Scheduling and Planning Problem in Manufacturing Systems with Multiobjective Genetic Algorithm

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Abstract - In this paper an extensive earliness/tardiness production scheduling and planning(ETPSP) model with lot-size consideration and capacity balance is proposed. An innovative approach using multiobjective genetic algorithm (MOGA) is designed as its solutions. The presented MOGA approach can even deal with ETPSP problem which consists of highly complicated and non-linear functions for the measure performance. The effectiveness of this approach is demonstrated by simulation results as well as the comparisons with other techniques.

Keywords: Multiobjective Optimization, Multiobjective Genetic Algorithms, Manufacturing Resource Planning, Just-In-Time .

1. Introduction

Manufacturing resource planning (MRP-II) and Just-in-time (JIT) are two kinds of modern production and inventory management methods developed in western countries and Japan. Although they provide many advantages, the high in-process inventory, the nervousness of production planning in MRP-II manufacturing systems, the impact of bottlenecks, the sensitivity of unbalance and uncertainty in JIT manufacturing systems are the difficult problems remaining to be tacked[1,2,3,4].

In order to overcome these problems and to achieve the best result of production and inventory management, more and more researchers have focused on integrating MRP-II with JIT philosophy. The presented researches on miscellaneous MRP-II and JIT focused on how to use JIT philosophy to improve the production scheduling and planning (PSP) approach of MRP-II by an efficient master PSP (MPSP) method. Earliness/tardiness production scheduling and planning(ETPSP) method has been one of the most active and important research area[5,6].

As MPSP plays an important role in MRP-II systems[7], by utilizing the available capacity of manufacturing systems, a medium-term production planning process to meet the changing market requirements can be realized. This also provides a support for other procedures, such as business planning, material requirement planning, purchase planning, capacity planning and final assembly scheduling, etc.

As development of JIT, the production goal should be changed. In general, conventional MPSP methods considered the minimization of total production cost or the maximization of production output as the objective. However, as for the development of JIT, the due date gradually become a more and more important objective. This can be a winner for the manufacturer in a competitive market if the MPSP can be adjusted to changing requirements timely. As a result, the ETPSP method, an effective combination of MRP-II with JIT in the level of PSP, has therefore become an active research area [6,7].

Furthermore, conventional methods cannot effectively solve a large scale ETPSP problem. Despite a lot of current research which has mainly been focused on the MPSP problem based on single-machine/parallel multi-machine condition, only the constant process capacity were considered [8,9]. Even with an elementary ETPSP model [10,11], the obtained results were calculated for the case of two-type-product without the lot-size consideration.

To be able to support various and changing market requirements, the manufacturing systems should in practice, handle the involved processes and types of products with different lot-size. Hence, an ETPSP is therefore a large scale optimization problem [1,6,7].

Genetic Algorithms (GAs) were invented and developed to mimic some of the processes observed in natural selection. They have been used on machine learning, artificial intelligence, pattern recognition and operation research [12,13]. MOGA problems are characterized by a family alternatives which must be considered equivalent in the absence of information concerning the relevance of each objective relative to the others [14].

In this paper, an extensive nonlinear and discrete MOGA model was developed to address the ETPSP which also incorporating the consideration of lot-size, capacity balancing and multi-type-product. In so doing, the approach must also fulfill the requirement of completing the task within an agreeable time.

The organization of this papers starts with an introduction section. An extensive ETPSP model is given in Section 2. An overview of GA and the design of the MOGA approach are discussed in Section 3. Simulation results and comparisons for demonstrating the effectiveness of the MOGA approach are shown in Section 4, while the concluding summaries are provided in Section 5.

2. Model of ETPSP Problem

Without loss of generality, some useful notations are shown as follows to describe an ETPSP problem of a manufacturing systems.

- **N**: *the number of products*
- **i**: *the index of product, generally $i=1,2,...,N$*
- **M**: *the number of processes*
- **j**: *the index of process or assembling stage, generally $j=1,2,...,M$*
- **T**: *the length of a planning horizon*
- **k**: *the index of planning horizon, generally $k=1,2,...,T$*
- **Product i**: *the name of the i-th production*
- **Process j**: *the name of the j-th process or assembling stage*
- **Period k**: *the name of the k-th period in the planning horizon*
- **$d_i(k)$**: *the requirement quantity of Product i in Period k*
- **$c_j(k)$**: *the available capacity of Process j in Period k*
- **w_{ij}**: *the unit capacity requirement of Product i for Process j. It is assumed that the unit capacity requirements of all products should be kept in constants along a horizon.*
- **I_i**: *the initial inventory of Product i, $I_i<0$, implies the initial shortage of Product i*
- **α_i**: *the unit time earliness penalty of Product i*
- **β_i**: *the unit time tardiness penalty of Product i, α_i and β_i can be determined by the inventory cost and tardiness compensation in practice, generally $\alpha_i > \beta_i$,*
- **s_i**: *the lot-size of Product i*
- **$p_i(k)$**: *the planning production quantity of Product i in Period k.*

To suit the changing market requirements, an order should be produced either early or tardily. But all these two cases would increase the production cost. Meanwhile, in each production period, there is at least one key-process, whose capacity is the most limited and constrained to the production. The aim of ETPSP problem is to find an optimal or near-optimal PSP in a PSP horizon. In such way, the costs of earliness and tardiness penalties are minimized and the manufacturing process capacity constraints are confirmed.

2.1 Objective Functions of ETPSP

MO problems are characterized by a family alternatives which must be considered equivalent in the absence of information concerning the relevance of each objective relative to the others[14]. Based on the above description, for a ETPSP problem there are three objective functions constructed as follows,

(1) The Number of Unbalancing Processes,

$$f_1 = |P'|$$

$$P' = \{j \mid j \in P_{key-process}, \sum_{i=1}^{N} w_{ij} p_i(k) - c_j(k) > 0, \quad k = 1,2,\ldots,T\} \tag{1}$$

where $P_{key\text{-}process}$ is the set of key-processes.

(2) The Cost of Early Production Penalties,

$$f_2 = \sum_{i=1}^{N}\sum_{k=1}^{T} \alpha_i [I_i + \sum_{t=1}^{k} p_i(t) - \sum_{t=1}^{k} d_i(t)]^+ \tag{2}$$

where $(x)^+ = \max\{0, x\}$.

(3) The Cost of Tardy Production Penalties,

$$f_3 = \sum_{i=1}^{N}\sum_{k=1}^{T} \beta_i [\sum_{t=1}^{k} d_i(t) - \sum_{t=1}^{k} p_i(t) - I_i]^+ \tag{3}$$

where $(x)^+ = \max\{0, x\}$.

All above objective functions are to be minimized to achieve a satisfactory and considerable ETPSP.

2.2 Constraint Functions

Considering the process capacity balancing and production quality rationality, there are two groups of constraint functions stated as follows:

(1) Process Capacity Constraint Functions,

$$\sum_{i=1}^{N} w_{ij} p_i(k) \le c_j(k), \quad j \in P_{nonkey-process} \quad k=1, 2, \ldots, T. \tag{4}$$

where $P_{nonkey-process}$ is the set of nonkey-process. It can be calculated by the equation (5),

$$P_{nonkey-process} = P - P_{key-process} = M - s_{key-process} \tag{5}$$

where $s_{key-process}$ is the size of the set of key-process,

$$s_{key-process} = \left| P_{key-process} \right| \tag{6}$$

from the equation (4), it can be known that there are $s_{nonkey-process} \times T$ constraint functions.

(2) Production Quality Constraint Function,

$$0 \le p_i(k) \in S_i, S_i = \{r \cdot s_i, r \ge 0, i = 1,2,\ldots,N\}, \quad i = 1,2,\ldots,N; k = 1,2,\ldots T \tag{7}$$

the equation (7) indicates each production quality must be positive. Meanwhile, it can be drawn that there are $N \times T$ constraint functions.

3. Multiobjective GA Approach

In conventional methods, the number of unbalancing processes has not been regards as objective function. The conflicting multiobjective functions can not be solved without the aggregation of the objective functions. Even those methods show their effectiveness in solving small scale PSP problem, they step into calculation difficulty when they deal with large scale problems. In this paper, a MOGA approach is designed instead of conventional linear or heuristic approaches for solving a multi-constraint, multiobjective ETPSP problem.

3.1 MOGA Approach

The operational procedure of the proposed MOGA approach, shown in Fig. 2, is similar to a canonical GA. Each chromosome in the form depicted by a real-number representation as shown in the followings,

$$p_1(1)p_1(2)\cdots p_1(T)p_2(1)p_2(2)\cdots$$
$$\cdots p_2(T)\cdots p_N(1)p_N(2)\cdots p_N(T) \qquad (8)$$

An example is illustrated in *Table 1*, the chromosome representing this solution is,

10	5	15	25	30	5	5	60	20	40	50	70	30	10

Fig. 1. An Example of a Chromosome

Table 1: An example of production quantity

	Pd 1	Pd 2	Pd 3	Pd 4	Pd 5	Pd 6	Lot-size
Prod 1	10	5	15	25	30	5	5
Prod 2	60	20	40	50	70	30	10

Note: Pd - Period, Prod - Product.

To ensure the diversity, an initialization population is filled with randomly generated real-number strings. A linear normalization, which converts the evaluations of chromosomes into fitness values, is adopted to avoid premature convergence. A roulette-wheel-selection technique is used as a parent selection method to give more reproductive chances to those population members what are the fittest [14]. A two-point crossover and real-creep mutation [15] are practiced as genetic operators to perform evaluation.

3.2 Preferential Articulation

Multiobjective functions may be not be minimized simultaneously in the optimization process. A Parato-based ranking technique is used to quantify the available chromosomes. Consider following two individual chromosomes I_1 and I_2 with 3 objective values f_1^1, f_2^1, f_3^1

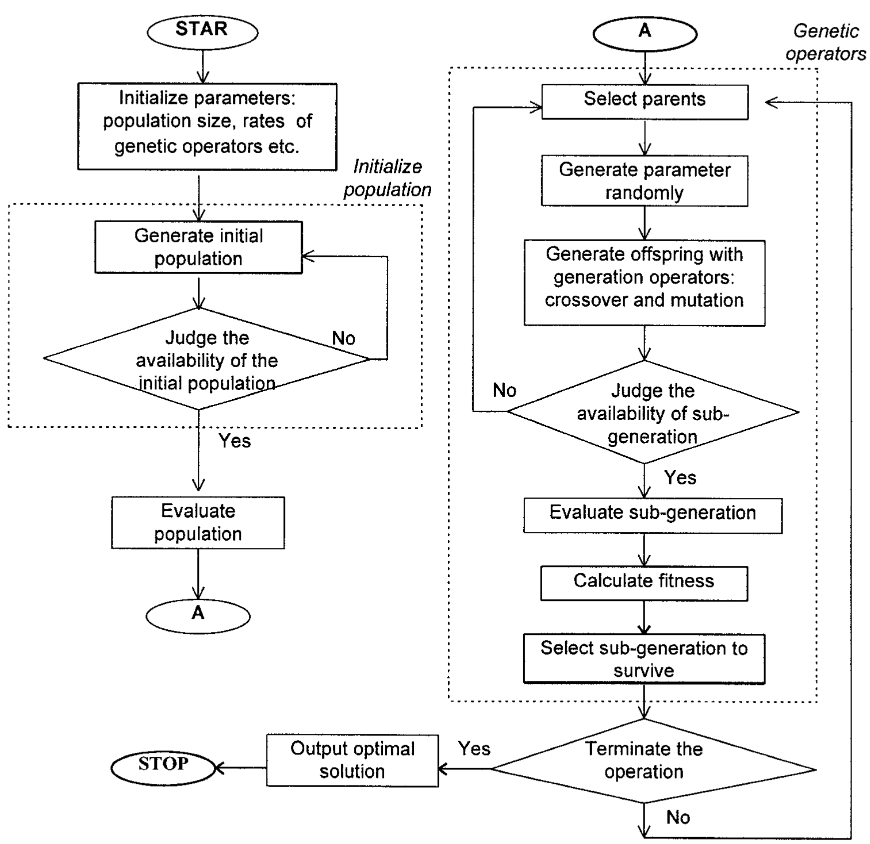


Fig. 2. The Operational Structure of MGA Approach

and f_1^2, f_2^2, f_3^2 respectively, I_1 is preferable to I_2 if and only if,

$$(1)\quad f_1^1 = f_1^2 = 0 \tag{9}$$

$$(2)\quad \forall i = 2,3, f_i^1 \le f_i^2, \text{ and}$$
$$\exists j, j = 2,3,\ f_j^1 < f_j^2 \tag{10}$$

3.3 Selection of key-process

In practical manufacturing, there are several processes, named key processes, whose capacities are mostly limited and will be constraints for a certain production. If a PSP can confirm all key process capacity constraints, the other unkey-process capacity constrains will be satisfied accordingly. In order to speed up the convergence of the MOGA approach, a Upper-Capacity-Function (UCF) $L(\alpha,t)$, which is described by the equation (11), is constructed to select key processes.

$$L(\alpha,t):$$
$$\begin{cases} L_1(\alpha,t): \alpha r_{11}(t) + (1-\alpha) r_{21}(t), \alpha_2 \le \alpha \le 1 \\ L_2(\alpha,t): \alpha r_{12}(t) + (1-\alpha) r_{22}(t), 0 \le \alpha < \alpha_1 \\ \ldots\ldots \\ L_K(\alpha,t): \alpha r_{1K}(t) + (1-\alpha) r_{2K}(t), \alpha_1 \le \alpha < \alpha_2 \end{cases}$$
$$t = 1,2,\ldots,T \tag{11}$$

where, α ($\alpha \in [0,1]$) is a Capacity-Assign Ratio(CAR),

$$r_{ij}(k) = \frac{c_j(k)}{w_{ij}}, i = 1,2,\ldots,N; j = 1,2,\ldots,M;$$
$$k = 1,2,\ldots,T \tag{12}$$

is the production quality of Product i produced by Process j in Period k.

4. Simulation Results and Comparison

To demonstrate the essence of the designed MOGA approach, a 6-period PSP problem is considered for a 5-process, 4-product manufacturing system. According to different products, the earliness and tardiness penalty, the order quantity and lot-sizes, the capacity requirement of various products to different processes and available capacity of each process are shown in Table 2, Table 3, Table 4 and Table 5, respectively. By the key-process selection, some key-processes are tabulated Table 6.

Table 2: Earliness and tardiness penalty α_i and β_i

	Earliness Penalties α_i	*Tardiness Penalties β_i*	*Lot-size s_i*
Prod 1	α_1=5	β_1=15	s_1=5
Prod 2	α_2=10	β_2=20	s_2=10
Prod 3	α_3=5	β_3=10	s_3=5
Prod 4	α_4=5	β_4=15	s_4=5

Table 3: Order quantity $d_i(k)$

	Pd 1	*Pd 2*	*Pd 3*	*Pd 4*	*Pd 5*	*Pd 6*
Prod 1	0	0	20	0	0	30
Prod 2	10	0	0	50	0	0
Prod 3	20	0	20	0	0	5
Prod 4	0	0	10	40	0	10

Table 4: Capacity requirement w_{ij}

	Pr 1	*Pr 2*	*Pr 3*	*Pr 4*	*Pr 5*
Prod 1	1.0	0.6	0.8	0.3	0.7
Prod 2	0.6	0.8	1.3	2.0	0.7
Prod 3	0.1	0.2	0.2	0.3	0.1
Prod 4	0.3	0.2	0.1	0.4	0.2

Table 5: Available capacity $c_j(k)$

	Pd 1	*Pd 2*	*Pd 3*	*Pd 4*	*Pd 5*	*Pd 6*
Pro 1	30	30	30	30	30	30
Pro 2	18	28	18	18	18	18
Pro 3	34	44	34	34	34	34
Pro 4	24	34	24	44	19	24
Pro 5	26	36	26	46	26	26

Table 6: Key-processes

	Pd 1	*Pd 2*	*Pd 3*	*Pd 4*	*Pd 5*	*Pd 6*
Key-process	2	2 4	2	5	2	2

(Note: Pd - Period, Prod - Product, Pr - Process)

An important and extra feature of this MGA approach is the trade off between the earliness/tardiness cost and the performance of the key-process balancing based on minimum of objectives f_1 and f_2. It should be noted that this is only possible when the condition of f_3=0. When n=2, the minimum of the cost of early production against the minimum of the cost of tardy production is identified and shown in Fig. 3.

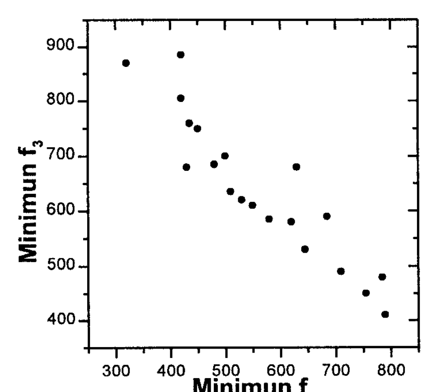
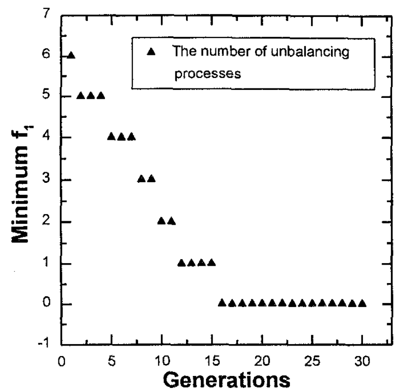


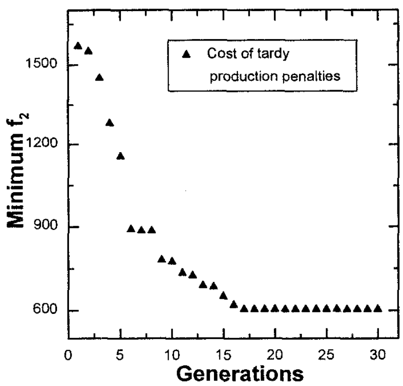
Fig. 3 The Final Population

Table 7: Achievable Performance

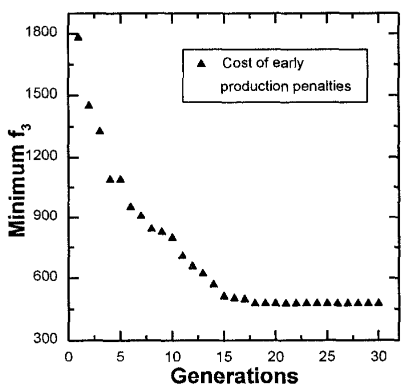
	f_1	f_2	f_3
N=2	0	605	475
N=3	0	1550	1370
N=4	0	2110	2200



(a) Trend of Minimum f_1



(b) Trend of Minimum f_2



(c) Trend of Minimum f_3

Fig. 4 The Trends of Different Objective Values

Some typical results are selected in Table 7. From this table, it is clearly demonstrated that the MOGA approach is capable of making an effective PSP for such a manufacturing system. The obtained PSP not only minimizes the cost of early production and the tardy production but also satisfies the capacity constraints.

When N=2, the trends of three different objective values are shown in Fig. 4. From this figure, it can be noted f_1 decreases and finally converges to zero(Fig. 4-(a)), f_2 and f_3 converges to their near-optimal values along with generations(Fig. 4-(2)). Meanwhile the comparison, tabulated in Table 8, among the MOGA approach and other methods has also demonstrate the effectiveness of the proposed MOGA approach.

5. Conclusion

An advanced MOGA model is proposed to address the ETPSP model with lot-size consideration and multi-process capacity balance for manufacturing systems. The MOGA approach has been presented as an effective and efficient solution of the ETPSP problem. Since without any requirement of unrealistic assumptions on objectives such as linearity, convexity and differentiability, a realistic large scale ETPSP problem is solved, an optimal or near-optimal solution can be reached in an agreeable time by this approach. In this way, the manufacturers can respond to the changing market requirements timely and fulfill the need of the customers. It is a noted improvement to any of existing techniques, and also in practice, provides a new trend of integrating the MRP-II and JIT together.

Table 8: Comparison Among GA Approach and Other Methods

Aspect ---------- **Method**	***Objective Functions***	***Lot-size Consi-deration***	***Capacity Balanc-ing***	***Product Type***
MOGA	Nonlinear Multiple	Yes	Yes	multi-type
SGAA	Nonlinear Single	Yes	Yes	multi-type
KPM	Linear Single	No	Yes	no more than 2-type
SFFRM	Linear Single	No	Yes	no more than 2-type

Note: MOGA - multiobjective GA approach; SGAA - a simple GA approach; KPM - a key-process method; and SFFRM - a shrinking-feasible-field relaxation method.

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