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Multi-Objective Fuzzy Flow Shop Scheduling Model in a Manufacturing Company

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Abstract

This study proposes a solving methodology for multi-product parallel multi-stage cellular manufacturing company. The problem studied in this paper is a case study from a shoe manufacturing plant for producing the products according to their due dates. The manufacturing process investigated had three stages: a lasting stage, a rotary machine stage, and a finishing stage. The performance of system is measured by minimizing the total flow time and the makespan. Due to the complexity of the problem, the families of the products are decided according to the operations time to maximize the utilization in all cells with using Genetic Algorithm. Flow shop scheduling is then performed on each part family formed to determine the product sequence for each cell group by using multi-objective fuzzy mixed integer linear programming modeling. The two objectives are considered to minimize the total flow time and the makespan in order to generate non-dominated solution.

1. Introduction

In global supply chains, customer satisfaction level is very important for the sustainability of the business. This paper analyzes a shoe manufacturing company that produces different volumes and varieties of shoes for the market. The objective of the manufacturing company is to meet the customer demand on time, at the desired quality and especially at lower cost because of a large number of manufacturers and brands available in the sector and intense competition in

the marketplace. Scheduling is one of the main problems to determine the allocation of the limited resources to a set of jobs. This paper discusses such a multi-product parallel multi-stage cellular manufacturing system. It involves i) determining manpower level for cell groups, ii) loading each cell group and iii) sequencing jobs to minimize a) total flowtime and b) makespan.
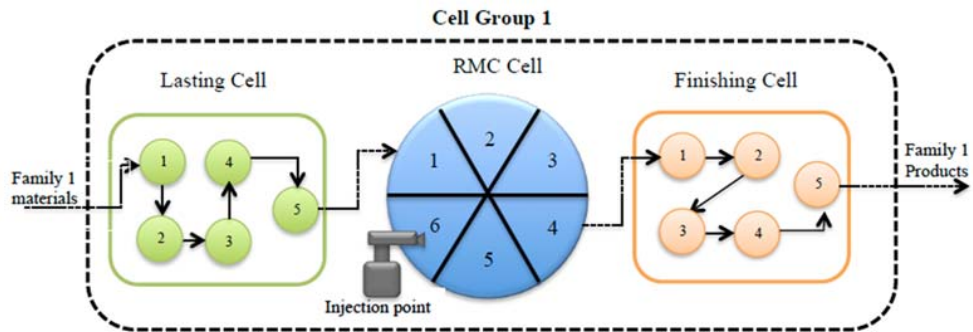

Figure 1. Cell groups and configurations

The manufacturing company has 6 cell groups and each group consists of a lasting cell (LC), a rotary machine cell (RMC), and a finishing and packing cell (FC). In the LC, shoes are prepared for injection molding in the RMC. The LC consists of multiple sequential processes. These processes are similar for all sole designs and shoe sizes. From the LC, shoes are transferred to the RMC, which has six pairs of stations, each of which can process one pair of shoes at a time. After injection molding in the RMC, the shoes go to the FC, where extra material is removed from the shoe, which is then finished and packed. A cell group and configurations are shown in Figure 1.

This paper constructs a multi-product parallel multi-stage cellular manufacturing with variety of products determines the manpower level for the cell groups, families of all products for each cell group and sequencing of the jobs to minimize the total flowtime and makespan for shoes manufacturing company.

The rest of this paper is organized as follows: Literature review is presented in Section 2. Section 3 defines the problem formulation and all three phases. Section 4 represents the fuzzy mathematical model. In order to demonstrate how the proposed methodology is applied, a real case study is carried out in Section 5. Finally, conclusions and recommendations are presented in Section 6.

2. Review of current literature

In this paper, a three-phase manufacturing cell loading and manpower allocation problem for a multi-stage cellular structure is proposed. Süer et al. [1] developed a three-phase methodology to perform cell loading and scheduling in a shoe manufacturing company. Huang and Süer [2] proposed a dispatching rule-based GA with the objective of minimizing makespan, average flowtime and total tardiness. They considered a two-level fuzzy approach that was used to evaluate overall fuzzy satisfaction levels. Yagmahan and Yenisey [3] considered the flowshop-scheduling problem with multi-objectives of makespan and total flowtime. Selen and Hott [4] proposed mixed integer goal programming with the objective of minimizing makespan and total flowtime to solve m-machine flowshop-scheduling problems. Framinan et al. [5] proposed a heuristic procedure to provide the decision maker with a good solution with respect to the objectives of makespan and flowtime minimization. Giannopoulos et al. [6] considered multi-objective flowshop-scheduling problems with the goal of minimizing makespan, maximum tardiness, and total flowtime. The fuzzy measures are addressed to show the importance of each criterion. Yenisey and Yagmahan [7] provided a brief literature review of multi-objective flowshop-scheduling problems but did not include fuzzy approaches. Süer et al. [8] studied a fuzzy bi-objective cell loading problem to minimize the amount of total manpower needed. Fuzzy programming is considered an important part of multi-objective optimization problems.

3. Solution Methodology

Three phases are used to describe and evaluate this manufacturing systems problem. The first phase decides the manpower allocation in the first cell and last cell that have five sequential operations in order to maximize the production rate. In the second phase, GA approached is applied to cell loading with the similar families in each cell group to minimize the deviation of the utilization rate among the cell groups. After all this decision, in the third phase, sequencing of the jobs are decided to minimize the makespan and flowtime separately. The structure used in this paper is summarized in Figure 2.
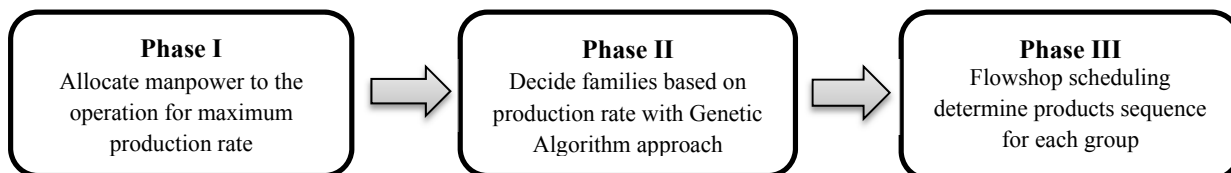
Phase I Allocate manpower to the operation for maximum production rate	→	**Phase II** Decide families based on production rate with Genetic Algorithm approach	→	**Phase III** Flowshop scheduling determine products sequence for each group

Figure 2. Mathematical model application sequence

4. Problem Formulation

Three mathematical models are used to describe and evaluate the manufacturing system studied in this paper. The first model seeks to allocate manpower to maximize the production rate in the LC and FC independently. The second model is to perform cell loading to minimize the deviation of utilization among the cell groups. With production rates and part families found in the first two models, the third model is used to schedule the products in their cells using flowshop scheduling approach. Fuzzy structure is applied to find the multi-objective solution by considering two objectives: makespan and total flowtime.

4.1. Phase I: Manpower Allocation

The problem on hand is to formulate a model that maximizes the total production rate subject to constraints on worker level, operation time for each cell. Integer linear programming (ILP) formulation developed by Suer et al. [9] is used in this study.

4.2. Phase II. Mathematical Model for Cell Loading

This mathematical model assigns products to cells in order to minimize the deviation of the utilization rate among families in the cell groups given number of cells and families. All definitions are represented as follow:

Sets and Indices:
M:　　　　Number of products, $i = 1, ..., M$
N:　　　　Number of cell group or families, $j = 1, ..., N$

Parameters:
t_i　　　　Total capacity requirements for cell grup j.
h_i　　　　Utilization rate for cell group j.
$\bar{h}$　　　　Average of h_j.
u_i　　　　Total capacity requirements for product i.
k　　　　Number of cells.
c　　　　Total available capacity.

Decision Variables:

x_{ij}: 1 if product i belongs to family j, 0 otherwise.

Objective Function:

$$Min\ Z = \sqrt{\sum_{j=1}^{N}(h_j - \bar{h})^2/(N-1)} \tag{1}$$

Subject to:

$$\sum_{i=1}^{M} u_i x_{ij} \leq 1 \qquad\qquad j = 1, \dots, N \tag{2}$$

$$\sum_{j=1}^{N} x_{ij} = 1 \qquad\qquad i = 1, \dots, M \tag{3}$$

$$t_j = \sum_{i=1}^{M} u_i x_{ij} \qquad\qquad j = 1, \dots, N \tag{4}$$

$$h_j = \sum_{j=1}^{N} t_j/(k*c) \qquad\qquad j = 1, \dots, N \tag{5}$$

$$\bar{h} = \sum_{j=1}^{N} h_j/N \tag{6}$$

$$x_{ij} \in \{0,1\} \qquad\qquad for\ \forall\ i, j \tag{7}$$

The objective, shown in Eq. (1), minimizes the standard deviation of utilization rate within cell groups or families. The constraint expressed in Eq. (2) requires utilization for each cell group to be no greater than 100%. Eq. (3) ensures that each product is assigned to a family. Eq. (4) calculates the total utilization rate for each family and Eqs. (5) and (6) calculate the average utilization rate of all families. Eq. (7) defines the binary condition of the decision variable. A GA approach is used to solve the cell loading problem. An example of the chromosome representation is shown in Figure 3. Convex combination crossover is performed by using the arithmetic operators as the combination of two chromosomes (Gen and Cheng [10]). The fitness function is calculated using Eq. (8), which is shown again below:

$$Fitness\ function = \sqrt{\sum_{j=1}^{N}(h_j - \bar{h})^2/(N-1)} \tag{8}$$

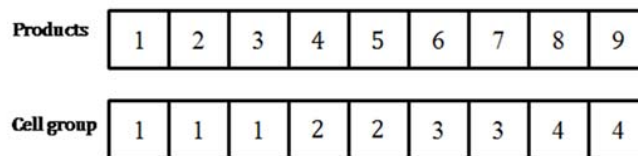| Products	1	2	3	4	5	6	7	8	9
Cell group	1	1	1	2	2	3	3	4	4

Figure 3. Chromosome structure

4.3. Phase III. Mathematical Model for Flowshop Scheduling

In this section, the flow shop scheduling problem with multiple objectives is addressed in detail.

4.3.1. Minimize makespan

The objective of this model is to schedule jobs in each cell group such that the selected performance measure is optimized. The objective is to complete the jobs so as to minimize either their makespan or total flowtime. Flowshop scheduling was run for each part family formed independently.

Sets and Indices:

C:	Number of cells, $i = 1, ..., C$
N:	Number of jobs, $j = 1, ..., N, k = 1, ..., N$

Parameters:

p_{ij}:	Processing time of job j in cell i.
d_j:	Due date of job j.
ε:	A positive small number.
M:	A positive large number.

Decision variables:

y_{ij}	Start time of job j in cell i.
ct_{ij}	Completion time of job j in cell i.
z_{ijk}	Binary variable: equal to one if the job j is processed before job k in cell i, and zero if the job j
MS	Makespan
$Ftime$	Total flowtime

The mathematical model for minimizing makespan that will be referred to as Model I is given below:

Objective Function:

$$\min Z = MS \qquad (9)$$

Subject to:

$$ct_{ij} \leq MS \qquad i = C, j = 1, ..., N \qquad (10)$$

$$y_{i+1j} - y_{ij} \geq p_{ij} \qquad i = 1, ..., C, j = 1, ..., N \setminus \{C\} \qquad (11)$$

$$ct_{ij} - y_{ij} \geq p_{ij} \qquad i = 1, ..., C, j = 1, ..., N \qquad (12)$$

$$M.z_{ijk} + (y_{ij} - y_{ik}) \geq p_{ik} \qquad i = 1, ..., C, j = 1, ..., N - 1, k = 1, ..., N \qquad (13)$$

$$M.(1 - z_{ijk}) + (y_{ik} - y_{ij}) \geq p_{ij} \qquad i = 1, ..., C, j = 1, ..., N - 1, k = 1, ..., N \qquad (14)$$

$$z_{ik} \in \{0,1\} \ \forall i, j, k \qquad (15)$$

$$MS \geq 0, ct_{ij} \geq 0 \ for \ \forall i, j, y_{ij} \geq 0 \ for \ \forall i, j \qquad (16)$$

The objective function is to minimize makespan and it is given in Eq. (9). Eq. (10) establishes the relationship between the job's completion time and its makespan, ensuring that makespan is equal to the completion time of the last job in the last cell group. Eq. (11) asserts that a job has to finish processing in its current cell before it can start in the following cell. In a similar manner, Eq. (12) ensures that a product must complete processing in the final cell before it can be labelled complete. According to the relations given in Eqs. (13) to (14), if job j precedes job k in cell i than Eq. (13) is implied, if the job j is not preceded before job k in cell i than Eq. (14) is implied. Eq. (15) ensures that the integer restrictions for all of the variables are used in the model. Eq. (16) restricts all variables to be positive.

4.3.2. Minimize total flowtime

The objective is to minimize total flowtime as given in Eq. (17). Eq. (18) defines the total flowtime.

Objective Function:

$$\min Z = FTime \qquad (17)$$

Subject to:

$$Ftime = \sum_{j=1}^{N} ct_{ij} - r_j \qquad i = C, j = 1, ..., N \qquad (18)$$

where r_j is the ready time job j. Eq.(11)-(16) are used the same in the model of minimizing makespan.

5. Proposed fuzzy flow-shop scheduling model

Decision makers in the manufacturing sector want to minimize the maximum completion time and also to minimize the work-in-process inventory level (related to minimizing total flowtime). These two objectives are very important in the real-world practice. This paper focuses on obtaining a schedule which highly satisfies these two measures. A fuzzy evaluation approach is proposed to solve multi-objective problem. Bellman and Zadeh [11] first applied fuzzy concepts in decision making field. In this study, a linear membership function and add fuzzy operator suggested by Sommer and Pollatschek [12] is used. The linear fuzzy mathematical model is defined as given in Figure 4.

$$\max ZZ = \sum_{s=1}^{S} \lambda_s$$
$$\lambda_s \le (ub_s - c_s x)/(ub_s - lb_s) \qquad \text{, for all s} \tag{19}$$
$$Ax \le b, \lambda_s, x \ge 0, \lambda_s \le 1$$

In this model, lb_s and ub_s are the lower and upper bounds of the objective functions (s), respectively. λ_s shows the satisfaction level with this membership function. From expression (19), it is understood that the bigger value of λ_s, the higher the satisfaction with the result of this performance measure.
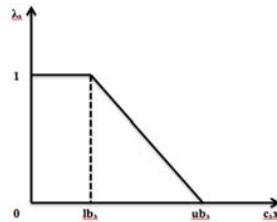

Figure 4. Linear membership function λ_s.

6. Experimental study

We focus on a shoe manufacturing company that produces a variety of designs, sizes, colors, and materials. There are parallel multi-stage cell groups and multiple processes in each cell. We make the following assumptions in expressing our multi-job multi-stage manpower allocation, cell loading and sequencing problem mathematically. An example problem with 20 products and six cell groups with three stages are considered on FC, RMC, and LC.

In the first phase of the model, 35 workers are considered to maximize the production rate. The six worker level combinations evaluated were 15/20, 16/19, 17/18, 18/17, 19/16, and 20/15, where the first number represents the workers assigned to the LC and the second number represents the workers assigned to the FC. Based on the data, we find the worker levels by using phase I mathematical model to maximize the production rates. Weekly standard hour is assumed 40 hours. After that, for each worker level, the jobs are grouped by using Phase II mathematical model. Table 1 shows the product families where deviation between utilizations of the FC, RMC, and LC cells based on 15/20 worker level. To assign products to cells, the Phase II mathematical model constructed and solved by using GA approach, which does not exceed the weekly capacity of each cell and minimizes the variation between the utilization of each cell.

Table 1. Assigned products to cell groups for 15/20 worker level

Cell Group	Products	FC	RMC	LC
1	14,19,20	0.923	0.649	0.809
2	2,12,15	0.999	0.829	0.600
3	3,4,10	0.966	0.654	0.577
4	1,8,9,18	0.965	0.978	0.813
5	6,7,13,16	0.981	0.782	0.636
6	5,11,17	0.903	0.737	0.541
Deviation for all cell groups				0.157

For each of worker levels, product families are determined by using GA approach with population size 100, number of generations 200 and 0.01 mutation rate, by using Analytic Solver Platform on a computer of Intel(R) Core(TM) i3-4005U CPU @ 1.70GHz, 4.0 GB RAM within a small range from 80s to 122s. A flowshop scheduling is performed to find a sequence that minimizes the performance measures of the makespan and total flowtime simultaneously. Firstly, we try to find the lower bound of the performance measure. Fuzzy flowshop scheduling model is applied to find the schedule for all cell groups to reach the desired satisfaction level. We add the following fuzzy equations to obtain the maximum satisfaction level for both objectives.

$$\text{Max ZZZ} = \lambda_1 + \lambda_2 \tag{20}$$
$$\lambda_1 \leq (ub_1 - H^*)/(ub_1 - lb_1) \tag{21}$$
$$\lambda_2 \leq (ub_2 - Ftime^*)/(ub_2 - lb_2) \tag{22}$$

where H* and Ftime* show that minimum values of makespan and total flowtime and obtained from solving single objective models. The decision maker desires to maximize the satisfaction level. Thus, the sums of the satisfaction functions λ1 and λ2 have to be maximized in Eq. (20). Eq. (21) and (22) calculates the satisfaction level of makespan and flowtime, respectively.

Table 2. Results of the fuzzy flow shop scheduling for each worker level

Worker level	Families	Sequence	MS	Ftime	λ_1	λ_2	Max ZZZ	Total Satisfaction
15/20	1	19,14,20	56.198	138.834	0.790	0.330	1.120	8.624
15/20	2	2,12,15	57.452	133.218	1.000	0.864	1.864	
15/20	3	4,3,10	57.445	129.085	0.515	0.070	0.585	
15/20	4	8,1,18,9	53.048	178.731	1.000	0.250	1.251	
15/20	5	7,6,16,13	54.120	140.801	0.871	1.000	1.871	
15/20	6	17,11,5	56.132	110.836	0.933	1.000	1.934	
16/19	1	7,6,13,16	50.007	135.528	1.001	0.916	1.917	9.848
16/19	2	18,11,1	52.316	125.955	0.945	0.670	1.615	
16/19	3	9,14,15	52.423	117.675	0.041	0.943	0.984	
16/19	4	10,8,5	55.374	123.141	0.698	1.000	1.697	
16/19	5	17,19,2,20	47.972	138.824	1.000	0.988	1.988	
16/19	6	4,3,12	59.882	126.662	0.647	1.000	1.647	
17/18	1	9,14,5	55.382	120.305	0.240	1.000	1.241	10.145
17/18	2	6,19,3	54.871	115.866	1.000	1.000	2.000	
17/18	3	8,15,16	48.921	124.886	1.000	0.789	1.788	
17/18	4	7,2,20,10	47.844	137.903	0.999	0.846	1.845	
17/18	5	18,1,12	56.667	123.818	0.714	1.000	1.714	
17/18	6	17,4,11,13	54.181	138.652	0.850	0.707	1.557	
18/17	1	7,2,1,13	51.707	145.138	0.000	0.000	0.000	9.965
18/17	2	6,19,12	51.704	114.595	0.999	1.000	1.999	
18/17	3	8,20,15	50.154	128.899	0.999	0.495	1.494	
18/17	4	17,11,3	54.547	107.140	0.895	1.000	1.895	
18/17	5	9,14,5	56.090	122.683	0.720	0.130	0.849	
18/17	6	4,10,18,16	51.541	148.930	0.972	0.892	1.865	
19/16	1	10,2,12	51.503	113.204	0.999	1.000	1.999	10.296
19/16	2	19,11,15	51.089	123.828	1.000	0.756	1.756	
19/16	3	20,14,5	60.597	134.529	0.460	1.000	1.460	
19/16	4	18,1,3	56.365	122.196	1.000	1.000	2.000	
19/16	5	17,4,6,13	45.469	120.369	0.967	1.000	1.967	
19/16	6	7,9,16,8	56.202	131.851	0.114	1.000	1.114	
20/15	1	20,15,14	63.298	124.105	0.013	1.000	1.012	10.458
20/15	2	2,19,5	54.663	126.817	0.999	1.000	2.000	
20/15	3	16,8,12	56.801	127.799	0.792	1.000	1.792	
20/15	4	7,4,9,3	56.244	130.254	0.657	1.000	1.656	
20/15	5	17,10,1,13	48.000	129.005	1.000	0.999	1.999	
20/15	6	6,18,11	51.450	116.342	1.000	1.000	2.000	

Two lower bounds (lb) are determined using the above two models for (MS*, Ftime*) by using LINDO 17. The decision maker wants to maximize the total satisfaction level. Thus, the sums of the satisfactions functions λ_1 and λ_2 have to be maximized. In this study, the overall objective is to determine product families and the best worker level that

provides the maximum satisfaction level for the company with three stages and six cell groups. According to Table 2, in the LC and FC cells with 20/15 worker levels and 6 cell groups {(20,15,14); (2,19,5); (16,8,12); (7,4,9,3); (17,10,1,13); (6,18,11)} the total maximum satisfaction level is obtained that shown in the last column in Table 2. 17/18, 19/16, and 20/15 showed the best total satisfaction rate for families 1,2,3,4,5, and 6. If we take the difference between the maximum and the minimum satisfaction rates into consideration, it will be concluded that 17/18 worker level is the best result.

7. Conclusion

In this paper. we have solved a real life shoe manufacturing scheduling problem. We have formulated a three-phase solution methodology to solve the multi-product parallel multi-stage cellular manufacturing system problem with the objectives of minimizing the makespan and flowtime. The first model allocates manpower to maximize the production rate in the LC and FC independently. All the cell loading results are applied to find the scheduling getting the best makespan and flowtime response.

In future research. this model can further be generalized to include with stochastic demand for all types of jobs. We also plan to validate our system with handling manufacturing systems problems by using simulation.

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