University of Tabriz

11th Iranian Conference on Manufacturing Engineering

19-21 Oct. 2010
University of Tabriz

Society of Manufacturing Engineering of Iran

# MACHINE LOAD BALANCING BASED ON MINIIMIZING SYSTEM UNBALANCE IN A FLEXIBLE MANUFACTURING ENVIRONMENT

**Amir Musa Abazari *, [1], Maghsud Solimanpur and Hossein Sattari [3]**

*1. Master of Science Student, Faculty of Engineering, Urmia University, am.abazari@gmail.cpm*
*2. Associate Professor, Faculty of Engineering, Urmia University, m.solimanpur@urmia.ac.ir*
*3. Master of Science Student, Faculty of Engineering, Urmia University, hossein.sattari@gmail.com*

## Abstract

Operational effectiveness of flexible manufacturing systems largely depends on a good quality solution to the machine loading problem (MLP). Thus, this problem is considered as a vital pre-release decision-making problem in a manufacturing environment. Since MLP affects performance of manufacturing systems, this problem has been considered by several researchers in recent years and some techniques, meta-heuristic and heuristic procedures have been suggested to obtain a local optimal solution for this problem. This paper formulates machine loading problem as a linear mathematical programming model to determine an exact solution for it. The objective function of the proposed model is to minimize the load variation between machines. The proposed model has been coded in Lingo 8 Software environment. Some benchmark problems are solved through the proposed model with Lingo Software and results are compared with those available in the literature. The solutions of the proposed model are obtained in an acceptable time and it can result in a significant cost-effectiveness in a mass production environment.

**Keywords:** machine load balancing - machine allocating - linear mathematically programming - lingo coding

## 1. Introduction

The manufacturing industry is presently being affected by the structural changes caused the internal and external factors for an enterprise. The market conditions are becoming more dynamic, more global and more customers driven. The manufacturing performance is no longer driven by the product price; instead other competitive factors such as flexibility, quality delivery, and customer service have become equally important. The demand of the customer for tailored product has resulted in a shorter product life, reduced batch quantities and increased product varieties. Manufacturing firms need to give prominence to issues such as reduction of manufacturing lead time and flexibility to adapt to changes in the market. The improvement in productivity and reduction of costs of goods and services has become the key for maintaining the market share.

Over the past years, the concept of flexible manufacturing system (FMS) has emerged as a viable answer to the problems of flexibility and efficiency. A flexible manufacturing system (FMS) can be defined as an integrated configuration of numerical control (NC) machine tools, other auxiliary production equipment, and a material handling system designed to simultaneously manufacture a low to medium volumes of a wide variety of high quality products at low cost [1]. Operations management in a FMS is more complex than that of the conventional manufacturing systems. The benefits that can be accrued due to installation of an FMS are: increased machine utilization, fewer machines, reduction in required factory floor space, greater responsiveness to changes, reduced inventory requirements, lower manufacturing lead times, reduced direct labor requirement, higher labor productivity, opportunity for automated production, etc. [2].

The optimal selection of machines and tools and the assignment of part operations to the selected machines turn out to be difficult tasks for the production planner. This is due to the versatile machine tools capable of performing many different operations resulting in many alternative routes for a part type, and due to system capability for processing of the parts concurrently [3].

The decisions related to FMS operations are of two types: pre-release and post release decisions. Pre-release decisions include the FMS 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 of the FMS. Various types of pre-release decision problems are part type selection, machine grouping, determining of production ratios, batching of the part type, allocation of pallets and fixtures and allocations of operations and tools among machines i.e. loading problem [2, 3]. Among pre-release decisions, machine loading is considered as one of the most vital production planning problems because performance of FMS largely depends on it. Loading problem, in particular, deals with allocation of jobs to various machines under technological constraints with the objective of meeting certain performance measures.

Stecke [3] formulated the loading problem in a flexible manufacturing system as a non-linear mixed integer program with the objective of balancing the workloads. Kusiak [4], Stecke and Morian [5], Singhal et al. [6] and van Looveren et al. [7] have addressed interrelationship of various decisions and their hierarchies in FMS. Kim and yano [8] also presented a number of heuristic approaches for loading problems in flexible manufacturing systems; Kim and Yano [9] also presented a model of the loading problem in FMS with unequal workload targets across machine groups, and demonstrated how an existing branch-and-bound algorithm for the workload balancing objective may be used to solve the model. Stecke and Raman [10] presented a queuing network production planning model to determine the optimal machine work load assignments in an FMS. Liang [11] proposed a two stage approach to the joint problem of part selection, machine loading and machine speed selection problem in FMS. In the first stage, the mathematical model solves the part selection and machine loading problem, whereas in the second stage, it determines the optimal cutting speed for all job-tool-machine combinations.

Ammons et al. [12] resolve the loading problem considering a bi-criteria objective of balancing workload and minimizing work stations visits whereas Shankar and Tzen [13] consider balancing workload and meeting due-date of part types. Tiwari et al. [14] and Mukhopadhyay et al. [15] tackle machine loading problem using heuristic approaches with an objective of minimizing system unbalance and maximizing throughput. Prakash et al. [16] used a modified immune algorithm for machine

loading problem with considering minimization of system unbalance and maximization of throughput as their objective function by taking into account the technological constraints such as available machining time and tool slots on machines and considered both under-utilized and over-utilized times on machines for calculating system unbalance.
In summary, the machine loading problems pertaining to automated manufacturing systems belong to the category of NP-hard problems. To illustrate the complexity associated with machine loading problems, assume the data shown in Table 1.

**Table 1. Description of problem no.10 (adopted from Mukhopadhayay et al. [15]).**

| Job | Batch size | Operation number | Unit processing time | Machine number |
|---|---|---|---|---|
| 1 | 13 | 1 | 7 | 3 |
| | | | 7 | 4 |
| | | 2 | 8 | 1 |
| | | | 8 | 4 |
| | | 3 | 9 | 2 |
| 2 | 9 | 1 | 9 | 3 |
| | | 2 | 8 | 4 |
| | | 3 | 8 | 1 |
| | | | 8 | 3 |
| 3 | 9 | 1 | 11 | 1 |
| | | 2 | 10 | 2 |
| 4 | 11 | 1 | 10 | 3 |
| | | 2 | 9 | 4 |
| | | 3 | 13 | 1 |
| 5 | 13 | 1 | 25 | 1 |
| | | | 25 | 2 |
| | | | 25 | 3 |
| | | 2 | 7 | 2 |
| | | | 7 | 4 |
| | | 3 | 20 | 4 |
| 6 | 12 | 1 | 14 | 3 |
| | | 2 | 19 | 1 |

There exist 6 jobs, which can be sequenced in 6! ways, all together 48 combination of operation–machine allocation are possible for one of the job sequences. Hence, for 6! job sequences the total number of possible allocation turns out to be $48 \times 6! = 34560$. Some of these allocations are not possible because they are not able to satisfy system constraints such as available machining time. Enumerating an optimal/near optimal solution in such a huge search space is computationally complex.
In this article, machine loading problem can be viewed as selecting a subset of jobs

from the job pool and allocating them among machines. The objective considered is minimization of system cost based on minimization of system unbalance and so gaining maximum profit while satisfying the constraints, viz. available machining time. Furthermore, the unit cost of working machines out of time and their being free of work costs is assumed to be 1 in this paper to make the results of the proposed model comparable with those reported for other methods in the literature. The proposed model has been tested on ten problems and the results are compared with solutions obtained by Modified Immune Algorithm reported in Prakash et al. [16] and Shankar et al. [17]. Results show that the proposed model is very reliable and efficient.

The paper is organized as follows. In section 2, problem environment is described and modeled. In section 3, the results of proposed model are compared with the Modified Immune Algorithm (MIA) [16] and Shankar et al. [17]. The conclusions are given in section 4.

## 2. Experimental Procedures

### 2.1. Problem description

The FMS under consideration in this paper consists of a number of multifunctional CNC machines and tools with the potential to execute several operations, automated material handling devices and other amenities, where several types of jobs arrive with varied processing requirements. Jobs are available in batches and some of them are to be selected for processing during a given planning horizon. Job selection and loading constitute two major components of a tactical planning problem of any FMS. The job selection problems are concerned with selecting the sets of jobs to be produced during the upcoming planning horizon while the loading problem involves allocation of operations.

A job includes one or more operations and each of them can be performed by one or more machines. The particularities related to the production requirement of the job, number of operations for each job and their machining time required by each operation of each job are known in advance. Essential and optional types of operations are allied with each job. Essential operations of a job means that this operation can be performed only on a particular machine whereas optional operations imply that they can be carried out on a number of machines with the same or varying processing time. In this problem, the flexibility lies in the selection of a machine for processing the optional operations of the jobs.

The machine loading problem can be defined as "…given a set of jobs to be produced, using a set of resources such as material handling systems, pallets and fixtures, how the job be assigned so that some measures of productivity is optimized".

The complexity associated with machine loading problem has been discussed in the previous section. Due to such a large complexity, it is fairly difficult to evaluate the optimal solution of operation allocations on machines in the presence of several alternatives for the given problem.

In the following subsections, formulation of objective functions and constraints are discussed in detail.

### 2.2. Units, terminology and symbols

The notations used to demonstrate the proposed model are shown below.

Subscripts

j index of job; $1 \le j \le J$
m index of machine; $1 \le m \le M$
o index of operation; $1 \le o \le O_j$

Parameters

$U_m$ under-utilized time on machine m
$O_m$ over-utilized time on machine m
$T_m$ time available on machine m
$C_m$ unit cost of being free of work machine m
$C'_m$ unit cost of working machine m out of time
$b_j$ batch size of job j
$t_{jom}$ time required by machine m for operation o of job j

Decision variables

$$x_{jom} = \begin{cases} 1 & \text{if operation o of job j is assigned to machine m,} \\ 0 & \text{otherwise.} \end{cases}$$

$$y_j = \begin{cases} 1 & \text{if job j is selected,} \\ 0 & \text{otherwise.} \end{cases}$$

### 2.3. Mathematical model

The machine loading problem described above is formulated here as fallows:
The objective is to minimize the cost of under- loading of machines and over-loading of them as formulated below:

$$Min. \sum_{m=1}^{M} C_m U_m + \sum_{m=1}^{M} C'_m O_m$$

Subject to the following constraints:

1. Over-loading and under-loading of machines are permitted. This can be expressed as:
$$\sum_{j=1}^{J} \sum_{o=1}^{O_j} b_j \, t_{jom} x_{jom} + U_m - O_m = T_m \,, \qquad \forall m \in 1, \dots, M$$
2. Once a job is considered for processing, all the operations are to be completed before undertaking a new job (non-splitting of job), and once a machine is selected for an operation, it has to be completed on the same machine (unique job routing). This can be expressed as:
$$\sum_{m \in B(j,o)} x_{jom} = y_j \,, \qquad \forall j \in 1, \dots, J, \forall o \in 1, \dots, O_j$$
3. Decision variables are binary. This can be expressed as:

$$x_{jom} = 0,1 \qquad y_j = 0,1$$

4. Under utilized and over utilized times of machines must be positive:

$$U_m, O_m \geq 0$$

The $C_m$ and $C'_m$ in objective function may be easily attached with weights. However, for the sake of simplicity and compatibility of our model results with those in articles for comparison, we have considered an equal weight to both parameters i.e. we assumed $C_m$ and $C'_m$ equal to unit.

## 3. Results and Discussion

To be comparable with the literature, we assume Cm ,C'm=1 for all machines, i.e. the unit cost of working machines out of time and their being free of work costs is assumed to be 1. The attempted model has been coded in Lingo Software. Performance of the proposed model is evaluated based on some benchmark problems adopted from the literature [15]. The proposed model is tested on ten benchmark problems and the results are compared with those reported in Prakash et al. [16] and Shankar et al. [17]. The solutions for ten problems are given in Table 2 and the comparative results are given in Table 3. From results, it can be seen that the proposed model performs better than the Modified Immune Algorithm (MIA) presented in [16] and Shankar et al. [17].
Furthermore, for showing the robust of proposed model throughput of the system for all problems are taken account for comparison with those in the literature. Throughput refers to unit of job produced when all the jobs in a sequence is allowed for loading in the machine in the system. Figure 1 compares system unbalance (a) and throughput (b) obtained by different methods through a bar chart.

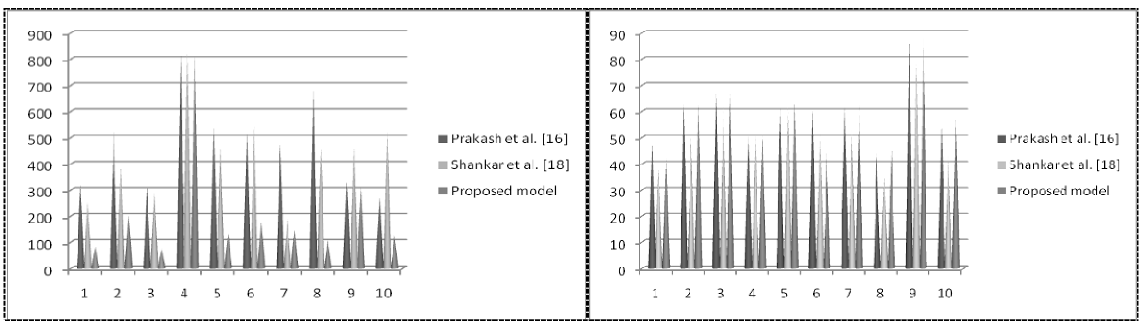
**Table 2. Summary of results obtained by the proposed model.**

| Problem number | Jobs assigned | Jobs unassigned | System unbalance | Throughput |
|---|---|---|---|---|
| 1 | 1,5,7,8 | 2,3,4,6 | 81 | 42 |
| 2 | 1,3,4,5,6 | 2 | 202 | 63 |
| 3 | 2,3,4,5 | 1 | 72 | 69 |
| 4 | 1,2,3,4,5 | - | 819 | 51 |
| 5 | 1,2,3,4,6 | 5 | 133 | 64 |
| 6 | 2,4,5,6 | 1,3 | 178 | 46 |
| 7 | 1,2,3,4,6 | 5 | 147 | 66 |
| 8 | 1,5,6,7 | 2,3,4 | 111 | 46 |
| 9 | 1,2,3,4,5,6,7 | - | 309 | 88 |
| 10 | 1,2,4,5,6 | 3 | 127 | 58 |

**Table 3. Comparison of proposed model with the MIA [16] and Shankar et al. [17].**

| Problem number | Total number of jobs | Prakash et al. SU | Prakash et al. TH | Shankar et al. SU | Shankar et al. TH | Proposed model SU | Proposed model TH |
|---|---|---|---|---|---|---|---|
| 1 | 8 | 318 | **48** | 253 | 39 | **81** | 42 |
| 2 | 6 | 524 | 63 | 388 | 51 | **202** | **63** |
| 3 | 5 | 312 | 69 | 288 | 63 | **72** | **69** |
| 4 | 5 | 819 | 51 | 819 | 51 | **819** | **51** |
| 5 | 6 | 536 | 61 | 467 | 62 | **133** | **64** |
| 6 | 6 | 518 | **61** | 548 | 51 | **178** | 46 |
| 7 | 6 | 477 | 63 | 189 | 54 | **147** | **66** |
| 8 | 7 | 677 | 44 | 459 | 36 | **111** | **46** |
| 9 | 7 | 333 | 88 | 462 | 79 | **309** | **88** |
| 10 | 6 | 272 | 56 | 518 | 44 | **127** | **58** |

*Note:* Bold digit showing the best results; SU: System Unbalance TH: Throughput




a b

**Figure 1. Column chart of results (a:SU, b:TH) illustrated in table 3.**

## 4. Conclusion

The main contribution of this research is to develop an efficient mathematical programming model for solving the machine loading problem for a random FMS. The objective of the loading problem considered in this research is the minimization of system cost based on minimization of system unbalance and so gaining maximum profit while satisfying the constraints, viz. available machining time. Some computational experimentation has been carried out to assess the effectiveness of the proposed model. Computational results indicate that the proposed model provides very promising solutions compared with those of Modified Immune Algorithm [16] and Shankar et al. [17].

It should be pointed out that the proposed solution methodology uses a fixed, predetermined sequencing rather than using a sequencing rule or determining the optimum. To rectify this shortcoming, one can easily solve this problem by using various sequencing rules and then selecting the best solution.

It is worth noting that application of the proposed model is limited to certain cases where there are sufficient number of jigs, fixtures, pallets and automated guided vehicles (AGVs) available in the shop floor. The work may be extended further by imposing constraints on the availability of these resources.

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