USING GENETIC ALGORITHM IN FMS PART ASSIGNMENT AND TOOL LOADING WITH RELIABILITY CONSIDERATIONS; NO TOOL SHARING ALLOWED

Abdulfatah Altumi

Mechanical & Industrial Engineering
Al-Fateh University, Tripoli, Libya

الملخص

تم تطبيق خوارزمية وراثية لتحديد الوفرة وبأقل تكلفة ومستويات المعولية (الاعتمادية) المثالية لنظام العدد في أنظمة التصنيع المرن. إذ انه وكلما زاد تطور نظم الإنتاج تعقيدا ومرونة زادت أهمية المنافسة والتكلفة. كما إن استخدام نظم العدد قد ساهم في تقليل الجودة ما بين متطلبات التصنيع المختلفة.

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 إن نظام التصنيع المرن يجب أن لا يكون مصمما لانجاز مهامه فقط وإنما لانجاز تلك المهام بنجاح فان متطلبات تصميم المعولية تكون في مراحل تخطيط 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 (بناء) 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 (تخصيص) 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.

ABSTRACT

In this research paper, application of genetic algorithms (GA) to flexible manufacturing systems (FMS) tooling system reliability in the context of the machine-loading and part assignment problem is investigated. As manufacturing systems become increasingly complex, competition and cost grow more rapidly. Flexible manufacturing systems became the means to narrow the gap between the various different pressures. 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 FMS can perform different operations required in the production of a variety of low to mid size part types. 0/1 integer-programming model is developed. The formulation considers an objective function with a set of governing constraints. Initially a reliability level is decided for the tooling system. The model will simultaneously return with optimum number of tools and tool copies for each tool type as well as the assignment of different operations of part types to different machines for processing. The overall objective is cost minimization while achieving maximum desired tooling system reliability for the FMS under consideration. The model developed considers an FMS where tool sharing is not allowed. Consequently, each tool magazine will be required to carry the required tools and tool copies on its magazine to achieve the reliability levels requirement and carry

the required machining operations on the different parts assigned to each machine during each production period.

KEYWORDS: FMS; Reliability; Optimization; Part assignment; Tool loading; Redundancy allocation; Mathematical modeling; Genetic algorithms.

INTRODUCTION

The difficulty of achieving high reliability in FMSs is due to the complexity and sophistication of the equipment and the requirement that large numbers of tools must work together without malfunctioning for long periods. In an attempt to improve a tool's reliability, one could easily over design the tool by choosing tools with higher ratings and greater safety margins. This would increase the size, weight, and cost of the tool. Trade off between size, cost, weight and reliability are necessary to reach a practical compromise. The reliability performance of an FMS under various different conditions is of utmost importance in the industrial world. The qualitative concepts of reliability are not new; its quantitative aspects have been developed over the past two decades [1,2]. These developments were the result of the demand for highly reliable systems and components with more safety and less cost. There exist several methods to improve systems reliability. Some of these methods approach the problem by using large safety factors, reducing the complexity of the system, increasing the reliability of constituent components through a product improvement program, using structural redundancy, and or practicing a planned maintenance and repair schedule.

When we study flexible manufacturing systems, we speak of highly sophisticated, technically complex and very expensive systems. FMSs are capital intensive and FMS users are concerned with achieving high system utilization [3]. An FMS is a system that is able to quickly respond to change and flexibility is the system's ability to respond effectively to that change [4]. Change varies with the conditions and circumstances under which FMS performs, these circumstances can be internal such as machine breakdowns, variations in processing times and quality issues. The external disturbances include, design changes, demand fluctuations and product mix. The ability of the system to survive internal problems can be made possible through the introduction of redundancy in the system. Whereas; the ability of the system to cope with external changes requires the system to be versatile. It would also need to be capable of producing a variety of part types with minimal changeover times and costs to switch from one type of product to another. These systems are prone to failure and as stated in the literature FMS tooling accounts for approximately 30% of the overall cost of the system [5]. This is true since an FMS contains a large number of expensive and specialized tools. When a tool failure occurs the system is halted and eventually a tool replacement takes place, a cost is associated with this event. The idle time is certainly unwelcome because of the different sequence of events related to it; these involve lost production, disturbances to end product volumes and the like.

MODEL DEVELOPMENT

0/1 integer programming model is developed for part routing and tool allocation of different tool types along with tooling system reliability requirements. The model includes tooling reliability constraints along with the conventional problem of resource allocations. The literature documents various types of formulations that deal with reliability improvements and or cost minimization of different system configuration through redundancy [6-8]. The following assumptions were made when the model was developed:

- The demand for each part type is known; and will not change during the production period. If the forecasted demand varies, proper adjustments are made.
- Tool failures are independent of one another. That is, the failure of one tool does not affect the failure of another tool in the system.
- Tool spares of each tool type are identical.
- Machining parameters including spindle speed, feed, depth of cut etc. is all known before the production period, and will not change during the production run.
- Each machine has limited tool magazine capacity; and hence only a limited number of copies of each tool type can be loaded on each machine.
- The changeover time on machine spindles is considered negligible; this is so due to its relative shortness when compared with the processing time of the different operations.
- The detection of tool failures is immediate and perfect. Tool magazines are replenished after each production period. Switch and tool exchange devices are 100% reliable.

Notations Used

i: parts	i = 1, 2, ….., I
j : operations	j = 1, 2,…..., J
k : machine index	k = 1, 2,…..., K
s : tool index	s = 1, 2, ….., S
m : spares index	m = 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_{ksms} = I If m copies of tool type 's' are to be loaded on 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.

Minimize

$$\sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{k=1}^{K}\sum_{s=1}^{S} Ci_{jks} \;.\; t_{ijks} \;.\; X_{ijks} + \sum_{k=1}^{K}\sum_{s=1}^{S}\sum_{m_s}^{M_s} C_s \;.\; m_s \;.\; Y_{ksm}$$

Subject to

Tool life requirements

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

Upper limit of tools available

$$\sum_{K=1}^{K}\sum_{m_s}^{M_s} \, . \, m_s \, . \, Y_{ksm_s} \leq A_s \qquad \forall \; k,s \qquad (2)$$

Magazine capacity

$$\sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{s=1}^{S}\sum_{m_s=1}^{M_s} Z_s \, . \, m_s \, . \, Y_{ksm_s} \leq E_k \qquad (3)$$

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

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

Minimum tooling system reliability requirements

$$\prod_{s=1}^{S}\prod_{m_s=0}^{M_s} Rksm_s \, . \, Yksm_s \geq RkR_q \qquad \forall \; k \qquad (6)$$

The linearized form of equation (6) is;

$$\sum_{s=1}^{S}\sum_{m_s}^{M_s} \log \; Rksm_s \, . \, Y_{ksm} \geq \log \; RkRq \qquad \forall \; k \qquad (7)$$

Where, X_{ijks} are integers and Y_{ksms} is a 0/1 variable which indicate that a machine ‘k’ has ‘m_s’ spares of tool type ‘s’. Thus (m_s .Y_{ksms}) gives the number of spares of tool type ‘s’, on machine ‘k’.

GENETIC ALGORITHM MODEL

The mathematical models developed work efficiently on small size problems. However, as the problem size becomes larger, the computational times increase exponentially due to the increased number of integer variables. This in turn makes it impossible for carrying out on time decisions; a genetic algorithm is developed to reduce computational times required for achieving optimal or near optimal solutions for large size problems [9]. There are several different algorithms that deal with the part assignment and tool loading problem; however, tooling system reliability coupled with the choice of multiple tool copies to boost overall tooling system reliability was not extensively studied. Figure (1) shows flowchart for the basic structure of a GA.

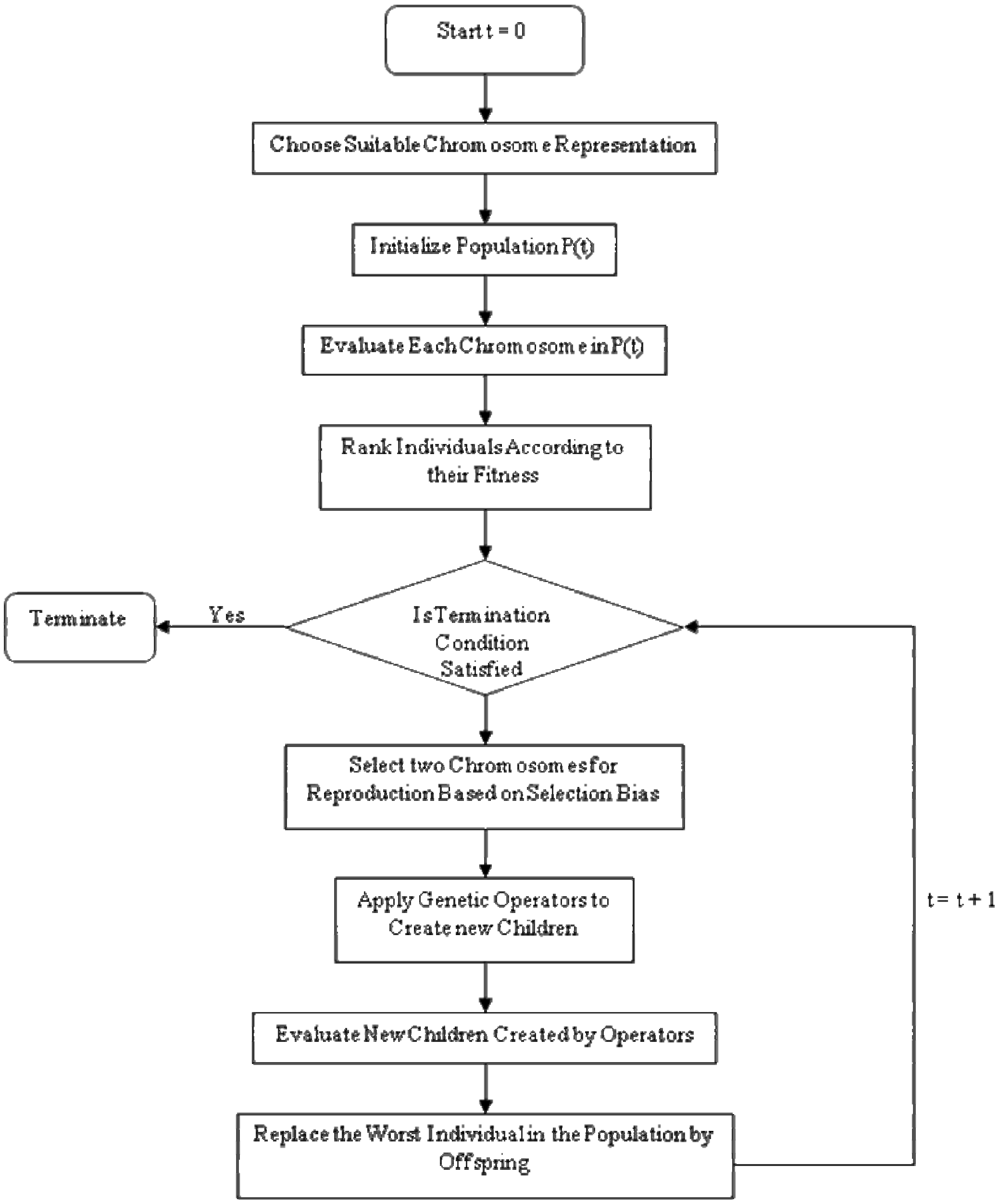

Figure 1: Genetic Algorithm Representation

For the optimization problem with reliability constraint, the GA needs to contain the following components:

1. A genetic representation for the different potential solutions to the problem.
2. A procedure for creating initial population.
3. Fitness functions to evaluate potential solutions.
4. Genetic operators for altering composition of off spring resulting from reproduction.

Parameter values such as population size, number of generations, crossover probability and location, etc.

Chromosome Representation

The first step in solving the cost minimization of the part assignment, tool-loading problem with a preset tooling system reliability level, is to choose an appropriate representation. The GA approach for the reliability problem in hand utilizes a permutation type representation. Potential solutions differ according to the operation-machine-tool-tool copy(s) assignments. Each chromosome embodies a list of operation-machine-tool and tool copy(s), which represents a potential solution to the problem. Different combinations of part-operation-machine-tool and tool copy(s) point to different sets of solutions, Figure (2). Each chromosome is composed of genes where each gene is constructed as follows:

[Part Number | Machine Number | Tool Type | Number of tool copy(s) assigned]

For illustration the chromosome representation of a problem, which consists of 2 part numbers, 2 machines and any number of copies as seen in Figure (2).

1 2 7 6	1 2 3 4	2 1 2 2	2 1 7 3
Operation 1, Part 1	Operation 2, Part 1	Operation 1, Part 2	Operation 2, Part 2

Figure 2: Chromosome Representation

The relative position of each gene in the chromosome represents the operation number for that part type. That is the first appearance of part 1 in the chromosome means the first operation. The second appearance is operation two of that part type and so on.

Initialization

Once the chromosome representation is completed, the creation of an initial population is started. The initial parameters along with a diversified population of solutions are selected; this is done in the following manner:

1. Set population size.
2. Set the number of generations.
3. Set selection bias, where selection bias is a floating number that sets the elected favor to be allocated for superior individuals in a particular population.
4. Read the processing times, processing cost, number of tools available of each tool type, tool life and reliability data for all tools.
5. Create initial population of solutions and name it old population.
6. Calculate the objective function for all the solutions present in the initial population using the reliability algorithm.
7. For initial generation; set new population = 1.

Recombination

Recombination is explained in the following steps;

1. Apply recombination to the old population to form a new population.
2. Select two parents from the initial population based on the following criterion:
3. Solution number to be selected is found through Roulette wheel relationship.
4. Simple crossover is applied to both selected feasible solutions (parents) to form a new feasible solution (offspring).
5. Objective function is calculated for the resulting offspring.

6. Objective function value of offspring is compared to that of all solutions in population. If value is better than any of the solutions in the population then replace offspring with that with worst objective function in population.

New Generation

If generation < new generation; then increment generation by 1 and the current generation becomes old population.
Go to 3.
If generation = new generation stop.
The best solution is the solution with lowest objective function value in the current population. This step serves as a counter in the GA process.

Genetic Parameters

The selection of best combination of genetic algorithm parameters is the most difficult and time consuming. In this problem, the genetic algorithm parameters are population size, selection bias and mutation, which represent the mutation rate. Different combinations of these parameters need to be tested in order to arrive at a suitable set for the tooling system reliability problem. The performance measure is cost minimization for various minimum tooling system reliability. The search process begins with the proper representation in the form of a feasible solution and evaluation of each solution in the population, and the application of genetic operators to this population for improved solutions. The process continues for a specified number of generations.

CONCLUSIONS

Earlier work in FMS was limited to the part assignment and tool-loading problem and ignored tooling system reliability as another limiting resource. The research related to FMS part assignment and tool allocation to date is also limited to analytical techniques and simulation techniques as well as heuristics. The main criticism to using analytical techniques is that for large-size problems, no optimal solution can be found in a reasonable amount of time. Simulation can potentially be expensive and time consuming to develop, debug and run for FMS planning. The accuracy of any simulation model is limited by the judgment and skill of the programmer. The other drawback is the large amount of time this search approach takes (compared to genetic algorithm) to reach an optimal or near optimal solution because of its experimental nature. The basic problem of using heuristics for part assignment, tool loading and tooling system reliability requirements is that they represent a set of locally greedy strategies that ignore the possibility for global optimization.

As Reliability gets considered at the early stages of the design process, changes can easily and economically be made. Necessary improvements and trade-off can be considered early in the design stage. Once the weaknesses in the tooling system are identified, solutions may include addition of spares, providing better quality tools or increasing reliability by shortening the predefined tool life. The objective of this research has been to use existing theory to develop a methodology that quantifies and incorporates reliability within the design of flexible manufacturing tooling systems and one that evaluates their performance during their operation. Consequently, the main contribution of this research is both methodological and practical. This indicates that the model and procedures developed constitute tools that can be used by designers and analysts of automated manufacturing systems. The constructed models are capable of describing and predicting the output of FMS. Models also permit the user to establish; a prior; desired tooling system reliability parameter levels; as well as other FMS operational parameter levels, within the design and/or operational phases of FMS activity.

It was realized that solutions obtained through analytical methods were time consuming, thus genetic algorithm was developed for the part assignment and tool loading in FMS with tooling system reliability considerations. Finally, genetic algorithms have been successfully developed and implemented for solving different optimization problems.

The present work contributes to the area of flexible manufacturing systems by introducing a cost minimization model that assigns parts to machines, tools to different machines for processing parts while satisfying a minimum level of tooling system reliability. The contributions of this research paper are summarized as follows:

- An integer programming model for the part assignment, tool loading problem in FMS with tooling system reliability considerations has been developed.
- A genetic algorithm model to solve developed model has been developed.
- Costs are minimized through the use of the optimal number of spare tools in order to process the assigned parts operations.

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