysis) is a measurement tool that can be used in the labor-intensive clothing industry.

This fuzzy-based assessment procedure is applied to a real-world clothing factory in China. Table 1 shows that the Chinese clothing industry has increased its presence in the global market over the past decades, with its production amount at about 41% of the worldwide clothing volumes (WTO, 2013). Looking at a clothing factory in China as a case study, this paper proposes a quantitative evaluation that can offer contributions in both academic and practical terms. This clothing factory, located in the Yangtze River Delta, China, has more than 3000 employees making polo shirts for several famous international brands. The clothing factory is a flow-shop system in which products (polo shirts) are make-to-order and set up as a network, namely a clothing production network (CPN). Both component-level (i.e., workstations) and factory-level performance evaluations are studied in the CPN.

To prevent and reduce inefficient work that may increase work-in-process (WIP) and result in a longer waiting time, a performance indicator is needed to evaluate the efficiency of the CPN. Reliability is an appropriate indicator to analyze how efficiently the CPN can satisfy customer demand as well as consider waste prevention. In order to take human performance into consideration, fuzzy mathematics is utilized to evaluate the possibility that the workload (process amount) can be processed by each workstation. First, the workload to satisfy the given demand is estimated for each workstation. Fuzzy multistate is applied to determine the workload state of each workstation by three membership functions, "under-normal workload (U)," "normal workload (N)," and "over-normal workload (O)." Second, the workstation reliability, defined as the possibility that a workstation will reliably process the workload, is measured by these membership functions. Third, a system-level performance evaluation is assessed for the whole factory. Once all workstation reliabilities are obtained, the overall reliability is derived in terms of fuzzy intersections. On the basis of the fuzzy-based assessment procedure, the reliability analysis will be beneficial for adopting a sensitivity analysis. That is, the production manager can improve processes by investigating the inefficient workstation that affects overall reliability the most. Subsequently, waste-prevention action will need to be implemented for such a workstation.

2. Literature review

This section reviews related research devoted to waste prevention, network production models, and the concept of fuzzy mathematics. The issue of throughput analysis is also reviewed to evaluate workload for customer demand satisfaction.

2.1. Actions for waste prevention

Waste is defined as unproductive resources; reducing waste can free up resources as well as enhance production (Stevenson, 2013). Therefore, actions should be taken to minimize waste as much as possible in any factory. To eliminate waste, a factory can improve its production system from the aspects of factory layout, process design, and materials management.

Factory layout is a fundamental issue that can prevent waste from a long-term perspective. Generally, a U-shaped layout is more compact than a straight-line layout. Additionally, the U-shaped layout permits communication among workers on the factory floor (Stevenson, 2013). That is, a U-shaped layout can remove both unnecessary transportation and processing waste among workstations. The U-shaped layout is also widely applied in clothing factories to facilitate the efficiency of production and communication (Black and Schroer, 1993; Black and Chen, 1994).

From the process design perspective, the production process should be efficient to minimize waiting time and avoid inefficient work methods. For a flow-shop production system, line balancing is an effective and efficient method for assigning tasks to workstations. The goal of line balancing is to minimize the waiting time (between one step and another) in production, resulting in higher utilization (Stevenson, 2013).

Materials management is required to calculate the amount of raw materials needed in routine production (Lindahl et al., 2014). Lin et al. (2012) suggest that the amount of raw materials can be calculated precisely according to the defect rates of workstations to avoid inventory and overproduction. Several studies (Lin and Chang, 2012; Lin et al., 2012; Chang and Lin, 2015, 2014) indicate that the amount of raw materials needs to be calculated when adopting a production network model for reliability evaluation.

2.2. Network analysis in production

The network analysis approach is applicable for production managers to use to evaluate the performance of factories (Lin and Chang, 2012; Lin et al., 2012). In a network-structured factory, namely a production network, each arc represents a workstation and each node represents an inspection station. In particular, workstations in the production network may exhibit multiple levels of capacity due to the possibility of malfunctioning, partial malfunctioning, and machine maintenance. Therefore, a production network characterized by such components (workstations) also possesses multistate capacities, which is therefore a multistate production network. To evaluate the performance of a multistate production network, overall reliability is generally used to measure

Table 1
Production amount of the worldwide clothing volumes.

Rank	Country	2010		2011		2012	
	Worldwide	Export ($mln)	Percent	Export ($mln)	Percent	Export ($mln)	Percent
		605,313	100	711,474	100	708,354	100
1	China	242,047	40	283,973	39.9	288,183	40.7
2	E.U.	168,058	27.8	193,763	27.2	178,262	25.2
3	India	24,062	4	30,012	4.2	29,107	4.1
4	Turkey	21,724	3.6	24,720	3.5	25,344	3.6
5	Bangladesh	16,118	2.7	20,803	2.9	21,582	3
6	U.S.	16,863	2.8	19,024	2.7	19,099	2.7
7	Vietnam	13,451	2.2	16,919	2.4	18,185	2.6
8	Korea	12,578	2.1	14,209	2	13,880	2
9	Pakistan	11,778	1.9	13,632	1.9	12,919	1.8
10	Indonesia	10,964	1.8	12,836	1.8	12,065	1.7