A NEW METHOD OF FMS SCHEDULING USING OPTIMIZATION AND SIMULATION

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ABSTRACT

Nowadays, in modern manufacturing the trend is the development of Computer Integrated Manufacturing, CIM technologies which is a computerized integration of manufacturing activities (Design, Planning, Scheduling and Control) that to produce right products right at right time to react quickly to the global competitive market demands. The productivity of CIM is highly depending upon the scheduling of Flexible Manufacturing System (FMS). Shorting the makespan leads to decreasing machines idle time which results improvement CIM productivity. Conventional methods of solving scheduling problems such as heuristic methods based on priority rules still result schedules, sometimes, with significant idle times. To reduce these, the present paper proposes a new high quality scheduling method. This method uses multi-objective optimization and simulation. The method is called **"B**reak and **B**uild **M**ethod**"**, **BBM**. The BBM procedure has three stages, in the first **Building stage**; the steps are to build up some schedules using any scheduling methods for example: heuristic ones which are tested by simulation. In the second **Breaking stage**, optimum sizes of batches are determined. In the final **Rebuilding stage**, the most proper schedule is selected using simulation. The goal of use of simulation within manufacturing scheduling is to achieve the two following objectives: first is the visual representation of manufacturing process behavior of a chosen schedule. The second is testing and validation of schedules to select the most proper schedule what can be successfully implemented. There are two-objectives achieved by BBM to the given simple example, one is improved productivity by 31.92% and the other is meeting delivery dates.
The method produces a new direction of manufacturing scheduling using differential calculus, gives a new results and new information for solving simple manufacturing scheduling problem.

INTRODUCTION

Flexible Manufacturing System (FMS) is an automated manufacturing system which consists of group of automated machine tools, interconnected with an automated material handling and storage system and controlled by computer to produce products according to the right schedule.
Manufacturing scheduling theory is concerned with the right allocation of machines to operations over time.
FMS scheduling is an activity to select the right future operational program and/or diagram of an actual time plan for allocating competitive different demands of different products, delivery dates, and/or sequencing through different machines, operations, and routings that for combination the high flexibility of job shop type with high productivity of flow-shop type and meeting delivery dates.
FMS Scheduling system is one of the most important information-processing subsystems of CIM system. The productivity of CIM is highly depending upon the quality of FMS scheduling. The basic work of scheduler is to design an optimal FMS schedule according to a certain measure of performance, or scheduling criterion. This paper focuses on productivity oriented-makespan criteria. Makespan is the time length from the starting of the first operation of the first demand to the finishing of the last operation of the last demand.
Conventional methods of solving scheduling problems such as heuristic methods based on priority rules (FIFO, SPT, SLACK…) determined the corresponding schedule but usually, still having idle times. To reduce these and improving CIM productivity, this paper presents a new method so called **"B**reak and **B**uild **M**ethod**"**, **BBM**. The paper can be classified into forth parts as follow:-First Part: Scheduling using BBM. Second Part: Application of BBM to the simple scheduling problems. Third Part: Conclusion, and References.

SCHEDULING USING BBM

BBM is a multi-criteria optimization and simulation approach in which the optimum schedule of tasks of High Number of Parts (HNP) are divided into optimum sub-series (batches), then rebuild the schedule again and overlapping production can be realized at certain

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condition and tested using one of simulation methods (e.g.: Taylor ED). BBM has two-objectives for this situation, one is a higher productivity and the second is meeting delivery dates.

BBM Procedure

The BBM procedure is consists of the following three stages:-

1. Building Stage

In the building stage, the steps are to built up an optimum schedule using any scheduling methods such as heuristic method and tested by simulation

Scheduling Problem

The shop considered in this paper consist of 2-different independent machines M_1, M_2 of load, L_1, L_2 respectively will process 2 demands, d_1, d_2 of units, X_1, X_2 .Each demand processed by 2 operations O_1,O_2 each operation consists of run time t and set up time δ with precedence relationship O_1 precedes O_2 and the processing times are P_1, P_2 respectively, The due date of d_1 and d_2 is D. Data is summarized at demand table in fig.1. The Objective is to determine the best schedule using productivity criteria.

Table (1) Demand Table.

d	**O_1**	**O_2**	**P**
d_1	O_1^{11}	O_1^{22}	**P_1**
d_2	O_2^{11}	O_2^{22}	**P_2**
L	**L_1**	**L_2**	S_t

Notations

O_i^{om} :O (Operation time), o (operation number) , m (machine number),i (demand number) , t_i^{om} : run time, r: ready time, s: start time, f: flow time, S_t : Schedule time, Π_s :Number of schedules, T: Makespan L_{max}:bottleneck machine load, η :Schedule Productivity Index, η_R :Schedule Productivity Rate

Assumptions

1. No Cancellation. No Breakdown. No Preemption.

2. Operating cost is constant.

3. δ is constant , r =0

Demand chart as in fig. (1), shows how much time required to processing each demand P_1, P_2 , . Load chart as in fig. (2) Shows how much time to be loading each machine L_1, L_2 required to produce the two demands.

Solution

As in fig. (3), Gantt chart clearly display that the schedule is satisfied according to the precedence relationship but it is infeasible schedule due to the conflict of overload.

Heuristic Scheduling Methods

A heuristic is a rule of thumb procedure that determines a "good-enough" , satisfactory and feasible solution within certain constraints, but not necessarily guarantees the best or optimal, solution to a problem. A good heuristic is generally within 10% of optimality, the amount of error is not known and degree of optimality is not known. Heuristic methods based on priority rules for job-shop scheduling problem are not a convenience but a necessity for selecting which job is started first on certain machine. Some of the rules used to scheduling problems are FIFO (First In First Out), SPT (Shortest Processing Time) and SLACK…. rules. in this paper the number of schedules to be evaluated is Π_s = n!=2 schedule, where, n: number of demands = 2 . The priority rules used in the present paper are FIFO and SPT as following:-

a) SPT rule

Table (2) SPT Table

M_1			**M_2**		
s	**O**	**f**	**s**	**O**	**f**
0	O_2^{11}	O_2^{11}	O_2^{11}	O_2^{22}	f_1
O_2^{11}	O_1^{11}	L_1	L_1	t_1^{22}	**T_1**

b) FIFO rule

Table (3) FIFO Table

M_1			**M_2**		
s	**O**	**f**	**s**	**O**	**f**
0	O_1^{11}	O_1^{11}	O_1^{11}	O_1^{22}	f_2
O_1^{11}	O_2^{11}	L_1	L_1	t_2^{22}	**T_2**

Mathematical Model

The mathematical model for the formulated problem is

Objective Function: Minimize

$$T = t_1^{11} + t_1^{22} + t_2^{11} + t_2^{22} + 4\delta \quad \ldots(1)$$

Subject to $t_1^{11} \rightarrow t_1^{22}$, $t_2^{11} \rightarrow t_2^{22}$

$t_1^{11} \geq t_1^{22} \geq t_2^{11} \geq t_2^{22}$, $L_1 \leq T \leq D \leq S_t$

$T_1 = L_{max} + t_1^{22}$, where L_{max}= max (L_1, L2) = L_1

$T_2 = L_{max} + t_2^{22}$

Since $t_2^{22} \leq t_1^{22}$, L_{max} = constant

$T_2 \leq T_1$

$T_2 = T^* = L_{max} + t_2^{22}$, $L_{max} = O_1^{11} + O_2^{11}$ $O_i^{om} = t_i^{om}$ + δ

$$\boxed{T^* = t_1^{11} + t_2^{11} + t_2^{22} + 2\delta} \ldots(2)$$

The makespan of FIFO (T_2) T_2 is better than of SPT (T_1) but it is not the optimal.

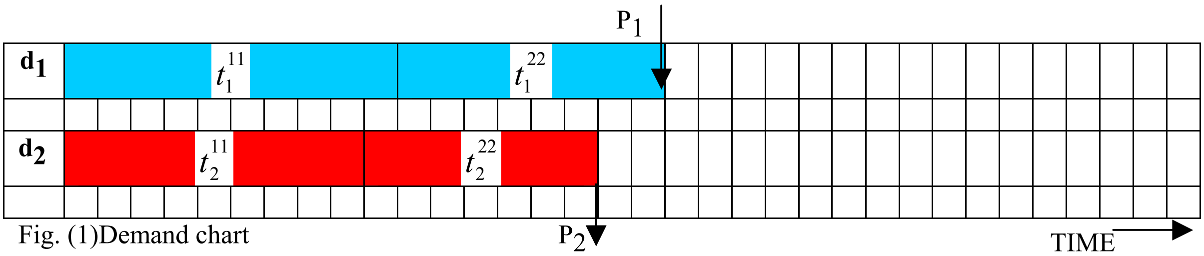

Fig. (1)Demand chart

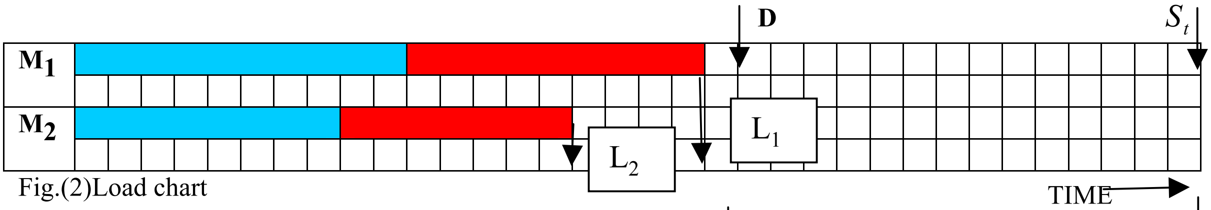

Fig.(2)Load chart

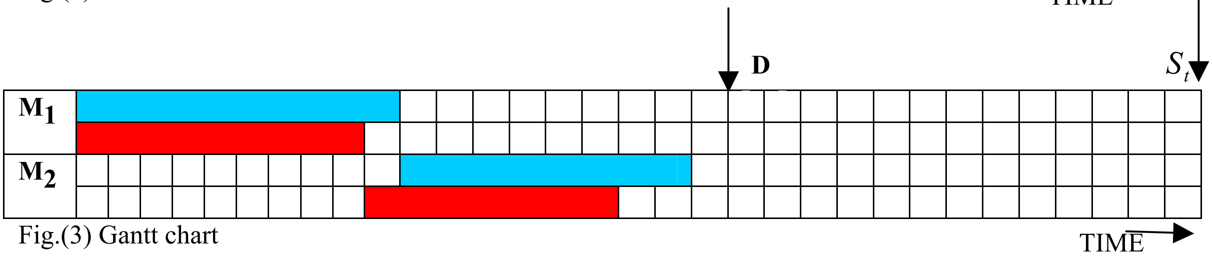

Fig.(3) Gantt chart

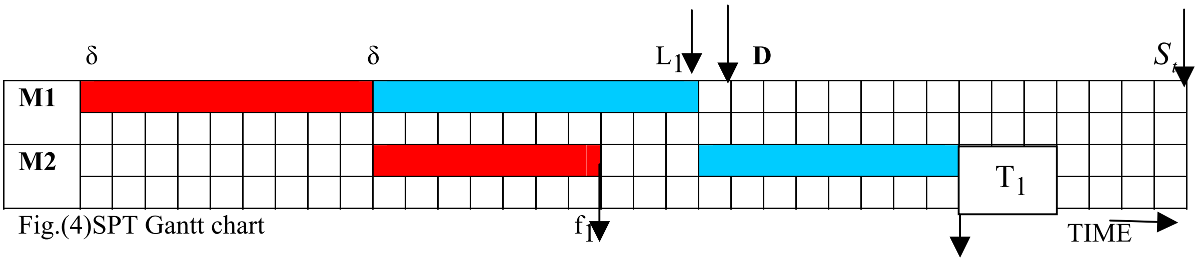

Fig.(4)SPT Gantt chart

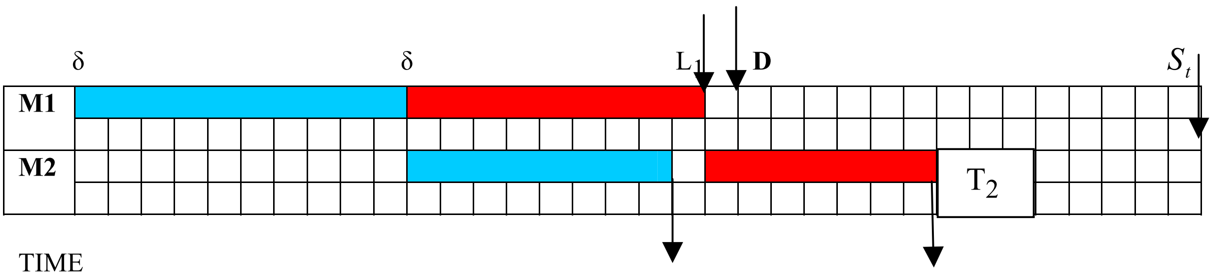

Fig.(5) FIFO Gantt chart f2

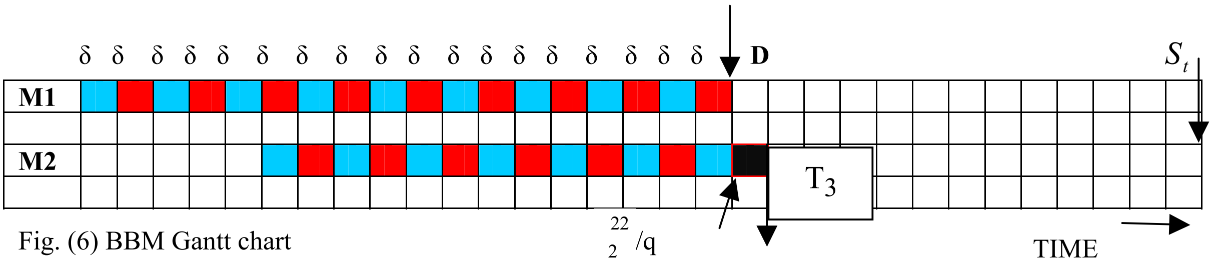

Fig. (6) BBM Gantt chart

The solution of equation (2) can be tested by one of simulation methods (e.g.: Taylor ED) as shown in fig.(7). Then, build up the proper design of schedule model, but, still there is idle time in machine 2 and also $T^* \geq$ D.

To minimize (optimize) T^* and to meet the delivery date, the following breaking stage of productivity criteria oriented-makespan is used.

2. Breaking Stage

By dividing the bottleneck machine times (**L_1**) into sub-division of batches of time q with total set up times of Bottleneck machine 1, (qδ), the last sub-division of batch of time of last operation time at idle machine 2 is the Schedule Black Box (t_2^{22} /q), as shown in the Gantt chart fig.(6).The purpose of breaking stage is to determine the schedule breakeven point using breakeven analysis. The **schedule breakeven point** is defined as the optimal sub-division quantity of time at which the total set times (qδ) of Bottleneck machine is equal to the Schedule Black Box (t_2^{22} /q),At the schedule breakeven point the makespan is a minimum and the schedule productivity rate is a maximum.

Determination of Schedule Breakeven Point B_t^*

$T_3 = t_1^{11} + t_2^{11} + q\delta + t_2^{22}/q$ ………..(3)

Since, t_1^{11} and t_2^{11} are constant,

$B_t = T_3 - (t_1^{11} + t_2^{11})$ and called "Schedule Break time"

$B_t = T_3 - (t_1^{11} + t_2^{11}) = q\delta + t_2^{22}/q$, … (4)

Taking the derivative of B_t w.r.t q and equaling zero

$$\frac{\partial B_t}{\partial q} = \delta - \frac{t_2^{22}}{q^2} = 0 \rightarrow \boxed{q^* = \sqrt{\frac{t_2^{22}}{\delta}}} \quad .. (5)$$

$$\boxed{B_t^* = 2\sqrt{t_2^{22}\delta}} \quad (6)$$

B_t^* is called "Schedule Breakeven Point"

$T_3 = t_1^{11} + t_2^{11} + 2\sqrt{t_2^{22}\delta}$

If $T_3 \leq T_2$ and $T_3 \leq D$, then, $T_3 = T^{**}$

$$\boxed{T^{**} = t_1^{11} + t_2^{11} + B_t^*} \ldots (7)$$

$$\eta = (T^* / T^{**}) \rightarrow \boxed{\eta_R = (\eta - 1)*100} \ldots (8)$$

It concluded that as the number of sub-division of batches q increases, E.(3), the total time(qδ) increase**,** the Schedule black box(t_2^{22} /q) decrease.(4), makespan decrease and schedule productivity rate increase.(8) until certain point which is schedule breakeven point B_t^* ,E.(6) at which the makespan T is minimum and schedule productivity rate η_R is maximum.

Determination of Optimum Units Per Batch X_i^{om}

To find out X_i^{om} (unit/batch) and X_{1L}^{22} which is the number of units of last batch (unit/batch of time). it must be determined first, the Number of batches of time per operation of demand through machine m, q_i^{om} (batch of time) , Length of batch time (h/batch of time) τ_i^{om}, and : τ_{1L}^{22} : Last batch length (h/batch) also it can be specify the time required to process one unit of batch of demand through certain machine, α (min/unit). Approximation can be done if required. The following formula are used.

$$q_1^{11} = t_1^{11} * q^* /(t_1^{11} + t_2^{11}), \quad q_2^{11} = t_2^{11} * q^* /(t_1^{11} + t_2^{11})$$

$$\tau_1^{11} = t_1^{11} / q_1^{11}, \quad \tau_2^{11} = t_2^{11} / q_2^{11}, \quad \tau_{1L}^{22} = t_2^{22} / q^*$$

$$X_1^{11} = X_1 / q_1^{11}, \quad X_2^{11} = X_2 / q_2^{11}, \quad X_{1L}^{22} = X_1^{11}$$

$$\alpha_1^{11} = \tau_1^{11} / X_1^{11}, \quad \alpha_2^{11} = \tau_2^{11} / X_2^{11}, \quad \alpha_{1L}^{22} = \tau_{1L}^{22} / X_1^{11}$$

3. Rebuilding Stage

In this stage the most proper schedule is selected using simulation. The simulation model rebuild up a gain according to the new condition due to the effect of BBM that to design the final Simulation Model. Corrective actions could be taken if necessary, then, testing and validation of schedules guaranteeing to select the most proper schedule and can be successfully implemented.

Application of BBM

Building Stage

As shown in demand table fig,(4) t_1^{11} =1000 h, t_1^{22} =800 h, t_2^{11} =900 h, t_2^{22} =700 h, δ = 1.75 h, X_1=1200 unit, X_2= 540 unit, D=2000 h

Table (4) Demand Table

d	O_1	O_2	P
d_1	1000	800	**1804**
d_2	900	700	**1604**
L	**1904**	**1504**	**3408**

Solution

$L_{max} = L_1$=1903.5h

SPT: T_1 = 2703.5 h

FIFO: T_2 =2603.5 h

$T_2 \leq T_1 \rightarrow T_2 = T^*$ But, $T^* \geq$ D.

so, the following breaking stage must be done.

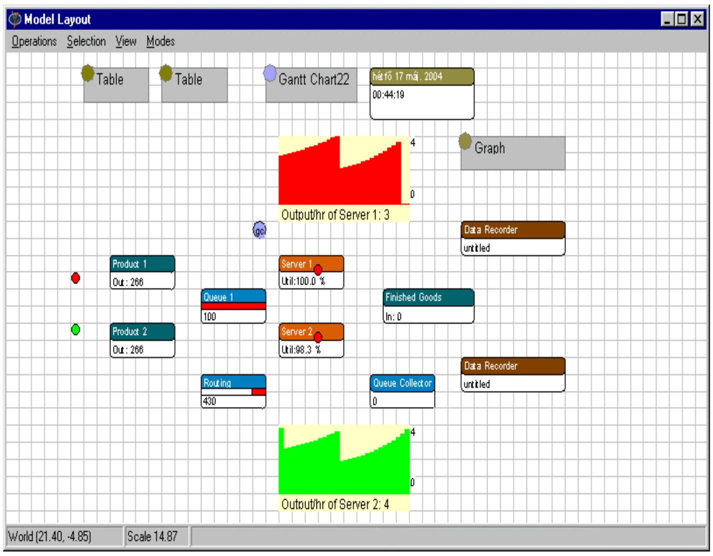

Fig.(7) Simulation Model

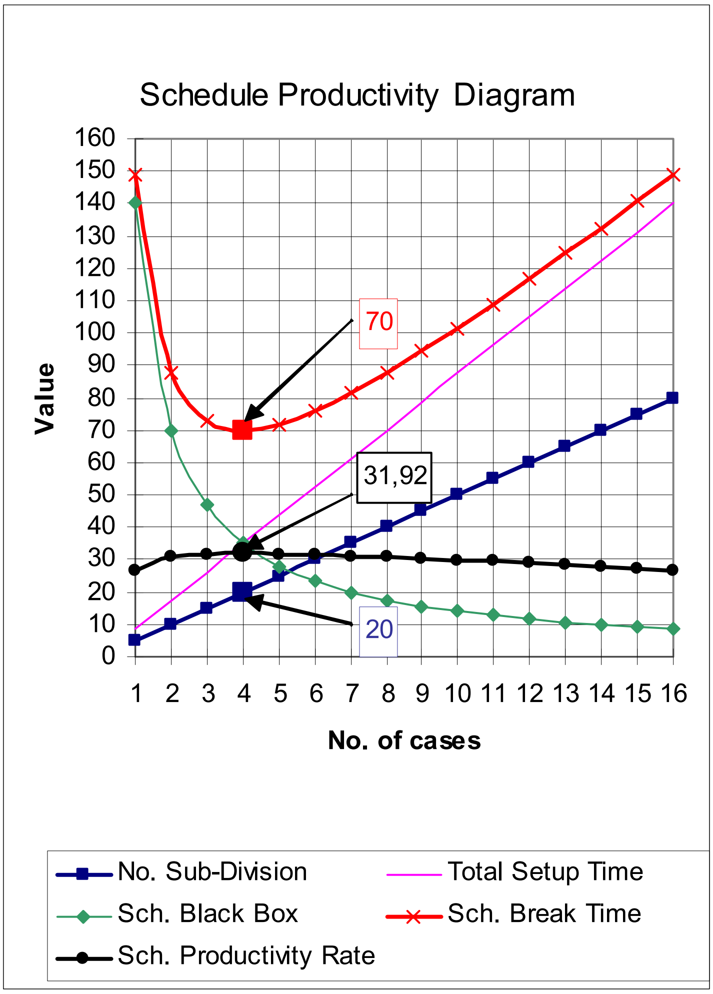

Fig.(8) Schedule Productivity Diagram

Breaking stage

Determination of Schedule Productivity Rate

q^{*} = 20 (batch of time) , T_3 =1973.5 h

$T_3 \leq T_2$, $T_3 \leq D$ $T_3 = T^{**}$ =1973.5 h ,

B_t^{*} = 70 h → η_R = 31.92 %

The schedule breakeven point B_t^{*} (70h)at which the Minimum makespan T(1973.5h) and the maximum schedule productivity rate η_R are(31.92%) as shown in figure (8).

Determination of Optimum Units Per Batch of Time

q_1^{11} =10 (batch of time), q_2^{11} = 9 (batch of time)

τ_1^{11} =100h/batch, τ_2^{11} =100h/batch, τ_{1L}^{22} =35 h/batch

X_1^{11} = 120 (unit / batch of time), X_2^{11} =60 (unit/ batch of time) , X_{1L}^{22} = 120(unit/batch of time)

α_1^{11} =50 min/unit, α_2^{11} = 70 min/unit, α_{1L}^{22} =17.52 min/unit

Rebuilding Stage

According to the previous figures of the breaking stage, it could be design the optimum schedule of such problem and tested by simulation

CONCLUSION

The sub-division of batches is a powerful tool for improving the quality of FMS scheduling. In the present paper, for the simplest case (two machine group, two part types), a new method is proposed to use the above approach. The proposed BBM (Break and Build Method) provide solution for the problem. The results clearly show the effectiveness of the given approach. Future research should be directed to generalize the method to multipart, multi machine group cases.

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