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An Optimal Solution to the Linear Programming Problem using Lingo Solver: A Case Study of an Apparel Production Plant of Sri Lanka

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ABSTRACT

Operations Research (OR) is often concerned with determining the maximum of profit, performance, yield etc. or minimum of cost, loss, risk, etc. of some real-world objectives. The Linear Programming Problem (LPP), a branch of Operations Research consists of an objective function which is linear and constraints are linear equations or inequalities. This research paper presents a Mathematical Model of a LPP which is to minimize the production cost, while satisfying operational limitations, of a production plant producing t-shirts. This production plant is known as Silk Line (pvt) Ltd which is located in Sri Lanka. The developed model is considered to be a large scale one which provides a fully functional cost effective system finding optimum number of machine operators and workers in each of the departments in the production plant as well as finding optimum raw material for the entire t-shirts production. The optimal solution to the model is found using the commercial software package called "**LINGO SOLVER**". Moreover, a sensitivity analysis is performed to complete the target (entire t-shirts production) within a given specific period of time.

Keywords

Linear Programming Problem, Optimum number of machine operators, Lingo Solver, Sensitivity analysis.

1. INTRODUCTION

Linear programming is an optimization technique which was developed during the Second World War. An LPP consists of an objective function which is linear and constraints are linear equations or inequalities. Objective function and constraints are formed using the decision variables which are defined according to the given problem. Decision variables are continuous to be real valued variables which may have lower or upper bounds.

Objective function is to be maximized or minimized subject to the constraints which form a convex feasible region. An LPP can be solved using an iterative algorithm known as the Simplex Algorithm which was developed by Dantzig in 1950's. This is the most the widely used and accepted algorithm to solve LPPs because of its simplicity. The optimal solution of the objective function may be bounded or unbounded whereas optimal solution to the decision variables may or may not be unique.

Linear Programming has a broader area of applications in the fields of productions, telecommunications, transportations, scheduling etc. The main focus of linear programming is to optimize the available resources in the best possible manner while achieving the objective.

This research paper is focusing on optimizing production cost of a t-shirts production plant which is located in Sri Lanka. Although the plant's monthly target is 30,000 t-shirts, the records show that the target level has not been reached in a regular basis. Also, it can be observed that the plant's operational costs are mainly due to workers monthly payments which are more than what is needed. Due to low productivity and unnecessary expenditures, at present the plant is facing major financial difficulties and several other problems in designing the production process. Therefore, the management is interested in implementing a cost effective system to reduce the production cost while improving the production efficiency of t-shirts. In fact, in this research paper, a large scale linear programming model is developed to achieve these objectives. Then LINGO SOLVER is used to solve the developed large scale model.

The remainder of this paper is organized as follows: Related literature review is given in section 2. Section 3 deals with the Methods and Materials of the LPP. In section 4 the solution to the large scale LPP is summarized. Finally, the conclusion given in section 5 highlights the limitations and future research scope on the topic.

2. LITERATURE REVIEW

Linear Programming problem and its solution have been studied by many authors. Few of them are James and Tom [5], Brain [1], Dantzig [2] and Taha [13]. A number of computer software is available in obtaining the solutions to LPP. Some are based on the simplex method and its variants, e.g. CPLEX, LINDO, TORA, MATLAB, EXCEL SOLVER, AMPL and LINGO, and some are based on the interior point algorithms, e.g. MOSEX. See Fourer [3]. Though the software based on simplex method and its variants have been used widely in solving linear programming problems, they solve LPP in exponential time. An algorithm that solves LPP in polynomial time is considered to be efficient. A first attempt of solving LPP in polynomial time was the development of interior point algorithm by Karmarkar [8]. How to solve a large scale LPP by interior point method under MATLAB environment was proposed by Zhang [15]. The existing interior point algorithms have some drawbacks such as extensive calculation requirements, large number of iterations and large computer space requirements. See Terlaky and Boggs [14].In addition, Hitchcock [4] was first to develop the transportation model. After that, the transportation problem, a special class of linear programming problem has been studied by many researchers. Sharma and Sharma [12] presented the transportation problem in a slightly different form in getting a dual problem which has a special structure. Then they proposed a new solution procedure to solve the dual of the incapacitated transportation problem. Sharma and Prasad [11] presented a heuristic that provides a very good initial solution to the transportation problem in polynomial time. Schrenk et al. [10] analyzed degeneracy characterizations for two classical problems: the transportation paradox in linear transportation problems and the pure constant fixed charge (there is no variable cost and the fixed charge is the same on all routes) transportation problems. A new result on complexity of the pure constant fixed charge transportation problem has been proved. Liu [9] investigated the transportation problem when the demands and supplies were varying within their respective ranges. Following these variations the minimal total cost were also varied within an interval. So, he built a pair of mathematical programs where at least one of the supply or the demand was varying, to compute the lower and the upper bounds of the total transportation cost. Then the Lingo solver was used to solve the both mathematical programs to attain the lower and the upper bounds of the minimal total transportation costs. Juman and Hoque [7] demonstrated the deficiency of Liu's [9] method in getting an upper bound of the minimal total costs of transportation. Then they extended this Liu's model to include the inventory costs of the product during transportation and at destinations, as they are interrelated factors. In addition, they developed two new efficient heuristic solution techniques - Algorithms 1 & 2 to find the upper and the lower minimal total cost bounds respectively. By comparative studies of the solution techniques on the solutions of small size numerical problems, it is observed that our proposed heuristic technique (Algorithm1) performs the same or significantly better in finding the upper bound of the minimal total cost as compared with Liu's [9] approach. Algorithm 2 provided the same lower bound of the minimal total costs to each of the numerical problems studied as the one found by Liu's [9] approach. Moreover, numerical studies demonstrated that the inclusion of inventory costs during transportation and at destinations with the transportation costs changes the lower and the upper minimal total cost bounds reasonably. Juman, Hoque and Bhuhari [6] designed a C++ computational program of Vogel's Approximation Method (to solve an unbalanced transportation problem by considering both the balanced and unbalanced features respectively with and without adding a dummy column) in obtaining an initial feasible solution (IFS) to an unbalanced transportation problem (UTP). In order to get an initial feasible solution to a large scale TP, this computational program of VAM is preferred. Moreover, we examine the effect of dealing with the balanced and the unbalanced features in applying the well-known VAM method for solving an unbalanced transportation problem. First we illustrated the solution procedures with numerical examples (chosen from the literature). Then we demonstrated this effect by a comparative study on solutions of some numerical problems obtained by VAM by considering the balanced and the unbalanced features.

3. METHODS AND MATERIAL

3.1Current approach

The current methodology, adopted by the plant, to increase the production has failed due to several drawbacks. At present, the plant finds a feasible solution by manually comparing alternative resource allocations. Although the management is fully committed to improve the production process in order to reach the optimum production, it has failed to achieve the objective. It was observed that the current production process in the plant has several weaknesses. This is mainly due to following reasons:

- Mismanagement of human resources
- Mismanagement of orders
- Improper resource utilization

3.2Data Collection

Data were collected using Questionnaires and Interviews. Then the mathematical model for the month of August 2012 was formulated using the collected data.

3.3Formulation of the Mathematical Model

3.3.1Decision Variables of the Model

Decision variables of the proposed model are as follows:

$x_1, x_2, \ldots, x_{19}, x_{20}$ and x_{52}, x_{53} = # trained and untrained cutter, band knife, normal, 5-tread, 4-tread, flat lock, button hole, button attach, blind hem, double needle, and fusing machine operators; x_{21}, x_{22} = # mechanics needed in cutting and sewing departments; $x_{23}, x_{24}, x_{54}, x_{44}$ = # instructors needed in cutting, sewing, QC (quality control) and packing departments; $x_{31}, x_{32}, x_{55}, x_{42}$ = # supervisors needed in cutting, sewing, QC and packing departments; x_{29}, x_{30} = # table checkers needed in cutting and sewing departments; x_{25}, x_{26}, x_{39} = # helpers needed in cutting, sewing and packing departments; $x_{33}, x_{34}, x_{56}, x_{43}$ = # clerks needed in cutting, sewing, QC and packing departments; x_{40} = # menders needed in packing department; x_{41} = # quality checkers needed in QC department; $x_{38}, x_{35}, x_{37}, x_{45}$ = # in chargers needed in packing, cutting, QC and sewing departments; x_{48} = # personal managers; x_{47} = # account clerks; x_{27}, x_{28} = # quality instructors needed in cutting and sewing departments; x_{36} = # production managers; x_{46} = # iron tables; x_{49}, x_{50}, x_{51} = # small, medium, large t-shirts produced in a month. (Here, # denotes 'number of ')

3.3.2 Objective Function of the Model

The objective of the linear programming model presented below is to determine the minimum production cost of the production plant.

Mathematical formulation of objective function:
Cost Function

Minimize Production Cost $Z = \sum_{\substack{i=1 \\ i \neq 46,49,50,51}}^{56} c_i \; x_i + 4500 x_{46} + \sum_{j=49}^{51} c_j \; x_j$, where c_i is the salary of the i^{th} employee and c_j is the raw material cost of the j^{th} type t-shirt subject to the following constraints :

3.3.3 Constraints of the Model

All the constraints in the model can be categorized into five different types as shown in Table 1 below.

Table 1 Types of model constraints

Constraints	**Inequalities**
	$30x_j + 120x_{j+1} \geq c_j$; j=5,7,9,...,19;

Machine	c_j = # t-shirts completed in a day by j^{th} type of machines in the sewing department
	$x_k + x_{k+1} \geq c_k$; $k = 1,3,5,...,17,19,52$; c_k = # machine operators needed for the k^{th} type of machines in cutting and sewing departments
Workers	Cutting, Sewing, QC and Packing Departments must have a minimum # workers to perform the duties.
	$x_{55} \leq 1$; # supervisors needed in QC department.
	$x_{33} = x_{56} = x_{43}$; same # clerks needed in cutting, QC and packing departments.
	$x_{28} \leq 7$; # quality instructors needed in sewing department.
Raw material	$29x_{49} + 30x_{50} + 32x_{51} \leq 899964$ inches (raw material needed for the entire t-shirt production)
Raw material cost	$\left(\frac{29 \times 80}{36}\right)x_{49} + \left(\frac{30 \times 80}{36}\right)x_{50} + \left(\frac{32 \times 80}{36}\right)x_{51} \leq Rs.1999920$ (raw material cost for the entire production)
Time	$\left(\frac{11.66}{20}\right)x_{49} + \left(\frac{11.66}{20}\right)x_{50} + \left(\frac{11.66}{20}\right)x_{51} \leq 12480$ minutes (time available for the entire t-shirt production)

3.4 Linear Programming Model (LPM)

Finally, Linear Programming Model (LPM) for the existing problem could be formulated as below. Optimal solution of the model is obtained using the software known as **LINGO** as illustrated below:

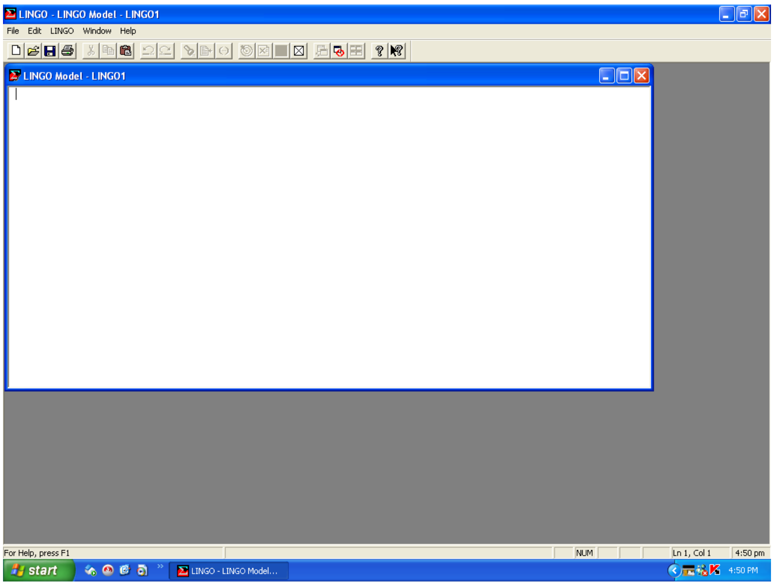

Figure 1 LINGO Mainframe Window

Linear Programming Model:

$$MinZ = 4200X_1 + 6200X_2 + 4200X_3 + 6200X_4 + 4200X_{52} + 6200X_{53} + 4200X_5 + 6200X_6 + 4200X_7 + 6200X_8 + 4200X_9 + 6200X_{10} + 4200X_{11} + 6200X_{12} + 4200X_{13} + 6200X_{14} + 4200X_{15} + 6200X_{16} + 4200X_{17} + 6200X_{18} + 4200X_{19} + 6200X_{20} + 10000X_{21} + 10000X_{22} + 15000X_{23} + 15000X_{24} + 10000X_{54} + 10000X_{44} + 8000X_{27} + 8000X_{28} + 4500X_{29} + 4500X_{30} + 4500X_{40} + 10000X_{31} + 10000X_{32} + 10000X_{55} + 10000X_{42} + 5000X_{33} + 5000X_{34} + 5000X_{56} + 5000X_{43} + 12000X_{47} + 5000X_{41} + 4000X_{25} + 4000X_{26} + 4000X_{39} + 14000X_{48} + 30000X_{36} + 20000X_{35} + 20000X_{37} + 20000X_{38} + 20000X_{45} + 4500X_{46} + (2320 \div 36)X_{49} + (2400 \div 36)X_{50} + (2560 \div 36)X_{51} \tag{1}$$

subject to

$$30X_5 + 120X_6 \geq 1200;\ 30X_7 + 120X_8 \geq 600;\ 30X_9 + 120X_{10} \geq 600;\ 30X_{11} + 120X_{12} \geq 1000;\ 30X_{13} + 120X_{14} \geq 1500;\ 30X_{15} + 120X_{16} \geq 1500;\ 30X_{17} + 120X_{18} \geq 1500;\ 30X_{19} + 120X_{20} \geq 1500 \tag{2}$$

$$X_1 + X_2 \geq 3;\ X_3 + X_4 \geq 1;\ X_{52} + X_{53} \geq 2;\ X_5 + X_6 \geq 115;\ X_7 + X_8 \geq 15;\ X_9 + X_{10} \geq 8;\ X_{11} + X_{12} \geq 4;\ X_{13} + X_{14} \geq 2;\ X_{15} + X_{16} \geq 3;\ X_{17} + X_{18} \geq 2;\ X_{19} + X_{20} \geq 12 \tag{3}$$

$$3X_2 \geq 1200;\ 3X_4 \geq 1200\ ;\ 3X_{53} \geq 1200 \tag{4}$$

$$45X_{22} \geq \begin{pmatrix} X_5 + X_6 + X_7 + X_8 + X_9 + X_{10} + X_{11} + X_{12} + X_{13} + X_{14} + X_{15} + X_{16} + \\ X_{17} + X_{18} + X_{19} + X_{20} \end{pmatrix} \tag{5}$$

$$45X_{21} - X_1 - X_2 - X_3 - X_4 - X_{52} - X_{53} \geq 0\,;20X_{23} - X_1 - X_2 - X_3 - X_4 - X_{52} - X_{53} \geq 0 \tag{6}$$

$$X_{24} \geq 2X_{23};\ \ X_{54} \geq 2X_{23}\ ;\ \ X_{44} \geq X_{23} \tag{7}$$

$$20X_{31} \geq \left(X_1 + X_2 + X_3 + X_4 + X_{52} + X_{53}\right) \tag{8}$$

$$60X_{32} \geq \begin{pmatrix} X_5 + X_6 + X_7 + X_8 + X_9 + X_{10} + X_{11} + X_{12} + X_{13} + X_{14} + X_{15} + X_{16} + \\ X_{17} + X_{18} + X_{19} + X_{20} \end{pmatrix} \tag{9}$$

$$X_{55} \leq 1\ ;\ 50X_{42} \geq \left(X_{39} + X_{40} + X_{46}\right);\ X_{29} \geq 8;\ X_{30} \geq X_{29} \tag{10}$$

$$9X_{26} \geq \begin{pmatrix} X_5 + X_6 + X_7 + X_8 + X_9 + X_{10} + X_{11} + X_{12} + X_{13} + X_{14} + X_{15} + X_{16} + \\ X_{17} + X_{18} + X_{19} + X_{20} \end{pmatrix} \tag{11}$$

$$20X_{25} - 13X_{26} \geq 0;\ 20X_{39} - 8X_{26} \geq 0 \tag{12}$$

$$40X_{34} \geq \begin{pmatrix} X_5 + X_6 + X_7 + X_8 + X_9 + X_{10} + X_{11} + X_{12} + X_{13} + X_{14} + X_{15} + X_{16} + \\ X_{17} + X_{18} + X_{19} + X_{20} \end{pmatrix} \tag{13}$$

$$4X_{33} - X_{34} \geq 0;\ \ X_{33} = X_{56} = X_{43} \tag{14}$$

$$X_{40} \geq 12\ ;\ \ X_{41} \geq 24 \tag{15}$$

$$X_{38} \geq 1\,;\ X_{35} \geq 1\,;\ X_{37} \geq 1 \tag{16}$$

$$X_{48} \geq 3;\ X_{47} \geq X_{48};\ X_{22} \geq \frac{161}{45}\ ;\ X_{28} \leq 7;\ 2X_{27} - X_{28} \geq 0;\ X_{36} \geq 1;\ X_{45} \geq 1 \tag{17}$$

$$X_{46} \geq 8;\ 29X_{49} + 30X_{50} + 32X_{51} \leq 899964 \quad (18)$$

$$2320X_{49} + 2400X_{50} + 2560X_{51} \leq 71997120 \quad (19)$$

$$\left(\frac{11.66}{20}\right)X_{49} + \left(\frac{11.66}{20}\right)X_{50} + \left(\frac{11.66}{20}\right)X_{51} \leq 12480 \quad (20)$$

$$X_{49} = 14350\ ;\ X_{50} = 10450;\ X_{51} = 5200 \quad (21)$$

$X \geq 0$ and integers ; X is the column vector consisting of decision variables. **(22)**

4. RESULTS

By solving the developed large scale mathematical model (as shown in section 3.4) using Lingo solver, the solutions obtained are given below in Table 2 and Figures 2-5. The comparison between the optimal number of each type of machines and number of machines currently being used in the plant is shown in the following table:

Table 2The optimal table for the types of machines

Departments	Type of machine	Available # machines	Optimal # machines
Department of cutting	Cutter	3	3
	Band knife	1	1
	Fusing	2	2
Department of sawing	Normal	115	115
	5-tread	13	15
	4-tread	8	8
	Flat lock	4	8
	Button hole	12	13
	Button attach	12	13
	Blind hem	10	13
	Double needle	12	13

where x_1+x_2 =# cutter machines;x_3+x_4= # band knife machines; $x_{52}+x_{53}$ = # fusing machines;x_5+x_6 =# normal machines;x_7+x_8 =# 5-tread machines;x_9+x_{10}= # 4-tread machines;$x_{11}+x_{12}$ = # flat lock machines;$x_{13}+x_{14}$

= # button hole machines;$x_{15}+x_{16}$ = # button attach machines; $x_{17}+x_{18}$= # blind hem machines; $x_{19}+x_{20}$= # double needle machines.

The Table 2 clearly shows the available number of machines and their respective optimal amount. The cutting department consists of three cutter, one band knife and two fusing machines in the plant. The optimum quantities for these machines in the cutting department are the same. The sawing department consists of hundred and fifteen normal machines, thirteen 5-tread machines, eight 4-tread machines, four flat lock machines, twelve button hole machines, twelve button attach machines, ten blind hem machines, and twelve double needle machines. The optimum quantities for these machines in the sawing department are 115, 15, 8, 8, 13, 13, 13, 13 respectively.

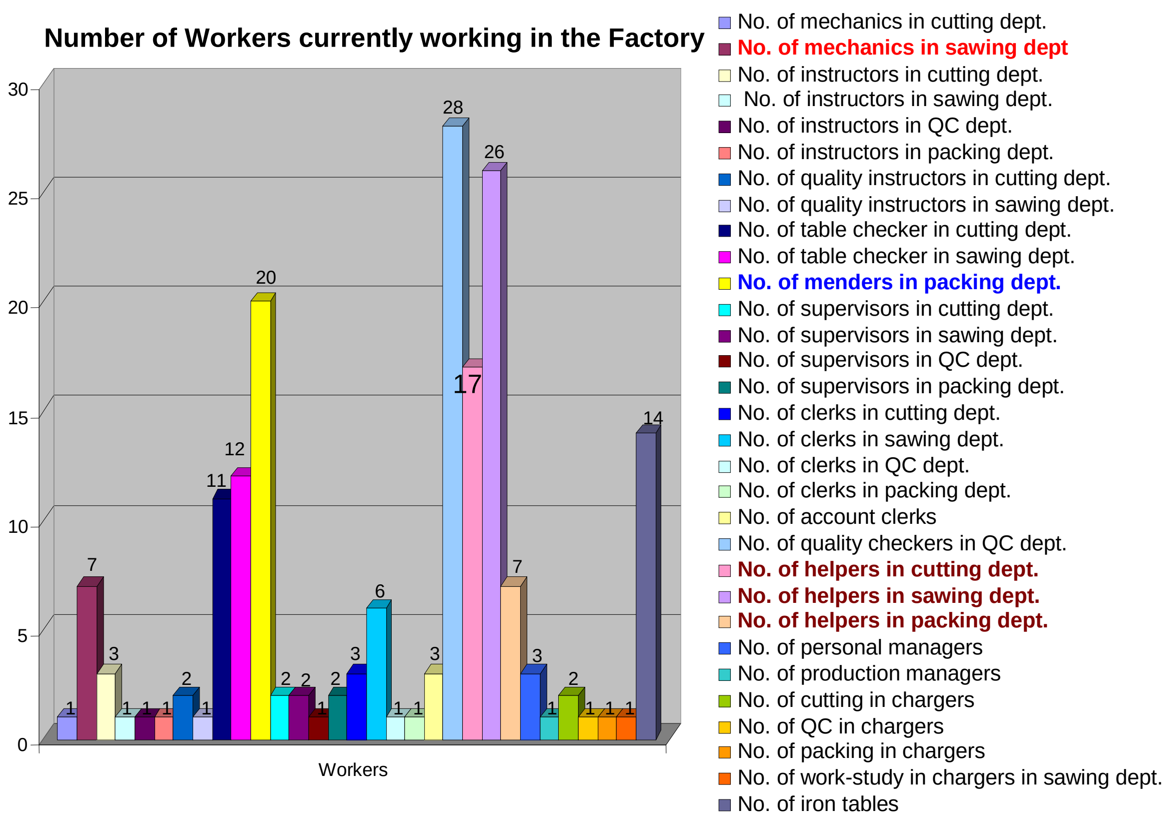

Figure 2 Number of workers currently working in the factory

The bar charts in Figure 2 clearly depict the available number of workers who are currently working in the plant as follows: The cutting department consists of a mechanic, three instructors, two quality instructors, eleven table checkers, two supervisors, three clerks, seventeen helpers, and two cutting-in-chargers. The sawing department consists of seven mechanics, one instructor, one quality instructor, twelve table checkers, two supervisors, six clerks, twenty six helpers, and one work-study-in-charger. The QC department consists of one instructor, one supervisor, one clerk, twenty eight quality checkers, and one QC in-charger. The packing department consists of one instructor, twenty menders, two supervisors, one clerk, seven helpers, and one packing in-charger. In addition to there are three account clerks, three personal managers, one production manager, and fourteen iron tables in the factory.

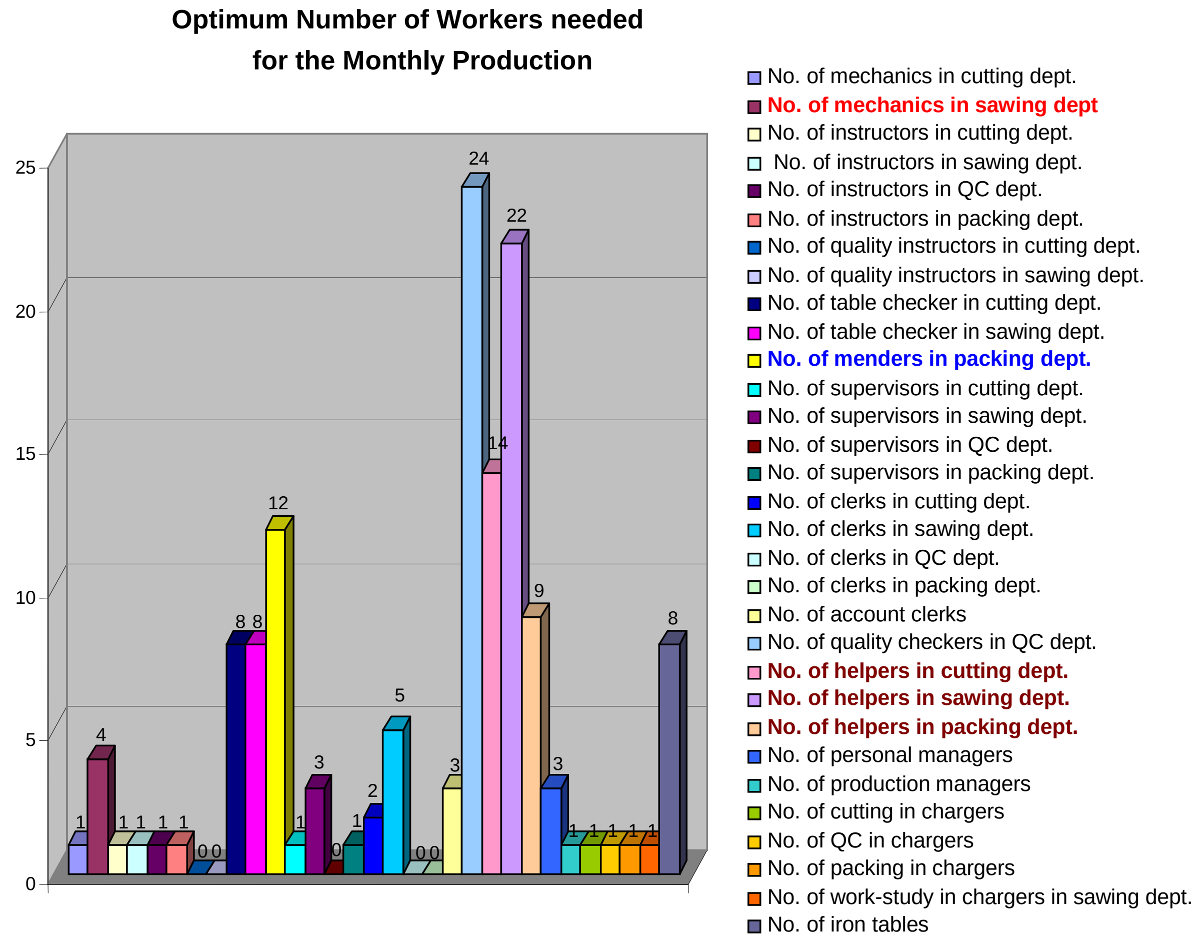

Figure 3 Optimum number of workers needed for the monthly production

The bar charts in Figure 3 clearly depict the optimum number of workers needed for the monthly production of the plant as follows: The cutting department consists of one mechanic, one instructor, eight table checkers, one supervisor, two clerks, fourteen helpers, and one cutting-in-charger. The sawing department consists of four mechanics, one instructor, eight table checkers, three supervisors, five clerks, twenty two helpers, and one work-study-in-charger. The QC department consists of one instructor, twenty four quality checkers, and one QC in-charger. The packing department consists of one instructor, twelve menders, one supervisor, nine helpers, and one packing in-charger. In addition to there are three account clerks, three personal managers, one production manager, and eight iron tables in the factory.It should be noted that the total number of workers working in the plant is 182 (see Figure 2). The Optimum number of workers needed for the monthly production of t-shirts is 137 (see Figure 3). Thusour model which is presented in this paper reduces the total number of workers by 32.9 %.

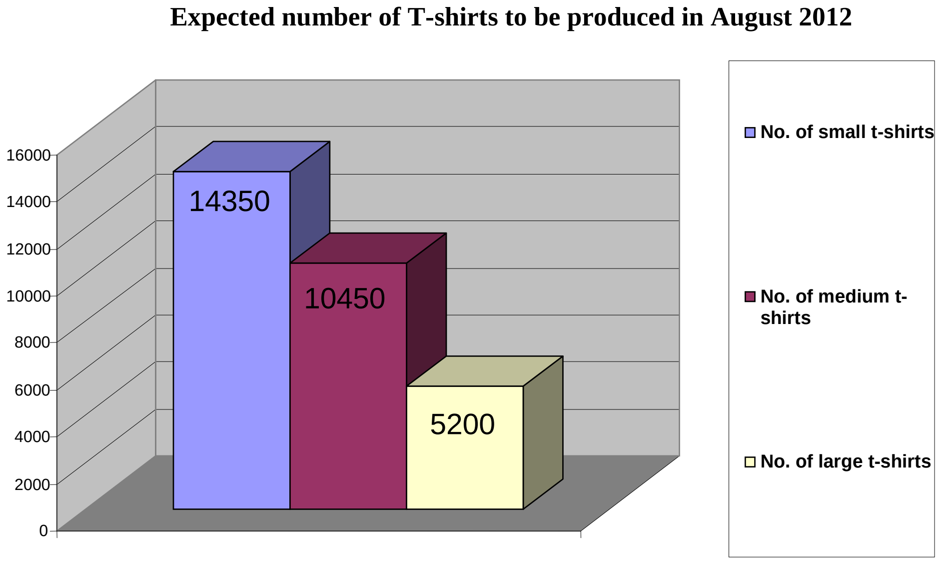

Figure 4 Expected numbers of t-shirts (small, medium, and large) to be produced in August

The bar charts in Figure 4 clearly depict the expected total number of t-shirts to be produced in August 2012. The expected numbers of small, medium and large size t-shirts are 14350, 10450, and 5200 respectively.

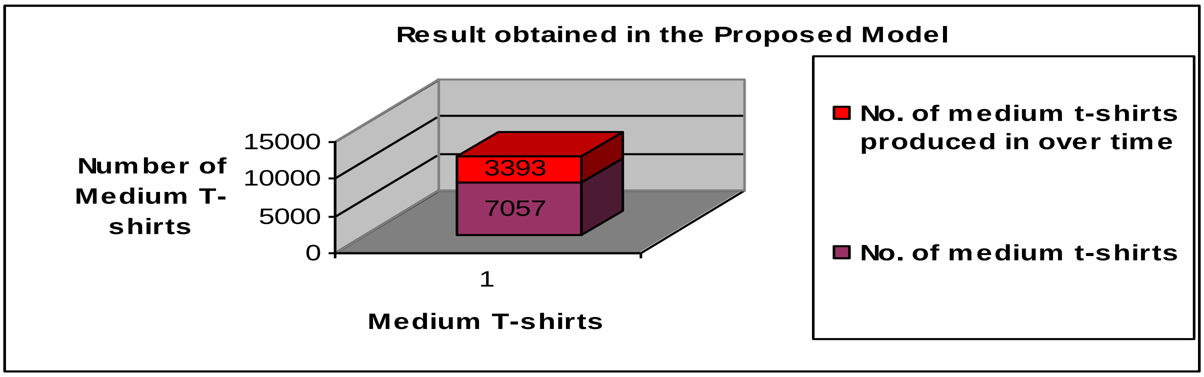

Figure 5 Number of medium size t-shirts produced in normal and over time

The bar chart in Figure 5 clearly shows the exact numbers of medium size t-shirts produced in normal and over times. The bottom of the bar chart represents that the 7057 medium size t-shirts are produced in normal time whereas the remaining 3393 (shown in top of the bar chart) are produced in over time. It should be noted that, in order to complete the entire t-shirts production in a specific time period, 3393 medium sized t-shirts must be produced in overtime. See the Figure 5 given above.

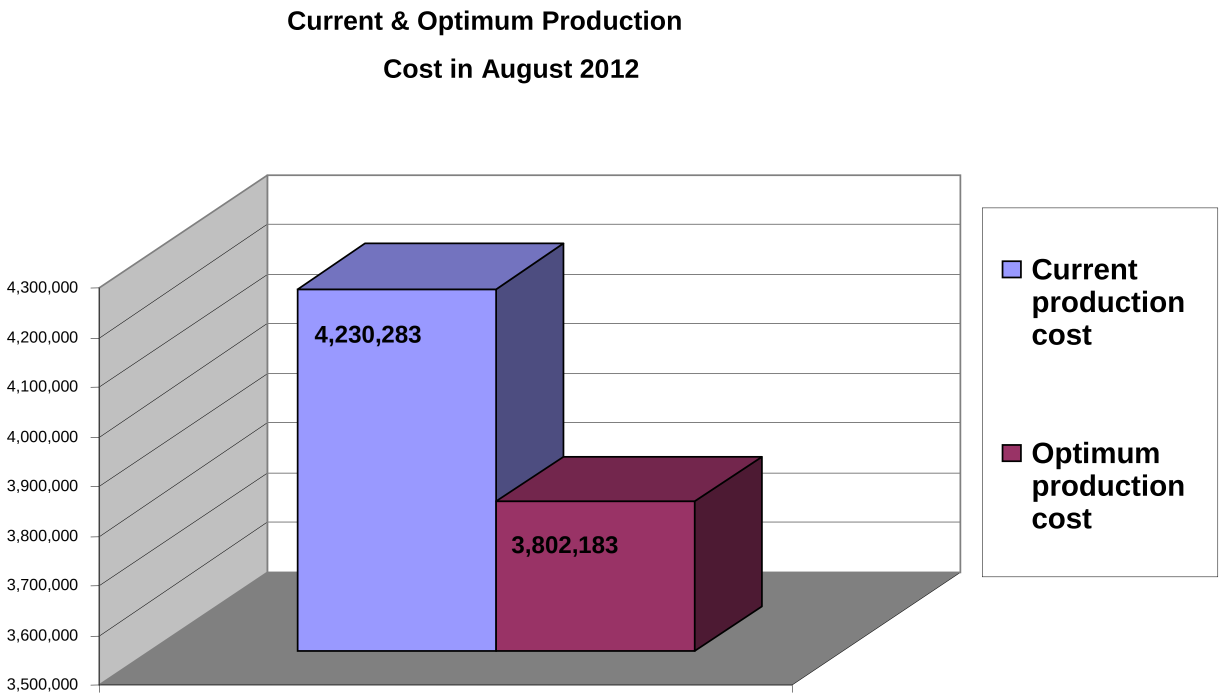

Figure 6 Comparative result of current and optimum production cost

Figure 6 clearly shows that the optimal monthly production cost of the plant is Rs. 3,802,183. But, for the same month the plant estimated average monthly production cost for this plant to be Rs. 4,230,283.

5. CONCLUSION

According to the optimal solution of the proposed model for the month of August 2012, the monthly optimal production cost of the plant is Rs. 3,802,183. But in the same month the plant's estimated average monthly cost is Rs.4,230,283. This clearly indicates that the plant is spending in excess of Rs.428,100 than what is actually needed. Therefore, the plant can save a maximum of Rs. 428,100 (10%) per month by implementing the proposed method. Moreover, a sensitivity analysis is performed to complete the t-shirts production within the specified period of time (one month). After performing a sensitivity analysis, it was revealed that the production plant needs at least 22760 meters of raw material to meet the given target.

In this research only the production cost is considered while assuming that the monthly demand is a fixed quantity. But, in practice, for the manufacture (production plant), there are setup costs and inventory costs of raw-material, work-in-process and finished goods as well. In addition, buyers incur transportation costs, ordering costs and inventory costs during transportation and at the destination (buyer/retailer). Thus, future research might be carried out by taking these costs of setup, inventory, ordering and transportation into account. Also, demand can be considered as stochastic. Hence, an integrated single-manufacture-multi-buyer model with stochastic demand can be obtained. How to develop a streamline method to tackle this large scale LPP after considering these costs is challenging and potential future research.

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