USING GENETIC ALGORITHM IN FMS PART ASSIGNMENT AND TOOL LOADING WITH RELIABILITY CONSIDERATIONS TOOL SHARING ALLOWED

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الملخص

تتطرق هذه الورقة لمفاهيم تحميل العدة وتعيين الجزء وتحديد الوفرة بأقل كلفة ومستويات المعولية (الاعتمادية) المثالية لنظام العدد في أنظمة التصنيع المرن. تتمثل المشكلة في تعيين (تخصيص) الأجزاء لمختلف الآلات لغرض تشغيلها باستخدام مختلف العدد المثبتة في الآلات حيث إن القرارات التي تشمل عدد العدد ونسخ العدة وتنفيذها يستغرق وقتا حقيقيا وحيث ان نظام التصنيع المرن يجب أن لا يكون مصمما لانجاز مهامه فقط وإنما لانجاز تلك المهام بنجاح فان متطلبات تصميم المعولية يجب أن تتم في مراحل تخطيط وتصميم النظام

إن أنظمة التصنيع المرن تبشر بطرق أكثر كفاءة وفعالية في استغلال الموارد والمعلومات والأصول النافعة ، ووفقا لقدرتها على حمل تنوع من العدد المختلفة فان لها القدرة على انجاز العمليات المختلفة اللازمة في إنتاج مختلف الأنواع من الأجزاء بحجم إنتاج قليل إلى متوسط . لقد تم تطوير نموذج رياضي حيث تتألف الصيغة من دالة هدف مع مجموعة قيود وتم تحديد أدنى مستوى معولية لنظام العدد ، وقد أعطى حل النموذج العدد الأمثل من العدد وكذلك نسخ العدة لكل نوع من أنواع العدد متلازما مع تعيين كل نوع من الأجزاء. إن الهدف النهائي هو تقليل الكلفة الكلية (كلفة التشغيل وكلفة العدة) مع تحقيق أقصى معولية مطلوبة لنظام العدد في نظام التصنيع المرن تحت الدراسة حيث تم بناء خوارزمية وراثية لهذا الغرض.

ABSTRACT

This paper considers the tool loading, part assignment and redundancy allocation for minimum cost and optimum tooling system reliability levels in flexible manufacturing systems (FMS). The problem is to assign parts to different machines for processing using different tools mounted on various machines. The decisions involving the number of tools and tool copies are carried and executed in real time. An FMS must not be designed to fulfill its intended functions only, but also to perform the intended functions successfully. The latter requires the design of reliability into the planning stages of the system. FMS promises more efficient and effective ways of utilizing resources, information and assets. Due to its capability to carry a variety of different tools so that it can perform different operations required in the production of a variety of low to mid size part types [1]. A mathematical model was developed; the formulation consists of an objective function with a set of governing constraints. Minimum tooling system reliability level is decided, the model solution gives optimum number of tools and tool copies for each tool type along with the part assignment of each part type. The overall objective is the minimization of the total cost (processing and tooling cost), while achieving maximum desired tooling system reliability for the FMS under consideration. A genetic algorithm (GA) is developed.

KEYWORDS: FMS; reliability optimization; Part assignment; Tool loading; Tool sharing; Genetic algorithms.

INTRODUCTION

FMSs are designed to attain a trade-off between the efficiency of transfer lines and the flexibility of job shops. FMSs are able to accomplish this trade-off due to their reduced level of human interaction and their ability to eliminate the setup times between consecutive operations. The changing market demands and intense competition have contributed to a need for flexibility and automation in manufacturing systems. Although such systems promise flexibility, they also generate new problems. Misconceptions in the design or mistakes in implementation can lead to unreliable systems with low level of availability, inadequate production efficiency, low reliability and high operational cost. A high degree of reliability is essential to justifying the investments. When FMS is employed for machining, assembly, or fabrication, they utilize sets of tools to perform different operations [2]. Such tools wear out, break out, or require resetting and maintenance to ensure successful operations. Industry data indicate that tooling accounts for approximately 30% of the fixed and variable cost of production in an automated machining environment [3]. A certain level of reliability is required of the tooling system to ensure uninterrupted production runs. Sufficient redundancies must be foreseen at the production planning stage in order to account for the random failure of tools. Whereas the cost of redundancy is a negative factor, the additional reliability gained is a positive one. Therefore, redundancy is an issue requiring economic justification. Figure (1) shows the planning model components.

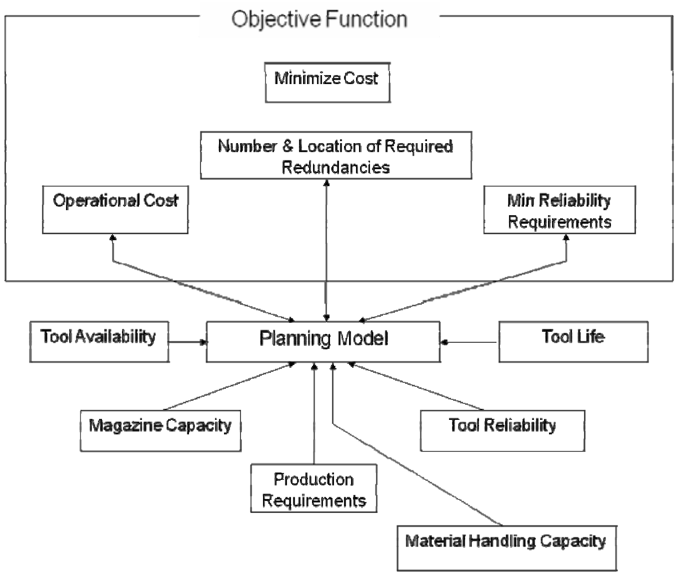

Figure 1: Planning Model Components

In the case where tool sharing is permitted, all tools within the system are available to all other machines in the entire system. However, tools will need to be passed back and forth between machines as required and to serve as means of reducing overall tooling system cost [4]. Tools transportation from one machine to the other involves lost production time, for both donor and recipient machines. This system configuration includes tool transporter as a new piece of hardware. Each time a tool is transported from one machine to the other, tool transporter carries away the worn tool into a specified location on the tool transporter device. Therefore, tool magazine capacity of any tool is not violated at any given time. Each tool on any given machine is actually backed-up by all other tools in the system; this in turn reduces the required number of tools in the system [5]. In such case and for reliability analysis, the aggregate processing time is independent of the machine on which any given tool is loaded. The tooling reliability in this case is a function of cumulative hazard rates and total number of spares for each tool type. The model was solved for various values of minimum required tooling system reliability. The total cost was observed for different values of minimum tooling system reliability levels. A tool transporter is ready to transport tools form tool storage room to different machines as well as to exchange tools amongst machines. If a particular tool is required on a machine is not available on its tool magazine, the tool transporter could bring the tool from another machine, where a spare tool is available. The model assigns parts to machines for different required operations and allocates tool and tool spares to different machines while minimizing total cost of operation [6].

An optimization technique was presented for determining optimal index positioning of cutting tools on machine tool magazines [7]. Position selection is performed using a genetic algorithm, which ranks a list of cutting tools assigned to certain machining operations together with total number of index positions available on machine magazine. A fitness function is used to evaluate the goodness of each solution in terms of total tool indexing time. Tool indexing is described as the process of automatic tool positioning and or changing on machine magazine or tool exchanger.

A genetic algorithm was applied to the reliability allocation problem of typical pressurized water reactor [8]. The Genetic Algorithms (GA) was used to determine the reliability of reactor systems, subsystems and major components of the system. Various cases were analyzed which, show the genetic algorithm is suitable for solving complex reliability allocation problems.

SYSTEM CONFIGURATION

The system under consideration consists of a number of machining centers. Parts enter the shop, if the local queue of the scheduled machine has the capacity to accommodate the batch to be reprocessed. Parts enter and leave the system by the common gangway. It is assumed that in general, all the operations required to be performed on a part can be done by a single CNC machine in the flexible manufacturing system. This is true as long as the required tools are available [9]. The model however, can accommodate the need of restricting a particular tool or operation to specific machine(s). Each machine has a tool magazine of a limited tool capacity. While the tools are interchangeable between the machines, the tool magazines are fixed to the machine.

ASSUMPTIONS

In the development of this model, the following assumptions were made, to simplify the modeling:

- The demand for each part type is known in advance, and will not change during the production period.
- All the spares of a particular tool type are assumed identical.
- Tool failures are independent of one other. Therefore, the failure of one tool does not affect the failure of another tool in the system.
- A machining center can perform all the required operations of the assigned parts, as long as the required tools are available in the tool magazine.
- Machining parameters such as feed, spindle speed, depth of cut, etc are determined before the production run, and do not change during the production run.
- The life of the tool transporter is much larger than the production period. So the tool transporter has a constant reliability during this period.
- The tool life distribution of all cutting tools is exponential. However, the mean would depend on the tool type. Stochastic, single catastrophic injuries to the tool are ignored.
- The detection of a tool failure is perfect, and the replacement of a tool is considered a renewal process.

MODEL DEVELOPMENT

The model discussed is formulated to assign tools to machines and to find the optimal number of spares to be carried by the system, so that the parts can be processed with a certain level of reliability. In the system considered, a part enters a machine, and then the cutting tools are utilized one after the other to perform their operations on the part. For reliability considerations this system can be considered as a series system, where the operations are performed in series, on a part clamped on the machine. To calculate the reliability of a tool type, the absolute life of the tool type should be known. The reciprocal of the absolute tool life would be 'λ' the hazard rate of the tool with an exponential failure distribution. The cumulative hazard function of such a tool would be 'λt' where t (for this context only) is the cumulative usage time of the component. A flow chart of the genetic algorithm model is given below, Figure (2).

Notations Used

i	: parts	i = 1, 2,… ., I
j	: operations	j = 1, 2,….., J
k	: machine index (from)	k = 1, 2,…., K
I	: machine index (to)	I = 1, 2,….., K
s	: tool index	s = 1, 2,… .., S
m_s	: spares index	m_s = 0, 1, 2,.., M

Decision Variables

X_{ijks} = Number of part type 'i' for which operation 'j' is performed on machine 'k' using tool type 's'.

Y_{klsms} = 1 If 'm' copies of tool type 's' are to be transported from machine 'l' to machine 'k' and 0 otherwise.

Parameters

C_{ijks}= Processing cost per unit time for performing the j^{th} operation of part type 'i' on machine 'k' using tool 's'.

T_{ijks}= Processing time of the j^{th} operation of part type 'i' on machine 'k' using tool type 's'.

q_i = Demand of part type 'i' for each production period.
C_s = Cost of tool type 's'.
E_k = Magazine capacity of machine 'k'.
T_s = Average tool life of tool type 's'.
A_s = Maximum available tools of tool type 's'.
Z_s = Number of slots required by tool type 's'.
R_{ks} = Reliability of the s^{th} tool on machine 'k'.
R_{kRq} = Minimum required tooling system reliability for each machine type 'k' in the system.

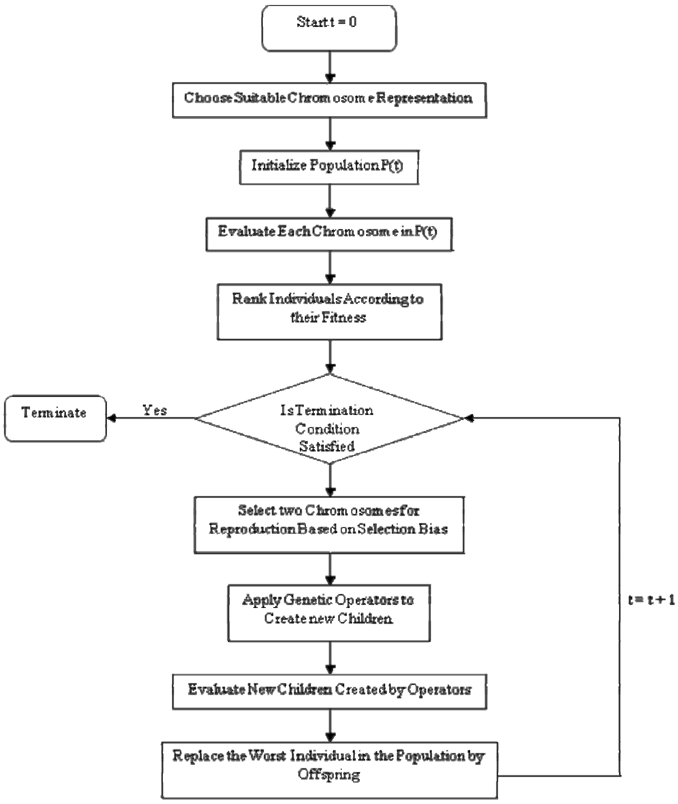

Figure 2: Genetic Algorithm Representation

Minimize

$$\sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{k=1}^{K}\sum_{s=1}^{S} C_{ikks} \;.\; t_{ijks} \;.\; X_{ijks} + \sum_{k=1}^{K}\sum_{l=1,l\neq k}^{K}\sum_{s=1}^{S}\sum_{m_s}^{M_s} C_s \;.\; m_s \;.\; Y_{klsm_s}$$

Subject to

Tool life requirements

$$\sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{k=1}^{K} t_{ijks} \;.\; X_{ijks} \leq \sum_{m_s}^{M_{ss}} T_s \;.\; m_s \;.\; Y_{klsms} \qquad \forall\; l \neq k, s \qquad (1)$$

Upper limit of tools available

$$\sum_{K=1}^{K}\sum_{l=1,l\neq k}^{K}\sum_{ms=0}^{Ms} m_s \;.\; Y_{klsm} \leq A_s \qquad \forall\; s \qquad (2)$$

Magazine capacity

$$\sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{s=1}^{S}\sum_{m_s=0}^{M_s} Z_s \;.\; m_s \;.\; Y_{klsm_s} \leq E_k \qquad \forall\; k,l,l\neq k \qquad (3)$$

Output requirements of each part type for a given production period

$$\sum_{K=1}^{K}\sum_{s=1}^{s} X_{ijks} = q_i \qquad \forall\; i,j \qquad (4)$$

Spare Tool requirements

$$\sum_{m_s=0}^{M_s} Y_{klsm} = 1 \qquad \forall\; k,l,l\neq k, s \qquad (5)$$

Minimum Tooling System Reliability Requirements

$$\prod_{s=1}^{S}\prod_{m_s=0}^{M_s} R_{klsm} \;.\; Y_{klsm} \geq R_{kR_l} \qquad \forall\; k,l,l\neq k \qquad (6)$$

The linearized form of equation (6) is then as follows;

$$\sum_{k=1}^{K}\sum_{l=1,l\neq k}^{K}\sum_{s=1}^{S}\sum_{m_s=0}^{M_s} \log\; R_{klsm} \;.\; Y_{klsm} \geq \log\; R_{kR_l} \qquad \forall\; s \qquad (7)$$

Where, X_{ijks} are integers and Y_{klsms} are 0/1 integers.
Where t is the cumulative working time for tool type'‘s’ in the system. The objective function of this model will minimize the overall tooling system cost when tool sharing is allowed for a preset tooling system reliability, which again is governed by the minimum tooling system constraint.

$$R^{ms}(t) = \prod_{k=1}^{K} \prod_{S=1}^{S} \left\{ \sum_{ms}^{Ms-1} \frac{(\lambda\ (t)_s\ ,\ dt)^{ms}\ \exp\left[-\int_0^t \lambda\ (t)_s\ ,\ dt \right]}{ms\ !} \right\} \qquad (8)$$

CONCLUSIONS

With the advent of complex and expensive manufacturing systems, reliability is an important performance index to evaluate a system. Tool reliability is a critical measure for the effectiveness of a Flexible Manufacturing System, and has a significant influence on overall system reliability. This paper aimed to evaluate the impacts of tool sharing on performance of FMSs, with respect to system reliability requirements. It has been shown that, in terms of reliability assessment, the tooling system of FMS can be treated as a series system with standby redundancies. It is also shown that reliability of such systems can be predicted with various failure distributions.

Based on distinct criteria, the model was developed to optimize the tooling cost of EMS. The model provides the number and location of required spares when a desired level of tooling system reliability is specified.

REFERENCES

[1] Rajamani, D and Adil, G. K. (1996), “Machine Loading in Flexible Manufacturing Systems Considering Routing Flexibility”, International Journal Advanced Manufacturing and Technology, 11, 372-3 80.

[2] Koo, P.H and Tanchoco, J.M.A. (1999), “Real-Time Operation and Tool Selection in Single Stage Multi machine Systems”, International Journal of Production Research, 37 (5), 1023-1039.

[3] Ayres, R. U. (1988), “Future trends in Factory Automation, Manufacturing review”, 1 (2), 93-103.

[4] Altumi, A. A. and Taboun, S. M. (2001), “Effect of Tool Sharing on the Reliability Optimization of Flexible Manufacturing Systems”, International Journal of Production Planning & Control, 12, 265-273.

[5] Altumi, A. A. (2000), “Reliability Optimization of FMS Tooling System with Redundancies Using Genetic Algorithms”, Proceedings of the 2000 Pacific Conference on Manufacturing, Southfield, MI., 554-559.

[6] Altumi, A. A., Philipose, A. M. and Taboun, S. M. (2000), “Modeling of FMS Tooling System with Reliability Considerations”, International Journal of Advanced Manufacturing Technology, 16 (8), 551-558.

[7] Dereli, T. and Filiz, I. H. (2000), “Allocating Optimal Index Positions on Tool Magazines Using Genetic Algorithms”, Robotics and Autonomous Systems, 33, 155-167.

[8] Yang, J. E., Hwang, M. J, Sung, T. Y., and Jin, Y. (1999), “Application of Genetic Algorithm for Reliability Allocation in Nuclear Power Plants”, Reliability Engineering and System Safety, 65 (3), 229-23 8.

[9] Avci, S. and Akturk, M. 5. (1996), “Tool Magazine Arrangement and Operations Sequencing on CNC Machines”, Computers and Operations Research, 23 (11), 1069-1081.