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Decision making procedure of demand satisfaction and production policy for capacitated production systems

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ABSTRACT

This paper develops a reliability-based decision making procedure for production systems to (i) evaluate the system reliability and (ii) determine the reliable production policy. The production system is represented as a capacitated production network (CPN) for system reliability evaluation, in which the system reliability is defined as the probability of demand satisfaction. The decision making to determine a reliable production policy is based on the derived system reliability. Two layouts are considered in this paper: the first layout is for the CPN with parallel lines; while the second layout is for the CPN with joint lines. Transformation and decomposition techniques are proposed to generate all minimal capacity vectors that workstations should provide to satisfy demand. In terms of the minimal capacity vectors, the system reliability is derived by applying the recursive sum of disjoint products (RSDP) algorithm. A case study in the context of footwear production system is utilized to demonstrate the decision making procedure.

1. Introduction

The main objective of manufacturing industry is to consistently produce products with high service levels. A reliable production policy is helpful to improve demand satisfaction with high service levels (Guo, Wong, Leung, & Fan, 2009; Hemmati, Ebadian, & Nahvi, 2012). For a production system, the decision making of production policy is to achieve desired goal of productivity (He, Chen, & Xu, 2011; Yalcin, Bayrakdaroglu, & Kahraman, 2012). That is, the production system has to provide sufficient capacity to satisfy the requirements and orders from customers. The production manager and decision maker always intend to well comprehend the demand satisfaction of a production system. The demand satisfaction reflects whether the productivity of the production system achieves the desired goal or not. Furthermore, for a production system with multiple production lines, to assign the production amount for each line is a crucial task in decision making. Therefore, an appropriate decision making is required for the evaluation of demand satisfaction and determination of production policy. This paper proposes a reliability-based decision making procedure for production systems to (i) evaluate the system reliability of demand satisfaction and (ii) determine the reliable production policy. We measure the probability that the production system can produce a given demand. Such a probability is referred to as system reliability, which supports decision making in the production system.

Network analysis is an applicable approach to be employed for decision making (Chen & Lin, 2009; Lin, Chang, & Chen, 2012). In particular, components (arrows and nodes) in a network may exhibit multiple levels of capacity due to the possibility of failure, partial failure, and maintenance. Hence, a network characterized by such components also possesses stochastic capacities, which is typical of capacitated-flow networks (Lin, 1998; Lin, 2010; Lin, Jane, & Yuan, 1995). For a production system in which each workstation consists of a group of machines, indicating that such a workstation performs stochastic capacity levels. For instance, a workstation consisting κ identical machines indicates that $(\kappa + 1)$ capacity levels are available. The lowest level zero corresponds to all machines complete malfunction, while κ is the highest level of operation. Similarly, the capacity can be described in terms of laborers in a workstation for the labor-intensive industry as well. That is, a workstation with κ laborers performs the lowest level zero corresponding to no laborer in the workstation at a time, while κ is the highest level of operation with all laborers. Hence, the production network comprising such workstations also possesses stochastic capacity levels and it can be treated as the so-called capacitated-flow network (Lin, 1998, 2010; Lin et al., 1995). For the production network with stochastic capacity levels, we name it capacitated production network (CPN) in this paper. To make a proper decision for such a CPN is a challenge for production manager and decision maker because the stochastic capacity of workstation is involved.

Applying the capacitated-flow network model, some studies (Lin, 2009a; Yeh, 2008; Yeh, 2011) have been devoted to evaluating

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the performance of production system from the perspective of system reliability. Those studies focused on demand satisfaction of a CPN in terms of minimal path (MP), in which an MP is a sequence of arrows from source to sink which contains no cycle, and which carries sufficient capacity to satisfy a given demand (Zuo, Tian, & Huang, 2007). In addition to production system, a significant amount of research (Alexopoulos, 1995; Aven, 1985; Hudson & Kapur, 1985; Lin, 2009b; Lin & Chang, 2011; Lin & Chang, 2012; Xue, 1985) has also been contributed to studying the system reliability of a capacitated-flow network in terms of MP. However, previous works all assumed that the demand transmitted through a network must obey the so-called flow conservation law (Ford & Fulkerson, 1962), implying that no flow will be increased or decreased during transmission. In a CPN, defect rate influences the capacity of a workstation and leads to defective products, in which defective products might be scrapped or reworked. That is, the input flow processed by each workstation would not be the same as the output flow. Thus, the traditional technique for the capacitated-flow networks could not be applied for a CPN due to the violation of the flow conservation. In addition, due to a growing environmental concern and economic incentives, rework for defective products is therefore having received increasing attention for eliminating unnecessary scrap. In several practical CPN, the reworking action is implemented by the same workstations, implying that the CPN may output products from two sources, from the general production path(s) and the reworking path(s), to satisfy demand (Buscher & Lindner, 2007; Teunter, Kaparis, & Tang, 2008). Since defective WIP (work-in-process) from a workstation could be reworked starting from an upstream workstation(s) or the same workstation(s) (Buscher & Lindner, 2007; Teunter et al., 2008), it violates the basic concept of MP. Besides, based on the MP concept, an arrow (workstation) would not appear on the same path more than once; otherwise it would not be an MP.

Recently, Lin and Chang (2012) proposed a graphical model to measure the system reliability of a CPN with only one line by taking reworking actions into account. However, the previous work is lack utility for multiple lines in most real-world cases. Besides, decision making was not involved in that work. More recently, an extension work studied by Lin et al. (2012) have been devoted to modeling a CPN with multiple lines in parallel. However, the extension works considered only one reworking action in each line. For a more general CPN, this paper addresses two practical characteristics, multiple lines and multiple reworking actions, in decision making. We propose a transformation technique to transform a production system into a network-structured CPN. The transformed CPN is decomposed into several paths, the general production path(s) and the reworking path(s), by a decomposition technique. Based on these decomposed paths, we generate the minimal capacity vectors that workstations should provide to meet a given demand. In terms of such minimal capacity vectors, we derive the system reliability that the CPN could produce d units of product per unit time. Two layouts are taken into account in this paper, in which Layout I considers parallel lines; while Layout II considers joint lines with common workstations.

The remainder of this paper is organized as follows. Problem statement for two layouts and assumptions are described in Section 2. Transformation and decomposition techniques are established in Section 3 to build the CPN model. Input flow determination and system reliability evaluation are formulated in Section 4. Two algorithms are proposed in Section 5 to generate the minimal capacity vectors for demand satisfaction in both layouts. A case-based example in terms of a footwear production system is demonstrated in Section 6. Decision making issues for the footwear production system are discussed in Section 7. Conclusion is remarked in Section 8.

2. Problem statement and assumptions

A flow-shop production system is considered in this paper. That is, this CPN is a high-volume system that produces identical or highly similar products (Chiou, Chen, Liu, & Wu, 2012; Stevenson, 2007). To analyze the capacity of a CPN, we emphasize the input flow of each workstation, in which the input flow is defined as the input amount of raw materials or WIP that each workstation processes per unit time. The CPN is requested to produce d units of product per unit time.

2.1. Problem statement

The system reliability is defined as the probability of demand satisfaction for d. In particular, we address a real-world CPN to consider two important characteristics including multiple lines and multiple reworking actions. Thus, the probability that a workstation operates successfully is also considered in this paper. We name such a successful probability success rate (i.e., success rate = 1 – defect rate), which is utilized for the following techniques and model building. For simplicity of illustration, we concentrate on the case of two lines. The proposed techniques and algorithms can then be easily extended to the case of more than two lines. Two layouts are considered in this paper.

Parallel lines (Layout I): Two identical lines in parallel produce the same product type. The ordered workstations and their functions in both lines are the same.

Joint lines (Layout II): Two distinct lines produce the same product type. In this layout, most workstations and their functions in both lines are the same. However, one of the two lines may produce a compact product type by fewer workstations. Another line produces more than one product types (regular product type by all workstations and compact product type by fewer workstations). Hence, a common workstation shares its capacity when producing regular product type by both lines.

2.2. Assumptions

This paper constructs the CPN model to evaluate the system reliability of a production system based on the following assumptions.

1 Each inspection station (node) is perfectly reliable, meaning that inspection would not damage any WIP/products.
2 The capacity of each workstation (arrow) is a random variable which takes possible values $0 = x_{i1} < x_{i2} < \cdots < x_{ic_i} = M_i$ according to a given probability distribution.
3 The capacities of different workstations are statistically independent.
4 Each defective WIP is reworked at most once by the same workstation. That is, the defective WIP is repaired until a usable state is achieved. If the defective WIP after reworking is still defective, indicating that such a defective WIP is non-repairable. Then it is scrapped.

3. Model building for a CPN

Two common techniques, transformation and decomposition, are proposed for both layouts to model a production system as a CPN. First, a transformation technique is proposed to transform the production system in the form of AOA (activity-on-arrow) diagram into a network-structured CPN. Second, by the decomposition technique, the transformed CPN is decomposed into paths for further network analysis.