Can Ünal[1],
Alime Dere Yüksel[2]

Cut Order Planning Optimisation in the Apparel Industry

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[1] **Namık Kemal University, Textile Engineering Department,**
Tekirdag, Turkey,
e-mail: cunal@nku.edu.tr

[2] **Ugurteks Tekstil Ürünleri Tic. ve San. A.Ş.,**
Tekirdag, Turkey,
e-mail: alime.yuksel@ugurteks.com.tr

Abstract
Nowadays, apparel businesses have to cut down on their costs in order to ensure the continuity of their activities and to expand them. Fabric costs cover about 50-60% of production costs. In this study, for the minimisation of fabric costs, the cutting department in enterprises was investigated and the cut order plans developed by mixed integer nonlinear programming. Examples were taken from the enterprises that were implemented. A mathematical model was then developed to be used in mixed integer nonlinear programming for a manual cut order plan, and a program code was created in LINGO optimisation software. With the program code developed, optimum results that cannot be manually calculated by an operator is obtained. The amounts of fabric to be used as a result of the cut order plan were applied to the samples taken from the enterprises, and the manual solution and model developed were compared. As a result of the comparisons made, thanks to the model, fabric developed, usage is reduced and fabric cost minimisation ensured.

Key words: *apparel industry, LINGO, cutting department, cut order planning.*

Introduction

The primary preassembly operations in the clothing industry are marker making, spreading, and cutting. Marker making is the process of determining the most efficient layout of pattern pieces for specific styles, fabrics, and distributions of sizes. Spreading or laying-up is the process of superimposing predetermined lengths of fabric on a spreading table for the cutting process. Cutting is the pre-assembly process of separating a spread into garment pieces that are the precise size and shape of the pattern pieces on the marker. Minimising fabric loss during preassembly operations thus contributes to the minimisation of the total production costs in garment manufacturing [1]. Material cost is a major component of manufacturing costs in the apparel industry. Of primary importance in managing material cost is the establishment of control over marker utilisation and the cut order plan (COP). The cut order plan takes the targets established by the cutting schedule and translates them into a plan of loading of successive batches to the cutting room, so that cutting proceeds in a most efficient and cost-effective manner. The cutting schedule gives the input necessary to achieve the sewing schedule.

Waste in markers cause serious financial losses by reducing the profitability of the line. It is common knowledge that increasing the number of garments along with the number of sizes in a marker can give higher marker utilisation [2]. However, increasing the number of sizes makes it difficult to achieve an optimum cut order plan, especially for manual calculations.

As many optimal decision problems in scientific, engineering, and public sector applications involve both discrete decisions and nonlinear system dynamics that affect the quality of the final design or plan, the problem addressed in this study leads us to mixed-integer nonlinear programming (MINLP), which combines the combinatorial difficulty of optimising with discrete variable sets with the challenges of handling nonlinear functions. The LINGO (Language for Interactive General Optimisation) computer program is used to solve problems expressed by mathematical formulas. As a result of the research, the amount of fabric used in the current situation and that of fabric removed as a result of the optimisation were compared for different products and order samples.

As this problem has not been extensively investigated, studies in the related literature on the cutting process and cut order plan have been examined and some of them have been included here;

Paşayev investigated the effects of production planning on fabric costs. It was proven that in garment production during the production line calculation process, the possibility of ground preparation for reducing fabric losses is available, and the realisation of determining the optimal fabric width in terms of fabric losses can reduce them significantly [3].

Rose and Shier tried to establish an efficient schedule for cutting the garments required from cloth, with all demands met exactly. They introduced a two-stage approach; an exact enumerative approach that produces all optimal cutting schedules. Two different implementations were considered for enumeration based on the SD Tree and MF Tree, respectively. While the SD Tree was ultimately selected as superior for carrying out the two-stage approach, the MF Tree provides a valuable heuristic approach for generating one or more feasible cutting schedules [4].

Degraeve and Vandebroek, propose a mixed integer programming model that determines an optimal set of cutting patterns, each giving a combination of articles to be cut in one operation, and corresponding stack heights. Also, they developed a special enumerative search procedure with node pruning criteria using bounds and dominance rules to obtain results requiring less computing time [5]. For this reason, small order samples have been handled. However, the speed of today's computers and the use of LINGO's sets allowed this problem to be overcome in this study.

Wong and Leung proposed a genetic optimised decision-making model using adaptive evolutionary strategies to assist the production management of the apparel industry in the decision-making process of COP in which a new encoding method with a shortened binary string was devised. Four sets of real production data were collected to validate the the decision support method proposed. The experimental results demonstrate that the method proposed can reduce both the material costs and the production of additional garments while satisfying the time constraints set by the downstream sewing department [6].

Ng et al. explained how the problem of roll planning could be formulated for (Genetic Algorithms) GA to solve. They tried to determine an optimal fabric roll sequence for a cutting lay to minimise the spreading loss. The result of the study showed that an optimal roll plan could be worked out using the GA approach [1].

Hui and Leaf developed a theoretical model for the calculation of fabric loss as a result of splice loss and excessive end loss during spreading. Computation results of the the effect of changing the roll length and that of changing the number of rolls are calculated. It is concluded that as the rolls of fabric get longer, the splice loss will be smaller, though the trend is not a steady one [7].

Jacobs-Blecha et al. propose a mathematical model for cut order planning. Its objective is to minimise the total cutting cost, which includes fabric, spreading, cutting, and marker makingcosts. The model is solved using two constructive (savings and cherry picking) and one local search algorithm. The algorithms, were tested on real-life data consisting of

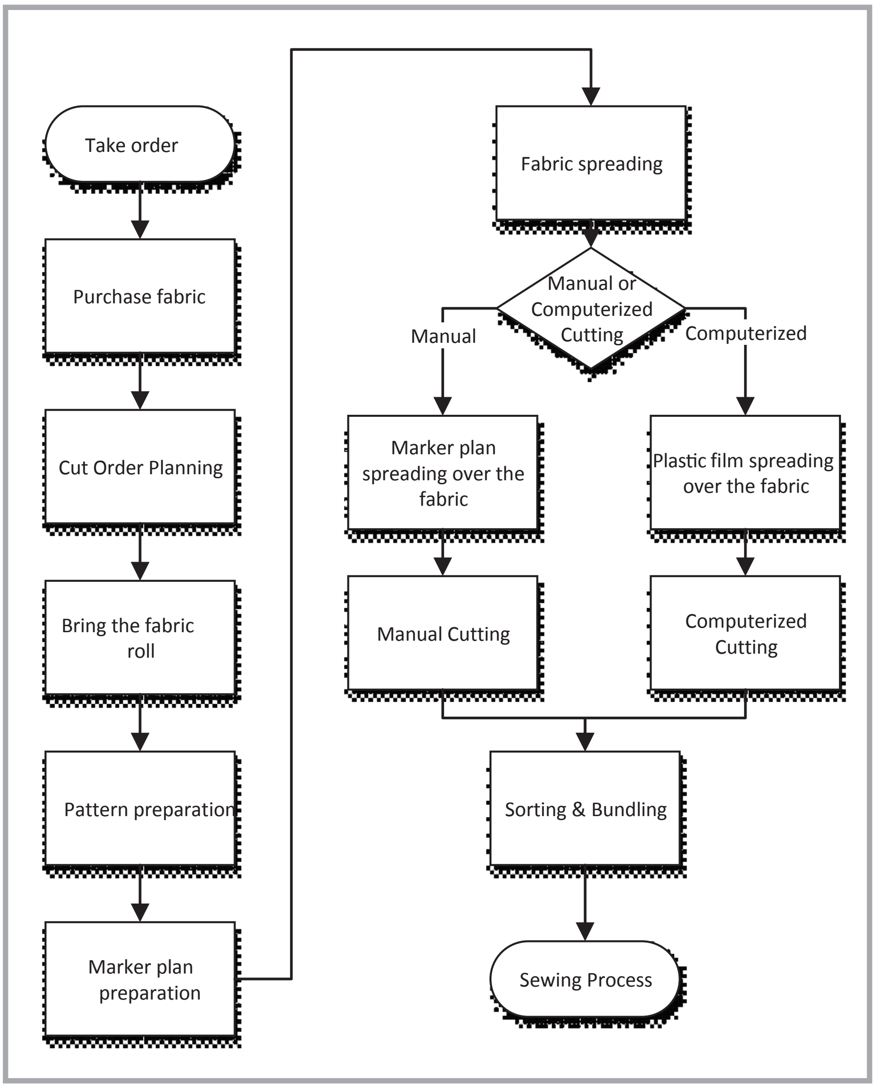

Figure 1. *Process flow of cutting department.*

20 orders with one to six sizes per order. Validated with representative industry problems, the approach is shown to be effective and versatile [8].

Nascimento et al. studied the problem of determining the lowest cost spreading and cutting schedule for garments of different styles, colours and sizes. They proposed the use of an innovative state-space approach using heuristic rules to solve the problem. It was modelled as a least-cost search in a graph where each node represents a different spreading and cutting schedule. Several solution algorithms and heuristics were proposed and tested, and an illustrative application in a Brazilian apparel company was presented for four different styles [9].

Although some of the assumptions made by the studies above are far from actual practice examples, they have reached various solutions by expanding or narrowing the scope of the existing COP problem with different solution proposals. The basic approach of this study was to carry out research that can be easily implemented in the apparel industry and provide the desired solution by making small changes to a single item of software. Although the code, written using the lingo program, is not shared in this study, due to commercial privacy reasons, the results obtained from the different products and the mathematical model generated are explained in detail.

Material and method

Cutting department

Since the most important department effecting fabric productivity is the cutting department, any improvement work to be done in this department will indirectly effect the overall business. With a view to COP optimisation, data were collected from two different enterprises

Table 1. *Manual solution for shirt production.*

Sizes	T39	T41	T43	T45	No. of plies	Marker plan length, cm
Total order	69	96	90	45		
1. Spreading	1	2	2	1	45	792.19
2. Spreading	3	2	0	0	8	619
No. of pieces	69	106	90	45	Total length, cm	
ECR, %	0	10.41	0	0	40600.55	

Table 2. *LINGO solution for shirt production.* ***Note:*** **Average length of a size calculated as 127.28 cm.*

Sizes	T39	T41	T43	T45	No. of plies	Marker plan length(cm)
Total order	69	96	90	45		
1. Spreading	2	2	3	0	30	891.01*
2. Spreading	1	4	0	5	9	1272.8*
No. of pieces	69	96	90	45	Total length, cm	
ECR, %	0	0	0	0	38186.33	

producing different garments. The first company employs 450 employees and produces shirts, coats and trousers, while the second company has 250 employees and produces sweatshirts. Before starting the optimisation study, the process flow of the cutting department was first established ***(Figure 1)***.

Nonlinear programming

In one general form, the nonlinear programming is to find $x = (x_1, x_2, ..., x_n)$ so as to maximise $f(x)$,
Subject to

$$g_i(x) \leq b_i, \text{ for } i = 1, 2, ..., m$$
$$\text{and } x \geq 0,$$

Where $f(x)$ and $g_i(x)$ are given functions of the n decision variables.

There are many different types of nonlinear programming problems, depending on the characteristics of the $f(x)$ and $g_i(x)$ functions. Different algorithms are used for different types. For certain kinds where the functions have simple forms, problems can be solved relatively efficiently. For some other types, solving even small problems is a real challenge [10].

Mixed integer nonlinear programming (MINLP) refers to optimisation problems with continuous and discrete variables and nonlinear functions in the objective function and/or the constraints. MINLPs arise in applications in a wide range of fields, including chemical engineering, finance, and manufacturing. The general form of MINLP is

$\min f(x, y)$

s.t. $c_i(x, y) = 0 \quad \forall i \in E$

s.t. $c_i(x, y) = 0 \quad \forall i \in \mathrm{I}$

$x \in \mathrm{X}$

$y \in \mathrm{Y}$ integer

Where, each $c_i(x, y)$ is a mapping from R^n to R, and E and I are index sets for equality and inequality constraints, respectively. Typically, functions f and c_i have some smoothness properties, i.e., once or twice continuously differentiable.

Software developed for MINLP has generally followed two approaches:

- Outer Approximation/Generalised Bender's Decomposition: These algorithms alternate between solving a mixed-integer LP master problem and nonlinear programming subproblems.
- Branch-and-Bound: Branch-and-bound methods for mixed-integer LP can be extended to MINLP with a number of tricks added to improve their performance [12]. LINGO uses the Branch-and-bound method in order to solve models with integer restrictions.

Whether or not a problem is solved by a method, it is important to correctly identify the current problem. To be able to express the problem correctly, a suitable model is created.

LINGO (Language for Interactive General Optimisation) software

LINGO is a comprehensive tool designed to make building and solving Linear, Nonlinear (convex & nonconvex/Global), Quadratic, Quadratically Constrained, Second Order Cone, Semi-Definite, Stochastic, and Integer optimisation models faster, easier and more efficient. LINGO provides a completely integrated package that includes a powerful language for expressing optimisation models, a full featured environment for building and editing problems, and a set of fast built-in solvers. LINGO formulates your linear, nonlinear and integer problems quickly in a highly readable form. There is no need to specify or load a separate solver because LINGO reads the formulation and automatically selects the appropriate one.

For developing models interactively, LINGO provides a complete modelling environment to build, solve, and analyse models. For building turn-key solutions, LINGO comes with callable DLL and OLE interfaces, which can be called from user written applications. LINGO can also be called directly from an Excel macro or database application [12].

Mathematical expression of the problem

Explanations of the variables used in the COP optimisation model are given below:
K_i: number of plies of i[th] spreading,
K_{max}: maximum number of plies that can be cut,
T_i: length of i[th] spreading,
A_{ij}: COP number of j[th] size belonging to i[th] spreading,
S_j: order quantity of j[th] size,
P: excess cutting rate (ECR) (%) to be allowed,
B_j: estimated length of j[th] size in marker plan,
M: table length,

An optimisation model of the problem is as follows;

$$Min \sum_{i=1}^{n} K_i * T_i \quad (1)$$

Subject to

$$K_i - K_{max} \leq 0 \quad (2)$$
$$(i = 1, 2, \ldots n)$$

$$\sum_{j=1}^{m} \sum_{i=1}^{n} K_i * A_{ij} \geq S_j \quad (3)$$
$$(i = 1, 2, \ldots n; j = 1, 2, \ldots m)$$

$$\sum_{j=1}^{m} \sum_{i=1}^{n} K_i * A_{ij} \leq S_j \left(1 + \frac{P}{100}\right) \quad (4)$$
$$(i = 1, 2, \ldots n; j = 1, 2, \ldots m)$$

$$\sum_{i=1}^{n} \sum_{j=1}^{m} A_{ij} * B_j \leq M \quad (5)$$
$$(i = 1, 2, \ldots n; j = 1, 2, \ldots m)$$

$$K_i - K_j \geq 0 \text{ for } i > j \quad (6)$$
$$(i = 1, 2, \ldots n; j = 1, 2, \ldots m)$$

$$\sum_{i=1}^{n} \sum_{j=1}^{m} A_{ij} * B_j - T_i = 0 \quad (7)$$
$$(i = 1, 2, \ldots n; j = 1, 2, \ldots m)$$

$$A_{ij}, K_i, T_i, S_j, B_j, K_{max}, P, B, M \geq 0 \quad (8)$$

The objective function of the problem which minimises the total usage of fabric is written in ***Equation (1)***. In ***Equation (2)***, it is stated that the condition of the number of plies belonging to each spreading is smaller than the maximum number . In ***Equations (3)*** and (***4***), the following condition is provided; the number of cut pieces must be more than the order and less than the excess cutting share for each size. In ***Equation (5)***, it is stated that the length of the marker plan must be shorter than that of the table for any spreading. In ***Equation (6)***, the condition that the maximum number of plies is smaller than the previous ones is indicated. ***Equation (7)*** is used to calculate the length of different spreadings separately. ***Equation (8)*** provides the condition that all variables are greater than 0.

Findings and results

The results obtained from the COP of shirts, coats, trousers and sweatshirts are given, and the findings obtained from the software were compared with manual solutions in terms of the total spreading length.

Findings in shirt production

The maximum length of the table is 16 meters. Up to 200 plies can be laid for shirt fabric. ***Table 1*** shows the distribution of the order for each size and the solution produced by the employee.

In ***Table 2***, the results of 3082 iterations are given by LINGO software. The key issue is to calculate the average length of a size for the solution. To calculate the average length of a size; different samples were taken and the total length of the fabric used for each order was divided by the total number of sizes in that order. The average size was calculated as 127.28 cm for the same product group (shirt).

Findings in coat production

The maximum length of the table is 16 meters, where up to 50 plies can be laid for shirt fabric. ***Table 3*** shows the distribution of the order for each size and the solution produced by the employee and LINGO. In the manual solution, the COP was prepared for 4 spreadings, and the total spreading length was calculated as 88560 cm. After 3087495 iterations, LINGO calculated the total spreading length as 85486 cm, and cutting was planned for 4 spreadings with a 0% excess cutting rate.

Table 3. *Manual and LINGO solutions for coat production.* ***Note:*** **Average length of a size calculated as 205.49 cm.*

Sizes	T48	T50	T52	T54	T56	T58	T60	T62	No. of plies	Marker plan length, cm
Total order	**37**	**84**	**84**	**84**	**59**	**38**	**22**	**8**		
1. Spreading	0	0	0	0	2	0	0	1	8	615
2. Spreading	0	0	0	0	2	0	1	0	24	615
3. Spreading	2	0	0	0	0	2	0	0	21	820
4. Spreading	0	2	2	2	0	0	0	0	42	1230
No. of pieces	42	84	84	84	64	42	24	8	**Total length, cm**	
ECR, %	13.51	0	0	0	8.47	10.52	9.09	0	88560	
LINGO Solution										
Sizes	**T48**	**T50**	**T52**	**T54**	**T56**	**T58**	**T60**	**T62**	**No. of plies**	**Marker plan length, cm**
Total order	**37**	**84**	**84**	**84**	**59**	**38**	**22**	**8**		
1. Spreading	0	2	1	2	1	1	0	0	38	1438.48
2. Spreading	2	0	2	0	1	0	2	0	11	1438.48
3. Spreading	0	1	3	1	0	0	0	1	8	1232.98
4. Spreading	3	0	0	0	2	0	0	0	5	1027.48
No. of pieces	37	84	84	84	59	38	22	8	**Total length, cm**	
ECR, %	0	0	0	0	0	0	0	0	85486.51	

Table 4. *Manual and LINGO solutions for trouser production.* ***Note:*** **Average length of a size calculated as 112,22 cm.*

Sizes	T24	T26	T28	T30	T32	No. of plies	Marker plan length, cm
Total Order	**40**	**205**	**35**	**10**	**10**		
1. Spreading	0	2	0	1	1	11	472.09
2. Spreading	0	4	0	0	0	30	435.22
3. Spreading	1	2	1	0	0	44	433.28
No. of pieces	44	230	44	11	11	**Total length, cm**	
ECR, %	10	12.19	25.71	10	10	37313.91	
LINGO Solution							
Sizes	**T24**	**T26**	**T28**	**T30**	**T32**	**No. of plies**	**Marker plan length, cm**
Total Order	**40**	**205**	**35**	**10**	**10**		
1. Spreading	2	9	1	0	0	15	1346.71*
2. Spreading	1	7	2	1	1	10	1346.71*
No. of pieces	40	205	35	10	10	**Total length, cm**	
ECR, %	0	0	0	0	0	33667.85*	

Table 5. *Manual and LINGO solutions for sweatshirt production.* ***Note:*** **Average length of a size calculated as 100 cm.*

Sizes	S	M	L	XL	XXL	No. of plies	Marker plan length, cm
Total Order	**130**	**348**	**444**	**304**	**152**		
1. Spreading	0	2	3	2	1	40	800
2. Spreading	0	2	3	2	1	40	800
3. Spreading	0	2	3	2	1	40	800
4. Spreading	0	2	3	2	1	40	800
5. Spreading	1	1	1	0	1	13	400
6. Spreading	4	1	0	0	0	35	500
No. of pieces	153	368	493	320	173	**Total length, cm**	
ECR. %	17.69	5.74	11.03	5.26	13.81	150700	
LINGO Solution							
Sizes	**S**	**M**	**L**	**XL**	**XXL**	**No. of plies**	**Marker plan length, cm**
Total Order	**130**	**348**	**444**	**304**	**152**		
1. Spreading	1	1	6	8	4	38	2000
2. Spreading	3	10	7	0	0	31	2000
No. of pieces	131	348	445	304	152	**Total length, cm**	
ECR. %	0.76	0	0.22	0	0	138000	

Table 6. *Manual and LINGO solution comparison for different orders.*

Product	Manual solution, m	LINGO solution, m	Difference, m	No. of sizes in Order	Fabric savings, %
Shirt 1	406	381	25	4	6.56
Shirt 2	198	176	22	4	11.11
Shirt 3	327	309	18	4	5.50
Shirt 4	332	317	15	4	4.51
Shirt 5	695	635	60	4	8.63
Shirt 6	507	444	63	8	12.42
Coat	885	854	31	8	3.5
Trousers 1	373	336	37	5	9.91
Trousers 2	42.9	42.5	0.4	4	0.93
Sweatshirt 1	1507	1380	130	5	8.62
Sweatshirt 2	1490	1400	90	5	6.04
Average Efficiency					7.06

Table 7. *Comparison of the length of the marker plan for manual and LINGO solutions.*

Product	Manual Solution		LINGO Solution		Fabric savings, %
	Maximum no. of sizes	Maximum marker plan length, m	Maximum no. of sizes	Maximum marker plan length, m	
Shirt 1	6	7.92	10	12.72	6.56
Shirt 2	3	3.83	11	13.97	11.11
Shirt 3	7	9.46	9	11.43	5.50
Shirt 4	2	2.62	12	15.24	4.51
Shirt 5	4	5.30	10	12.70	8.63
Shirt 6	4	5.65	9	11.43	12.42
Coat	6	12.3	7	14.38	3.5
Trousers 1	4	4.72	12	13.46	9.91
Trousers 2	3	3.38	13	14.56	0.93
Sweatshirt 1	8	8	17	20	8.62
Sweatshirt 2	8	8	20	20	6.04
Average Efficiency					7.06

Findings in trouser production

The maximum length of the table is 16 meters, where up to 100 layers can be laid for trousers. ***Table 4*** shows the distribution of the order for each size and the solution produced by the employee. In the manual solution, the COP was prepared for 3 spreadings, and the total spreading length was calculated as 37314 cm. After 2549 iterations, LINGO calculated the total spreading length as 33668 cm, and cutting was planned for 2 spreadings with a 0% excess cutting rate.

Findings in sweatshirt production

The maximum length of the table is 20 meters, where up to 45 layers can be laid for pants. ***Table 5*** shows the distribution of the order for each size and the solution produced by the employee. In the manual solution, the COP was prepared for 6 spreadings, and the total spreading length was calculated as 150700 cm. After 57277 iterations, LINGO calculated the total spreading length as 138000 cm, and cutting was planned for 2 spreadings with a 0,76% excess cutting rate.

Results and discussion

In this study, the cutting department of apparel enterprises was examined, problems therein investigated, and what should be done for a more efficient study discussed. In this context, fabric cost, which constitutes a large part of the production costs, is emphasised. As a result of the interviews and analyses carried out in the enterprises, it was determined that the fabric could be used more efficiently with a cut order plan optimisation study. In order to decrease fabric losses and use fabric more efficiently, the parameters affecting this problem were determined. These are the length of the cutting table, the maximum number of plies of each order, the average length calculated for each size, and the order quantity of each size. In order to reach an optimum solution to this problem, a model was created using mixed integer nonlinear programming, and the LINGO computer program was used to implement this model. The LINGO program evaluates all the possibilities that cannot be solved manually by an employee in a very short period of time and results obtained with the branch and bound algorithm used by the software. The algorithm aims to find the best solution for a given function. The results of the program were transferred to Excel software for easier understanding. As a result of the study, it is ensured that fabric can be used more efficiently with respect to today's apparel application, which is solved by a manual method for different types of products.

In the study, the results obtained from different models belonging to 4 different products show that approximately 7% fabric gain was achieved for all products (see ***Table 6***). The resulting fabric gain varies between 4% and 13%. The main reasons for this variation are the order and size of the order and how effectively the employee solved the COP problem. In the solution for the second model of trousers, since the number of orders and body variations were low, the operator was able to produce the best solution, and the algorithm developed was able to provide an approximately 1% improvement. The results obtained for the shirt show that as the size diversity increases (as the problem becomes more complex), the employee's probability of producing the best solution is decreased.

Although fabric gain optimisation is based on different models and products, the complexity of the cut order plan plays an active role in the development of the results rather than the product type. However, it is possible to reach a general conclusion about marker planning: a longer marker plan results in less fabric loss. This result is more clearly shown in ***Table*** *7*.

Even though the fabric savings and the marker plan length of the LINGO and employee solutions cannot be correlated by a linear relationship, it is a fact that the tendency of the optimisation program, which gives better results for all applications, is for a longer marker plan.

The following points are recommended to researchers who will work on this in the future:

- To develop an algorithm for cuttings of different coloured fabrics on top of each other,
- After determining the standard times of all operations in the cutting department, change the objective function to minimising the total time of the spreading process,

- To improve the algorithm by including the marker plan efficiencies estimated for the problem,
- To solve the same problem with different optimisation methods (such as artificial neural networks and a genetic algorithm).

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