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Optimisation of Apparel Manufacturing Resource Allocation Using a Generic Optimised Table-Planning Model

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Many small and medium-sized apparel manufacturers are employing traditional manual methods and computerised fabric-cutting systems for the fabric-spreading and cutting operations. This paper introduces a generic optimised table-planning (GOTP) model to minimise the spreading and cutting resources of fabric-cutting departments for the apparel manufacturing process. The proposed GOTP model consists of an AutoModule*, a* ManualModule *and a* BalanceModule *to handle three types of manufacturing setup, namely manual, computerised and manual–computerised systems. Three sets of production data reflecting the different characteristics of the nature of production involving small, medium-sized and large production orders are captured to validate the performance of the proposed model. A comparison of the results in industrial practice, and the GOTP model before and after applying the* BalanceModule *is also presented.*

Keywords: Apparel manufacture; Genetic algorithm; Optimisation

1. Introduction

Between the late 1960s and early 1970s, apparel machinery suppliers first began to introduce computerised fabric-cutting technology. In the late 1980s, many apparel manufacturers sought to implement computerised fabric-cutting systems in their manufacturing process. Since then, the demands on the fabric-cutting departments for greater accuracy, faster throughput, and larger fabric and labour savings have made adopting a computerised cutting system essential.

However, many small and medium-sized apparel manufacturers still rely on a manual method for fabric-spreading and cutting operations in their fabric-cutting departments. The current practice is that before production starts, the production supervisors assign specific jobs (fabric lays) to each table for spreading and cutting, based on their experience. This is called table-planning. The method is non-systematic and not optimal which, in turn, causes line unbalance in the fabric-cutting department. The delivery time of fabric bundles to the sewing lines for the downstream assembly process cannot be guaranteed and the spreading and cutting capacity cannot be fully utilised. Even the large apparel manufacturers who use computerised cutting systems, still assign a portion of their daily production orders to the manual method. In other words, the manual and computerised spreading and cutting methods are operated simultaneously. Skyes and McGregor [1] proposed the use of object-oriented technology to design a computer simulation model of the pinning and cutting processes in apparel manufacturing so that the fabric-cutting manager could estimate the effects of various fabric-cutting department resource allocations to meet the production goals. One of the weaknesses of these approaches is that the studies are confined to the computerised cutting method. The traditional manual method, which is still employed by many apparel manufacturers, has been neglected. Another weakness is that the work schedule of fabric-roll preparation in any factory, which is a key factor to the success of the smooth running of a fabric-fabric-cutting department, is not considered.

This work develops a generic optimised table-planning (GOTP) model to handle the different modes of work of the fabric-cutting department, namely manual, computerised and manual–computerised systems. The effectiveness of the proposed GOTP model for different types of production is considered, i.e. small, medium-sized, and large production orders. Both the fabrication time within the fabric-cutting department and the preparation of fabric-roll in a factory before fabric-spreading are also considered in order to reflect actual industrial environment more adequately.

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2. Nomenclature of the GOTP model

The following notation is used in developing the GOTP model addressed in this study:

X	fabric lay
j	spreading sequence $j = \{1, 2, \ldots, J\}$
n	cutting sequence $n = \{1, 2, \ldots, N\}$
m	machine for spreading fabric lay $m = \{1, 2, \ldots, M\}$
f	machine for cutting fabric lay $f = \{1, 2, \ldots, F\}$
d	ready time for spreading
w	width of fabric roll
r	quantities of fabric rolls required to constitute a fabric lay
t	spreading table $\{t = 1, 2, \ldots, T\}$
p	location of fabric lay for spreading $p = \{1, 2, \ldots, P\}$
X_{nm}	cutting sequence of fabric lay which has been set up by spreading machine $n = \{1, 2, \ldots, L\}$, $m = \{1, 2, \ldots, M\}$
X_{jm}	spreading sequence of fabric lay which has been set up by spreading machine $j = \{1, 2, \ldots, J\}$, $m = \{1, 2, \ldots, M\}$
iso	idle time of spreading operatives
ico	idle time of cutting operatives
ism	idle time of spreading machine
icm	idle time of cutting machine
sa	standard automatic spreading time of fabric lay
ca	standard computerised cutting time of fabric lay
su	standard manual spreading time of fabric lay
cu	standard manual cutting time of fabric lay

3. Preparation of Fabric-Roll for Fabric-Spreading

In conventional fabric-lay planning of the apparel manufacturing process, the planning personnel divide the total quantity of like items (by style, fabric type or size as appropriate) into separate fabric-lays. In order to maximise the fabric utilisation, fabric-rolls having the same width are grouped together and then spread onto a fabric lay. According to the priority of fabric width preferred by the fabric-cutting department, the factory assigns and delivers a batch of the fabric-rolls with the same width to the fabric-cutting department for fabric-spreading. This is called "by-width" fabric delivery. The spreading operatives then spread the fabric-lays with the same width of fabric. An optimal table-planning cannot be achieved as the spreading operatives must finish spreading the fabric rolls with same width first before starting to spread fabric rolls with another width. In other words, the existing fabric rolls with the same width restrict table-planning, which directly prolongs the time taken by the fabric-cutting department. This conventional practice is ineffective in today's quick-response working environment.

A concept of "by-lay" fabric delivery is proposed. The factory assigns and delivers the fabric-rolls in the required quantity and width, rather than delivering a number of fabric rolls with the same width, to the fabric-cutting department for fabric-spreading. According to the result generated by the GOTP model, the required quantities and widths of fabric rolls assigned to each fabric lay for spreading is fed back to the factory for fabric preparation before the starting time of spreading. Unlike the "by-width" approach, in which table-planning is restricted by the fabric width, the fabric-rolls that are of the required quantity and width are prepared by the factory based on the table-planning output of the GOTP model, which will be discussed in Section 4. This proactive "by-lay" approach can better support the fabric-spreading and cutting operations of any fabric-cutting department. The representation of each fabric lay for the assignment of fabric preparation is as follows:

X_{wr} where w = width of fabric roll
r = quantities of fabric rolls required to constitute a fabric lay

Fabric lay with required width and quantities of fabric rolls must be prepared at

$$X_{dj} = X_{d(j-1)} + X_{ism(j-1)} + X_{sa(j-1)}$$

where d = ready time for spreading
ism = idle time of spreading machine
sa = standard automatic spreading time of fabric lay

4. GOTP Model for a Manual-computerised Cutting System

4.1 Characteristics of a Manual Cutting System

One of the main characteristics of the operating procedures of a traditional fabric-cutting department is that the spreading, cutting, and bundling operations are carried out in the same place. In an efficient fabric-cutting department, after spreading and cutting, the fabric pieces will be transported from the spreading tables to a separate bundling area for immediate bundling. The purpose of this is to leave space on the spreading tables for spreading and cutting another new fabric lay, so that the area of the spreading table can be fully used. In this study, a model is developed based on the operation of an efficient fabric-cutting department. Another characteristic is that the cutting operatives cut the fabric lay according to the spreading sequence which is equivalent to the cutting sequence, $X_j = X_n$.

Figure 1 shows an example of a conventional manual spreading table. In this study, it is assumed that the spreading location X_p for spreading is constrained between 1 and 3, namely the front, middle, and end on each spreading table. The exact length of each location varies with the length of fabric lays.

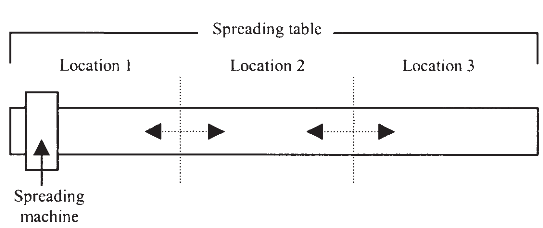

Fig. 1. Layout of a manual spreading table.

The representation of the table-planning for a fabric lay in a conventional fabric-cutting department can be expressed as

X_{jpt} where j = fabric lay spreading sequence $\{j = 1, 2, \ldots, J\}$
p = spreading location $\{p = 1, 2, \ldots, P\}$
t = spreading table $\{t = 1, 2, \ldots, T\}$
subject to $1 \leq X_p \leq 3$

In an efficient conventional fabric-cutting department, a group consisting of four to six operatives is assigned to each spreading table t. This group of operatives is divided into two subgroups in which two to three operatives, depending on the pattern of the fabric, are responsible for fabric-spreading. The remaining operatives are responsible for cutting the fabric lay which has already been spread. In some situations, the spreading operatives have finished spreading a specific fabric lay, e.g. X_7, but the cutting operatives have not yet finished cutting the fabric lay X_6, so idle-time $isw(X_7)$ occurs. The spreading operatives will assist the cutting operatives to speed up the cutting of fabric lay X_6 in order to provide more room on the spreading table for spreading another fabric lay X_8.

On the other hand, the cutting operatives may have finished cutting fabric lay X_3, but the spreading operatives have not finished the spreading of fabric lay X_4. The cutting operatives will then be allocated to spread another fabric lay, X_5, if sufficient spreading area of the spreading table provided. As a result of this reallocation of spreading and cutting operatives, the spreading and/or cutting time of some fabric lays can be decreased, and this can be expressed as $isw(X_{nm})$ and $icw(X_{nm})$. This reallocation minimises the fabrication time.

4.2 Characteristics of Computerised Cutting Systems

A fabric lay is spread on the spreading table and the first few feet, called the "bite" of the fabric lay, are moved onto the cutting surface. Once the first "bite" is cut, the cut fabric is moved to a bundling take-off table while the next "bite" is conveyed onto the cutting position. This operation is repeated until the whole lay is cut. The cutting machine can be moved laterally from the existing spreading table to another table for the cutting of another fabric lay. In order to minimise the idle-time of the cutting system, the rule is first-come first-served.

The representation of table-planning of fabric lay in a computerised cutting system can be expressed as

X_{jnpt} where j = fabric lay spreading sequence $\{j = 1, 2, \ldots, J\}$
n = fabric lay cutting sequence $\{n = 1, 2, \ldots, N\}$
p = spreading location $\{p = 1\}$
t = spreading table $\{t = 1, 2, \ldots, T\}$

Figure 2 shows a comparison of a table-planning Gantt chart between manual and computerised cutting systems adopted by a fabric-cutting department. In the manual system, the spreading sequence is equivalent to the cutting sequence, $X_j = X_n$, while in the computerised system, the spreading sequence is independent of the cutting sequence. Another difference is that the spreading location of fabric lay varies from 1 to 3 in the manual system, while the spreading location is confined to 1 only in the computerised system.

4.3 GOTP Model for a Fabric-Cutting Department Using Manual–Computerised Cutting Method

The set of feasible table-planning schemes for the manual and computerised spreading and cutting approach are denoted as I and II, respectively. For the given schedules σ ∈ I, II, let $f(\sigma)$ represent their corresponding objective function values of the two schedules. For the given schedule (δ ∈ III, let $f(\delta)$ represent the final objective function value.

$$\min_{\delta \in III} f(\delta) = \min_{\sigma \in 1} \mathrm{f}(\sigma) + \min_{\sigma \in II} f(\sigma) \quad (1)$$

$$= \left[\sum_{t=1}^{T} \sum_{j=1}^{J} iso\ (X_{tj}) + \sum_{t=1}^{T} \sum_{j=1}^{J} ico\ (X_{tj}) \right] \quad (2)$$

$$+ \left[\sum_{m=1}^{M} \sum_{n=1}^{N} ism\ (X_{mn}) + \sum_{f=1}^{F} \sum_{n=1}^{N} icm\ (X_{fn}) \right]$$

$$\text{where} \quad \sum_{t=1}^{T} \sum_{j=1}^{J} iso\ (X_{tj}) \quad (3)$$

$$= \sum_{t=1}^{T} \sum_{j=1}^{J} cu\ (X_{j-3})t - \sum_{t=1}^{T} \sum_{j=1}^{J} su\ (X_{jt}) \quad (4)$$

$$\text{where} \quad \sum_{t=1}^{T} \sum_{j=1}^{J} ico\ (X_{tj}) \quad (5)$$

$$= \sum_{t=1}^{T} \sum_{j=1}^{J} su\ (X_{tj}) - \sum_{t=1}^{T} \sum_{j=1}^{J} cu\ (X_{j-1})_t \quad (6)$$

$$\text{where} \quad \sum_{m=1}^{M} \sum_{n=1}^{N} ism\ (X_{mn}) \quad (7)$$

$$= \sum_{m=1}^{M} \sum_{j=1}^{J} ca\ (X_{j-3})m - \sum_{m=1}^{M} \sum_{j=1}^{J} sa\ (X_{jm}) \quad (8)$$

$$\text{where} \quad \sum_{f=1}^{F} \sum_{n=1}^{N} icm\ (X_{fn}) \quad (9)$$

$$= \sum_{m=1}^{M} \sum_{n=1}^{N} sa\ (X_{nm}) - \sum_{f=1}^{F} \sum_{n=1}^{N} ca\ (X_{n-1})_f \quad (10)$$

The negative value of $icm(X_{fn})$ will be converted into zero once

$$\sum sa(X_{jm}) < \sum ca(X_{n-1})_f$$

$$\text{if} \sum S(X_{nm}) - \sum C(X_{n-1}) < 0,\ i(X_n) = 0 \quad (11)$$

The proposed GOTP model is composed of *ManualModule*, *AutoModule*, and *BalanceModule*. Depending on the system used by the apparel manufacturers, *ManualModule* and/or *AutoModule*, can be selected to handle traditional, computerised or manual–computerised cutting systems. Figure 3 shows a diagram of the proposed GOTP model. The allocation of production orders to *ManualModule* and *AutoModule* is pre-

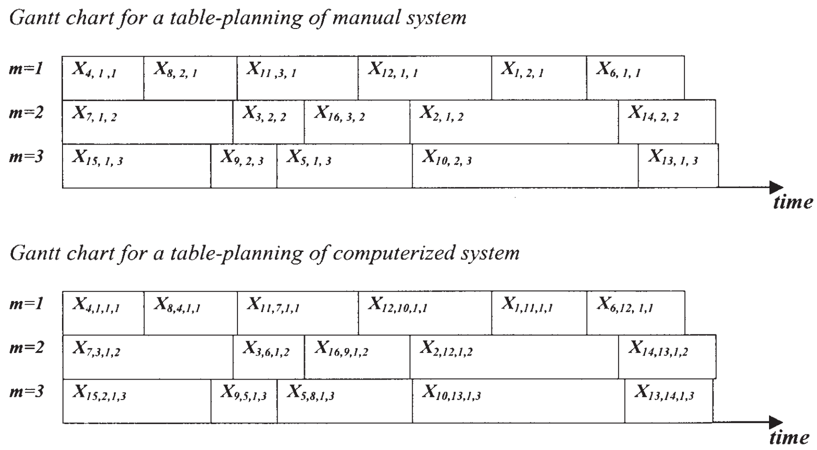

Fig. 2. Comparison of Gantt charts for table-planning of manual and computerised systems.

determined before production starts each day. The fabric lays for each production day are divided into two subsets. A subset of fabric lays H of production orders which is initially assigned to the spreading tables of the manual system is planned by *ManualModule*. *AutoModule* plans another subset of fabric lays A of production orders which will be processed by the computerised cutting system.

In the environment of a manual–computerised cutting system, *BalanceModule* generates schedule III by minimising the deviation of total fabrication time D between schedules I and II by shifting and rescheduling the fabric lays between schedules I and II. Based on the result of schedules I, II or III, the factory can prepare and deliver the required fabric rolls on time to the fabric-cutting department.

5. The Genetic Algorithm (GA) Approach

The genetic algorithm (GA), one of the artificial intelligence techniques, was developed by John Holland and his associates in the 1960s and 1970s. Grefenstette [2] defines a GA as an iterative procedure maintaining a population of structures that are candidate solutions to specific domain challenges. A GA is an adaptive heuristic search algorithm based on mimicking biological evolution. The concept is developed to simulate processes in a natural system for evolution and represents an intelligent exploitation of a random search, within a defined search space, in order to solve a problem. It provides an alternative method to solving problems and consistently outperforms other traditional methods in terms of ability to deal with problem complexity and computational speed.

GAs have been used successfully for machine learning, artificial intelligence, pattern recognition, operational research, and scheduling and planning problems. Fleury and Gourgand [3], Chen et al. [4], Lee and Choi [5], Watanabe et al. [6] and Khoo [7] have applied GAs to line balancing, job sequencing, and to the travelling salesman problem in different industries. In the apparel manufacturing process, Lo [8] proposed a GA approach to solve the problem of the production planning of sewing lines.

The following is a general GA procedure modified by Grefenstette and Baker [9]. $P(t)$ and $C(t)$ are parents and offspring in generation t.

```
begin
  t ← 0;
  initialise P(t);
  evaluate P(t);
  while (not termination condition) do
    recombine P(t) to yield C(t);
    evaluate C(t);
    select P(t + 1) from P(t) and C(t);
    t ← t + 1;
  end
end
```

A real-number representation is used. The gene-code representation of the feasible sequence to the problem of spreading and cutting is a string of a chain of the job sequence $(X_i)j$ where $i = 1, 2, \ldots, I$, $j = 1, 2, \ldots, J$. That means the gen-code of a feasible sequence is

$$(X_1)1(X_1)2 \ldots (X_1)J(X_2)1(X_2)2 \ldots (X_2)J \ldots (X_1)1(X_1)2 \ldots (X_1)J \quad (12)$$

5.1 Initial Population

The population initialisation technique can be performed by Procedure 1. The code string for the developed computer program is a real-number representation.

Each chromosome is a list of a fabric-lay spreading sequence.

Procedure 1

Step 1. Initialise parameters: index $q = 1$, a population size s and population $P = \{\Phi\}$.

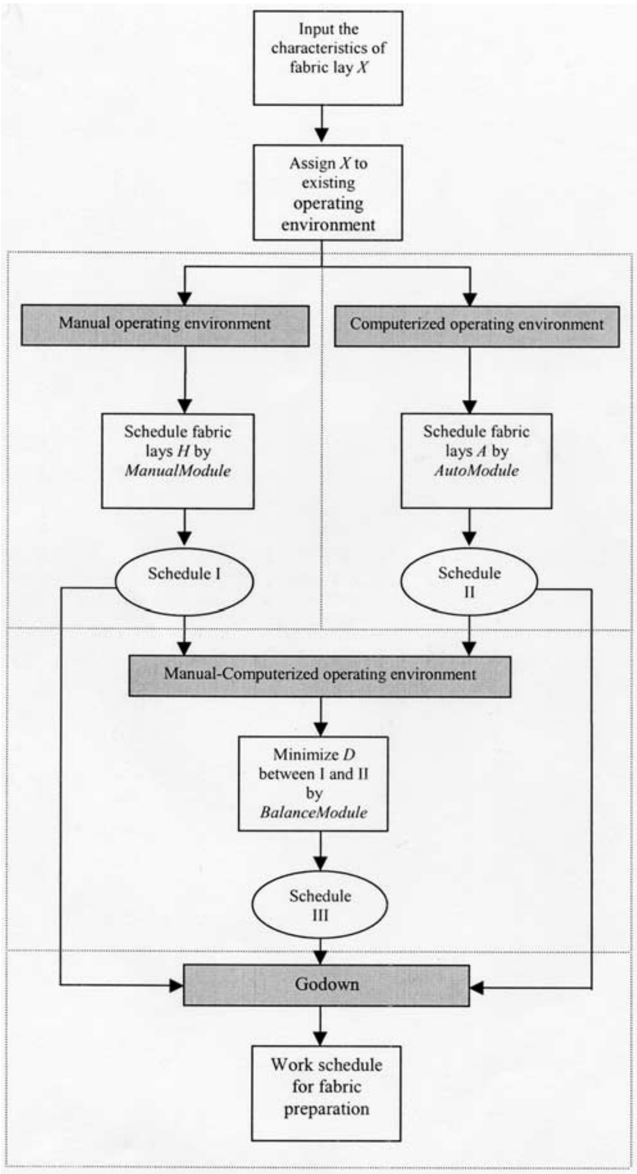

Fig. 3. Diagram of the GOPT model.

Step 2. Randomly produce a real number string, $P_q = (X_1)1(X_1)2 \ldots (X_1)J(X_2)1(X_2)2 \ldots (X_2)J \ldots (X_1)1(X_1)2 \ldots (X_1)J$.

Step 3. If P_q is feasible, go to step 4, else go to step 2.

Step 4. If P_q is new and different from any previous individuals, then $P = P + \{P_j\}$, $q = q + 1$, else go to step 2.

Step 5. If $q > s$, then $P = \{p_1, p_2, \ldots, p_s\}$ is the initial population and stop; else go to step 2.

5.2 Evaluation and Fitness

Chromosomes are evaluated to determine whether they can survive into the next generation. The system has an evaluator which rates the fitness of each chromosome. Chromosomes

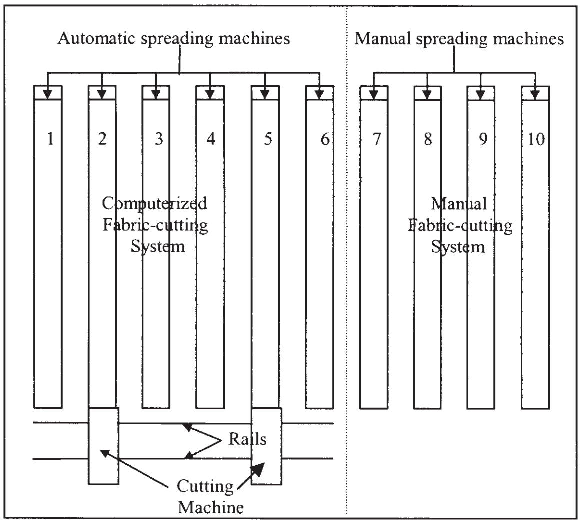

Fig. 4. Layout of a typical fabric-cutting department using a computerised-manual fabric-cutting system.

with the lowest idle-time of spreading and cutting resources are chosen and treated as the seeds for the next generation.

5.3 Parents Selection and Genetic Operators

The aim of parent selection is to select parents to produce offsprings in the next generation. Procedure 2 shows the roulette-wheel-selection technique which is used in the proposed GA method.

Procedure 2

Step 1. Compute the fitness value for each chromosome f_p $p = \{1, 2, \ldots, s\}$.

Step 2. Compute the total fitness value F for the population $F = \sum_{p=1}^{s} f_p$.

Step 3. Compute the selection probability b_p for each chromosome f_p

$$b_p = f_p/F.$$

Step 4. Compute cumulative probability c_p for each chromosome f_p.

Step 5. Generate a random number n from 0 to total fitness value.

Step 6. Select the first chromosome if n is smaller than or equal to the sum of cumulative probability of proceeding chromosomes.

The genetic operators of crossover and mutation are randomly used in the proposed GA method. Mitsuo [10] stated that crossover is the major genetic operator which operates on two chromosomes at a time and generates individuals by combing the features of both chromosomes. Randy and Sue [11] showed that mutation is a background operator which produces spontaneous random change in various chromosomes of the N_{pop} chromosomes in a given generation. Only the top N_{good} are kept for mating and the bottom N_{bad} are discarded to make room for the new offspring.

6. Experimental Results and Discussion

6.1 Characteristics of Production Data

Three sets of real production data reflecting different production characteristics, namely small, medium-sized and large production orders, were collected from the apparel industry for testing the performance of the proposed GOTP model. Small production orders, referring to those customer orders having many ranges of sizes with small quantities of garments per size, were captured for Test 1. In Test 3, large production orders were used, having a small range of sizes with many garments per size so that a longer fabric-spreading time was involved. In Test 2, medium-sized orders had both the characteristics of small and large orders. A comparison of the data used in the three experiments is shown in Table 1, based on the classification of small, medium-sized and large production orders in terms of quantity of garments.

6.2 Background of Industrial Environment Used for Model Testing

A typical fabric-cutting department employing a manual–computerised cutting system from the apparel industry was selected for investigating the three working environments, namely manual, computerised and manual–computerised cutting systems, as shown in Fig. 4. In one part of the computerised cutting system, there were two computerised fabric-cutting machines serving the first six fabric-spreading machines. In one part of the manual system, there were four manual spreading tables, from tables 7 to 10, handled by spreading and cutting operatives. The detailed background of the industrial environment in this study can be described as follows:

Spreading and cutting machine breakdowns do not occur.

Both spreading and cutting operatives achieve 100% working efficiency.

Standard manual spreading and cutting times per fabric lay is deterministic and known.

Table 1. Comparison of data used in 3 tests.

Quantity of garment	Test 1	Test 2	Test 3
0–200	87 (83.7%)	38 (46.9%)	16 (21.3%)
201–400	11 (10.6%)	30 (37.0%)	23 (30.7%)
401–600	6 (5.7%)	3 (3.7%)	25 (33.3%)
>601	0 (0%)	10 (12.4%)	11 (14.7%)

Table 2. Predetermined fabrication sequence adopted by industry.

Test	Predetermined industrial practice
1	Computerised system:
	Table 1 = [1 2 3 4 5 6 7 8 9];
	Table 2 = [10 11 12 13 14 15 16 17 18];
	Table 3 = [19 20 21 22 23 24 25 26 27 28];
	Table 4 = [29 30 31 32 33 34 35 36 37 38];
	Table 5 = [39 40 41 42 43 44];
	Table 6 = [45 46 47 48 49 50 51 52 53 54 55 56]
	Manual system:
	Table 7 = [57 58 59 60 61 62 63 64 65 66 67];
	Table 8 = [68 69 70 71 72 73 74 75 76 77 78];
	Table 9 = [79 80 81 82 83 84 85 86 87 88 89 90];
	Table 10 = [91 92 93 94 95 96 97 98 99 100 101 102 103 104]
2	Computerised system:
	Table 1 = [1 2 3 4 5 6 7];
	Table 2 = [8 9 10 11 12];
	Table 3 = [13 14 15 16 17 18 19 20 21 22 23 24 25];
	Table 4 = [26 27 28 29 30 31 32 33 34 35];
	Table 5 = [36 37 38 39 40 41 42 43];
	Table 6 = [44 45 46 47 48 49 50 51 52 53 54 55 56]
	Manual system:
	Table 7 = [57 58 59 60 61 62];
	Table 8 = [63 64 65 66 67 68];
	Table 9 = [69 70 71 72 73 74 75];
	Table 10 = [76 77 78 79 80 81]
3	Computerised system:
	Table 1 = [1 2 3 4 5 6 7 8];
	Table 2 = [9 10 11 12 13 14 15 16];
	Table 3 = [17 18 19 20 21 22 23];
	Table 4 = [24 25 26 27 28 29 30];
	Table 5 = [31 32 33 34 35 36 37 38 39];
	Table 6 = [40 41 42 43 44 45 46 47 48]
	Manual system:
	Table 7 = [49 50 51 52 53];
	Table 8 = [54 55 56 57 58 59];
	Table 9 = [60 61 62 63 64];
	Table 10 = [65 66 67 68 69]

Standard automatic spreading and cutting times per fabric lay is deterministic and known.

Standard spreading times of fabric lays are independent of spreading sequence.

Standard cutting times of fabric lays are independent of cutting sequence.

Feeding(transporting) time of fabric lays from spreading table into cutting machine is negligible.

Fabric lays of each production order are known before production starts.

Cutting operatives choose the fabric lay with the longest cutting time to cut when more than one fabric lay is available on the spreading tables

To evaluate the effectiveness of the proposed GOTP model, the typical fabrication sequence adopted by the industrial practice and the sequence produced by the GOTP model were compared. The fabrication sequence before and after applying

Table 3. Experimental result of fabrication time generated by the *AutoModule* and *ManualModule* of GOTP model.

	Test 1		Test 2		Test 3	
	Industrial practice	GOTP model	Industrial practice	GOTP model	Industrial practice	GOTP model
Computerised system	681	429 (−37.0%)	1012	476 (−53.0%)	1801	692 (−61.6%)
Manual table 7	881	651 (−26.1%)	1024	610 (−40.4%)	1183	1005 (−15.0%)
8	998	740 (−25.9%)	720	473 (−34.3%)	984	894 (−9.1%)
9	956	748 (−21.8%)	1425	607 (−57.4%)	1207	1013 (−16.0%)
10	681	485 (−28.8%)	1059	641 (−39.5%)	1011	933 (−7.7%)
Overall	4197	3704 (−11.8%)	5240	2807 (−46.4%)	6186	4537 (−26.7%)

Table 4. Fabric lays shifting from manual to computerised system by *BalanceModule*.

Test	Fabric lays shifted from manual to computerised system
1	Table 7 = [61 63] Table 8 = [72 74 78] Table 9 = [79 80 84 86]
2	Table 7 = [58] Table 9= [71] Table 10 = [76]
3	Table 7 = [50] Table 9 = [64] Table 10 = [65]

the *BalanceModule* was also compared based on the total fabrication time.

6.3 Comparison Between Industrial Practice and GOTP Model Without Applying *BalanceModule*

Table 2 shows the predetermined fabrication sequences adopted by the industrial practice in three tests. Based on these sequences, the total fabrication times of the three tests were 4197, 5240, and 6186 min, as shown in the column designated "Industrial practice" in Table 3. By applying the *ManualModule* and *AutoModule* of GOTP model in which the *AutoModule* was based on [12], fabric-roll preparation schedules I and II for the factory were produced as shown in the column designated "Before applying *BalanceModule*" Table A1 (see Appendix), their corresponding fabrication times could be reduced to 3704, 2807, and 4537 min (see the "GOTP model" column in Table 3).

Table 3 presents the fabrication time of both the computerised system and each table of the manual system, i.e. from spreading tables 7 to 10. The fabrication time of the computerised system could be improved considerably over that of most of the manual tables in each test. In one part of the computerised system, the GOTP model performed best in Test 3 which referred to the manufacturing plant running the largest production orders. The results of the three tests indicated that the GOTP model could handle the computerised system and the traditional manual system in the three different production types, in which the performance of the manufacturing environment handling large production orders was better than the environment handling medium-sized and small production orders.

6.4 Comparison of GOTP Model Before and After Applying *BalanceModule*

The fabrication time of all three tests could be further improved after applying the *BalanceModule*. The resulting fabric-roll preparation schedules III for the factory are shown in Table A1. Table 4 shows the *BalanceModule* shifting the fabric lays from the manual tables to the computerised system in each test. The improvement rates before (see Table 3) and after applying *BalanceModule* (see Table 5), show that the rates of Tests 1 and 2 were reduced from 37.0% to 21.4% and from 53.0% to 48.8%, respectively. For the computerised system, the fabrication times of 3 of the 4 manual tables were improved. As a result, the overall improvement rate could still be increased from 11.8% to 21.4% and from 46.4% to 57.8% in both tests. In Test 3, the fabrication time of both the computerised system and the manual system could be further improved, which finally increased the improvement rate from 26.7% to 39.1%. The results showed that *BalanceModule* was effective for further shortening the overall fabrication time of the manual–computerised manufacturing environment of the apparel manufacture.

7. Conclusion

This paper demonstrates a GOTP model for handling a traditional manual spreading and cutting system, and a computerised system and a manual–computerised system. The experimental results indicate that the proposed GOTP model could help the factory to generate the fabric-roll preparation schedule and help the production management on decision-making for table-planning for different production requirements, i.e. small, medium-sized, and large production orders. The fabrication time of the computerised system could be improved considerably more than that for most of the manual tables in each test before applying the *BalanceModule*. The performance of the GOTP model was especially effective in the manufacturing environment handling large production orders. The *Bal-*

Table 5. Experimental result of fabrication time generated by the *AutoModule*, *ManualModule*, and *BalanceModule* of GOTP model.

	Test 1		Test 2		Test 3	
	Industrial practice	GOTP model	Industrial practice	GOTP model	Industrial practice	GOTP model
Computerised system	681	535 (−21.4%)	1012	518 (−48.8%)	1801	514 (−71.5%)
Manual table 7	881	511 (−42.0%)	1024	388 (−62.1%)	1183	783 (−33.8%)
8	998	516 (−48.3%)	720	473 (−34.3%)	984	894 (−9.1%)
9	956	500 (−48.0%)	1425	397 (−72.1%)	1207	853 (−29.3%)
10	681	485 (−28.8%)	1059	433 (−59.1%)	1011	725 (−28.3%)
Overall	4197	2547 (−39.3%)	5240	2209 (−57.8%)	6186	3769 (−39.1%)

anceModule could further shorten the overall fabrication time in the manual–computerised manufacturing environment of an apparel manufacturer.

Acknowledgement

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Appendix A

Table A1. Fabric-roll preparation schedule of factory.

	Before Applying *BalanceModule*	After Applying *BalanceModule*
Fabric-roll Preparation Schedule of Godown (Test 1)	Schedule II: Subset of fabric lays *A* (Fabric Lay# / Order# / FabricWidth / Quantities of Fabric-roll Prepared / Preparation Due Time) Table 1: 6/2/122/14/0-7/2/122/14/0-8/2/121/1/39-10/2/121/3/44- 9/2/121/1/57-11/2/123/16/66-45/8/154/2/97-31/6/121/1/111- 32/6/121/2/114-30/6/123/18/119 Table 2: 41/8/153/31/0-47/8/154/1/0-44/8/154/12/12-48/8/154/10/42- 43/8/153/6/78-40/8/153/28/100-29/6/123/18/135 Table 3: 16/3/152/23/0-13/3/152/3/0-15/3/152/1/10-12/3/152/1/23- 17/3/152/1/36-14/3/152/26/49-49/9/122/10/90-28/5/122/12/127- 3/1/152/7/156 Table 4: 55/9/124/8/0-54/9/123/6/0-52/9/123/1/31-51/9/122/4/44- 50/9/122/10/53-53/9/123/4/79-42/8/153/3/96-26/5/122/5/105- 24/5/123/18/129 Table 5: 22/4/152/5/0-18/4/153/2/0-20/4/153/2/17-19/4/153/1/29- 23/4/152/5/31-21/4/153/28/47-56/9/124/1/82-46/8/154/3/94- 27/5/122/6/105-25/5/123/2/123-5/1/153/2/132-1/1/152/2/149- 2/1/152/12/159 Table 6: 37/7/123/18/0-35/7/123/1/0-33/7/124/18/5-36/7/123/1/40- 38/7/124/1/51-34/7/123/18/54-39/7/124/22/99-4/1/153/8/140 Schedule I: Subset of fabric lays *H* (Fabric Lay#/Order#/FabricWidth/Quantities of Fabric-roll Prepared/Prepartion Due Time/Loading Position) Table 7: 60/10/123/9/0/1-66/12/122/1/0/2-59/10/122/4/23/3- 65/10/123/7/80/1-67/12/122/4/170/3-64/10/123/1/227/2- 57/10/122/7/250/1-62/10/123/1/340/3-58/10/122/4/356/2- 63/10/123/5/413/1-61/10/123/5/490/2- Table 8: 76/12/123/7/0/1-81/11/122/4/0/2-71/11/123/1/53/3- 75/12/123/7/82/1-77/12/123/4/172/2-73/11/123/7/225/1- 69/11/122/7/312/3-68/11/122/4/399/2-78/12/123/1/452/3- 72/11/123/1/481/1-74/11/123/7/510/2- Table 9: 81/10/122/7/0/1-88/11/123/3/0/2-89/11/121/4/60/3- 82/10/122/3/117/2-83/10/122/3/165/3-85/11/122/4/224/2- 90/11/121/1/277/3-87/11/123/3/307/1-86/11/123/3/355/2- 84/10/122/4/415/3-80/10/122/3/468/2-79/10/122/7/516/3- Table 10: 101/12/123/8/0/1-98/12/123/1/0/2-93/12/122/1/20/3- 104/12/122/3/48/1-94/12/122/1/107/3-99/12/123/1/127/2- 103/12/122/3/150/1-91/12/122/3/209/2-95/12/122/1/259/3- 97/12/123/1/278/1-102/12/122/3/295/2-92/12/122/1/345/1- 96/12/122/1/366/3-100/12/123/1/384/2-	Schedule III: Subset of fabric lays *A* (Fabric Lay# / Order# / FabricWidth / Quantities of Fabric-roll Prepared / Preparation Due Time) Table 1: 37/7/123/18/0-36/7/123/1/0-34/7/123/18/11-33/7/124/18/56- 38/7/124/1/91-35/7/123/1/94-39/7/124/22/99-18/4/153/2/140- 22/4/152/5/157-20/4/153/2/173-19/4/153/1/185-23/4/152/5/187- Table 2: 58/1/123/5/0-65/1/123/3/0-64/1/22/4/30-59/1/23/1/41- 62/1/122/7/54-60/1/123/7/86-3/1/152/7/118-4/1/153/8/142- 57/1/123/5/172- Table 3: 41/8/153/31/0-46/8/154/3/0-47/8/154/1/11-44/8/154/12/23- 43/8/153/6/53-42/8/153/3/75-48/8/154/10/84-45/8/154/2/120- 40/8/153/28/134-1/1/152/2/169-63/1/122/3/179- Table 4: 55/9/124/8/0-54/9/123/6/0-51/9/122/4/31-50/9/122/10/40- 52/9/123/1/66-56/9/124/1/79-53/9/123/4/91-49/9/122/10/108- 11/2/123/16/145-5/1/153/2/176- Table 5: 30/6/123/18/0-32/6/121/2/0-31/6/121/1/5-29/6/123/18/8- 8/2/121/1/45-9/2/121/1/50-6/2/122/14/59-10/2/121/3/98- 7/2/122/14/111-27/5/122/6/150-61/1/123/1/168-2/1/152/12/181- Table 6: 16/3/152/23/0-12/3/152/1/0-17/3/152/1/13-13/3/152/3/26- 15/3/152/1/36-14/3/152/26/49-25/5/123/2/90-26/5/122/5/99- 28/5/122/12/123-24/5/123/18/152-21/4/153/28/188- Subset of fabric lays *H* (Fabric Lay#/Order#/FabricWidth/Quantities of Fabric-roll Prepared/Prepartion Due Time/Loading Position) Table 7: 60/10/123/9/0/1-66/12/122/1/0/2-59/10/122/4/23/3- 65/10/123/7/80/1-67/12/122/4/170/3-64/10/123/1/227/2- 57/10/122/7/250/1-62/10/123/1/340/3-58/10/122/4/356/2- Table 8: 76/12/123/7/0/1-81/11/122/4/0/2-71/11/123/1/53/3- 75/12/123/7/82/1-77/12/123/4/172/2-73/11/123/7/225/1- 69/11/122/7/312/3-68/11/122/4/399/2- Table 9: 81/10/122/7/0/1-88/11/123/3/0/2-89/11/121/4/60/3- 82/10/122/3/117/2-83/10/122/3/165/3-85/11/122/4/224/2- 90/11/121/1/277/3-87/11/123/3/307/1- Table 10: 101/12/123/8/0/1-98/12/123/1/0/2-93/12/122/1/20/3- 104/12/122/3/48/1-94/12/122/1/107/3-99/12/123/1/127/2- 103/12/122/3/150/1-91/12/122/3/209/2-95/12/122/1/259/3- 97/12/123/1/278/1-102/12/122/3/295/2-92/12/122/1/345/1- 96/12/122/1/366/3-100/12/123/1/384/2-
Fabric-roll Preparation Schedule of Godown (Test 2)	Schedule II: Subset of fabric lays *A* (Fabric Lay# / Order# / FabricWidth / Quantities of Fabric-roll Prepared / Preparation Due Time) Table 1: 33/3/153/14/0-22/3/152/15/0-36/3/153/8/4-28/3/154/9/43- 23/3/152/7/83-31/3/153/8/107-34/3/153/3/141-25/3/152/1/161- 27/3/152/12/165-24/3/152/9/203-30/3/153/32/209-8/1/123/48/318- Table 2: 13/2/153/28/0-19/2/154/14/0-20/2/154/14/47-21/2/154/15/94- 18/2/152/14/141-16/2/153/14/144-17/2/152/3/190- 14/2/153/17/200-15/2/153/40/259- Table 3: 52/6/153/10/0-56/6/154/9/0-55/6/152/1/40-54/6/152/1/53- 53/6/152/15/66-26/3/152/12/118-32/3/153/7/156-35/3/153/8/191- 5/1/123/7/232-9/1/124/6/251-12/1/124/18/279- Table 4: 47/5/153/15/0-50/5/152/15/0-46/5/153/9/22-51/5/152/8/38- 48/5/152/11/68-49/5/152/1/105-45/5/153/17/118-29/3/154/9/173- 2/1/122/13/213-3/1/123/8/260-11/1/124/35/297- Table 5: 6/1/123/48/0-7/1/123/43/0-1/1/122/5/122-4/1/123/25/140- 10/1/124/43/210- Table 6: 43/4/122/53/0-41/4/122/2/0-38/4/123/5/14-44/4/122/15/37-	Schedule III: Subset of fabric lays *A* (Fabric Lay# / Order# / FabricWidth / Quantities of Fabric-roll Prepared / Preparation Due Time) Table 1: 33/3/153/14/0-22/3/152/15/0-25/3/152/1/4-27/3/152/12/8- 29/3/154/9/46-26/3/152/12/86-31/3/153/8/124-24/3/152/9/158- 35/3/153/8/164-32/3/153/7/205-28/3/154/9/240-12/1/124/18/280- 60/1/152/16/340- Table 2: 8/1/123/48/0-2/1/122/13/0-3/1/123/8/47-58/1/121/20/84- 1/1/122/5/146-5/1/123/7/164-59/1/153/16/183-4/1/123/25/248- 11/1/124/35/318- Table 3: 47/5/153/15/0-49/5/152/1/0-48/5/152/11/13-46/5/153/9/50- 50/5/152/15/66-51/5/152/8/88-45/5/153/17/118-23/3/152/7/173- 36/3/153/8/197-34/3/153/3/236-30/3/153/32/256- Table 4: 52/6/153/10/0-54/6/152/1/0-56/6/154/9/13-55/6/152/1/53- 53/6/152/15/66-9/1/124/6/118-10/1/124/43/146-57/1/153/18/266- 7/1/123/43/328- Table 5: 43/4/122/53/0-39/4/123/43/0-37/4/123/3/113-40/4/122/9/128- 41/4/122/2/139-38/4/123/5/153-44/4/122/15/176-42/4/122/60/223- Table 6:

Table A1. Continued.

	39/4/123/43/84-40/4/122/9/197-37/4/123/3/208-42/4/122/60/223- Schedule I: Subset of fabric lays *H* (Fabric Lay#/Order#/FabricWidth/Quantities of Fabric-roll Prepared/Prepartion Due Time/Loading Position) Table 7: 57/7/153/18/0/1-62/8/121/5/0/2-60/8/122/14/62/3-59/8/122/5/228/2-61/8/122/5/290/3-58/7/153/18/352/2- Table 8: 68/9/122/20/0/1-67/9/121/1/0/2-64/8/122/5/28/3-65/8/122/5/90/1-63/8/122/43/152/2-66/9/121/20/274/3- Table 9: 73/7/152/17/0/1-70/7/153/1/0/2-74/7/152/1/27/3-72/7/152/17/54/1-75/7/152/1/280/2-69/7/153/1/315/3-71/7/153/16/342/1- Table 10: 80/8/123/16/0/1-79/7/151/5/0/2-78/7/151/5/62/3-77/7/152/16/124/2-81/8/123/1/332/3-76/7/152/16/367/1-	13/2/153/28/0-19/2/154/14/0-21/2/154/15/47-20/2/154/14/94-14/2/153/17/141-16/2/153/14/200-18/2/152/14/246-17/2/152/3/249-15/2/153/40/259-6/1/123/48/345- Subset of fabric lays *H* (Fabric Lay#/Order#/FabricWidth/Quantities of Fabric-roll Prepared/Prepartion Due Time/Loading Position) Table 7: 57/7/153/18/0/1-62/8/121/5/0/2-60/8/122/14/62/3-59/8/122/5/228/2-61/8/122/5/290/3- Table 8: 68/9/122/20/0/1-67/9/121/1/0/2-64/8/122/5/28/3-65/8/122/5/90/1-63/8/122/43/152/2-66/9/121/20/274/3- Table 9: 73/7/152/17/0/1-70/7/153/1/0/2-74/7/152/1/27/3-72/7/152/17/54/1-75/7/152/1/280/2-69/7/153/1/315/3- Table 10: 80/8/123/16/0/1-79/7/151/5/0/2-78/7/151/5/62/3-77/7/152/16/124/2-81/8/123/1/332/3-
Fabric-roll Preparation Schedule of Godown (Test 3)	Schedule II: Subset of fabric lays *A* (Fabric Lay# / Order# / FabricWidth / Quantities of Fabric-roll Prepared / Preparation Due Time) Table 1: 46/6/123/13/0-48/6/123/10/0-47/6/123/31/28-36/5/122/9/102-45/5/123/13/125-28/4/152/13/160-34/4/151/27/191-38/4/151/11/258-40/4/151/37/287- Table 2: 15/2/153/36/0-14/2/153/8/0-16/2/153/10/22-11/2/152/9/52-10/2/152/12/81-9/2/152/27/117-13/2/153/20/188-12/2/153/33/247-17/2/154/38/350- Table 3: 41/5/122/28/0-43/5/122/24/0-44/5/123/25/69-42/5/122/28/138-25/4/152/24/213-30/4/153/20/275-37/4/151/9/332-31/4/153/37/355- Table 4: 29/4/152/37/0-27/4/152/25/0-33/4/151/27/78-26/4/152/20/145-35/4/151/11/202-32/4/151/25/233-39/4/151/30/300- Table 5: 21/3/122/26/0-20/3/122/26/0-18/3/122/26/69-19/3/122/10/138-23/3/123/22/166-24/3/123/22/231-22/3/123/31/296- Table 6: 1/1/122/21/0-2/1/122/17/0-8/1/121/14/53-3/1/121/12/90-7/1/121/9/125-4/1/121/17/151-6/1/121/16/213-5/1/121/35/261- Schedule I: Subset of fabric lays *H* (Fabric Lay#/Order#/FabricWidth/Quantities of Fabric-roll Prepared/Prepartion Due Time/Loading Position) Table 7: 49/7/122/18/0/1-52/8/153/15/0/2-51/8/154/14/180/3-53/8/153/15/346/2-50/7/122/18/526/3- Table 8: 58/8/153/20/0/1-56/7/123/5/0/2-55/7/123/5/62/3-57/8/154/20/124/2-59/8/153/20/304/1-54/7/123/18/494/3- Table 9: 63/9/122/16/0/1-62/9/122/17/0/2-60/9/123/16/160/3-61/9/122/17/370/2-64/9/123/16/530/3- Table 10: 68/9/122/16/0/1-67/8/153/13/0/2-66/8/153/13/160/3-69/9/122/16/320/2-65/8/154/16/490/3-	Schedule III: Subset of fabric lays *A* (Fabric Lay# / Order# / FabricWidth / Quantities of Fabric-roll Prepared / Preparation Due Time) Table 1: 46/6/123/13/0-48/6/123/10/0-47/6/123/31/28-37/4/151/9/102-39/4/151/30/125-34/4/151/27/197-32/4/151/25/264-29/4/152/37/331- Table 2: 50/1/122/22/0-7/1/121/9/0-3/1/121/12/26-8/1/121/14/61-2/1/122/17/98-51/1/154/16/151-4/1/121/17/213-49/1/122/18/275-1/1/122/21/337- Table 3: 31/4/153/37/0-30/4/153/20/0-26/4/152/20/57-28/4/152/13/114-40/4/151/37/145-33/4/151/27/227-38/4/151/11/294-27/4/152/25/323- Table 4: 15/2/153/36/0-16/2/153/10/0-9/2/152/27/30-13/2/153/20/101-10/2/152/12/160-12/2/153/33/196-14/2/153/8/299-11/2/152/9/321-17/2/154/38/350- Table 5: 18/3/122/26/0-19/3/122/10/0-21/3/122/26/28-23/3/123/22/97-24/3/123/22/162-20/3/122/26/227-35/4/151/11/296-25/4/152/24/327-5/1/121/35/389- Table 6: 41/5/122/28/0-43/5/122/24/0-44/5/123/25/69-45/5/123/13/138-36/5/122/9/173-42/5/122/28/196-22/3/123/31/271-6/1/121/16/352- Subset of fabric lays *H* (Fabric Lay#/Order#/FabricWidth/Quantities of Fabric-roll Prepared/Prepartion Due Time/Loading Position) Table 7: 49/7/122/18/0/1-52/8/153/15/0/2-51/8/154/14/180/3-53/8/153/15/346/2- Table 8: 58/8/153/20/0/1-56/7/123/5/0/2-55/7/123/5/62/3-57/8/154/20/124/2-59/8/153/20/304/1-54/7/123/18/494/3- Table 9: 63/9/122/16/0/1-62/9/122/17/0/2-60/9/123/16/160/3-61/9/122/17/370/2- Table 10: 68/9/122/16/0/1-67/8/153/13/0/2-66/8/153/13/160/3-69/9/122/16/320/2-