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Meta-hierarchical-heuristic-mathematical- model of loading problems in flexible manufacturing system for development of an intelligent approach

Ranbir Singh[a*], Rajender Singh[b] and B.K. Khan[c]

[a]*Research Scholar, Deptt. of Mech. Engg., DCRUST Murthal, Sonipat (Haryana), 131039, India*
[b]*Professor, Deptt. of Mech. Engg., DCRUST Murthal, Sonipat (Haryana), 131039, India*
[c]*Director, MSIT Jagdishpur, Sonipat (Haryana), India*

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A B S T R A C T

Flexible manufacturing system (FMS) promises a wide range of manufacturing benefits in terms of flexibility and productivity. These benefits are targeted by efficient production planning. Part type selection, machine grouping, deciding production ratio, resource allocation and machine loading are five identified production planning problems. Machine loading is the most identified complex problem solved with aid of computers. System up gradation and newer technology adoption are the primary needs of efficient FMS generating new scopes of research in the field. The literature review is carried and the critical analysis is being executed in the present work. This paper presents the outcomes of the mathematical modelling techniques for loading of machines in FMS's. It was also analysed that the mathematical modelling is necessary for accurate and reliable analysis for practical applications. However, excessive computations need to be avoided and heuristics have to be used for real-world problems. This paper presents the heuristics-mathematical modelling of loading problem with machine processing time as primary input. The aim of the present work is to solve a real-world machine loading problem with an objective of balancing the workload of the FMS with decreased computational time. A Matlab code is developed for the solution and the results are found most accurate and reliable as presented in the paper.

1. Introduction

Flexible Manufacturing System in 1960's has evolved with the composition of machines with different capability and capacity constraints. Installation of flexible manufacturing system can be increased through research with physical significance and practical approach & acceptance. In coming decades, the diversity has reduced to negligible amount with technological improvements and advances with the development of advanced CNC's, tool changers, tool transportation systems, automatic material handling system, developments in computer technologies etc. The acceptance and installation of FMS is much lower than expected because of higher installation, running and maintenance cost. FMS is the most

* Corresponding author. Tel: +91-9813043366
E-mail: ranbirsheoran@gmail.com (R. Singh)

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accepted manufacturing strategy in the Computer Integrated Manufacturing system. The FMS is composed of a large number of CNC's, with automatic material handling systems, automatic storage and retrieval system, robots, automatic tool changers, tool transporters, which involve a higher installation and running cost. Thus the cost of installation and operating a FMS needs to be initially identified and approved. Production planning is the pilot element in estimating manufacturing cost which is the ever ending research element for any strategy. As the objectives of production planning varies, which requires optimization ideas to implement for different cost reduction manufacturing functions, the need of research arises.

There are a large number of production planning objectives, and different types of manufacturing industries require single or combination of different production planning objectives. Along with the large number of different production planning objectives there are various kinds of objectives. Thus the problem pertaining to multi-production planning objectives coupled with evaluation of multi optimization objectives needs to be investigated. One of the production planning problems is the loading of machines. The elements of loading are the jobs, machines, tools and operations under constraints to achieve some objectives. Manufacturing has different operational requirements; the operations can be performed on different machines using various tools in different times. The same operation can be performed in different times on same machine with various tools, and also in different times on different machines, and there are some capacity and technical constraints and some objectives. Hence as the number of elements, constraints and objectives increases, the complexity of the problem increases too. There are three types of grouping in FMS yielding three various kinds of environments for the loading problem in an FMS, i.e., no grouping, partial grouping, and total grouping (Lee & Kim, 2000).

To increase the acceptability of FMS, the group technology requirement of FMS needs to be modified from no grouping to full grouping as per the requirement of the manufacturing industry for their survival in today's global customer driven market. Also the multi-vendor concept has also evolved in the market, which has changed the concept of FMS from a group of machines to a group of systems. The small scale industries (SSI) and medium scale industries (MSI) these days are striving for their existence. The major factor is the lack of manufacturing strategy in SSI and MSI. Manufacturing strategy is responsible for the life, health and growth of the firm. The stronger is the manufacturing strategy of the firm, the more is its stability in market, the higher the level of its growth. A manufacturing industry survival in the market depends mainly on the manufacturing strategy. The strategy requirement of SSI and MSI is the flexibility requirement of job shop production and productivity of line layout for multi vendor solution for their survival and growth. To optimally utilize the machines and tools the production planning needs to be carried out prior to scheduling, i.e. loading of machines. The present work focuses on the development of Hybrid-Hierarchical-Heuristic-Mathematical-Model of Loading Problems in Flexible Manufacturing System for Throughput Optimization for loading of machines in FMS.

2. The literature review

A model is a representation of the construction and working of some system of interest which is similar to but simpler than the system it represents. It enables the analyst to predict the effect of changes to the system. The beauty of any model lies in its close approximation to the real system, incorporation of its salient features and minimum complexity. An important issue in modelling is model validity. According to Maria model validation techniques include simulating the model under known input conditions and comparing model output with system output (Maria, 1997). Mathematics, heuristics, queuing theory etc. have been utilized for modelling various types of complex problems of FMS's. Different modelling methods and approaches utilized by earlier researchers for modelling FMS's, particularly the loading problem of FMS's have been identified, analyzed, classified and presented them in tabular form. Table 1 is review of literature on mathematical modelling of loading problem of FMS.

Table 1
Mathematical modelling of loading problem of FMS

Author	Loading objectives	Results
	(i) **Mixed Integer Programming (MIP)**	
Stecke (1981)	Balance assigned machine processing time, maximize number of consecutive operations on each machine and sum of operation priorities	Linearization methods are suggested Results are applicable for a particular range of problems
Stecke (1983b)	Grouping and loading	Need to decrease computational time
Ammons et al. (1985)	General loading problem for discrete optimization	Heuristics improves computational efficiency & effectiveness
Berrada & Stecke (1986)	Minimize machines workload	Heuristics gives efficient solution
Wilson (1992)	Balancing of workload	Used approximate solution technique linearization is necessary
Taboun & Ulger (1992)	Minimize cost	Computational requirements for large size problems are impractical
Stecke & Brian (1995)	Optimize real-time solution of loading problems	Requirement of real-time FMS control Impractical computational time and cost requirements for nonlinear MIPs Optimal solution is cost inefficient in real
Lee et al. (1997)	Minimize subcontracting costs	Iterative algorithms were developed Research on such problems is needed to develop planning software that can be actually implemented in real systems
Lee & Kim (1998)	Minimize earliness, tardiness costs and subcontracting costs	Iterative procedures were developed Computer generated test results
Dobson & Nambimadom (2001)	Minimize scheduling cost	Heuristics provides more optimal solution
Swarnkar & Tiwari (2004)	Minimize system unbalance and maximize throughput	Proposed tabu search and simulated annealing-based hybrid heuristic approach Exhaustive computations were required
Sujono & Lashkari (2007)	Minimize manufacturing cost and maximize compatibility	Validated by numerical example
Jahromi & Tavakkoli (2012)	Minimize production cost	heuristic method is proposed
Kim et al. (2012)	Balancing of workloads	Suggested two-stage heuristics
	(ii) **Integer Programming (IP)**	
Stecke (1983a)	Maximize throughput and machine utilizations	Future need to develop efficient heuristic algorithms for more real life solution
Stecke (1986)	Optimal allocation ratios	Developed queueing network model where information is suppressed
Greene & Sadowski (1986)	Minimize make span, flow time and lateness	Identified variables and constraints necessary to solve real world program
Sarin & Chen (1987)	Minimize machining cost	Lagrangian relaxation is proposed
Ventura et al. (1988)	Minimize make-span	Heuristic algorithms are proposed
Henery et al. (1990)	Balancing of workload and maximize flexibility	Mathematical solution was found impractical
Rajamani & Adil (1996)	Routeing flexibility	Routing flexibility is required for rigid loading schedules
Nayak & Acharya (1998)	Minimize number of batches	heuristic has been proposed
Ozdamarl & Barbarosoglu (1999)	Minimize the holding cost	GA-SA hybrid heuristics were developed
Lee & Kim (2000)	Minimize maximum workload	Better performance with partial grouping than total grouping, solved by heuristics
Kumar & Shanker (2000)	Genetic algorithms for constrained optimization	GA shows near-optimum performance and need of modern heuristic techniques
Kumar & Shanker (2001)	Balancing of workloads	Results are in agreement with previous findings
Yang & Wu (2002)	Balancing of workloads	Tested for small size test problems only
Gamila & Motavalli (2003)	Minimize total processing time	Used computer generated data for validation
Tadeusz (2004)	Minimize inter-station transfer time	Very high computational effort is required for realistic problems
Chan et al. (2004)	Minimize system unbalance and maximize throughput	Validated only for small set of test problems Require further extension of research
Chen & Ho (2005)	Minimize flow time & tool cost and workload unbalancing	multi-objective genetic algorithm (GA) is proposed
Bilgin & Azizoglu (2006)	Optimization of total processing time	near-optimal solution in reasonable time
Nagarjuna et al. (2006)	Minimize system unbalance	Proposed heuristic yields good results Further extension of work is required
Goswami & Tiwari (2006)	Minimize system unbalance and maximize throughput	Performed extensive computational experiments
Kumar et al. (2006)	Minimize system unbalance and maximize throughput	Proposed constraint-based genetic algorithm comprehensive exploration of research is required
Turkcan et al. (2007)	Minimize tardiness and manufacturing cost	Used sequential and simultaneous approaches for solution
Biswas & Mahapatra (2007)	Minimize system unbalance	need to consider more realistic variables and constraints
Biswas & Mahapatra (2008)	Minimize system unbalance with improved solution quality and reduced computational effort	Proposed particle swarm optimization based meta-heuristic approach Future study to solve the loading problem for multiple-objective framework is required
Ponnambalam & Kiat (2008) Yogeswaran et al. (2009)	Bi-criterion objective to minimize system unbalance and maximize throughput	Used Particle Swarm Optimization Need of further optimization GA-SA hybrid algorithms were proposed
Ozpeynirci & Azizoglu (2010)	Maximize total weight of the assigned operations minus total tooling cost	Used Lagrangian relaxation approach for near optimal results
Mandal et al. (2010)	Maximise throughput and minimize system unbalance & make-span	Need to solve the problem in a more realistic environment with more objectives Felt the need of new solution methodology
Yusof et al. (2011)	Balancing of productivity and flexibility	Proposed harmony search algorithm Optimization based methods tend to become impractical with the increase in problem size
Mgwatu (Mgwatu, 2011)	Machining optimisation and part scheduling sub-problems	two-stage sequential methodology was adopted
Yusof et al. (2011)	Minimize system unbalance and increase throughput	Proposed hybrid GA-Harmony Search algorithm Need to solve multi-objective real life large scale machine loading problems
Murat & Erol (2012)	Minimize system unbalance	Proposed hybrid simulated annealing-tabu search algorithm
Yusof et al. (2012)	Minimize system unbalance and maximize throughput	Proposed constraint-chromosome genetic algorithm and identified the need to solve the problem for solve multi-objectives
Kumar et al. (2012)	Minimize system unbalance and maximize throughput simultaneously	Proposed GA-PSO based meta-hybrid heuristic technique
Yaqoub & Abdulghafour (2012)	Meeting delivery dates and reducing manufacturing cost	Need of further research for cost oriented analysis
Abazari et al. (2012)	Maximize profitability and utilization of system	Evaluated unconstrained results by mathematical programming model Felt the need to solve the problem optimally
Mahmudy et al. (2012)	Maximize throughput and balancing of system	Proposed real coded genetic algorithms Stated the requirement of more powerful GA
Kosucuoglu & Bilge (2012)	Minimize total distance travelled by parts	Need of research for multi-objective meta-heuristic solution
	(iii) **Integer constraint**	
Kouvelis & Lee (1991)	Minimizae operating cost	Need to avoided non-linearity to reduce computational time
	(iv) **Goal Programming (GP)**	
Kumar et. al. (1991)	Grouping	Sequential search algorithms were developed Solution obtained by box-complex method
Atmaca & Erol (Atmaca & Erol, 2000)	Maximize throughput, workload balancing and minimize material handling	Tested for small problems

The loading problems of FMS were observed to be modelled with Mathematical Modelling during the period of 1981-2012. Most of the developed mathematical model are not suitable to solve large problems (Nayak & Acharya, 1998). Taboun and Ulger (1992) concluded that computational requirements of mathematical model for large size problems can be impractical (Taboun & Ulger, 1992). Wilson (1992) outlined that linearization is necessary (Wilson, 1992) for near real and optimal results. Further Table 2 outlines the research carried out with modelling loading of machines in FMS with heuristics.

Table 2
Modelling loading of machines in FMS with heuristics

Athor	Title	Conclusion
Stecke (1983a)	Maximize throughput and machine utilizations	Need exists to develop efficient heuristic algorithms for more real life solution
Stecke & Talbot (1983)	Minimize part movements, balancing and unbalancing of workload	None of the developed heuristics was able meet the need of all FMS
Hsu & De-Matta (1997)	Recognize infeasibility of a loading solution	Proposed Lagrangian-based heuristics Need of research to develop better methods
Shankar & Tzen (1985)	Minimize workload & system unbalance and number of late jobs	Developed heuristic methods
Ammons et al. (1985)	General loading problem for discrete optimization	Heuristics improves efficiency and effectiveness
Shankar & Tzen (1985)	Minimize workload & system unbalance and number of late jobs	Proposed heuristic and sequential methods
Shankar & Srinivasulu (1989)	Bi-criterion objective of minimizing workload unbalance and maximizing the throughput	Problem with machine-dependent processing times need to be solved
Mukhopadhyay et al. (1992)	Minimize system unbalance	Heuristic approach was proposed
Kato et al. (1993)	Batch formation to minimize total number of required tools	Heuristic approach was proposed
Roh & Kim (1997)	Minimize total tardiness	Solved with limiting part visit to one machine for entire processing and outlined need of practical research
Farkas et al. (1999)	Workload balancing and maximize capacity utilization	Results are demonstrated
Rahimifard & Newman (2000)	Elimination of tardy jobs	Evaluated series of computer based experiments
Tiwari & Vidyarthi (2000)	Minimize system unbalance and maximize throughput	GA-based heuristic were proposed for optimal solution
Tiwari et al. (2007)	Minimize system unbalance and maximize throughput	Genetic algorithm based heuristics were found more efficient than fixed job sequencing rules
Mukhopadhyay et al. (1998)	Minimize system imbalance	Proposed modified insertion scheme Reported higher computational time
Basnet (Basnet, 2012)	Minimize system unbalance	Hybrid GA was presented Stated the need for better heuristics Outlined the need of empirical research

Heuristics was the name of a certain branch of study, not very clearly circumscribed, belonging to logic, or to philosophy or to psychology often outlined, seldom presented in detail. A wide range of heuristics procedures have been developed for different manufacturing strategies. Stecke (1986) stated that for large loading problems, heuristics should be used to find good solutions. The loading problems of FMS excessively depend on efficient heuristics for optimum results. Almost all the researcher during 1983-2013, felt the need of heuristics development for efficient practically acceptable results because the computational cost and time requirement are very less compared to any other technique (Stecke, 1986). Heuristics has been used by many researchers since 1983 for modelling loading of machines in FMS. Literature review outlines that none of the developed heuristics was able meet the need of all FMS (Stecke, 1983a; Stecke & Talbot, 1983; Hsu & De-Matta, 1997; Basnet, 2012), thus the need to have a better heuristics for realistic solution is major literature gap. The heuristics always showed improved results with realistic and practical nature with reduced computational requirements whenever used to solve the machine loading problem.

2.1. Major findings from the literature review

Mathematical formulation increases the accuracy of the result on the other hand results in complexity resulting with increased computational requirements. There is a need to develop realistic mathematical model with less computational requirements (Swarnkar & Tiwari, 2004; Tadeusz, 2004). The computational requirements are major identified issues (Stecke, 1983b). literature also reveals that much of the information is usually suppressed in pure mathematical model (Stecke, 1986) may lead to impractical solution (Co et al., 1990). Thus mathematical modelling also needs to be combined with some other techniques to yield practically acceptable realistic results with reasonable computational requirements. There is a need to develop efficient heuristic algorithms for more real life solution (Stecke, 1983a). Requirement of further extension of research was outlined by all researchers (Chan et al., 2004;

Nagarjuna et al., 2006; Kumar et al., 2006). A real life solution to machine loading problems of FMS with a new solution methodology is still awaited (Yusof et al., 2012; Biswas & Mahapatra, 2008; Ponnambalam & Kiat, 2008; Mandal et al., 2010; Yusof et al., 2011; Yusof, Budiarto, & Venkat, 2011; Abazari et al., 2012; Petrovic & Akoz, 2008). Researchers also felt the need of real-time FMS control (Stecke & Brian, 1995) and to develop planning software that can be actually implemented in real systems (Lee et al., 1997). Ammons et al. (1985) stated that the use of heuristics in model development improves computational efficiency & effectiveness and provides more optimal solution (Berrada & Stecke, 1986; Ammons et al., 1985; Dobson & Nambimadom, 2001). Heuristic based methods are more robust in practicality (Yusof et al., 2011). Infeasibility of results can be controlled by condition check on heuristics (Hsu & De-Matta, 1997). The major issue for need to further reduce computational requirements was outlined in 1983 (Stecke, 1983b) and is still existing (Mandal et al., 2010; Abazari et al., 2012; Mahmudy et al., 2012; Prakash et al., 2008). Heuristics is found to be most suited. Heuristic reasoning is often based on induction, or on analogy. Heuristics are defined as the set of rules that provides optimal or non-optimal solution to the problem with less computational work (Greene & Sadowski, 1986). With these research gaps and findings to fulfil the research demand the present paper proposes a heuristics--mathematical meta-model for loading of machines in FMS.

3. Model presentation

A hybrid hierarchical-heuristic-mathematical modelling and solution methodology has been developed for the optimum utilization of resources in a FMS. The following notations were used for modelling the loading problem.

Variables

J_i	Job number, with i as job index	$i = 1,2,\dots,I$
M_x	Machine number with x as machine index	$x = 1,2,\dots,Z$
O_y	Operation number with y as operation index	$y = 1,2,\dots,Y$
To_z	Tool number with z as tool index	$z = 1,2,\dots,Z$
t	Time index	$t = 1,2,\dots,T$
t_{ixyz}	Time requirement by job "J_i" on machine "M_x" for operation "O_y" with tool "To_z" (hrs)	
t_{ix}	Material (Job) handling time for job "J_i" on machine "M_x" (min)	
C_{xz}	Cost of machining per unit time on machine "M_x" with too "To_z" (in Rs/min)	
C_{ix}	Handling (Job) cost for job "J_i" on machine "M_x" (in Rs/min)	
Av_z	Available number of tool type "To_z"	
Mc_x	Tool Magazine capacity of machine "M_x"	
TAl_x	Tools allocated to machine "M_x"	
To_{ixy}	Number of tools required for operation "O_y" on machine "M_x" of job "J_i"	

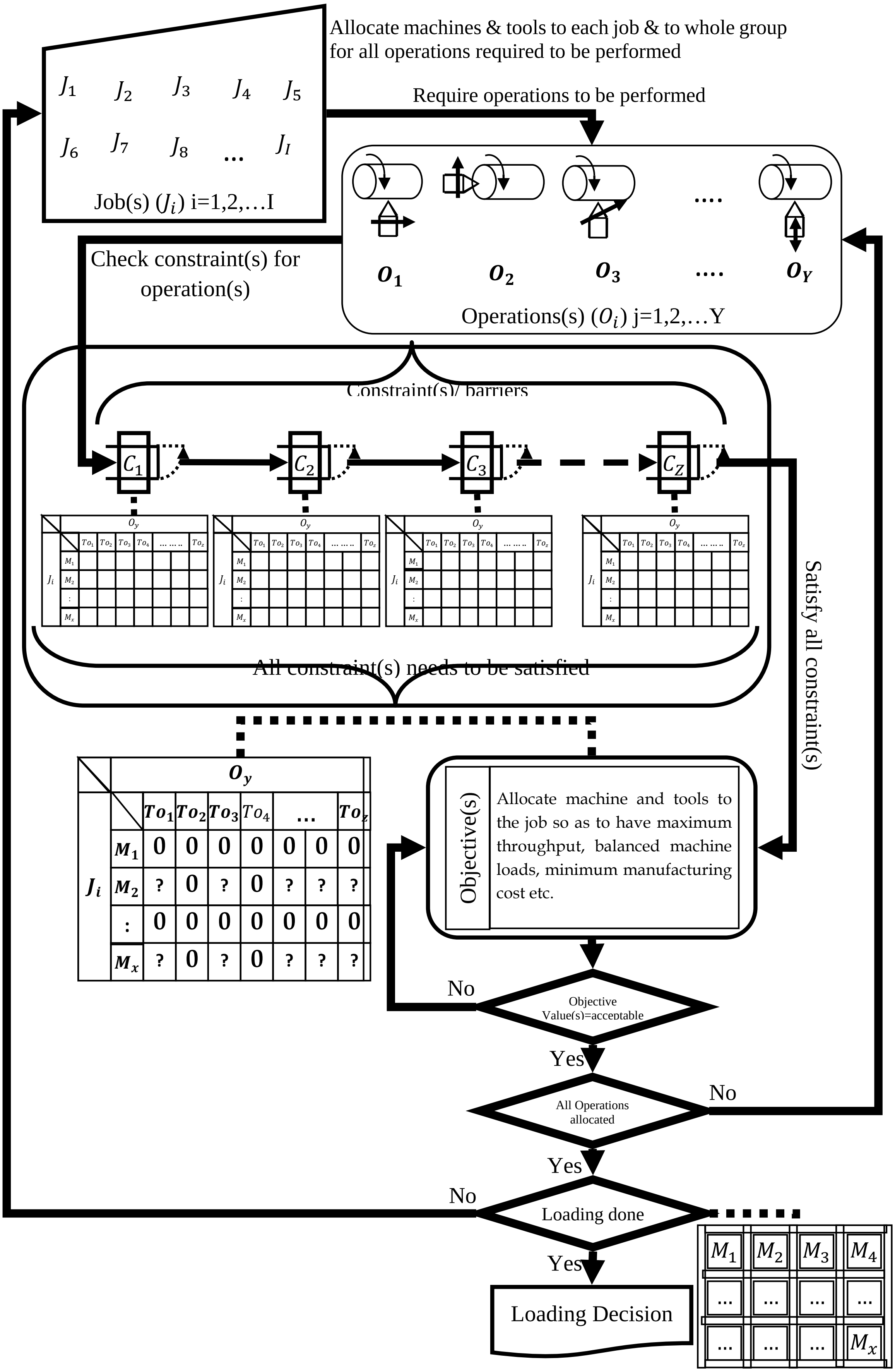

Fig. 1. Diagrammatic representation of the loading problem

Objective function is $Min(F)$

where,

$$F = Min\left[Min\left(\sum_{x=1}^{X} Min(f_1)\right) - Min(f_2) + Min(f_3)\right] \tag{1}$$

where,

$$f_1 = Min\left(\sum_{i=1}^{I}\sum_{y=1}^{Y}\sum_{z=1}^{Z}(t_{ixyz})(l_{\boldsymbol{ixyx}})\right) \tag{2}$$

$$f_2 = Max\left(\frac{I * X}{\sum_{i=1}^{I}\sum_{x=1}^{X}\sum_{y=1}^{Y}\sum_{z=1}^{Z}(t_{ixyz})(l_{\boldsymbol{ixyx}})}\right) \tag{3}$$

$$f_3 = min\left(\sum_{i=1}^{I}\sum_{y=1}^{Y}\sum_{z=1}^{Z}(l_{\boldsymbol{ixyz}})(t_{ixyz}) - \sum_{i=1}^{I}\sum_{y=1}^{Y}\sum_{z=1}^{Z}(l_{\boldsymbol{i(x+1)yz}})(t_{i(x+1)yz})\right) \approx 0 \qquad \forall\, \boldsymbol{M_x}, x = 1,2,,(X-1) \tag{4}$$

Decision variables and constraints

$$\sum_{y=1}^{Y}\sum_{x=1}^{X}\sum_{z=1}^{Z}(l_{\boldsymbol{ixyz}}) = \sum_{y=1}^{Y}\sum_{x=1}^{X}(M_{ixy})(To_{\boldsymbol{ixy}}) \;\; \forall\, \boldsymbol{O_y}\ of\ \boldsymbol{J_i}\ and\ i,\;\; i = 1,2,,I\ \&\ y = 1,2,,Y \tag{5}$$

$$\sum_{x=1}^{X}\sum_{z=1}^{Z} l_{\boldsymbol{ixyz}} = \sum_{x=1}^{x}(M_{ixy})(To_{\boldsymbol{ixy}}) \quad \forall\, \boldsymbol{O_y}\&\boldsymbol{J_i}\ , \qquad i = 1,2,,I\ \&\ y = 1,2,,Y \tag{6}$$

$$\sum_{x=1}^{X}(M_{ixy}) = 1 \quad \forall\, \boldsymbol{O_y}\ of\ \boldsymbol{J_i}, and\ i,\;\; i = 1,2,,I\ \&\ y = 1,2,,Y \tag{7}$$

$$M_{xy} = \begin{Bmatrix} 1\ if\ \ machine\ \boldsymbol{M_x}\ can\ perform\ operation\ \boldsymbol{O_y} \\ 0\ otherwise \end{Bmatrix} \tag{8}$$

$$M_{\boldsymbol{xy}} = \begin{Bmatrix} 1\ \ if\ \left[\left(\sum_{i=1}^{I}\sum_{y=1}^{Y}\sum_{z=1}^{Z} l_{\boldsymbol{ixyz}}\right) + To_{\boldsymbol{ixy}}\right] \le \boldsymbol{Mc_x}\ \ \forall\ \boldsymbol{M_x}, \\ 0\ \ otherwise \end{Bmatrix} \tag{9}$$

$$M_{\boldsymbol{ixy}} = \begin{Bmatrix} 1\ if\ tool\ transportation\ (l = 1)\ is\ allowed \\ 0\ otherwise \end{Bmatrix} \tag{10}$$

$$To_{\boldsymbol{yz}} = \begin{Bmatrix} 1\ if\ \ machine\ \boldsymbol{M_x}\ can\ perform\ operation\ \boldsymbol{O_y}\ with\ tool\ \boldsymbol{To_z} \\ 0\ otherwise \end{Bmatrix} \tag{11}$$

$$To_{\boldsymbol{yz}} = \begin{Bmatrix} 1\ \ if\ \left[\left(\sum_{i=1}^{I}\sum_{x=1}^{X}\sum_{y=1}^{Y} l_{\boldsymbol{ixyz}}\right)\right] \le \boldsymbol{Av_z}\ \ \forall\ \boldsymbol{To_z} \\ 0\ \ otherwise \end{Bmatrix} \tag{12}$$

$$l = \begin{Bmatrix} 1\ if\ new\ tool\ can\ be\ buyed \\ 0\ otherwise \end{Bmatrix} \tag{13}$$

$$l_{\boldsymbol{ixyz}} = \begin{Bmatrix} 1\ if\ job\ \boldsymbol{J_i}\ is\ loaded\ on\ machine\ \boldsymbol{M_x}\ for\ operation\ \boldsymbol{O_y}\ with\ tool\ \boldsymbol{To_z} \\ 0\ otherwise \end{Bmatrix} \tag{14}$$

$$M_{\boldsymbol{ixy}} = \begin{Bmatrix} 1\ if\ \ machine\ \boldsymbol{M_x}\ is\ allocated\ for\ operation\ \boldsymbol{O_y}\ on\ job\ \boldsymbol{J_i} \\ 0\ otherwise \end{Bmatrix} \tag{15}$$

$$M_{\boldsymbol{ix}} = \begin{Bmatrix} 1\ if\ \ machine\ \boldsymbol{M_x}\ is\ allocated\ \ to\ job\ \boldsymbol{J_i}\ for\ any\ operation \\ 0\ otherwise \end{Bmatrix} \tag{16}$$

$$To_{\boldsymbol{iz}} = \begin{Bmatrix} 1\ if\ \ tool\ \boldsymbol{To_z}\ is\ allocated\ \ to\ job\ \ \boldsymbol{J_i} \\ 0\ otherwise \end{Bmatrix} \tag{17}$$

$$To_{\boldsymbol{yz}} = \begin{Bmatrix} 1\ \ if\ \ tool\ \boldsymbol{To_z}\ is\ allocated\ \ for\ operation\ \ \boldsymbol{O_y} \\ 0\ otherwise \end{Bmatrix} \tag{18}$$

$$JO_{iy} = \begin{cases} 1 \; if \; job \; \boldsymbol{J_i} \; requires \; operation \; \boldsymbol{O_y} \; to \; be \; performed \\ 0 \; otherwise \end{cases} \quad (19)$$

$$MO_{xy} = \begin{cases} 1 \; if \; Machine \; \boldsymbol{M_x} \; can \; perform \; operation \; \boldsymbol{O_y} \\ 0 \; otherwise \end{cases} \quad (20)$$

$$OTo_{yz} = \begin{cases} 1 \; if \; operation \; \boldsymbol{O_y} \; can \; be \; performed \; by \; tool \; \boldsymbol{To_z} \\ 0 \; otherwise \end{cases} \quad (21)$$

$$e_{iy} = \begin{cases} 1 \; if \; operation \; \boldsymbol{O_y} \; is \; essential \; type \; for \; joi \; J_i \\ 0 \; otherwise \end{cases} \quad (22)$$

$$Tr = \begin{cases} 1 \; if \; tool \; travel \; is \; permitted \\ 0 \; otherwise \end{cases} \quad (23)$$

$$j_s = \begin{cases} 1 \; if \; job \; is \; spiliting \\ 0 \; otherwise \end{cases} \quad (24)$$

$$j_a = \begin{cases} 1 \; if \; job \; is \; allocated \\ 0 \; otherwise \end{cases} \quad (25)$$

$$TMC_x = \begin{cases} 1 \; if \; tool \; magazine \; of \; machine \; M(x) if \; full \\ 0 \; otherwise \end{cases} \quad (26)$$

$$ToAv_z = \begin{cases} 1 \; if \; tool \; of \; type \; To(z) is \; available \\ 0 \; otherwise \end{cases} \quad (27)$$

$$To_b = \begin{cases} 1 \; if \; new \; tool \; can \; be \; buyed \\ 0 \; otherwise \end{cases} \quad (28)$$

$$ToS_{iyz} = \begin{cases} 1 \; if \; job \; \boldsymbol{To_z} \; is \; specified \; for \; operation \; \boldsymbol{O_y} \; to \; be \; performed \; on \; Job \; J(i) \\ 0 \; otherwise \end{cases} \quad (29)$$

$$y_{iyz} = \begin{cases} 1 \; if \; job \; \boldsymbol{To_z} \; is \; specified \; for \; operation \; \boldsymbol{O_y} \; to \; be \; performed \; on \; Job \; J(i) \\ 0 \; otherwise \end{cases} \quad (30)$$

Heusitics procedure

As shown from Fig. 2, the following steps are followed:

Step-1 : Allocate all essential operations

Step-2 : Evaluate the differences $(Max(t_{xz}))$- $(Min(t_{xz}))$ between maximum $(Min(t_{xz}))$ and minimum $(min(t_{xz}))$ time required by the job (J_i) for an operation (O_y) considering all machines and tools in the system, for all jobs $(i = 1,2,3,\dots,I)$) and operations $(y = 1,2,3,\dots,Y)$ for optional operations only

Step-3 : Select 1st maximum time difference $[Max((Max(t_{xz})) - (Min(t_{xz})))]$, evaluated in step 2

Step-4 : Allocate optional operation corresponding to the selected time on the machine with least processing time

Step-5 : Put the machine out of selection which reaches above the ideal allocation time

Step-6 : Repeat step 3 for next maximum time difference $[Max((Max(t_{xz})) - (Min(t_{xz})))]$ in the order of descending processing times till all operations are allocated

Step-7 : Allocation completed

Step-8 : Analyse the values of objectives

Step-9 : Select the 1st objective need to be modified say cost

Step-10: Provide value of cost that needed to be reduced

Step-11: Evaluate the differences $(Max(c_{xz}))$- $(Min(c_{xz}))$ between maximum $(Min(c_{xz}))$ and minimum $(min(c_{xz}))$ cost required by the job (J_i) for an operation (O_y) considering all machines and tools in the system, for all jobs $(i = 1,2,3,\dots,I)$) and operations $(y = 1,2,3,\dots,Y)$ for optional operations only

Step-12: Select 1st maximum time cost difference $[Max((Max(t_{xz})) - (Min(t_{xz})))]$, evaluated in step 11

Step-13: Allocate optional operation corresponding to the selected cost on the machine with least cost

Step-14: Put the machine out of selection which reaches above the ideal allocation value

Step-14: Calculate cost reduction achieved by calculating cost differences between previous and current cost of manufacturing

Step-15: Repeat step 11 for next operation in the order of descending processing times till the desired cost cutting is achieved

Step-16: Allocation completed

Step-17: Analyse the values of objectives

Step-18: Repeat steps 10 to 17 to put any constraint or limitations or any number of objectives

Step-19: when objective values are acceptable, balance the workload on all machines, i.e. all machines when considered to be available for 24×7, the entire machines (×) should run for equal time for optimized loading schedule

Step-20: Select the machine with undesired load, if available shift the tool saving the desired cost/ time

Step-21: Repeat step 20 for all undesired loadings, either saving machining cost at the cost of increased machining time or saving machining time at the cost of increased machining cost.

4. Results

Test results of a problem with I=5, X=2, Y=3, Z=4 are discussed below for validation of the proposed model and solution methodology. From the table, ideal value of throughput is 0.02, balanced load on the system is 249.5 hours load per machine operating at 100% availability. Here all the operations are considered as optional, with scope of tool travel. The jobs are ordered in sequence of their due dates. All machines are capable of performing all operations, all tools can be loaded on any of the machine. All the jobs can be handled on any of the machines. The results are within known limits of optimal value of optimization, thus are acceptable as per literature guidelines. Thus the developed system is most realistic with least computational requirements best known in the literature.

Table 1
Processing times of various jobs on various machines with different tools for all operations

		O_1				O_2				O_3			
		To_1	To_2	To_3	To_4	To_1	To_2	To_3	To_4	To_1	To_2	To_3	To_4
J_1	M_1	36	6	182	166	137	28	19	103	69	158	22	162
	M_2	81	171	24	21	95	43	63	154	60	59	26	191
J_2	M_1	28	113	200	36	185	181	93	128	151	140	112	139
	M_2	7	173	110	73	22	15	21	19	3	113	99	27
J_3	M_1	190	71	143	12	151	49	202	17	10	81	180	146
	M_2	61	91	202	106	149	11	68	158	135	13	162	23
J_4	M_1	60	11	59	68	114	90	61	183	122	158	149	24
	M_2	68	36	84	36	38	3	13	108	107	69	11	130
J_5	M_1	95	134	94	43	121	182	61	23	148	123	15	67
	M_2	131	67	155	183	61	40	10	167	143	150	18	133

Table 2
Loading of machines in FMS

		O_1				O_2				O_3			
		To_1	To_2	To_3	To_4	To_1	To_2	To_3	To_4	To_1	To_2	To_3	To_4
J_1	M_1	0	0	0	0	0	0	0	0	0	0	0	0
	M_2	0	0	0	1	0	1	0	0	0	0	1	0
J_2	M_1	0	0	0	0	0	0	0	0	0	0	1	0
	M_2	1	0	0	0	0	1	0	0	0	0	0	0
J_3	M_1	0	0	0	0	0	0	0	1	1	0	0	0
	M_2	1	0	0	0	0	0	0	0	0	0	0	0
J_4	M_1	0	1	0	0	0	0	1	0	0	0	0	0
	M_2	0	0	0	0	0	0	0	0	0	0	1	0
J_5	M_1	0	0	0	0	0	0	0	1	0	0	1	0
	M_2	0	1	0	0	0	0	0	0	0	0	0	0

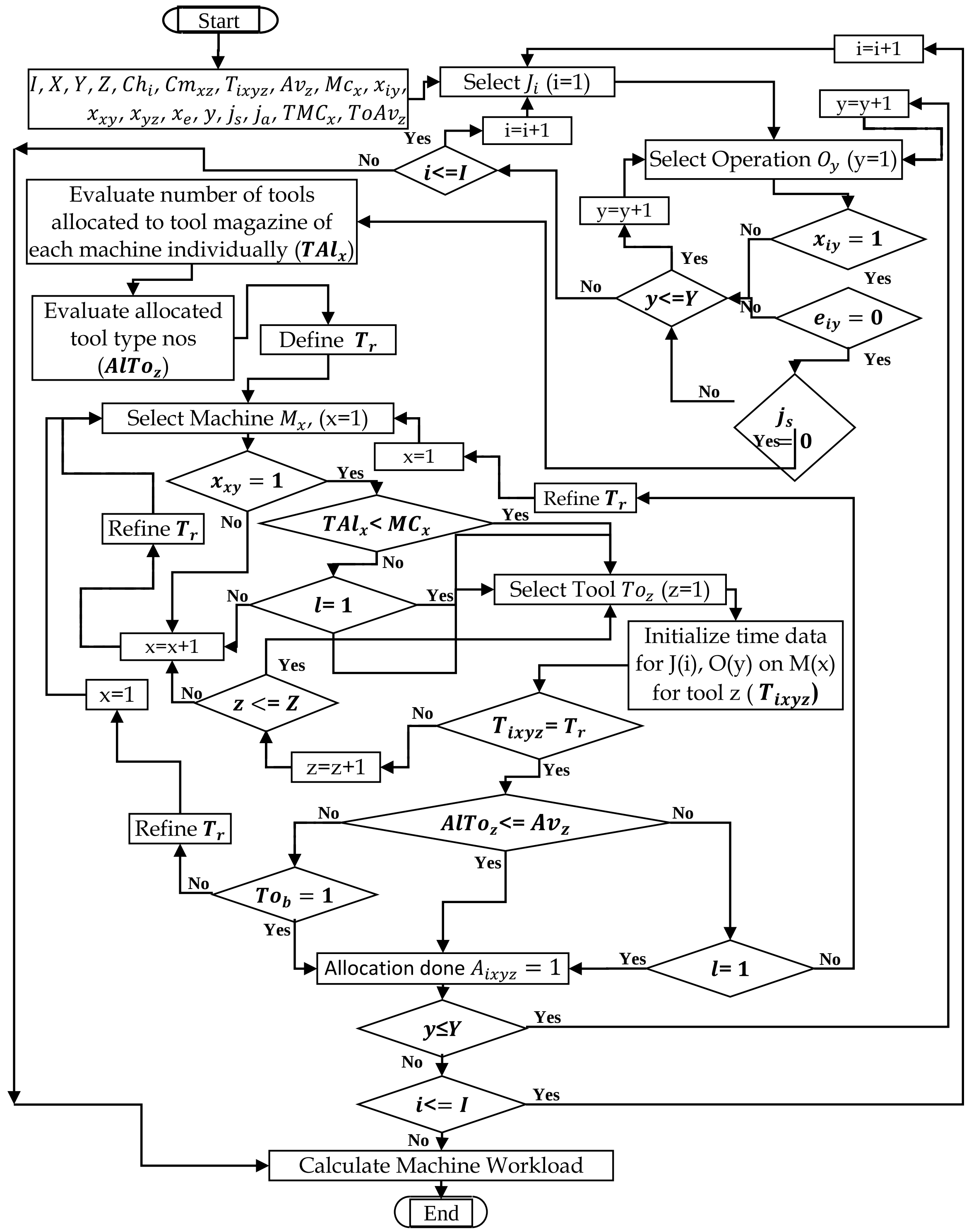

Fig. 2. Developed intelligent algorithm LOMFNEO for allocation of machines and tools for non-essential operations in general FMS

Table 2
Results value

	Load/ Machine		Throughput	
Ideal value	249.5		0.0200	
Actual value	249	251	249	251

5. Conclusion

Literature also reveals that validation of the a methodology can be accomplished with computationally randomly generated small set of test problems (Sujono & Lashkari, 2007; Yang & Wu, 2002; Gamila & Motavalli, 2003; Chan et al., 2004; Murat & Erol, 2012; Rahimifard & Newman, 2000; Yeong-Dae & Yano Candace, 1987; Rai et al., 2002). The results of this paper have shown that the on solving the proposed model by developed Matlab codes, yields results very close to the ideal values. For example the ideal and actual throughput through proposed modelling when solved with Matlab codes are nearly similar with negligible percentage difference, which are very real world and acceptable results. Also it is outlined in the literature that the solution are feasible within a known percentage of optimal objective value (Bretthauer & Venkataramanan, 1990).

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