Available online at www.sciencedirect.com
ScienceDirect
Computers & Industrial Engineering 54 (2008) 12–33
computers & industrial engineering
www.elsevier.com/locate/dsw

A comparative study of exponential distribution vs Weibull distribution in machine reliability analysis in a CMS design ☆

K. Das *

Department of Industrial and Manufacturing Systems Engineering, University of Windsor, 401 Sunset Avenue, Windsor, Ont., Canada N9B 3P4

Received 26 September 2006; received in revised form 1 May 2007; accepted 12 June 2007
Available online 17 June 2007

Abstract

The paper addresses machine reliability consideration by Weibull and exponential distribution approach in designing a cellular manufacturing system (CMS). A multi-objective mixed integer programming (MIP) model that considers machine system reliability and system cost simultaneously is presented to implement the approach. When a part has the option to be processed in alternative routes, the route with the highest system reliability can be selected by considering individual machine reliabilities along each route. A CMS design approach which selects processing routes for the part types with maximum system reliability, considering the machines along routes while optimizing system cost, will improve the overall performance of the system. The rerouting provision of the part types, integrated with the approach, will also help the user/designer to solve machine breakdown problems during processing of a part. This study offers the capability to model different failure characteristics, such as, an increasing, decreasing or constant machine failure rate. An example problem is solved to illustrate applicability of the model.

Keywords: Cellular manufacturing systems; Machine reliability; Exponential distribution; Weibull distribution; Part processing routes; Routing flexibility

1. Introduction

CMS has been recognized as an efficient manufacturing approach for discrete part manufacturers which seeks to achieve many advantages including reduction of set up times, cycle times, material handling costs, quality improvement, etc. Details of these advantages are reported in many impressive surveys (Askin & Estrada, 1999; Wemmerlov & Hyer, 1989). Ensuring right quality product with optimal cost and fulfillment of due dates have become the basic pre-requisites for the customer focused organizations of the present day manu-

☆ This manuscript was processed by Area Editor E.A. Elsayed.
* Tel.: +1 519 254 4658.
E-mail address: kkumardas@gmail.com

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doi:10.1016/j.cie.2007.06.030

facturing businesses. Though there are impressive survey results in favor of CMS implementation, some of the recent and past research (Agarwal & Sarkis, 1998; Boughton & Arokiam, 2000; Flynn & Jacobs, 1986; Morris & Tersine, 1990; and Suresh & Meridith, 1994) point out the disadvantages of CMS. The following are the main problems which can be drawn from these studies:

- flexibility is reduced compared to a job shop;
- machine utilization is reduced due to dedication of machines to cells;
- machine breakdown impacts the due date fulfillment adversely.

Machine reliability plays a major role to ensure the due date and achieve optimal cost. In the job shop situations machine breakdowns or machine reliability related problems can easily be handled by reloading the part onto a nearby machine due to the presence of more than one copy of each machine in close proximity. This same reliability related issue cannot be easily resolved in CMS unless it is designed and planned specifically for that purpose. Most of the existing CMS design models consider machines to be 100% reliable and, as such, parts are required to wait until the broken down machines are repaired. To handle the problem effectively the following steps may be planned:

(1) A proactive step to design the system to have the lowest failure probability for the machines along part routes.
(2) Including the provision to reroute a part incase of any machine failure.

Integration of the above two points will ensure due date fulfillment and improve the overall performance of the CMS by addressing most of the disadvantages of CMS mentioned earlier. This research proposes an approach of selecting machine routes with the highest system reliability for processing of each part type. It is obvious that system cost will increase when only reliability aspects are emphasized. To develop an effective CMS, the appropriate design approach should optimize cost and reliability simultaneously. In addition, incorporating provision for multiple routes for rerouting the parts in the case of machine failure will make the system more robust.

Analysis of machine reliability using the exponential distribution to model failure is popular because of the tractability of the approach. Another strong reason in favor of exponential model is perhaps the user perspectives. The exponential model is easy to understand, implement, and has been demonstrated in the literature to provide good approximations to machine failure distributions (Diallo, Perreval, & Quillot, 2001; Savsar, 2000; Yazhau, Molin, & Zhixin, 1995; etc.). Considering the practical situations that all manufacturing machines and plants have wear and tear effect and deteriorate with an increasing failure rate with increase in age, one may analyze manufacturing machines relevant to CMS using an increasing failure rate. Since, the exponential distribution has the practical limitation in representing reliability behavior of ageing machines; we resort to the Weibull distribution to model an increasing failure rate. The Weibull distribution is a versatile distribution which is expected to fit many different failure patterns (Ireson, Coombs, & Moss, 1996) by adjusting its distribution parameter values. Abernethy (1996) mentioned examples of machine tools and other engineering problems solved with Weibull analysis. The exponential distribution may be considered to be the specific case (shape factor $\beta = 1$ and characteristic life $\theta = 1/\lambda$) of the Weibull distribution. In this research both Weibull and exponential distributions have been used to analyze machine reliability in order to develop an effective CMS design model applicable to the random failure period as well as the wear out period of a machine's life cycle.

The remainder of the paper is organized as follows: relevant literatures are reviewed in Section 2. Reliability consideration of CMS design based on the exponential and the Weibull approach is presented in Section 3 to develop the objective of the model. The multi-objective MIP model for designing CMS is included in Section 4. An example problem is solved in Section 5 to illustrate the applicability of the model. Discussion and conclusions are given in Section 6.

2. Literature review

A large number of CMS design approaches have been proposed during the last 30 years with the noble aim of developing an effective CMS which will have the flexibility of functional layout and the efficiency of a