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MINIMIZATION OF WORK-IN-PROCESS INVENTORY IN HYBRID FLOW SHOP SCHEDULING USING FUZZY LOGIC

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This paper addresses the Hybrid Flow Shop (HFS) scheduling problems to minimize the total work-in-process inventory. Job scheduling problems are one of the oldest and real world combinational optimization problems. It is multi objective and complex in nature. There exist some criteria that must be taken into consideration when evaluating the quality of the proposed schedule. Consideration of job and machine reliability is very important during assignment of jobs in each stage to get realistic hybrid flow shop schedule. In this paper, flow shop problem concerns the sequencing of a given number of jobs through a series of machines in the exact same order on all machines with the aim to satisfy a set of constraint as much as possible and optimize a set of objectives. Fuzzy sets and logic can be used to tackle uncertainties inherent in actual flow shop scheduling problems. Fuzzy due dates, cost over time and profit rate result the job priority and to determine the machine priority processing time of each machine is considered. MATLAB fuzzy tool box is used to calculate the priorities of jobs and machines at different stages. Finally, jobs are assigned into machines based on a grouping and sequencing algorithm that minimizes the total work-in-process inventory.

Keywords: Flow shop, Fuzzy logic, Scheduling, Work-in-process inventory**.**

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1. INTRODUCTION

Scheduling is the process of organizing, choosing and timing resource usage to carry out all the activities necessary to produce the desired outputs of activities and resources. In flow shop there is more than one machine and each job must be processed on each of the machines- the number of operations for each job is equal with the number of machines, the *jth* operation of each job being processed on machine *j*. A Hybrid Flow Shop scheduling problem consists of series of production stages, each of which has several machines operating in parallel. Some stages may have only one machine, but at least one stage must have multiple machines. Each job is processed by one machine in each stage and it must go through one or more stages. Flow shop problem concerns the sequencing of a given number of jobs through a series of machines in the exact same order on all machines with the aim to satisfy a set of constraint as much as possible and optimize a set of objectives.

The flow shop scheduling problems exist naturally in many real life situations, since there are many practical as well as important applications for a job to be processed in series with more than one stage in industry. An ordinary flow shop is a multi stage production process with the property that all products have to pass through a number of stages in the same orders. The multi processor flow shop is an extension of the flow shop: at every stage a number of identical machines are available that can operate in parallel. Fuzzy set theory has been used to model systems that are hard to define precisely. As a methodology, fuzzy set theory incorporates imprecision and subjectively into the model formulation and solution process which deals with uncertainty. Recently, there has been significant attention given to modelling scheduling problems within a fuzzy framework. The advantage of the fuzzy logic system approach is that it incorporates both numerical results from a previous solution or simulation and the scheduling expertise from experiences or observation and it is easy to implement.

Fuzzy logic (FL) is a problem solving control system methodology that lends itself to implementation in systems ranging from simple, small embedded micro controllers to large, networked, multi- channel PC or workstation based data acquisition and control systems. It can be implemented in hardware, software or a combination of both. FL provides a simple way to arrive at a definite conclusion based upon vague, ambiguous, imprecise, noisy or missing input information. In this paper, triangular membership functions are used for different input and output variables. Fuzzy logic was used by different authors successfully with different approaches. Fuzzy set was introduced by Zadeh (1965). McCahonE and Lee (1992) used fuzzy logic for job scheduling in a flow shop. Ishibuchi et al. (1994) formulated a fuzzy flow shop scheduling problem where the due date of each job is given as a fuzzy set. Grabot and Geneste (1994) proposed a way to use fuzzy logic in order to build aggregated rules allowing obtaining a compromise between the satisfactions of several criteria. A fuzzy approach to operation selection was developed by Felix and Abhary (1997). Hong and Wang (2000) articulated that flexible flow shops can be thought of as generalizations of simple flow shops.Cheng et al. (2001) considered the three machine permutation flow shop scheduling problem with release times where the objective is to minimize the maximum completion time. Petroni and Rizzi (2002) used fuzzy logic based methodology to rank shop floor dispatching rules. Allet (2003) dealt with a particular scheduling problem inspired by a practical case coming from a Belgian Pharmaceutical company. Hybrid flow shop scheduling problems can be formally described by Engin and Döyen (2004). The problem of selecting and scheduling the orders to be processed by a manufacturing plant for immediate delivery to the customer site were optimized by Gracia and Lozano (2005). Allaoui and Artiba (2006) solved a two stage hybrid flow shop scheduling problem using branch and bound algorithm. An immune algorithm was used by Zandieh et al. (2006) to solve a hybrid flow shop scheduling problem. Nowicki and Smutnicki (2006) dealt with flow shop scheduling problem with the make span criterion. Valente (2007) considered the single machine scheduling problem with linear earliness and quadratic tardiness costs, and no machine idle time. Vob and Witt (2007) used heuristic solution algorithm for a hybrid flow shop scheduling problem. A constructive and metaheuristics algorithm was developed for hybrid flow shop scheduling by Janiak et al. (2007). Hendizadeh et al. (2007) considered a flowshop scheduling problem of a manufacturing cell that contains families of jobs whose setup times are dependent on the manufacturing sequence of the families. Two objectives, namely the makespan and total flow time, have been considered simultaneously in this work. Nepal et al. (2008) used fuzzy logic approach to handle the vague and imprecise product information available during the concept development phase of product development. Chen et al. (2009) developed a model that minimizes makespan by using the genetic algorithm to move from local optimal solutions to near-optimal solutions for Reentrant Permutation Flow-Shop scheduling problems.

The above proposed methods did not consider availability and reliability of both jobs and machines at the same time with minimization of work-in-process inventory. To optimize the considered multi-objectives addressing this uncertainty, a fuzzy rule based system is developed. This system provides the priority of each job by considering due dates, cost over time and profit rate as an appropriate fuzzy membership function.

Secondly, machine priority is based on processing time of each machine. The machine has lowest processing time is considered as highest priority machine. Based on the priority calculation for each job and machine for each stage, an algorithm is developed for grouping, sequencing and allocating the jobs to the machines at every stage in such a way that minimizes the total work-in-process inventory.

2. PROBLEM DEFINITION

In hybrid flow shop there may be a numbers of stages of processor and each stage has more than one machine. Machine priority is determined on the basis of their processing time. Simply, the machine with lower processing time has higher priority.

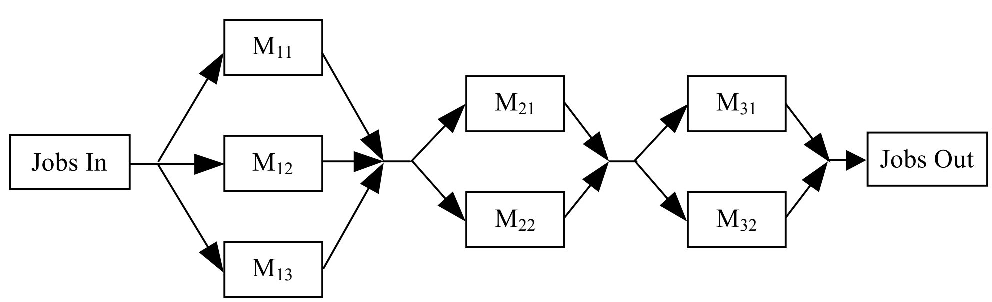

Figure 1. Typical scenario of hybrid flow shop

Each of the selected jobs needs to be processed on every stage. The priority of the jobs could be appraised by the values of their due dates, cost over time and profit rate. Figure 1 shows the typical flow shop structure in a manufacturing facility. Here M_{ij} indicates the machine j in stage i. So jobs in the system are passing through three different stages having seven machines.

Hence this problem involves determining the mechanism of priority determination of the jobs and machines in each individual stage, and grouping, sequencing and allocating the jobs in the machines at every stage in such a way that total work-in-process inventory will be minimum and top priority jobs will be processed using the top priority machines at the first stage and at the other stages jobs will be assigned to machines such a way that minimizes the differences of per hour production in two successive stages.

3. FUZZY MODEL IDENTIFICATION

Two types of fuzzy inference systems (FIS) can be implemented in the Fuzzy Logic Toolbox - Mamdani-type and Sugeno-type.

3.1 Mamdani-type FIS

Mamdani fuzzy inference method is the most common method used in fuzzy logic. Mamdani type is characterized by the following fuzzy rule schema:

if x is A and y is B, where A and B are fuzzy sets defined on input and output domains respectively. Here all the variables are expressed as linguistic variables. In this model, "minimum" is used for implication stage, "maximum" is used for aggregation stage and "centroid" is used for defuzzification.

3.2 Sugeno-type FIS

A Sugeno FIS has fuzzy inputs and a crisp output. It does not require a defuzzification to obtain a crisp result from the rules consequents. The crisp result can be obtained using a weighted average of the rules' crisp consequents using the firing levels. Sugeno FIS always generates continuous surfaces. The continuity of the output surface is important since the existence of discontinuities could result in similar inputs originating substantially different outputs; a situation which is undesirable from the control/ monitoring perspective. In this study Mamdani type fuzzy inference method is used because it has several advantages, e.g., it's intuitiveness, widespread acceptance, well suitability to human input and non-linearity.

4. DETERMINATION OF JOB PRIORITY USING FIS

To incorporate multi-objective scheduling, fuzzy job priority is calculated by developing a Fuzzy Inference System (FIS) using MATLAB fuzzy logic tool box. Three input variables, e.g., due dates, cost over time and profit rate have been used in this FIS which results job priority as output of this FIS. These input and output values should be expressed as a membership function to develop the FIS. A membership function (MF) is a curve that defines how each point in the input space is mapped to a membership value between 0 and 1.

All the input variables are considered triangular membership function and all variables are divided into three zones, i.e., low, medium and high. An output variable of the first stage is job priority (value between 0 and 1). Output membership function is also triangular shaped. It is divided into five possible zones, i.e., very low, low, medium, high, and very high. In this research triangular membership function is chosen for all variables and three membership functions for each input and five membership function for output are used because more number of the membership function , the more number of rules require The developed FIS model for job priority at this stage is shown in Figure 2.

To determine the job priorities, several rules have been developed in Fuzzy Inference System. These rules determine the output (priority) of following input variables. 11 rules for job priority are considered. These rules are given below.

1. If (Profit Rate is Low) then (Job Priority is Low)
2. If (Profit Rate is Medium) then (Job Priority is Medium)
3. If (Profit Rate is High) then (Job Priority is High)
4. If (Due Date is Low) then (Job Priority is High)
5. If (Due Date is Medium) then (Job Priority is Medium)
6. If (Due Date is High) then (Job Priority is Low)
7. If (Cost Over Time is Low) then (Job Priority is Low)
8. If (Cost Over Time is Medium) then (Job Priority is Medium)
9. If (Cost Over Time is High) then (Job Priority is High)
10. If (Profit Rate is High) and (Due date is Low) and (Cost Over Time is High) then (Job Priority is Very High)
11. If (Profit Rate is Low) and (Due date is High) and (Cost Over Time is Low) then (Job Priority is Very Low)

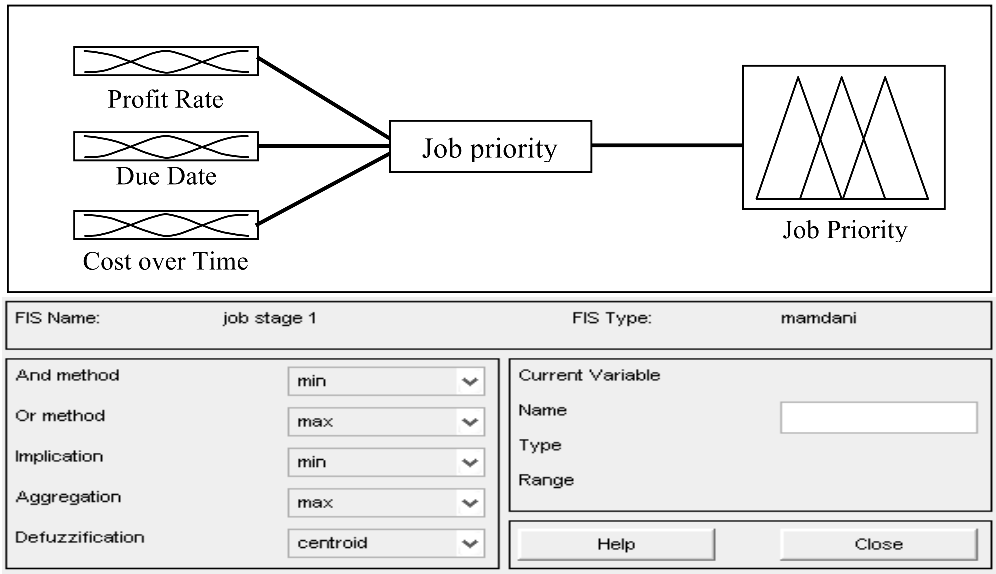

Figure 2. FIS model for job priority

5. GROUPING AND SEQUENCING ALGORITHM

5.1 Grouping

Main principle of this grouping algorithm is to perform the top priority job in the top priority machine. So first the top priority job is assigned to the highest priority machine until it minimizes the work-in-process inventory.

When it does not satisfy the mentioned condition, the job is assigned to the second highest priority machine; and the rest of the jobs are then assigned to other machines until the target is achieved. The complete flow chart for grouping and sequencing algorithm is shown in Figure 3.

In first step, top priority job is assigned to top priority machine. In the second step, job is assigned such a way that the difference of per hour production between first and second step is minimum. So, comparison between first and second steps, second and third steps, third and forth steps and so on are considered to minimize work-in-process inventory.

5.2 Sequencing

Sequencing is determined based on the priority of the job. Highest priority job on the group goes first, then second, third and so on. But except the first stage, sequencing may need to be modified in order to minimize the make span without hampering the main principle of grouping and sequencing, i.e., the higher priority job does not need to wait for the job which has less priority. It is modified in such a way that if the arrival time of the higher priority job is greater than the completion time of the less priority job at that stage of the same group, then the less priority job will be performed first.

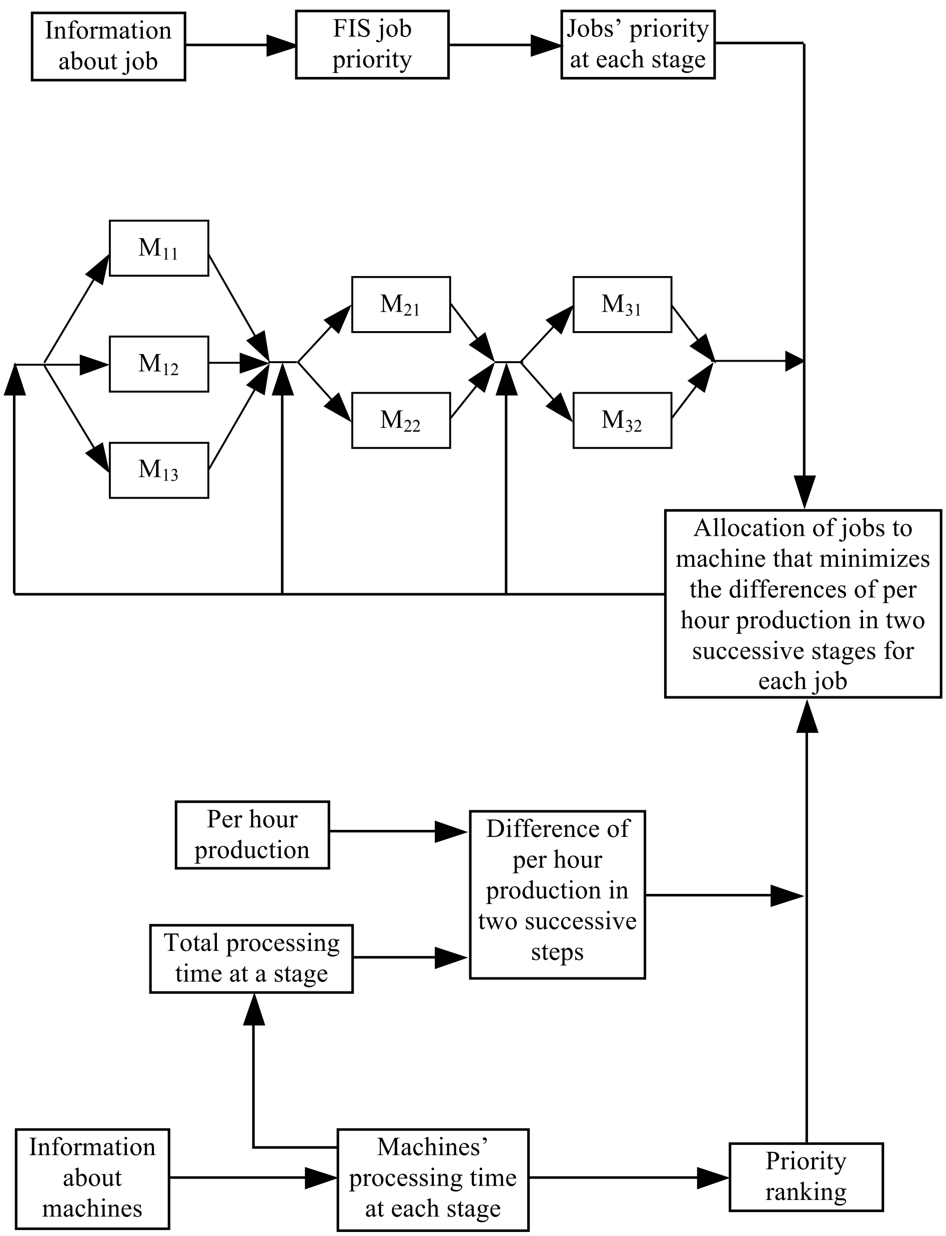

Figure 3. Flow chart for grouping and sequencing algorithm

6. MODEL FORMULATION

The developed algorithm for fuzzy multi objective machine reliability based multi processor flow shop scheduling has been coded in C++ programming languages with MATLAB fuzzy logic tool box to put the system into practice. MATLAB fuzzy logic tool box is used to prioritize the jobs in an individual stage to full fill the multi objective criteria. Using these priorities of jobs the developed scheduling algorithm then provides the final schedule. For analyzing the performance of the developed algorithm a study is presented.

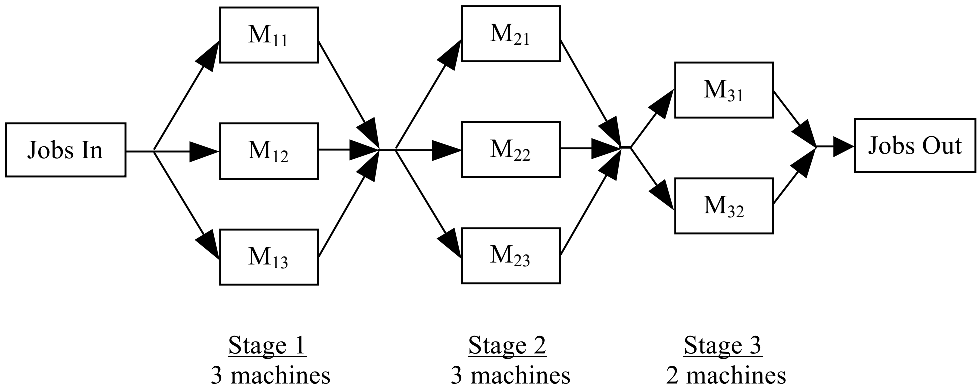

Figure 4. Hybrid flow shop for a production system

A study is presented here using hypothetical data to clarify the proposed process**.** Four different jobs have been considered in 3 separate stages for hybrid flow shop scheduling. Three machines are set at the first stage as well as second stage, whereas two machines are set at the third and final stage. The schematic diagram of the considered hybrid flow shop problem is presented in Figure 4.

Table 1. Information about jobs at different stages

Job name	Profit rate at stage 1	Profit rate at stage 2	Profit rate at stage 3	Due date (days)	Cost over time
A	10	15	7	5	60
B	7	14	18	7	50
C	13	8	14	3	70
D	15	13	9	9	80

Information about the jobs and machines at each stage is shown in Table 1 and Table 2 respectively. These data can be obtained from company's information centre and also from the customers. For this case study, hypothetical data are considered.

Table 2. Information about machines at different stages

Stage number	Processing Time (min)		
	Machine 1	Machine 2	Machine 3
Stage 1	24	32	20
Stage 2	10	60	40
Stage 3	10	30	

From the rule viewer and information about job, priority of each job is obtained. Priority values are got in the scale of 1, which are converted into scale of 100. Table 3 shows the priority table of jobs at different stages.

Table 3. Priority of jobs at different stages

Job name	Priority at stage 1 (%)	Priority at stage 2 (%)	Priority at stage 3 (%)
A	50	59	46
B	43	50	56
C	58	57	60
D	47	48	48

Per hour production of each machine at each stage is determined from the processing time of that machine. Table 4 shows the per hour production of machines at different stages.

Table 4. Per hour Production (pcs.) of each job at each stage

Production per hr at stage 1 (pcs.)		Production per hr at stage 2 (pcs.)		Production per hr at stage 2 (pcs.)	
Machine 1	2.5	Machine 1	6.0	Machine 1	6.0
Machine 2	1.875	Machine 2	1.0	Machine 2	2.0
Machine 3	3.0	Machine 3	1.5		

Using the developed grouping and sequencing algorithm, the following table provides the ultimate grouping of the jobs to the machines. For multiple jobs grouped to a single machine, sequencing of the concerned jobs is also obtained using the same algorithm. Table 5 shows the schedule of each job prioritized to be processed in each machine at each stage.

Table 5. Schedule of jobs in different machines at different stages

Stage	Machine	Job
1	1	A
	2	D
	3	C,B
2	1	A, C, B
	2	----
	3	D
3	1	C, B, A
	2	D

To determine the final schedule, number of stages, number of machines at each stage, number of jobs which to be processed; priority values of jobs and processing time of each machine are given input in the grouping and sequencing algorithm. Final schedule is obtained from the output of the grouping and sequencing algorithm, which is shown in Table 5. As obtained in the developed final schedule, at stage 1, job A should be processed in machine 1 and job D should be processed in machine 2. The remaining machine 3 should process job C first and then job B. At stage 2, job A, C and B should be processed in machine 1 and job D should be processed in machine 3 and no job should be processed on machine 2. Finally at stage 3, machine 1 should process job C first then job B and then job A, whereas job D should be processed by machine 2.

Table 6. Output for 8 hour shift

Job name	Output per 8 hour shift
A	16
B	12
C	12
D	12

Output of each job is calculated on the basis of 8 hour shift. In this case study, job A has output 16 units, and job B, C and D have the same output (12 units).

Work-in-process inventory per hour for a particular product at stage *i* is the differences between per hour production at stage *i-1,* and per hour production at stage *i*. Then work in inventory per hour is multiplied by 8 to get the work-in-process inventory per 8 hour shift. Work-in-process inventory will remain if per hour production at stage *i-1* is greater than per hour production at stage *i* otherwise no work-in-process inventory will remain. Work-in-process inventory per 8 hour shift is shown in table 7.

Table 7. Work-in-process inventory for 8 hour shift

Job name	Inventory per 8 hour shift	Location of inventory
A	4	Stage 2
B	0	
C	0	
D	3	Stage 2
Total	7	

Total work-in-process inventory per 8 hour shift is also determined for each job. In this case study, there is total 7 units of work-in-process inventory, 4 units for job A and 3 units for job D. Job B and C have no work-in-process inventory.

7. MODEL IMPLEMENTATION

A real life example is presented here using real data to clarify the proposed process**.** Data are collected from a machine tool company which produces different types of threaded shaft. Five different operations are needed to produce a job. These operations are turning, drilling, two end milling and thread cutting. Three different jobs named shaft1, shaft2 and shaft3 are processed in five separate stages for hybrid flow shop scheduling. Three lathe machines are set at the first stage to perform turning, two drill machines are set at the second stage to perform drilling, two milling machines are set at the third and fourth stage to perform end milling and three lathe machines set at the final stage to perform thread cutting. The schematic diagram of the hybrid flow shop problem is presented in Figure 5.

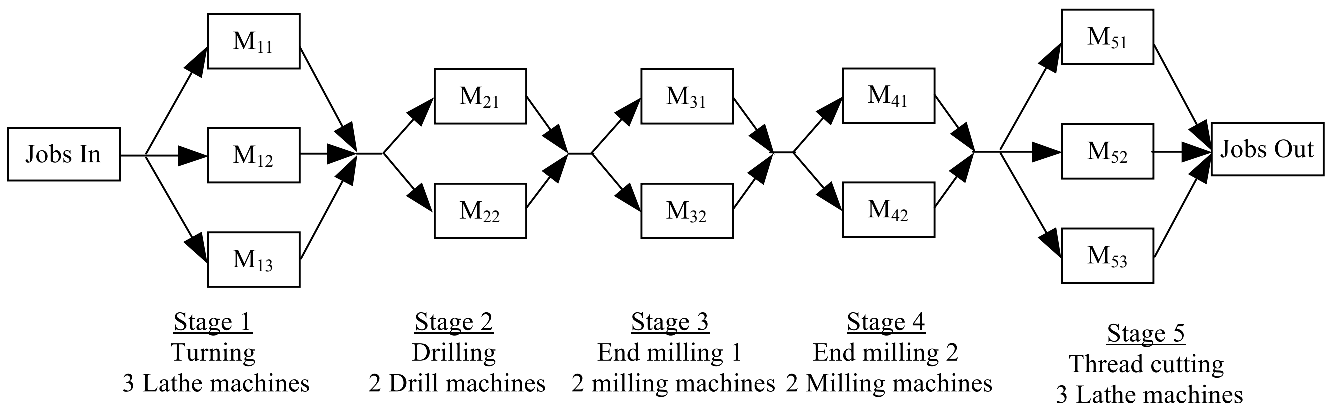

Figure 5. Hybrid flow shop in a machine tool company

Information about the jobs and machines at each stage is shown in Table 8 and Table 9 respectively. These data are collected from the machine tool company's information centre.

Table 8. Information about jobs at different stages

Job name	Profit rate at Turning	Profit rate at Drilling	Profit rate at End milling 1	Profit rate at End milling 2	Profit rate at Thread cutting	Due date (days)	Cost over time
Shaft1	5.5	10	5.25	12.5	5	10	40
Shaft2	8	8.5	15.5	6.5	4.5	8	30
Shaft3	12.5	6.25	12	9	6.75	2	80

Table 9. Information about machines at different stages

Stage	Processing Time (min)		
	Machine 1	Machine 2	Machine 3
Turning	25	30	35
Drilling	38	52	
End milling 1	23	27	
End milling 2	12	10	
Thread cutting	35	28	38

From the rule viewer and information about job, priority of each job is obtained. Priority values are got in the scale of 1, which are converted into scale of 100. Table 10 shows the priority table of jobs at different stages.

Table 10. Priority of jobs at different stages

Job name	Priority at Turning stage (%)	Priority at Drilling stage (%)	Priority at End milling 1 stage (%)	Priority at End milling 2 stage (%)	Priority at Thread cutting stage (%)
Shaft1	37	37.5	37	38.8	37
Shaft2	39.1	39.3	49	37.4	36.4
Shaft3	61.2	55.4	60.9	60.5	56.8

Per hour production of each machine at each stage is determined from the processing time of that machine. Table 11 shows the per hour production of machines at different stages.

Table 11. Per hour Production (pcs.) of each job at each stage

Production per hr at Turning (pcs.)		Production per hr at Drilling (pcs.)		Production per hr at End milling 1 (pcs.)		Production per hr at End milling 2 (pcs.)		Production per hr at Thread Cutting (pcs.)	
Lathe machine 1	2.4	Drill machine 1	1.58	Milling machine 1	2.61	Milling machine 1	5.0	Lathe machine 1	1.71
Lathe machine 2	2.0	Drill machine 2	1.15	Milling machine 2	2.22	Milling machine 2	6.0	Lathe machine 2	2.14
Lathe machine 3	1.71							Lathe machine 3	1.58

Using the developed grouping and sequencing algorithm, the following table provides the ultimate grouping of the jobs to the machines. For multiple jobs grouped to a single machine, sequencing of the concerned jobs is also obtained using the same algorithm. Table 12 shows the schedule of each job prioritized to be processed in each machine at each stage.

Table 12. Schedule of jobs in different machines at different stages

Stage	Machine	Job
Turning	Lathe machine 1	Shaft3
	Lathe machine 2	Shaft2
	Lathe machine 3	Shaft1
Drilling	Drill machine 1	Shaft3, Shaft1
	Drill machine 2	Shaft2
End milling 1	Milling machine 1	Shaft3, Shaft1
	Milling machine 2	Shaft2
End milling 2	Milling machine 1	Shaft1
	Milling machine 2	Shaft3, Shaft2
Thread cutting	Lathe machine 1	Shaft1
	Lathe machine 2	Shaft3
	Lathe machine 3	Shaft2

Final schedule is obtained from the output of the grouping and sequencing algorithm, which is shown in Table 12. As obtained in the developed final schedule, at turning stage, Shaft1 should be processed in lathe machine 3 and shaft2 should be processed in lathe machine 2. The remaining lathe machine 1 should process shaft3. At drilling stage, shaft3 and shaft1 should be processed in drill machine 1 and shaft2 should be processed in drill machine 2. At end milling 1 stage, milling machine 1 should process shaft3 first then shaft1, whereas shaft2 should be processed by milling machine 2. At end milling 2 stage, milling machine 1 should process shaft1, whereas shaft3 and shaft2 should be processed by milling machine 2 sequentially. Finally, at thread cutting stage, shaft1 should be processed in lathe machine 1 and shaft3 should be processed in lathe machine 2. The remaining lathe machine 3 should process shaft2.

Output of each shaft is calculated on the basis of 8 hour shift. In this real life example, shaft1 has output 6.3 units, shaft2 has output 9.2 units and shaft3 has output 6.3 units. Table 13 shows output of different shafts.

Table 13. Output for 8 hour shift

Job name	Output per 8 hour shift
Shaft1	6.3
Shaft2	9.2
Shaft3	6.3

Work-in-process inventory is determined on the basis of different of production rate between successive two stages. Work-in-process inventory for different shafts per 8 hour shift is shown in table 14. Total 27.04 units work-in-process inventory remains on the system. Location of work-in-process inventory is also identified and drilling stage is found to be responsible for higher work-in-process inventory.

Table 14. Work-in-process inventory for 8 hour shift

Job name	Inventory per 8 hour shift	Location of inventory
Shaft1	7.36	Drilling stage
Shaft2	6.80	Drilling stage
Shaft3	12.88	Drilling stage
Total	27.04	

Maintaining minimum work-in-process inventory is very important in production environment. Hybrid flow shop is not an exception. Work-in-process inventory is the main source of creating bottleneck in a production flow system. To smooth the material flow in a production system and to reduce material handling, it is necessary to maintain minimum work-in-process inventory. Costs of inspection, stocking, material handling, inventory tracking, and the risks of damage and obsolescence can be greatly reduced by decreased work-in-process inventory. In the real life example, shaft1, shaft2 and shaft3 are being processed in different machines at different stages. However, there was no systematic allocation of jobs into machines. As a result, there would be a lot of work-in-process inventory in different machines and it was of random nature. The current approach has been implemented to the existing production flow that could minimize work-in-process inventory. As the approach developed a systematic pattern of work-in-process inventory, location of work-in-process inventory has also been identified to help make decisions to improve the overall situation. As drilling stage is found to be responsible for higher work-in-process inventory, one extra drill machine can be added at this stage to reduce work-in-process inventory hence improve material flow. By implementing the present technique, work-in-process inventory has been minimized which resulted in improved situation of production flow process as well as cost minimization. Also the uncertainty of different inputs, which represents real situation in production arena, makes the model more acceptable to manufacturing industry. In a similar manner, the proposed model can also be implemented to minimize the work-in-process inventory in any type of flow shop, assembly line and automated production line.

8. CONCLUSIONS

A multi-objectives hybrid flow shop scheduling problem has been considered in this research to minimize work-in-process inventory using several parameters like due date, profit rate and cost over time. To represent the real situation in production environment, uncertainty is also added through fuzzy due date, fuzzy profit rate, and fuzzy cost over time to determine the job priority and machine reliability and availability affected variable fuzzy processing time. Fuzzy Inference System (FIS) is used to calculate the weight of jobs and machines at various stages. Several variables are used to calculate job and machine priority. In this research, triangular membership function is used for input and output variables and to calculate the priority of each job. Some other variables (where needed) can be added to make final schedule more realistic. Some other membership functions like Gaussian, trapezoidal, Z shaped, Pi shaped, S shaped, Bell shaped can be used to get more accurate result. A programming code is then generated to make the final schedule using priority of jobs and machines to minimize the total work-in-process inventory. The developed model has been implemented into a manufacturing factory to represent a real life situation. Compared to the previous techniques used by the production system, the proposed technique could significantly reduced work-in-process inventory which ultimately contributes to higher profit margin. This model could also clearly recognize the bottleneck operations so that measures can be taken to improve the overall production flow. The proposed model can be applied for any kind of production line and assembly line to minimize work-in-process inventory and to track the bottleneck location of the whole system.

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BIOGRAPHICAL SKETCH

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