Scheduling Production Using Genetic Algorithm for Elastic Knitted Fabrics with Wide Ranges of Quantities Demanded

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Abstract: - In dealing with the production of various products in some industries, many firms need to respond to wide ranges of quantities demanded. High responsiveness to wider ranges of quantities can be a competitive advantage for a firm in modern highly competing environments. To stay ahead of competitors, a firm should be able to schedule production in an efficient way. The purpose of this study is to investigate the effects of wide ranges of quantities demanded on the scheduling. The production scheduling problem of knitted fabrics is used to examine the influences. Genetic algorithm (GA) is employed to be the analytical tool. Optimal parameters including mutation rates and crossover rates that generate good performance are obtained experimentally. Results from this paper show that the makespan in wide ranges of quantities is lower than that in a small range. However, the machine utilization in wide ranges of quantities is lower than that in a small range. To schedule the production with a lower makespan and with reasonable machine utilization, one can divide a big customer order into many manufacturing orders with smaller quantities. In addition, the on-time delivery rate can be increased by adding a penalty factor of completion time of a job.

Key-Words: - Genetic algorithm, knitted fabric, production scheduling, responsiveness, wide ranges of quantities

1 Introduction

High responsiveness can be a competitive advantage for a firm. To achieve high responsiveness, it is very important for a firm to be able to response to a wider range of quantities demanded, which generally causes higher uncertainty in production and hence leads to a higher total cost. To schedule production efficiently, it is thus of great importance to understand the influences of wide ranges of quantities demanded on the performance of scheduling.

The production of various products in some industries involves dealing with wide ranges of quantities demanded. Take the production of knitted fabrics for example. An order for a prototype production of a new product is likely to be small; an order for an international big company is likely to be huge. The quantities can range from about 15 kg to 150,000 kg, causing the arrangement of production difficult. To schedule the production, schedulers generally divide a big customer order into some manufacturing orders. A question arising right away is that how many manufacturing orders should be split into? A higher number of manufacturing orders may lead to a positively higher machine utilization but a negatively higher makerspan (total production time), which implies a higher manufacturing cost. In addition, to best meet the requirements of customers' needs, a higher on-time delivery rate is preferred. The on-time delivery rate which means the percentage of on-time delivery orders is a very important performance metric for many industries today. It is very difficult to arrange each order requested by a customer into suitable machines within a short period in a manner of fulfilling all the company's objectives. Note that these objectives conflict each other frequently. Thus, a system that can meet the different requirements of company objectives is greatly needed.

In this paper, we investigate the influences of wide ranges of quantities on the scheduling. Optimal results are experimentally found and some suggestions are presented to better design a scheduling system for knitted fabrics. In this study, we use genetic algorithm (GA) [1-2] as the analytical tool of the production scheduling. Many pervious studies confirmed that GA is useful in scheduling production [3-11], especially of elastic knitted fabrics [12-13].

The remainder of the paper is organized as follows. The production of knitted fabrics is briefly introduced in section 2. The analysis is presented in section 3. In section 4, the results and discussion are presented. Finally, conclusions are drawn in section 5.

2 Production of Knitted Fabrics

Elastic yarn was considered to be one of the most important inventions in textile industry in last century. As a result of the elastic yarn's characteristics, which contain such as comfort, wrinkle resistance, flexibility, and good form-fitting, and so on, products made of elastic yarn become more and more popular. Consequently, the manufacture of elastic fabrics has turned out to be a focused issue since they were developed. In the production process of elastic knitted fabrics, one of the most important operations is the production scheduling. Only when an efficient scheduling of production is arranged can a manufacturer keep up its competitive advantages in modern competing environments. Hence, a good scheduling system is urgently needed for many manufacturers of elastic knitted fabrics. However, it is not easy for a manufacturer of elastic knitted fabrics to find a suitable scheduling system which can arrange production efficiently for versatile environments in practices. Some studies [12-13] have discussed the production scheduling of knitted fabrics. However, they did not investigate the influences of the wide ranges of quantities demanded on the scheduling.

In dealing with the scheduling of knitted fabrics, one of the most concerned issues is about the colors of yarn. Generally, the colors of yarn are divided into several groups: the lightest, light, generic, dark, and the darkest. As illustrated in Fig. 1, if the yarn's color of the former job is darker than the following one for two neighboring jobs in a certain machine, there will be a need to clean the knits and thus an extra setup time is required. Therefore, it is crucial to schedule the production in a way to be able to reduce the setup time. This involves high complexity and can not be done easily by manual. Thus, a good scheduling system for production of knitted fabrics is greatly needed.

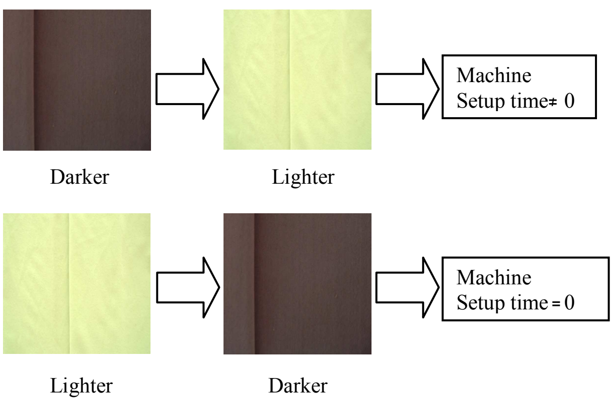

Fig. 1. Machine setup time: if the yarn color in the former job is darker than in the latter, an additional setup time is required

Another important issue for the production scheduling of knitted fabrics is to meet customer's needs and the objectives of the firm. Higher machine utilization, shorter total production times, and higher on-time delivery rates are usually favored for companies. However, the objectives generally conflict each other. Thus, there is a need to compromise between these objectives. In this paper, we will discuss on these conflicting objectives.

3 Analysis

In this section, the problem is depicted first and then the input data and modeling are presented and explained. Finally, the method of solution is described.

3.1 Problem Description

The problem can be depicted as a single production station with a number of parallel machines. The knitting machines can be categorized into several types. Each type has a fixed capacity and a fixed setup time. The flowchart for manufacturing elastic knitted fabrics is shown in Fig. 2. Totally, there are N_{MO} orders and N_{ma} knitting machines.

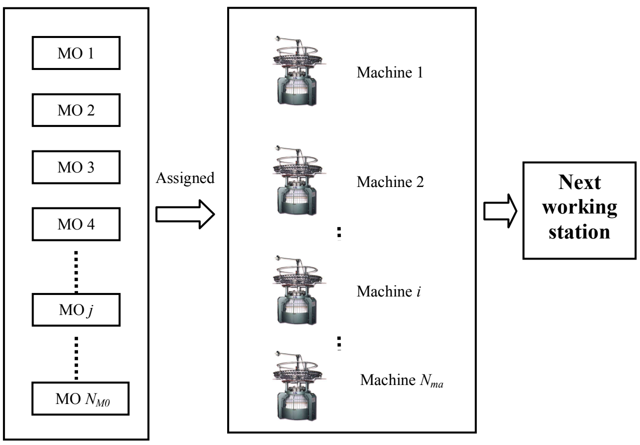

Fig. 2. A schematic diagram of order assignment with N_{MO} orders and N_{ma} machines. *MO* means manufacturing order

The machine setup time will occur when the yarn's color of the former job is darker than the following one for two adjacent jobs in the same machine. The problem considered here is to decrease the overall machine setup time to obtain the minimal makespan.

To solve the problem mentioned above, the following assumptions are made.
(1) The capacity of a specific type of machine is fixed. The same type machine has a same capacity, of which unit is kg per day or per hour.
(2) The setup time (the time to clean the knits of knitting machines) of a specific type of machine is constant. Different machines have different setup times.
(3) The colors of yarn can be roughly divided into five categories: the darkest, dark, middle, light, and the lightest.
(4) A customer order can be divided into some manufacturing orders. Each manufacturing order is assigned to a machine only and produces a single product.
(5) The shortage of raw material is neglected.
(6) The malfunction of the machines is negligible.
(7) The production environment is "make to order (MTO)" and thus there are no stocks.

3.2 Input Data

The data of customer orders are collected from an ERP (Enterprise Resource Planning) system. A typical order for knitted fabrics in a famous company in Taiwan is shown in Table 1. The main input data include order number, yarn color, order quantity, specifications, due date, and more. To facilitate the problem solving, the fabric color is briefly divided into 5 categories and each is represented by a color number.

Table 1. A typical order for knitted fabrics

Order Number	Color Number	Width	Weight	Quantity	Description and Specifications	Machine Type	Order Due Date
S03660051-1	3	54	295	1600	C/M15/2+OP2x1	30"28G 96F	2007/07/15
E03530104-1	3	54	295	1400	C/M15/2+OP2x1	30"28G 96F	2007/07/20
C13370072-1	3	54	295	2580	C/M15/2+OP2x1	30"28G 96F	2007/07/08
C13370072-2	5	60	310	1420	CVC32S/1+N45/12	36"23G 102F	2007/07/08
C13370074-1	1	56	370	1370	R34S/1+20P3*2	30"28G 96F	2007/07/13
E03530105-1	1	56	370	500	R34S/1+20P3*2	30"24G 108F	2007/07/10
E03530106-1	2	50	193	1200	CVC32S/1+ N45/12	30"24G 108F	2007/07/20
S03660052-1	5	54	300	1500	CVC32S/1+N45/12	36"23G 102F	2007/07/18
S03660052-2	1	56	370	1500	R34S/1+20P3*2	30"28G 96F	2007/07/18
C13370072-1	3	54	295	2580	C/M15/2+OP2x1	30"28G 96F	2007/07/08

Besides the order data, the data relating to machine are also required. These main data include the capacity of machine, the machine setup time, and the number of machines.

3.3 Fitness Function

After completing the encoding of chromosomes, we need a fitness function to measure the performance. The fitness function measures the fitness of the production makespan. The schedule which has the minimal makespan stands for a best schedule. The lower the makespan, the better is the assignment of orders to machines.

In this paper, we consider the penalty which is the product of the penalty coefficient μ_{ij} and P_i, where P_i is the machine setup time due to the improper scheduling of job j in machine i. There are different setup times for different knitted machines.

The fitness function for the production scheduling of elastic knitted fabrics can be described mathematically as

$$\text{Minimize } F = \sum_{i=1}^{N_{ma}} \sum_{j=1}^{N_{MO}} \{T_{ij} + \mu_{ij} \times P_i\} \qquad (1)$$

3.4 Solution Procedure

The procedure for GA is depicted in Fig. 3.

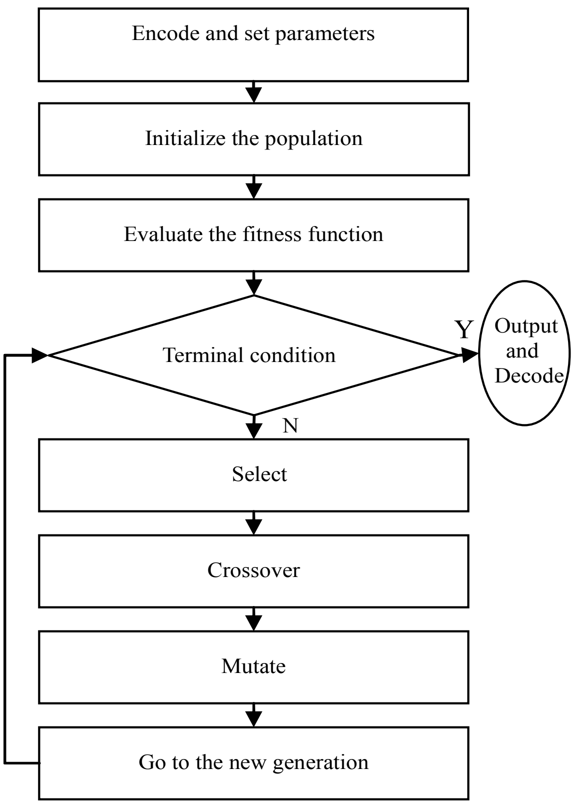

Fig. 3. The procedure for GA

In encoding, each chromosome is consisted of a sequence of genes g_i, where j = 1, 2,…, N_{MO} and N_{MO} is the number of manufacturing orders (or jobs). Each gene includes two bits of information: gene's position means the job number and gene's number means the machine number.

4 Results and Discussion

In this paper, we used GA to solve the production scheduling problem. We adopted Microsoft Visual C++ to develop the program. The operating system was Window 2000. We used the binary encoding method. The crossover and the mutation methods which were used to find a solution in this paper were two-point crossover and one-point mutation, respectively.

To investigate the influences of wide ranges of quantities on the performance, we let the quantity varies from 15 to 150,000 kg. For comparison, a small range of quantities is set and in which the quantities vary from 1,000 to 2,000 kg with an average of 1,500 kg. All the cases have a same total quantity of 300,000 kg. For the brevity of description, we designate the case with wide ranges of quantities as WRQ, the case of a small range of quantities as SRQ, the generation number as *G*, the crossover rate as *Pc*, the mutation rate as *Pm,* the average makespan as *AVG*, the standard deviation of makespan as *STD*, the number of machine as N_{ma}, and the number of manufacturing order N_{MO}.

4.1 Optimal Parameters

To find optimal parameters, first the population size and the generation number were tested. Suitable population size and generation number are chosen based on the average makespan and computer execution time. The population size was set to be 50, 100, 200, 300 and 500. Through testing, the population size for WRQ was chosen as 300 since it gave a lower makespan and a reasonable execution time. Similarly, *G* was varied with 50, 100, 200, 300, and 500 and the results showed that 200 is a suitable parameter value. Thus, the following experiments were run with a population size of 300 and *G* = 200 for the WRQ case. As for SRQ case, the experiments also showed that a population size of 300 and *G* = 200 are suitable settings.

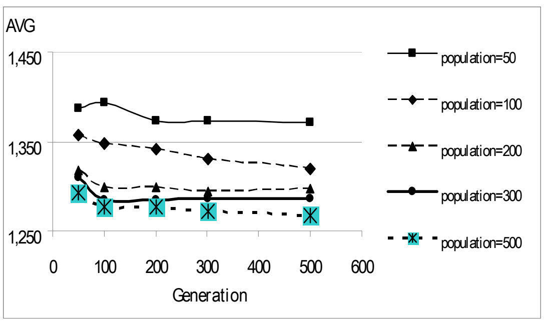

Fig. 4. Variation of population size on the average makespan *AVG*

The results for the optimal *Pm* and *Pc* are illustrated with a Bubble Chart in Fig. 5. The circle center represents the location of *AVG*, while the radius of the circle stands for *STD*. Thus, a small circle with a lower center location is preferred since it means the parameters yield better performance. As we can see from this figure that *Pc* = 0.9 and *Pm* = 0.05 are the best parameters for the WRQ case.

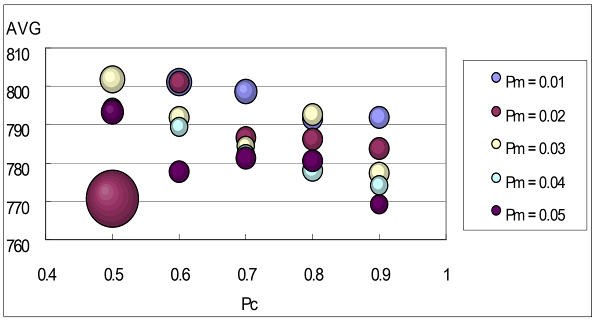

Fig. 5. The influences of crossover rate *Pc* and mutation rate *Pm* on the average makespan *AVG* with wide ranges of quantities (WRQ)

4.2 Effects of Wide Ranges of Quantities

The effects of wide ranges of quantities can be seen by comparing the results of the WRQ and the SRQ cases. Comparing Fig. 5 with Fig. 6 we can find that *AVG* is lower in the WRQ case than in the SRQ case. The reason for the WRQ case having a lower average makespan is that the big customer order with a quantity of 150,000 kg is assigned to the machine with the best capacity. However, in practice, this is inappropriate because a big customer order is generally divided into some manufacturing orders and assigned to different machines to meet the due date and balance the machine utilization. A question arising now is that how many manufacturing orders should be divided into? Thus, the value of the number of manufacturing order, $N_{MO,}$ should cause some influences on the scheduling efficiency.

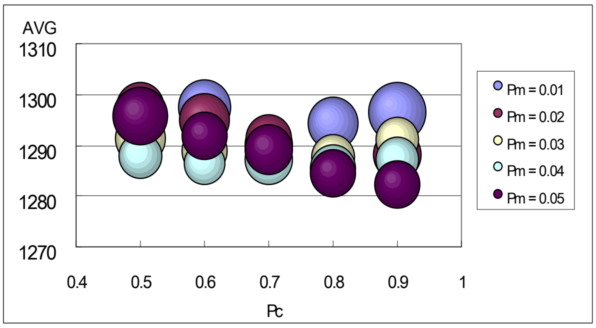

Fig. 6. The influences of crossover rate *Pc* and mutation rate *Pm* on the average makespan *AVG* with a small range of quantities (SRQ)

The effects of the number of divided manufacturing orders N_{MO} on the average makespan are shown in Fig. 7. A lower N_{MO} leads to a lower AVG, indicating a lower makespan. Figure 7 shows this trend. However, the machine utilization will be lowered as N_{MO} decreases, as we can see from this figure too.

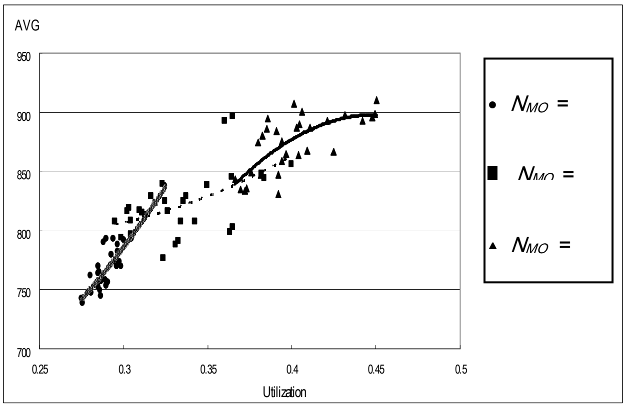

Fig. 7. The relation between the average makespan and the machine utilization

4.3 Effects of Due Date

The effects of due date on the scheduling are presented in Table 2. Two cases are studied: one is with due dates of 1 to 10 days and the other is with due dates ranging from 1 to 20 days. Both cases compare the results from $\upsilon = 0$ (without a penalty factor of completion time of job j) and $\upsilon \neq 0$ (with a penalty factor of completion time of job j).

The on-time delivery rate is also decreased if N_{MO} is increased, as depicted in Table 2. Thus, there should be a compromise for the scheduler to arrange the production schedule between the three different objectives. As we can see from Table 2 that short due dates cause lower on-time delivery rate. To increase on-time delivery rate, an added penalty factor can be used.

To obtain a higher on-time delivery rate, we can multiply the makespan of a late order by a penalty factor. Thus, the fitness function can be modified as e follows:

$$\text{Minimize } F = \sum_{i=1}^{N_{ma}} \sum_{j=1}^{N_{MO}} \{\upsilon_j \times T_{ij} + \mu_{ij} \times P_i\} \qquad (2)$$

Where υ_j is the penalty factor of completion time caused by past due.

Table 2. The effects of due date on the scheduling on the performance. * indicates no divided orders

	Penalty factor	Due date(days)	N_{MO}	AVG	Coefficient of variation	On-time delivery rate
WRQ	$\upsilon = 0$	1~10	10	825.367	15.473	0.019
			15	910.533	17.431	0.019
			20	924.967	21.537	0.023
		1~20	10	834.367	21.513	0.026
			15	913.100	24.640	0.027
			20	917.500	25.923	0.028
	$\upsilon \neq 0$	1~10	10	829.133	21.631	0.026
			15	913.933	25.261	0.028
			20	912.400	28.536	0.031
		1~20	10	830.700	20.944	0.025
			15	913.900	23.200	0.025
			20	913.033	32.932	0.036
SRQ	$\upsilon = 0$	1~10	*	1344.233	0.013	0.9108
		1~20		1327.533	0.013	0.9848
	$\upsilon \neq 0$	1~10	*	1355.700	22.778	0.017
		1~20		1349.533	18.818	0.014

5 Conclusion

In dealing with the production of some products in many industries, many firms need to respond to wide ranges of quantities demanded. High Responsiveness to wide ranges of quantities can be a competitive advantage for a firm in highly competing industries. To stay ahead of competitors, the firm should be able to schedule production in an efficient way.

The purpose of this paper is to investigate the effects of wide ranges of quantities on the scheduling. We use the production of elastic knitted fabrics as an example to discuss the influences of wide ranges of quantities. Genetic algorithm (GA) is employed to be the analytical tool.

Results from this paper show that the makespan in wide ranges of quantities is lower than that in a small range. However, the machine utilization in wide ranges of quantities is lower than that in a small range. To schedule the production with a lower makespan with reasonable machine utilization, one can divide a big customer order into many manufacturing orders with smaller quantities. As the number of divided manufacturing orders increase, the machine utilization is increased but the average makespan and the coefficient of variation are also increased. Results also show that the on-time delivery rates in short due dates are lower than those in longer due dates. To obtain higher on-time delivery rates for short due dates, an addition penalty factor of the completion time of a job can be added. Moreover, optimal parameters including mutation rates and crossover rates that generate good performance are obtained experimentally. And the results are presented in Bubble Charts, which is found to be a convenient and visualized tool to illustrate the results.

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References:

[1] J.H. Holland, *Adaptation in Natural and Artificial Systems*, University of Michigan Press, Ann Arbor, Michigan, 1975.

[2] M. Mitchell, *An Introduction to Genetic Algorithms*, Cambridge, MIT Press, 1996.

[3] M. Gen, and R. Cheng, *Genetic Algorithms and Engineering Design*, Wiley, New York, 1996.

[4] M. Gen, and R. Cheng, *Genetic Algorithms and Engineering Optimization*, Wiley, New York, 1999.

[5] D.A. Coley, *An Introduction to Genetic Algorithms for Scientists and Engineers*, Singapore: World Scientific, 1999.

[6] D. Goldberg, *Genetic Algorithms in Search, Optimization and machine Learning*, Addison-Wesley, Reading, MA, 1989.

[7] Y.Z. Wang, "Using Genetic Algorithm Methods to Solve Course Scheduling Problems," *Expert Systems with Application*, Vol. 25, pp. 39–50, 2003.

[8] T.S. Chan, S.H. Chung, and P.L.Y. Chan, "An Adaptive Genetic Algorithm with Dominated Genes for Distributed Scheduling Problems," *Expert Systems with Applications*, Vol. 5, pp. 364-371, 2005.

[9] S. Zolfagharia and M. Liang, "A New Genetic Algorithm for the Machine/Part Grouping Problem Involving Processing Times and Lot Sizes," *Computers and Industrial Engineering*, Vol. 45, pp. 713–731, 2003.

[10] S.S. Li, R.C. Chen, C.C. Lin, "A Genetic Algorithm-based Decision Support System for Allocating International Apparel Demand," *WSEAS Transactions on Information Science and Applications*, Vol. 3, No. 7, pp. 1294-1299, 2006.

[11] R.C. Chen, S.S. Li, C.C. Lin., and T.S. Chen, "Application of Self-Adaptive Genetic Algorithm on Allocating International Demand to Global Production Facilities," Proceedings of the *Sixth World Congress on Intelligent Control and Automation (WCICA 2006)*, Dalian, China, 2006.

[12] R.C. Chen, T.S. Chen, K.C. Lin, and C.C. Lin, "A Production Scheduling System Based on Self-adaptive Genetic Algorithm for Manufacturing Elastic Knit Fabrics," *Dynamics of Continuous, Discrete, and Impulsive Systems, Series B: Application & Algorithms, (DCDIS)*, Vol. 13(b) Supplement, pp. 176-180, 2006.

[13] R.C. Chen, T.S. Chen, C.C. Feng, C.C. Lin, and K.C. Lin, "Application of Genetic Algorithm on Production Scheduling of Elastic Knitted Fabrics," *Journal of Engineering and Applied Sciences*, Vol. 1, No. 2, pp. 149-153, 2006.