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Reliability analysis for an apparel manufacturing system applying fuzzy multistate network

Ping-Chen Chang, Yi-Kuei Lin *

Department of Industrial Management, National Taiwan University of Science & Technology, Taipei 106, Taiwan, ROC

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ABSTRACT

This paper addresses the reliability analysis for a real-world apparel manufacturing system by using fuzzy mathematics. The studied apparel manufacturing system is a precise handicraft profession which involves a great amount of labor-intensive processes. To consider human performance, the apparel manufacturing system is constructed as a fuzzy multistate network, termed apparel manufacturing network (AMN). The workload state of a workstation in the AMN is defined by three fuzzy membership functions: "under-normal-workload", "normal-workload", and "over-normal-workload". Hence, the workload of a workstation is fuzzy multistate and the workstation-reliability is measured by three fuzzy membership functions. Subsequently, the system reliability is evaluated in terms of all workstation-reliabilities, and is derived by fuzzy intersection. The reliability analysis can help the production manager to understand the demand satisfaction of the AMN.

1. Introduction

Clothing is one of the essentials for daily living and thus the apparel manufacturing is always important in manufacturing industries. In the apparel manufacturing industry, it is critical to keep the robustness of labor-intensive processes which involve a great number of manual operations. Robust labor-intensive operations also mean the reliable demand satisfaction in the apparel manufacturing system. Despite the fact that automated or semi-automated manufacturing systems can eliminate the labor-intensive processes, human beings continue to play an important role in an apparel manufacturing system. In particular, the apparel manufacturing industry is considered as a precise handicraft profession (Chen, Wang, & Hung, 2014). For an apparel manufacturing system, it is difficult to quantify the 'human specification' of the system by utilizing a conventional assessment model (Ding, Zuo, Lisnianski, & Tian, 2008; Chen & Lin, 2009; Chen, 2012). The conventional assessment model primarily measures the ability of a machine or a workstation according to the machine specification (i.e. designed capacity). However, it is difficult to determine the capacity of human beings because worker does not have a 'designed specification'. In order to overcome this challenge, a new assessment model for the quantitative performance evaluation is a niche in a labor-intensive industry such as the apparel manufacturing industry.

This paper works on the reliability evaluation for a high value-added apparel manufacturing system. The studied apparel manufacturing factory is located in Yangtze River Delta, China with more than 3000 employees making T-shirts for international well-known name brands. The apparel manufacturing system is a flow-shop system in which products (T-shirts) are make-to-order. A network model is utilized to construct the apparel manufacturing system. For the network-structured manufacturing system, workstations may exhibit multiple levels of performance due to the possibility of malfunctioning, partial malfunctioning, and maintenance of machines; or possibility of absence, temporal absence, and rest of workers. Hence, a manufacturing system characterized by such components (workstations) also possesses multistate performance, which is a multistate manufacturing network. The apparel manufacturing system is constructed as a multistate manufacturing network, termed apparel manufacturing network (AMN) herein. This paper primarily measures the system reliability, defined as the possibility of demand satisfaction, as a performance indicator of the AMN.

Consider human performance, fuzzy mathematics is utilized to measure the workload that can be burdened by workers in a workstation. In terms of the workload states, the system reliability of the AMN is calculated as a performance indicator to indentify the possibility of demand satisfaction. First, the workload vector that should be processed by workstations to satisfy the demand

* Corresponding author. Tel.: +886 2 27303277; fax: +886 2 27376344.
E-mail address: yklin@mail.ntust.edu.tw (Y.-K. Lin).

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Nomenclature

N	set of nodes
n	number of workstations
a_i	ith arc (workstation) where $i = 1, 2, \ldots, n$
A	$\{a_i \mid i = 1, 2, \ldots, n\}$: set of arcs (workstations)
q_i	defect rate of a_i, where $0 \leqslant q_i \leqslant 1$
p_i	success rate of a_i, where $p_i = 1 - q_i$
d	demand
I	units of input raw materials
w_i	number of workers in a_i where $i = 1, 2, \ldots, n$
l_i	cycle time of a_i where $i = 1, 2, \ldots, n$
c_i	maximum capacity of a_i where $i = 1, 2, \ldots, n$
C	maximum capacity of the production line (a reference value to investigate the system reliability under different demand levels)
U	under-normal-workload (linguist statement for workstation capacity)
N	normal-workload (linguist statement for workstation capacity)
O	over-normal-workload (linguist statement for workstation capacity)
y_i	workload of a_i (crisp value)
Y	$(y_1, y_2, \ldots, y_n)$: workload vector
$\mu_A(y)$	membership function for set A
μ_i	average of the historical processing amount in a_i
σ_i	standard deviation of the historical processing amount in a_i
$L_{low}^{(i)}$	center of fuzzy set "y_i is a under-normal-workload for a_i", where $L_{low}^{(i)} = \mu_i - 3\sigma_i$
$L_{avg}^{(i)}$	center of fuzzy set "y_i is a normal-workload for a_i", where $L_{avg}^{(i)} = \mu_i$
$L_{upp}^{(i)}$	center of fuzzy set "y_i is a over-normal-workload for a_i", where $L_{upp}^{(i)} = \mu_i + 3\sigma_i$
R_d	system reliability satisfying d
x_i	current state of a_i (used in conventional reliability example only)
X	$(x_1, x_2, \ldots, x_n)$: current system state (used in conventional reliability example only)

is generated. In terms of such a vector, three membership functions, "under-normal-workload (U)", "normal-workload (N)", and "over-normal-workload (O)", are utilized to measure the workload state of each workstation. Second, the workstation-reliability, defined as the possibility that a workstation is reliable to process the workload, is measured by these membership functions. Third, in addition to the assessment of a fuzzy multi-state component (i.e. the workstation), further performance evaluation for the whole system is needed. Once all workstation-reliabilities are obtained, the system reliability is derived by fuzzy intersection.

To the best of the authors' knowledge, this is the first study (associated with a real-life AMN) that develops the multistate manufacturing network model to evaluate the reliabilities for a labor-intensive manufacturing system at both component- and system-levels. A fuzzy-based assessment model is proposed to quantify the human performance in this labor-intensive manufacturing system. For the AMN, the production managers and customers focus on whether the orders can be fulfilled or not. That is, all workstations are reliable (component-level performance) to process the raw material or WIP. Furthermore, the system reliability (system-level performance) could be a more rational performance indicator to understand the possibility of demand satisfaction of the whole system.

2. Literature review

In order to study the system reliability of an AMN, this section reviews relevant works devoted to network model in manufacturing system and fuzzy reliability.

2.1. Network model in manufacturing systems

Network analysis is an applicable approach that supports production managers to evaluate the performance of manufacturing systems (Lin & Chang, 2012, 2013; Lin, Chang, & Chen, 2013). To evaluate the performance of a multistate manufacturing network, reliability analysis is beneficial for production managers to understand the possibility of demand satisfaction (Lin & Chang, 2012, 2013; Lin, Chang et al., 2013).

Lin and Chang (2012, 2013) proposed a graphical model to measure the system reliability of a multistate manufacturing network, in which the system reliability is defined as the probability of demand satisfaction. In the multistate manufacturing network, each workstation consists of identical functional machines. It implies that such a workstation has multiple capacity states, which is determined by the number of machines those are normally operating. However, such a capacity determination is inappropriate for a labor-intensive manufacturing system because the uncertainty of human nature. The capacity of a workstation is difficult to be determined in terms of number of workers by integer-valued states. Moreover, the capacity of a worker is not able to be measured exactly with that of the specification of a machine. Hence, this study intends to import the fuzzy multistate into the labor-intensive manufacturing system for reliability analysis.

2.2. Fuzzy reliability and fuzzy multistate

Several literatures related to fuzzy reliability were introduced by Cai, Wen, and Zhang (1993), Cai (1996), Pandey and Tyagi (2007), and Li and Kapur (2012); those studies primarily focused on the reliability evaluation that considers the binary-state (success/failure) of a component. In addition, the binary-state fuzzy reliability also has been widely adopted in production systems. A great amount of studies applied fuzzy method to quantify the uncertain attributes of production rate (Pan & Yang, 2008), process failure (Görkemli & Kapan Ulusoy, 2010), machine failure (Görkemli & Kapan Ulusoy, 2010; Erozan, 2011; Azadeh, Sheikhalishahi, Khalili, & Firoozi, 2014), quality feature (Jenab & Ahi, 2010), and demand (Pan & Yang, 2008; Huang, Song, Leon, & Wang, 2014) in reliability analysis. However, binary-state component may not accurately represent the possible states in all real-life systems (Chen & Bao, 2013), such as manufacturing (Lin & Chang, 2012, 2013; Lin, Chang et al., 2013), computer (Lin & Huang, 2013), and logistic (Lin, Yeh, & Huang, 2013) systems.

In contrast to the concept of binary-state fuzzy reliability, the multi-state fuzzy reliability can use multiple thresholds to divide the interval [0, 1] into several sub-intervals. In other words, this extension to define a multi-state component is still on the basis of the binary-state principle of failure and success (Li & Kapur, 2013). Ding et al. (2008) developed some general definitions to characterize the fuzzy multistate component and each state of a component is represented as a fuzzy set by their ordering criteria.