MACHINE LOADING IN A FLEXIBLE MANUFACTURING SYSTEM

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BY

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CERTIFICATE

This is to certify that the thesis entitled, —Machine Loading in A Flexible Manufacturing System by Anshuman Tripathy is in partial fulfillment of the requirements for the award of Bachelor of Technology Degree in Mechanical Engineering at National Institute of Technology, Rourkela (Deemed University), and is an authentic work carried out by him under my supervision. To the best of my knowledge the matter embodied in the thesis has not been submitted to any University/Institute for the award of any Degree or Diploma.

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ABSTRACT

The following project thesis addresses a vital pre-release decision that directly affects the operational effectiveness of a flexible manufacturing system- the machine-loading problem. Flexible manufacturing is a concept that allows manufacturing systems to be built under high customized production requirements. Issues such as cutting down of inventories and shortened product life cycles, reducing the cost of products and services to grab more market shares, etc have made it almost compulsory for many companies to switch over to flexible manufacturing systems (FMSs) as a viable means to accomplish the above goals while producing consistently good quality and cost effective products. The combinatorial and NP-hard nature of this problem makes it arduous to secure the best solutions. The objectives are minimization of the system unbalance and maximization of throughput, whereas the system's technological constraints are determined by the availability of machining time and tool slots. Due to the large number of random sequences generated as the number of jobs increase, an eliminator function displays and computes the system unbalance and throughput only for a fixed number of sequences, thus improving the quality of the solution and reducing the computational burden. The proposed algorithm is tested on three problems sourced from literatures and shows promising results and optimal solutions.

INTRODUCTION

Globalization, suddenly changing market requirements and the trends of modern living have thrown several tremendous challenges to manufacturing industries. The success of any manufacturing industry is determined by its ability to respond proactively to the rapidly changing market and produce high quality products at low costs. Product cost is no longer the prevalent agent affecting the manufacturers' production decisions. Other equally important factors valid in the present day scenario, such as flexibility, quality, efficient delivery and customer satisfaction are drawing their equal focus. Automation, robotics and other innovative concepts such as just-in-time (JIT), Production planning and control (PPC), enterprise resource planning (ERP) etc. are some of the many concepts that aid manufacturing in industries. Flexible manufacturing is a concept that allows manufacturing systems to be built under high customized production requirements. Issues such as cutting down of inventories and shortened product life cycles, reducing the cost of products and services to grab more market shares, etc have made it almost compulsory for many companies to switch over to flexible manufacturing systems (FMSs) as a viable means to accomplish the above goals while producing consistently good quality and cost effective products. According to Stecke [1983], an FMS is characterized as "an integrated, computer-controlled complex arrangement of automated material-handling devices and numerically controlled (NC) machine tools that can simultaneously process medium-sized volumes of a variety of part types".

The various types of flexibility that are required by a flexible manufacturing system are:

- **Machine Flexibility**. It is the ability of a given machine in the system to adapt to a wide range of operations and part types.
- **Mix Flexibility**. It is defined as the ability to produce the same parts in different proportions according to the change needed, while maintaining the production quantity.
- **Product Flexibility**. The ability of the system to change over to a set of new products economically and quickly in response to the changing requirements.
- **Routing Flexibility**. It can be defined as the ability to produce parts on an alternative workstation in case of breakdowns, tool failures, and any other hindrances.
- **Volume Flexibility**. It is the capacity of the system to change the production volumes to respond to the changes in demand while remaining profitable.

Types of FMS (depending upon the number of machines):

1. **Single machine cell (SMC)**
2. **Flexible manufacturing cell (FMC)**

3. **A Flexible Manufacturing System (FMS)**

   Depending upon the level of flexibility:

   - **Random FMS**: It is designed to produce a large variety of part types.
   - **Dedicated FMS**: It is designed to produce only a particular variety of part types.

   A flexible manufacturing system combines the best of both- the capability of the transfer line and flexibility of a job shop. However, acquiring the technology for flexible production is extremely expensive; to say the least, and initial capital investment by firms is very high. Hence, the developmental phase of any FMS, when the planning process is carried out, is extremely crucial as it evaluates the performance of the system, and justifies the high investment. Therefore, the operational success of a FMS needs more careful planning than any traditional production system.

The decisions pertaining to FMS operations can be classified into- pre-release and post-release decisions. Prerelease decisions include the FMS operational planning problem that deals with the pre-arrangement of jobs and tools before the processing begins, whereas post-release decisions deal with the scheduling problems (Stecke, 1983). Machine loading is a pre-release decision and is considered one of the most important planning decisions pertaining to production as it largely determines the performance of the FMS. Machine loading, to be precise, deals with the allocation of jobs to various machines under technological constraints, such as the available machining time and tool slots, In order to meet certain performance measures, such as the reduction of system unbalance or increasing the throughput.

LITERATURE REVIEW

The various literatures relating to the loading problem in a FMS are reviewed, according to the methods/approaches used.

The four major methods used to solve machine loading problems are:

a) Optimization-based/Mathematical Programming

b) Multi-criteria Decision-Making Based

c) Simulation Based

d) Heuristic oriented

a) Mathematical Programming Approaches

i) Stecke (1983) gave the first mathematical formula for grouping in FMS loading, as non linear 0-1 mixed integer programs (MIPs). It was assumed that the mix problem of is already solved and thus the model is suitable only for a dedicated FMS.

ii) A model incorporating goal programming was used by O‘Grady and Menon !1987) to load a real life FMS.

iii) A branch-and-bound algorithm was proposed by Berrada and Stecke (1986) in order to balance the workloads on various machines.

b) Multi-criteria Decision-Making Based

i) Ammons et al. proposed a bi-standard target for the loading problem, i.e., equilibrating workloads and reducing visits to the workstations.

ii) Shanker and Tzen (1985) approached the machine-loading problem in a random FMS with the bi-standard target of meeting the finishing times of the jobs and equilibrating the workload amongst the machining centers.They formulated a simulation model and examined the effects of loading on system performance under different dispatching rules.

iii) Swarnkar and Tiwari (2004) approached the loading problem of a FMS having the bi-standard objectives of minimizing the system unbalance and maximizing the throughput, using a hybrid algorithm running on the principles of tabu search and simulated annealing (SA).

c) Simulation Based

i) Stecke and Solberg (1981) had performed a simulation for dedicated FMS studying five loading strategies versus 16 dispatching rules.

ii) Gupta et al. (1999) portrayed a consigning approach for FMSs where all part types were stored in a central temporary storage unit. Parts were chosen by pre-determined loading rules.

d) Heuristic oriented methods

i) Mukhopadhyay et al.(1998) proposed a heuristic solution to the machine-loading problem in FMS by creating the concept of essentiality ratio for the goal of minimalizing SU and maximizing the throughput.

ii) Tiwari et al. (2000) worked with static pre-set job succession norms as input to their propounded heuristics of disturbance scheme known as ‘modified insertion scheme‘ for creating new job sequences.

iii) Vidyarthi and Tiwari (2001) propounded a fuzzy-based approach to solve the loading problem in a FMS. Honghong Yang and Zhiming Wu created a mixed integer-programming model that combines part type selection and machine loading.

PROBLEM DESCRIPTION

The loading problem in manufacturing deals with selecting a subset of jobs from a set of all jobs to be manufactured and assigning their operations to the relevant machines in a given planning horizon with technological constraints in order to meet certain performance measures, such as the minimization of system unbalance and the maximization of throughput. [Ref 1]

Key Terminologies/Assumptions

- **System Unbalance** is equal to the sum of all the unused or overused times on all the machines. Minimization of SU=Maximization of Machine Utilization.
- **Throughput** is equal to the sum of all the batch sizes of the jobs that have been accepted for production.
- **Essential Operations** can only be carried out on a specific machine using a fixed number of tool slots.
- **Optional Operations** can be performed on more than one machines using the same or different amount of tool slots and processing times.
- **The batch size, processing time and the tool slots required for each operation of the job are known beforehand.**

- **This dissertation approaches the loading problem in a RANDOM FMS.**
- **Overloading is NOT permitted.**

Hence the objective functions that are used to approach the loading problem in this dissertation are:

- Minimization of SU
- Maximization of Throughput
- A union of minimization of SU and the maximization of Throughput

In order to minimize the complexities, the following assumptions are made when analyzing the FMS loading problem [Ref 1] :

1. Initially, all of the jobs and machines are simultaneously available.
2. The processing time required to complete an entire job order is known a priori.
3. The job undertaken for processing is to be completed for all of its operation before considering a new job; this is called non-splitting of the job.
4. The operation of a job once started on a machine is continued until it is completed.
5. The transportation time required to move a job between machines in negligible.
6. The sharing and duplication of tool slots is not allowed.

Mathematical Notations Used To Model The Loading Problem

I: number of iterations/number of job sequences generated

J: total number of jobs

M: total number of machines

j: job types, j=1,2,…J

o: operation number of job j

m: machine types, m=1,2,…M

$Slot_m$: tool slot capacity of machine m

$Time_m$: available time on machine m

$Stime_m$: length of scheduling period for the m^{th} machine

$Slot_m$: available slots on machine m

$Batch_j$: batch size of job j

$Slot_{ojm}$: number of tool slots required for processing operation ‘o’ of job ‘j’ on machine ‘m’

Set(j,o): set of machines on which operation ‘o’ of job ‘j’ can be performed

$Ptime_{ojm}$: processing time of operation ‘o’ of job ‘j’ on machine ‘m’

$Rtime_m$: remaining time on machine m

$Rslot_m$: remaining slots on machine m

A_j= **1**(if job 'j' is selected)

0(otherwise)

A_{ojm}=**1**(if operation 'o' of job 'j' is assigned to machine 'm')

0(otherwise)

OBJECTIVE FUNCTION

Minimization of SU, the system unbalance

$$SU = \sum_{m=1}^{M} Stime_m - \sum_{m=1}^{M} \sum_{j=1}^{J} \sum_{o=1}^{O_j} Batch_j \, Ptime_{ojm} \, A_{ojm}$$

(1)

The constraints are

The job is loaded if and only if tool slots are available on the machine.

$$\sum_{j=1}^{J} \sum_{o=1}^{O_j} Slot_{ojm} A_{ojm} <= Slot_m \qquad \text{for } m=1,2,....M$$

A particular operation of a job is done only on one machine.

$$\sum_{G \in Set(j,o)} A_{ojG} <= 1 \qquad \text{for } j=1,2,...J \text{ and } o=1,2,...O_j$$

The job cannot be split.

$$\sum_{o=1}^{O_j} \sum_{m=1}^{M} A_{ojm} = A_j O_j \qquad \text{for } j=1,2,....J$$

PROPOSED METHODOLOGY

Let us deliberate and evaluate the number of decision variables and constraints for a typical machine loading problem. Assuming, say,

Number of jobs (J) = 6

Number of operations for each job (O_j) = 2

Number of machines (M) = 4

Then,

Total number of decision variables = J*((M*O) + 1) = 54

Total number of constraints = J +M + M + J*O = 26

Thus, there can be a fairly large number of combinations in which operations of the part type can be assigned on the different machines while satisfying all the technological and capacity constraints. These operation–machines allocation combinations are evaluated using two common performance measures: system unbalance and throughput.

However, the values of system unbalance and throughput vary for each assigned job sequence, as some jobs may eliminated in each sequence since they do not satisfy the technological and capacity constraints. Hence a number of job sequences need to be evaluated to find the optimal job sequence, by considering the minimum SU and maximum throughput. Take for instance, a loading problem with 8 jobs.

Number of possible job sequences = 8! = 40320

The computational burden would be too high, and the possibility of finding an optimal solution extremely faint in such a situation.

Thus, while creating the proposed algorithm, the number of iterations was fixed, and could be changed if needed. The computational effort was significantly lessened, and the chance of finding an optimal solution was increased.

PROPOSED ALGORITHM

Step 1: Input the total number of available machines, jobs, batch sizes, tool slots on each machine, operations of all jobs (both essential and optional), and the processing time of each operation of every job.

Step 2: Input the number of iterations (n), where (i=1,….,n) (the number of job sequences to be generated).

Step 3: Get the initial sequence (i=1) and do the following:

a) First, load the essential operation on the machine if and only if the available machining time and available tool slots on the machine is greater than the time and the tool slots required by the essential operation ; otherwise, reject the job.

b) then, load the optional operation on the machine if and only if the available machining time and tool slots on the machine is greater than the time and the tool slots required by the optional operation on the basis of the machine having the maximum available time ; otherwise, reject the job.

Step 4: Terminate if the maximum number of iterations is reached (i=n). Otherwise, go to step 2.

RESULTS AND DISCUSSIONS

The proposed algorithm for the loading problem was coded in Dev-C++ in C language, and the program was used to create .IN and .OUT files displaying the input data and the results. The results include the sequences generated and the system unbalance for each, followed by the minimum system unbalance for the given iterations. The performance of the algorithm is evaluated by using two benchmark problems available in the open literature. The output is displayed by opening the .OUT file using notepad, and exhibiting the screenshot.

CONCLUSION

The primary objective of this paper is to develop an efficient algorithm to solve the machine loading problem of a random FMS. The proposed algorithm reduces the computational burden due to the number of iterations being fixed, and displays the minimum system unbalance achieved within those iterations.

SAMPLE PROBLEM 1

JOB	BATCH SIZE	OPERATION NUMBER	MACHINE NUMBER	UNIT PROCESSING TIME(MINS)	TOOL SLOTS NEEDED
1	15	1	4,2	10,12	2,2
2	10	1 2	1 3	20 35	1 2
3	12	1	1	22	3
4	9	1	3,2	25,25	1,1
5	16	1 2	4,2,3 1,4	30,25,27 16,16	2,1,2 1,1
6	11	1	2	21	3

SOLUTION (DISPLAYED AS .OUT FILE IN NOTEPAD)

i=40

pr1 - Notepad

File Edit Format View Help

```
1 2 3 4 6 5 704
1 2 3 5 4 6 464
1 2 3 5 6 4 464
1 2 3 6 4 5 704
1 2 3 6 5 4 704
1 2 4 3 5 6 704
1 2 4 3 6 5 704
1 2 4 5 3 6 440
1 2 4 5 6 3 440
1 2 4 6 3 5 704
1 2 4 6 5 3 440
1 2 5 3 4 6 464
1 2 5 3 6 4 464
1 2 5 4 3 6 464
1 2 5 4 6 3 464
1 2 5 6 3 4 464
1 2 5 6 4 3 464
1 2 6 3 4 5 704
1 2 6 3 5 4 704
1 2 6 4 3 5 704
1 2 6 4 5 3 440
1 2 6 5 3 4 440
1 2 6 5 4 3 440
1 3 2 4 5 6 704
1 3 2 4 6 5 704
1 3 2 5 4 6 464
1 3 2 5 6 4 464
1 3 2 6 4 5 704
1 3 2 6 5 4 704
1 3 4 2 5 6 464
1 3 4 2 6 5 894
1 3 4 5 2 6 464
1 3 4 5 6 2 464
1 3 4 6 2 5 894
1 3 4 6 5 2 854
1 3 5 2 4 6 464
1 3 5 2 6 4 464
1 3 5 4 2 6 464
1 3 5 4 6 2 464
1 3 5 6 2 4 464

440
```

SAMPLE PROBLEM 2

JOB	BATCH SIZE	OPERATION NUMBER	UNIT PROCESSING TIME(MINS)	TOOL SLOTS NEEDED	MACHINE NUMBER
1	8	1	18	1	3
2	9	1 2 3	25 24 22	1 1 1	1,4 4 2
3	13	1 2	26 11	2 3	4,1 3
4	6	1 2	14 19	1 1	3 4
5	9	1 2	22 25	2 1	2,3 2
6	10	1 2 3	16 7 21	1 1 1	4 4,2,3 2.1
7	12	1 2 3	19 13 23	1 1 3	3,2,4 2,3,1 4
8	13	1 2 3	25 7 24	1 1 3	1,2,3 2,1 1

SOLUTION(DISPLAYED AS .OUT FILE IN NOTEPAD)

i=40

pr2 - Notepad

File Edit Format View Help

```
1 2 3 4 5 6 8 7 923
1 2 3 4 5 7 6 8 923
1 2 3 4 5 7 8 6 911
1 2 3 4 5 8 6 7 911
1 2 3 4 5 8 7 6 911
1 2 3 4 6 5 7 8 923
1 2 3 4 6 5 8 7 923
1 2 3 4 6 7 5 8 923
1 2 3 4 6 7 8 5 718
1 2 3 4 6 8 5 7 718
1 2 3 4 6 8 7 5 718
1 2 3 4 7 5 6 8 923
1 2 3 4 7 5 8 6 911
1 2 3 4 7 6 5 8 923
1 2 3 4 7 6 8 5 718
1 2 3 4 7 8 5 6 718
1 2 3 4 7 8 6 5 718
1 2 3 4 8 5 6 7 718
1 2 3 4 8 5 7 6 718
1 2 3 4 8 6 5 7 718
1 2 3 4 8 6 7 5 718
1 2 3 4 8 7 5 6 718
1 2 3 4 8 7 6 5 718
1 2 3 5 4 6 7 8 923
1 2 3 5 4 6 8 7 923
1 2 3 5 4 7 6 8 923
1 2 3 5 4 7 8 6 911
1 2 3 5 4 8 6 7 911
1 2 3 5 4 8 7 6 911
1 2 3 5 6 4 7 8 753
1 2 3 5 6 4 8 7 753
1 2 3 5 6 7 4 8 753
1 2 3 5 6 7 8 4 753
1 2 3 5 6 8 4 7 753
1 2 3 5 6 8 7 4 753
1 2 3 5 7 4 6 8 923
1 2 3 5 7 4 8 6 911
1 2 3 5 7 6 4 8 753
1 2 3 5 7 6 8 4 753
1 2 3 5 7 8 4 6 495

495
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