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Application of goal programming in the textile apparel industry to resolve production planning problems – a meta-goal programming technique using weights

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Abstract

In the present business environment, rapidly developing technology and the competitive world market pose challenges to the available assets of industries. Hence, industries need to allocate and use available assets at the optimum level. Thus, industrialists must create a good decision plan to guide their performance in the production sector. As a result, the present study applies the Meta-Goal Programming technique to attain several objectives simultaneously in the textile production sector. The importance of this study lies in pursuing different objectives simultaneously, which has been almost ignored till now. The production scheduling problem in a textile firm is used to illustrate the practicability and mathematical validity of the suggested approach. Analysis of the results obtained demonstrates that the solution met all three meta-goals with some original goals being met partially. An analysis of the sensitivity of the approach to the weights of the preferences was conducted.

Keywords: meta-goal programming, weighted goal programming, multi-objective decision-making, asset allocation, textile sector, sensitivity analysis

1. Introduction

The textile industry fulfills one of the basic requirements of human beings, clothing. The Indian textile industry is one of the country's largest earners of foreign currency and also a platform that can employ a huge number of workers. The Indian textile industry is one of the world's largest. According to the Ministry of Textiles' 2019-2020 annual report, India's textile sector contributed about 7% of industrial production (by value). In addition, the Indian textile and apparel industries together constituted 2% of Gross Domestic Production (GDP), 12% of export earnings, and held a share of 5% in the global trade of textiles and apparel in 2018-2019.

In the present scenario, the hastily developing technology and the competitive global market have become a challenge to the available assets of industries. To survive in the current competitive market,

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industries need to allocate and use available assets at their optimum level to position themselves in a good and profitable place. In an increasingly competitive market, a manufacturing company's survival closely depends upon its ability to produce the highest quality products at the lowest possible cost [20]. In the industrial sector, the scheduling of different systems becomes quite difficult, e.g. multi-phase processes with several units per phase, various planning prospects, and different production needs in each phase. Thus, industrialists have to create a production plan to plan and assess performance in processing and production, as well as allocating and utilizing available resources. Mathematical models play an important role in tackling such problems. Industrial managers wish to achieve different objectives simultaneously, including profit maximization. Thus, the present study formulates a meta-goal programming approach using weighted goals to handle multiple objectives during the production process in the textile manufacturing sector.

The Meta-Goal Programming (Meta-GP) approach or [GP]2 was proposed by Rodríguez Uría et al. [24]. The main purpose of meta-goal programming is to permit decision-makers to set a (some) meta-goal(s) and hence offer more flexibility. By definition, a meta-goal is an implicit goal, which is not a real goal but a construct above and over the directly noticeable and able-to-be-modelled (and measured) explicit goals. Zheng-Yun and Hocine [35] applied a meta-goal programming approach to the multi-criteria de Novo programming problem. From a methodological point of view, in terms of Goal Programming (GP), a meta-goal can be conceived via a weighted structure or lexicographically by the decision-maker. The goal programming technique minimizes the deviation from each of the goals that have been set within the given constraints. The main motive of such a goal programming model is that, whether goals are achievable or not, optimization gives a solution that comes as close as possible to the desired targets, i.e., it provides a satisfactory solution. Using the weighted goal programming technique, a weight is assigned to each goal based on the decision maker's preferences. Therefore, given an identical set of goal constraints, every fulfilment function results in a distinct solution, because the model is formulated as a distinct goal programming variant [9].

Karacapilidis et al. [16] presented a master production scheduling model in the textile production system for the management of production. Elamvazuthi et al. [10] solved a fuzzy linear programming problem with fuzzy parameters using a logistic membership function. The applicability of the technique was illustrated by a numerical example of a domestic textile producer planning production and managing profit. Telegin et al. [28] considered the role of liposomes in the dying, bleaching, finishing of wool and cotton in the textile industry. Yalçınsoy et al. [34] developed a model of optimization with constraints for the textile industries of Istanbul based on an enterprise's data from the previous three years, and the advice based on the proposed model resulted in the enterprise doubling its profits. Baykasoğlu [4] proposed a new fuzzy Multiple-Attribute Decision-Making (MADM) approach for assessing product pricing tactics and implemented the proposed model in a Turkish software company. Aboumasoudi et al. [1] formulated a model of network-ranking via linear programming in which the net profit management approach is evaluated by efficiency according to the connections between the stages and interstitial factors.

Karunanithi [17] analyzed the technical efficiency of 12 garment manufacturing firms located across south India using Data Envelopment Analysis. Adugna et al. [2] used forecasting to develop a linear programming model to maximize profit by taking into account workers' interests, market segmentation, utilization of machines and other available resources, the company's production capacity, and demand for required products in Almeda Ltd., an Ethiopian textile firm, as a case study. Khan [18] considered numerous currently used techniques with IT solutions in the garment industry of Bangladesh and mainly focused on the garment sewing plan, proper implementation of the plan, and its execution. Rabbani et al. [23] formulated a mixed-integer programming problem to solve the production and capacity planning problems for real-world cases in the textile industry and used commercial software packages to achieve the required result. Tesfaye et al. [29] applied a linear programming model to an Ethopian apparel producer to improve resource utilization and reported that the proposed model improved resource utilization from 46.41% to 98.57%.

Chang et al. [7] proposed a Revised Multi-Segment Goal Programming model by advocating certain aspects of the Multi-Segment Goal Programming model to help decision-makers who cannot anticipate and/or select appropriate coefficients in practice. Workie et al. [32] applied linear programming techniques in the textile sector to improve the utilization of resources and profitability as a case study. As a result, the textile company provided faster decisions on the volume of production to obtain a greater income compared to strategies obtained from trial-and-error techniques. Teke et al. [27] formulated a fuzzy linear programming model based on data from a textile firm and proposed the amount of each cloth type required to achieve the optimum profit. Chang et al. [8] developed a decision model that comprises an analytical decision-aid procedure, as well as the required programming models to facilitate interdepartmental decision making.

Woubante [33] applied linear programming to the optimization of the product mix in an Ethiopian apparel producer and claimed that the proposed model increased the existing profit of the firm. Bakator [3] analyzed the application of lean manufacturing principles in the textile industry to increase productivity and also proposed an approach focused on diminishing different forms of waste. Campo et al. [6] formulated and implemented a linear programming model for aggregating production planning problems and used this model to minimize the total cost associated with manpower and inventory levels in a textile company. Goel et al. [13] formulated a linear programming model to maximize profit in the Global Services firm, which manufactures hospital linen items in Indore. Harianto [14] applied linear programming to maximize profit in the textile industry of PT, Argo Pantes Tangerang.

Kimutai et al. [19] developed a linear programming model to minimize energy utilization during production in a textile manufacturing plant in Kenya as a case study. Shakirullah et al. [25] applied a linear programming model to maximize profit in a knit garment manufacturing unit situated in the Gazipur district of Bangladesh. Ferro et al. [12] presented a fascinating application of the existing commercial software platforms for simulation-optimization of the textile production process. Sumathy and Amirthalingam [26] formulated a linear programming model for worker scheduling problems in the textile industry. Broz et al. [5] formulated a model for the optimal planning of daily production in a sawmill and resolved this issue using a goal programming technique with appropriately weighted goals. Venkateshwarlu et al. [31] suggested a goal programming approach to designing data analysis, as well as data envelopement analysis, in production theory. Ezra et al. [11] proposed a goal programming approach to improving the daily production of a pastry firm, with three goals in mind: maximizing revenue, optimizing the usage of production machines and lowering production costs. Lakshmi et al. [30] used goal programming to improve the financial strategy of a business called SVR in Karnataka, India, as a case study.

In summary, research dealing with production issues has generally emphasized profit maximization or focused on a single object and mostly ignored other important aspects of the textile production environment. As a result, achieving different objectives simultaneously, such as maximizing profit and consumer demand, minimizing labour costs and utilization of raw materials, as well as optimizing the use of machine time, has been almost completely neglected in research related to the textile production sector. Thus, the objective of the present study is to formulate the concept of meta-goal programming using weights to attain several objectives simultaneously in the textile sector. It is argued that this technique may be more flexible than traditional goal programming models, since it allows decision-makers to set target values not just for objectives, but also according to other criteria. The production scheduling problem is used to illustrate the practicability and mathematical validity of the suggested approach in the textile industry. To the best of our knowledge, this may be the first study to provide a meta-goal programming model aimed at the textile manufacturing industry to aid managers in making decisions that simultaneously achieve multiple objectives.

2. Mathematical formulation

2.1. Weighted goal programming (WGP)

The objective function in weighted goal programming is a weighted sum of functions describing the desired targets of the related problem. Various formulations of weighted goal programming have also been used by different researchers [15, 22]. The weighted goal programming approach can be represented in the form:

$$\text{Minimize } Z = \sum_{k=1}^{m} (f_k^+ h_k^+ + f_k^- h_k^-)$$

Subject to:

Goal constraints:

$$\sum_{t=1}^{n} c_{kt} y_t + h_k^- - h_k^+ = p_k,\ k = 1, \ldots, m$$

Hard constraints:

$$\sum_{t=1}^{n} c_{kt} y_t \begin{pmatrix} \geq \\ = \\ \leq \end{pmatrix} p_k,\ k = m+1, \ldots, m+g$$
$$y_t, h_k^-, h_k^+, f_k^+, f_k^- \geq 0,\ k = 1, \ldots, m,\ t = 1, \ldots, n$$

where p_k denotes the desired target for the kth goal; h_k^+ and h_k^- denote positive and negative deviations from the decision-maker's defined target p_k; y_t represents a decision variable; c_{kt} denotes the coefficient of a decision variable; f_k^+, f_k^- are preferential weights.

Further, as a way to ensure that all the goal functions are analyzed on an equal scale, normalization is one of the most popular strategies used, because it enables one to define appropriate trade-offs between specific decision goals [21].

2.2. Weighted goal programming with a normalization constant

Consider the weighted goal programming (**WGP)** approach with normalization constant.

Objective function:

$$\text{Minimize } \sum_{k=1}^{m} (u_k h_k^+ + v_k h_k^-)$$

Subject to:

Goal constraints:

$$\sum_{t=1}^{n} c_{kt} y_t + h_k^- - h_k^+ = p_k,\ k = 1, \ldots, m$$

Hard constraints:

$$\sum_{t=1}^{n} c_{kt} y_t \begin{pmatrix} \geq \\ = \\ \leq \end{pmatrix} p_k \quad k = m+1, \ldots, m+g$$
$$y_t, h_k^-, h_k^+ \geq 0 \quad k = 1, \ldots, m,\ t = 1, \ldots, n$$

where p_k denotes the desired target for the kth goal; h_k^+ and h_k^- denote the positive and negative deviations from the decision-maker's defined target p_k; y_t represents a decision variable; c_{kt} denotes the coefficient of a decision variable; $u_k = f_k^+/r_k$ if h_k^+ is undesired, otherwise $u_k = 0$; $v_k = f_k^-/r_k$ if h_k^- is undesired, otherwise $v_k = 0$; f_k^+, f_k^- are preferential weights and r_k is a normalizing weight regarding the achievement of the kth goal.

2.3. Meta-goal programming (Meta-GP)

There are three types of meta-goals in terms of mathematical formulations.

Type – 1 meta-goal. Such an approach entails minimizing the sum of undesired relative deviations (represented by deviational variables), which should not surpass the bound $Q^{(1)}$. Suppose that a type – 1 meta-goal is executed on a set of explicit goals, ${s_t}^{(1)} \subset \{1, 2, 3 \ldots \mathrm{s}\}$ (as a subset of all the desired goals) and (h_k^+ or h_k^-) is an undesired deviation from a desired goal (p_k, as defined in WGP). This type – 1 of meta-goal can be represented as

$$\sum_{k=1}^{t} \frac{f_k^+ h_k^+}{r_k} \leq Q^{(1)} \text{ or } \sum_{k=1}^{t} \frac{f_k^- h_k^-}{r_k} \leq Q^{(1)}$$

Suppose that a type – 1 meta-goal is executed on the set of explicit goals, ${S_u}^{(1)} \subset \{1, 2, \ldots m\}$ (as a subset of all the desired goals), then a type – 1 meta-goal takes the following form:

$$\sum_{k \in S_u} \frac{f_k^+ h_k^+}{r_k} \leq {Q_u}^{(1)} \text{ or } \sum_{k \in S_u} \frac{f_k^- h_k^-}{r_k} \leq {Q_u}^{(1)}$$

This type of meta-goal is effective in decision making when several conflicting goals are analyzed. One advantageof this approach is that the decision-maker can regulate trade-offs continuously and create a new scheme of ranking till the desired result is attained.

Type – 2 meta-goal. Such an approach entails minimizing the maximum relative deviation from a set of targets. The relative deviation should not surpass a certain bound $Q^{(2)}$. A type-2 meta-goal can be represented as

$$\begin{cases} \dfrac{f_k^+ h_k^+}{r_k} - D \leq 0, \ k = 1, 2, \ldots, m \\ D \leq Q^{(2)} \end{cases} \text{ or } \begin{cases} \dfrac{f_k^- h_k^-}{r_k} - D \leq 0 \\ D \leq Q^{(2)} \end{cases}$$

Suppose that a type – 2 meta-goal is executed on the set of explicit goals, ${S_v}^{(2)}$ (i.e., another subset of all the explicit goals), then a type – 2 meta-goal takes the form

$$\begin{cases} \dfrac{f_k^+ h_k^+}{r_k} - D_v \leq 0, \ k \in {S_v}^{(2)} \\ D_v \leq {Q_v}^{(2)} \end{cases} \text{ or } \begin{cases} \dfrac{f_k^- h_k^-}{r_k} - D_v \leq 0, \ k \in {S_v}^{(2)} \\ D_v \leq {Q_v}^{(2)} \end{cases}$$

Among all of the goals, this approach identifies the most important weighted and normalized deviation and guarantees its minimization. This kind of meta-intention could be very beneficial in production enterprises for analyzing a set of operations in which the overall performance parameters need to be maintained at a high level.

Type – 3 meta-goal. Such an approach entails minimizing the range of unachieved goals or overall percentage of unachieved goals over all of the goals taken into consideration and hence this percentage should not surpass a given bound $Q^{(3)}$, hence resulting in the subsequent set of constraints. A type – 3 meta-goal can be represented as;

$$\begin{cases} h_k^+ - R_k z_k \le 0,\ k = 1, 2, \ldots, m \\ \sum_{k=1}^{t} \frac{z_k}{m} \ \le\ Q^{(3)} \end{cases} \quad \text{or} \quad \begin{cases} h_k^- - R_k z_k \le 0,\ k = 1, 2, \ldots, m \\ \sum_{k=1}^{t} \frac{z_k}{m} \ \le\ Q^{(3)} \end{cases}$$

Suppose that a type – 3 meta goal is executed on the set of explicit goals, ${S_w}^{(3)}$ (i.e., another subset of all the explicit goals), then a type – 3 meta-goal takes the form

$$\begin{cases} h_k^+ - R_k z_k \le 0,\ \ k \in {S_w}^{(3)} \\ \sum_{k \in S_w} \frac{z_k}{\operatorname{card}({S_w}^{(3)})} \ \le\ {Q_w}^{(3)} \\ z_k \in \{0, 1\}\,,\ \ \ k \in {S_w}^{(3)} \end{cases} \quad \text{or} \quad \begin{cases} h_k^- - R_k z_k \le 0,\ \ k \in {S_w}^{(3)} \\ \sum_{k \in S_w} \frac{z_k}{\operatorname{card}({S_w}^{(3)})} \ \le\ {Q_w}^{(3)} \\ z_k \in \{0, 1\}\,,\ \ \ k \in {S_w}^{(3)} \end{cases}$$

This type of meta-goal is beneficial in production companies that give identical priority levels to a number of the goals and wish to maximize the variety of completely attained goals. When $f_k^+,\ f_k^-$ are preferential weights for each imposed explicit goal considered in ${S_u}^{(1)}$; (h_k^+ or h_k^-) is an undesired deviation from a desired goal (p_k, as desired goals in WGP) as in ${S_v}^{(2)}$; r_k is the target value of each imposed explicit goal taken into consideration ${S_v}^{(2)}$ and may be regarded as a normalization constant; D is an additional continuous variable that measures the largest deviation; z_k is a binary variable for each imposed explicit goal k taken into consideration in ${S_w}^{(3)}$ with 0 indicating that a goal is satisfied and 1 otherwise; and R_k is a sufficiently large arbitrary number.

The meta-goal programming model is given by Rodríguez Uría et al. [24] with m_1 type – 1 meta-goals, m_2 type – 2 meta-goals and m_3 type – 3 meta-goals. In this way, the meta-GP or $[\mathrm{GP}]^2$ model is represented as

$$\text{Minimize}\ \left\{ {\beta_1}^{(1)}, \ldots, {\beta_{m_1}}^{(1)}, {\beta_1}^{(2)}, \ldots,\ {\beta_{m_2}}^{(2)}, {\beta_1}^{(3)}, \ldots,\ {\beta_{m_3}}^{(3)} \right\}$$

Subject to:

Goal constraints:

$$\sum_{t=1}^{n} c_{kt} y_t + h_k^- - h_k^+ = p_k,\ k = 1, \ldots, m$$

Meta Goals:

$$\begin{array}{ll} \sum_{k \in S_u} \frac{f_k^+ h_k^+}{r_k} + {\alpha_u}^{(1)} - {\beta_u}^{(1)} =\ {Q_u}^{(1)} \text{ or } \sum_{k \in S_u} \frac{f_k^- h_k^-}{r_k} + {\alpha_u}^{(1)} - {\beta_u}^{(1)} =\ {Q_u}^{(1)} & u = 1, \ldots, m_1 \\ \frac{f_k^+ h_k^+}{r_k} - D_v \le 0,\ k \in {S_v}^{(2)} \text{ or } \frac{f_k^- h_k^-}{r_k} - D_v \le 0,\ k \in {S_v}^{(2)} & v = 1, \ldots, m_2 \\ D_v + {\alpha_v}^{(2)} - {\beta_v}^{(2)} = {Q_v}^{(2)} & v = 1, \ldots, m_2 \\ h_k^+ - R_k z_k \le 0,\ \ or\ \ h_k^- - R_k z_k \le 0,\ k \in {S_w}^{(3)} & w = 1, \ldots, m_3 \\ \sum_{k \in S_w} \frac{z_k}{card({S_w}^{(3)})} + {\alpha_w}^{(3)} - {\beta_w}^{(3)} =\ {Q_w}^{(3)} & w = 1, \ldots, m_3 \\ z_k \in \{0, 1\}\,,\ k \in {S_w}^{(3)} & w = 1, \ldots, m_3 \end{array}$$

Hard constraints:

$$\begin{array}{ll} \sum_{t=1}^{n} c_{kt} y_t \begin{pmatrix} \geq \\ = \\ \leq \end{pmatrix} p_k & k = m+1, \ldots, m+g \\ h_k^+, h_k^- \geq 0 & k = 1, \ldots, m \\ {\alpha_u}^{(1)}, {\beta_u}^{(1)}, {\alpha_v}^{(2)}, {\beta_v}^{(2)}, {\alpha_w}^{(3)}, {\beta_w}^{(3)} \geq 0 & z \in F \end{array}$$

where f_k^+, f_k^- are preferential weights; r_k is the percentage normalization constant.

3. Description of the problem

To illustrate the applicability and mathematical validation of the proposed model in a small-sized textile manufacturing industry, a production planning problem is used. A set type of garment products in the production process is addressed as a descriptive case. The data is collected in primary and secondary forms. The combination of yarn formation, fabric formation, wet processing, wet processing, etc., is included in the production sector. The processing of garment products starts with fibre preparation, spinning, weaving, knitting, dyeing, cutting, sewing, etc. The general process of textile production is shown in Figure 1. The required resources for the preparation of each textile product are shown in Table 1. Profit margin, the notation of the variables and overall production requirements are displayed in Table 2. Table 3 details the available resources in the textile manufacturing industry.

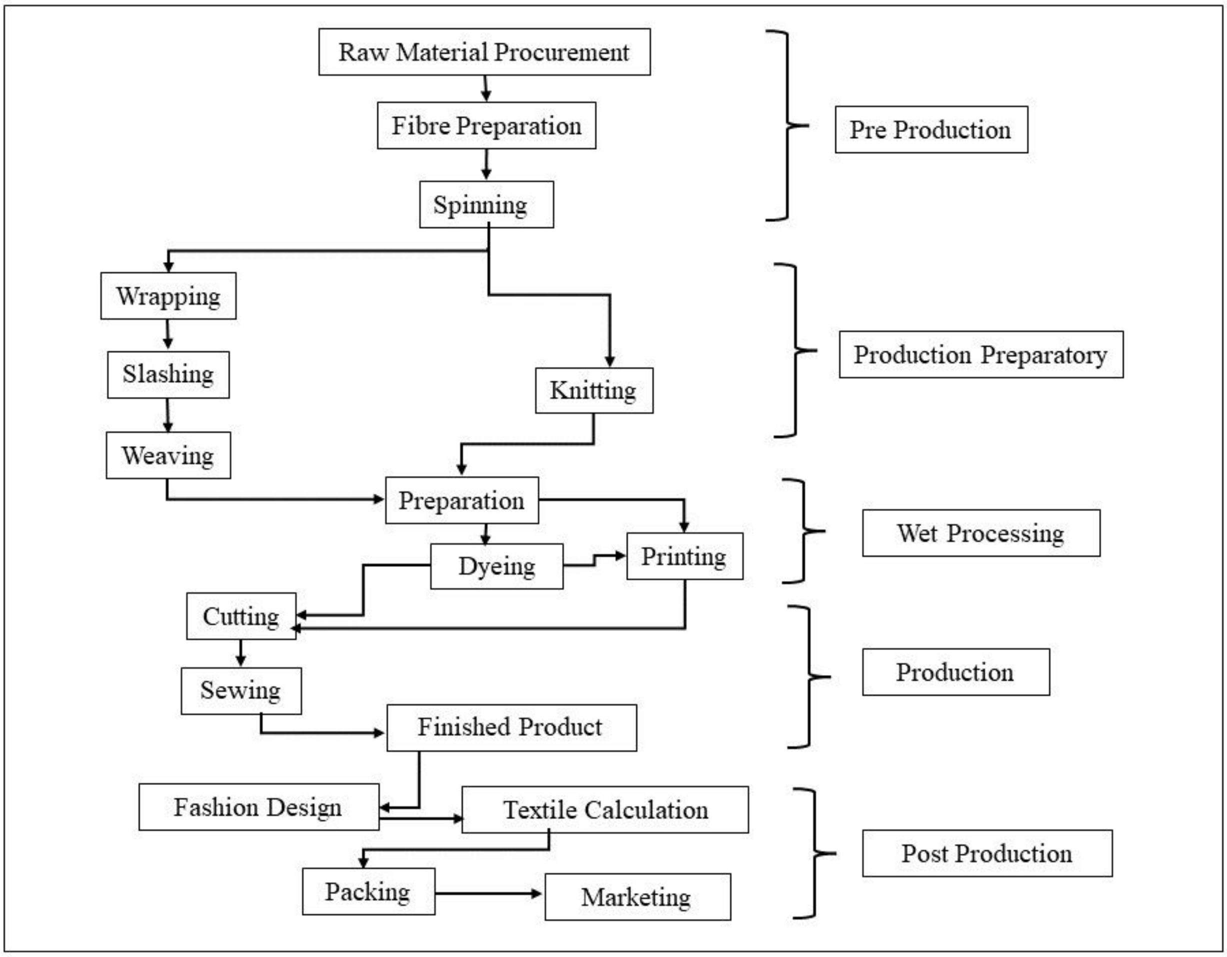

Figure 1. Flow chart for general textile production processing

Table 1. Resources required for each unit of product

		Products Type							
		Jeans Pant	**Short Pant**	**Trousers**	**T-Shirt**	**Shirt**	**Singlet**	**V Neck T-Shirt**	**Basic Shirt**
Resources used per unit of prod.	Fabric (Kg)	0.33	0.28	0.25	0.19	0.21	0.18	0.188	0.225
	Threads (Km)	0.24	0.20	0.21	0.11	0.14	0.10	0.130	0.175
	Labour Cost (Rs)	20.8	12	11.2	8	10.4	6.64	9.6	13.6
	Overhead Cost (Rs)	80	60	56.32	30.56	48.16	26.4	32.6	51.52
	Cutting (Min.)	3.0	2.6	2.3	1.1	1.9	1.0	1.5	2.0
	Sewing (Min.)	25.5	22.5	15.3	5.5	19.5	4.5	5	21.5
	Ironing (Min.)	4.5	3.5	3.2	2.6	4	2	3	4
	Packing & Fishing (Min.)	3.0	2.6	2.5	1.5	2.0	1.3	1.8	2.1

Table 2. Profit, notation of the variables and production requirements

	Product Type							
	Jeans Pant	**Short Pant**	**Trousers**	**T-Shirt**	**Shirt**	**Singlet**	**V Neck T-Shirt**	**Basic Shirt**
Variable	y_1	y_2	y_3	y_4	y_5	y_6	y_7	y_8
Profit (Rs)	11.2	10.8	9.6	5.7	6.4	4.96	5.488	7.2
Production Req.	15000	12000	10000	20000	14000	8000	18000	15000

Table 3. Total available resources

Resource Type	**Measurement unit**	**Value**
Fabric	Kg	25850
Threads	Km	18500
Labour Cost	Indian Rupees (Rs)	1303500
Overheads Cost	Indian Rupees (Rs)	5340000
Cutting	Minutes	212800
Sewing	Minutes	1637000
Ironing	Minutes	379500
Packing & Finishing	Minutes	233500

The present study focussed on the following goals:

- **Goal 1:** Attaining a profit of 843 600.
- **Goal 2:** Reducing babour costs.
- **Goal 3:** Reducing overhead costs.
- **Goal 4:** Lowering Cutting Time.
- **Goal 5:** Lowering Sewing Time.
- **Goal 6:** Lowering Ironing Time.
- **Goal 7:** Lowering Packing and Finishing Time.
- **Goal 8:** Production Requirements.

The above data in tabular form (Tables 1, 2, 3) are converted into the meta-goal programming model through a weighted structure. The decision-maker sets the following three meta-goals, apart from the original problem goals:

- **Meta-Goal 1:** The maximum percentage deviation from any goal should be no more than 50%.
- **Meta-Goal 2:** Any percentage deviation from a goal should be no more than 30%.
- **Meta-Goal 3:** The number of unsatisfied goals should be limited to five.

Thus, the meta goal program can be formulated as follows.

$$\text{Minimize } \beta_1 + \beta_2 + \beta_3$$

Subject to:

Goal Constraints:

***Original problem goals (Explicit goals)*:**

$$\begin{aligned}
&11.2y_1 + 10.8y_2 + 9.6y_3 + 5.7y_4 + 6.4y_5 + 4.96y_6 + 5.488y_7 + 7.2y_8 - h_1^+ + h_1^- = 843600\\
&20.8y_1 + 12y_2 + 11.2y_3 + 8.0y_4 + 10.4y_5 + 6.64y_6 + 9.6y_7 + 13.6y_8 - h_2^+ + h_2^- = 1303500\\
&80y_1 + 60y_2 + 56.32y_3 + 30.56y_4 + 48.16y_5 + 26.4y_6 + 32.6y_7 + 51.52y_8 - h_3^+ + h_3^- = 5340000\\
&3.0y_1 + 2.6y_2 + 2.3y_3 + 1.1y_4 + 1.9y_5 + 1y_6 + 1.5y_7 + 2y_8 - h_4^+ + h_4^- = 212800\\
&25.5y_1 + 22.5y_2 + 15.3y_3 + 5.5y_4 + 19.5y_5 + 4.5y_6 + 5y_7 + 21.5y_8 - h_5^+ + h_5^- = 1637000\\
&4.5y_1 + 3.5y_2 + 3.2y_3 + 2.6y_4 + 4y_5 + 2y_6 + 3y_7 + 4y_8 - h_6^+ + h_6^- = 379500\\
&3y_1 + 2.6y_2 + 2.5y_3 + 1.5y_4 + 2.0y_5 + 1.3y_6 + 1.8y_7 + 2.1y_8 - h_7^+ + h_7^- = 233500\\
&y_1 - h_8^+ + h_8^- = 15000\\
&y_2 - h_9^+ + h_9^- = 12000\\
&y_3 - h_{10}^+ + h_{10}^- = 10000\\
&y_4 - h_{11}^+ + h_{11}^- = 20000\\
&y_5 - h_{12}^+ + h_{12}^- = 14000\\
&y_6 - h_{13}^+ + h_{13}^- = 8000\\
&y_7 - h_{14}^+ + h_{14}^- = 18000\\
&y_8 - h_{15}^+ + h_{15}^- = 15000
\end{aligned}$$

***Meta-Goal 1*:**

$$\begin{aligned}
&\frac{h_1^-}{843600} + \frac{h_2^+}{1303500} + \frac{h_3^+}{5340000} + \frac{h_4^+}{212800} + \frac{h_5^+}{1637000} + \frac{h_6^+}{379500} + \frac{h_7^+}{233500} + \frac{(h_8^- + h_8^+)}{15000} +\\
&+ \frac{(h_9^- + h_9^+)}{12000} + \frac{(h_{10}^- + h_{10}^+)}{10000} + \frac{(h_{11}^- + h_{11}^+)}{20000} + \frac{(h_{12}^- + h_{12}^+)}{14000} + \frac{(h_{13}^- + h_{13}^+)}{8000} + \frac{(h_{14}^- + h_{14}^+)}{18000} +\\
&+ \frac{(h_{15}^- + h_{15}^+)}{15000} + \alpha_1 - \beta_1 = 0.5
\end{aligned}$$

***Meta-Goal 2*:**

$$\begin{aligned}
&h_1^- - 843600D \le 0,\ h_2^+ - 1303500D \le 0,\ h_3^+ - 5340000D \le 0\\
&h_4^+ - 212800D \le 0,\ h_5^+ - 1637000D \le 0,\ h_6^+ - 379500D \le 0\\
&h_7^+ - 233500D \le 0\\
&h_8^- + h_8^+ - 15000D \le 0,\ h_9^- + h_9^+ - 12000D \le 0,\ h_{10}^- + h_{10}^+ - 10000D \le 0\\
&h_{11}^- + h_{11}^+ - 20000D \le 0,\ h_{12}^- + h_{12}^+ - 14000D \le 0,\ h_{13}^- + h_{13}^+ - 8000D \le 0\\
&h_{14}^- + h_{14}^+ - 18000D \le 0,\ h_{15}^- + h_{15}^+ - 15000D \le 0\\
&D + \alpha_2 - \beta_2 = 0.3
\end{aligned}$$

***Meta-Goal 3*:**

$$\begin{aligned}
&h_1^- - 843600z_1 \le 0,\ h_2^+ - 1303500z_2 \le 0,\ h_3^+ - 5340000z_3 \le 0\\
&h_4^+ - 212800z_4 \le 0,\ h_5^+ - 1637000z_5 \le 0,\ h_6^+ - 379500z_6 \le 0\\
&h_7^+ - 233500z_7 \le 0\\
&h_8^- + h_8^+ - 15000z_8 \le 0,\ h_9^- + h_9^+ - 12000z_9 \le 0,\ h_{10}^- + h_{10}^+ - 10000z_{10} \le 0\\
&h_{11}^- + h_{11}^+ - 20000z_{11} \le 0,\ h_{12}^- + h_{12}^+ - 14000z_{12} \le 0,\ h_{13}^- + h_{13}^+ - 8000z_{13} \le 0\\
&h_{14}^- + h_{14}^+ - 18000z_{14} \le 0,\ h_{15}^- + h_{15}^+ - 15000z_{15} \le 0\\
&\frac{(z_1 + z_2 + z_3 + z_4 + z_5 + z_6 + z_7 + z_8 + z_9 + z_{10} + z_{11} + z_{12} + z_{13} + z_{14} + z_{15})}{15} + \alpha_3 - \beta_3 = \frac{10}{15}
\end{aligned}$$

Hard Constraints:

$$0.33y_1 + 0.28y_2 + 0.25y_3 + 0.19y_4 + 0.21y_5 + 0.18y_6 + 0.188y_7 + 0.225y_8 \leq 25850$$
$$0.24y_1 + 0.20y_2 + 0.21y_3 + 0.11y_4 + 0.14y_5 + 0.1y_6 + 0.13y_7 + 0.175y_8 \leq 18500$$

where $h_i^-, h_i^+ \geq 0, i = 1, \ldots, 15$, denote the positive and negative deviations; $y_j \geq 0$, $j = 1, \ldots, 8$; $\alpha_k, \beta_k \geq 0$, $k = 1, 2, 3$; $z_l \in \{0, 1\}$, $l = 1, \ldots, 15$; D is an additional continuous variable that measures the largest deviation.

4. Results and discussion

The solution of the problem described above was derived with the help of LINGO computer software and the solution obtained is shown in Table 4.

Table 4. Description of the solution

Type of Var.	Solution Values (from LINGO)
Product Var.	$(y_1, y_2, y_3, y_4, y_5, y_6, y_7, y_8)$ $= (15000, 12000, 10000, 19998.96, 14000, 7999.585, 17999.07, 15000)$
Explicit Deviational Var.	$(h_1^-, h_2^-, h_3^-, h_4^-, h_5^-, h_6^-, h_7^-, h_8^-, h_9^-, h_{10}^-, h_{11}^-, h_{12}^-, h_{13}^-, h_{14}^-, h_{15}^-) =$ $(0, 0, 633.0307,\ 2.9539,\ 12.2305,\ 6.3225,\ 3.7728,\ 0,\ 0,\ 1.0364,\ 0,\ 0.4145, 0.93283, 0)$, $(h_1^+, h_2^+, h_3^+, h_4^+, h_5^+, h_6^+, h_7^+, h_8^+, h_9^+, h_{10}^+, h_{11}^+, h_{12}^+, h_{13}^+, h_{14}^+, h_{15}^+)$ $= (50.91625,\ 0,\ 0,\ 0,\ 0,\ 0,\ 0,\ 0,\ 0,\ 0,\ 0,\ 0,\ 0,\ 0,\ 0)$
Meta-deviation Var.	$(\alpha_1,\ \alpha_2,\ \alpha_3) = (0.49984,\ 0.29994,\ 0.46666)$, $(\beta_1,\ \beta_2,\ \beta_3) = (0, 0, 0)$
Additional Cont. Var.	$D = 0.00005182$
Binary Var. (Imposed on Explicit Goal)	$(z_1, z_2, z_3, z_4, z_5, z_6, z_7, z_8, z_9, z_{10}, z_{11}, z_{12}, z_{13}, z_{14}, z_{15}) =$ $(0,\ 0,\ 0,\ 0,\ 0,\ 0,\ 0,\ 0,\ 0,\ 0,\ 1,\ 0,\ 1,\ 1,\ 0)$

Table 5. The satisfaction of goals based on the solution from Table 4

Goals			Satisfied
Original Problem Goals	Goal 1 = 843650.91625		Yes
	Goal 2 $= 1303500$		Yes
	Goal 3 $= 5339366.9693$		Yes
	Goal 4 $= 212797.04602$		Yes
	Goal 5 $= 1636987.76949$		Yes
	Goal 6 $= 379493.677446$		Yes
	Goal 7 $= 233496.227197$		Yes
	Goal 8	$y_1 = 15000$	Partially
		$y_2 = 12000$	
		$y_3 = 10000$	
		$y_4 = 19998.96$	
		$y_5 = 14000$	
		$y_6 = 7999.585$	
		$y_7 = 17999.07$	
		$y_8 = 15000$	
Meta-Goals	Meta-Goal 1= 0.00016		Yes
	Meta-Goal 2 $= 0.00006$		Yes
	Meta-Goal 3 $= 3$		Yes

It is evident from the results shown in Table 4 and Table 5 that in the present study, the decision-maker would attain an optimum solution that has met all three meta-goals, with some original goals being partially met. The utilization of several resources is also reduced, e.g., overhead cost by 633.037 rupees, cutting time by 2.93 minutes, sewing time by 12.23051 minutes, ironing time by 6.3225 minutes, and packing and finishing time by 3.7728 minutes, and the textile industry makes a profit of 843650.916

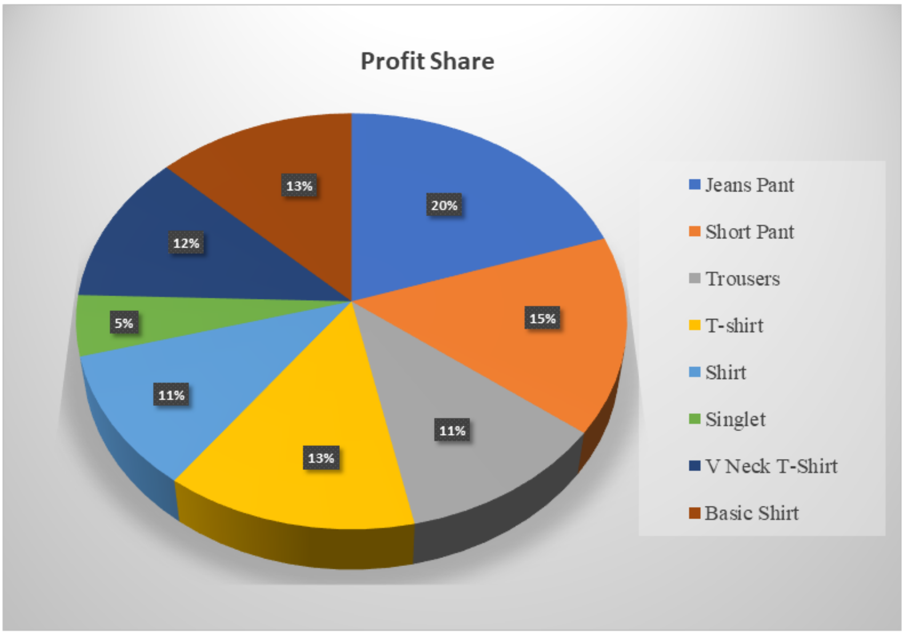

Figure 2. The share of each product in total profit.

rupees. The 'production requirement goal 8' is also partially satisfied, but can be regarded as an optimal solution due to the negligible deviation. Another aspect that is worthy of detailed analysis is the fact that the asset allocation and requirements of the products to be produced to meet the customers' demand are also obtained. It can be seen in Figure 2 that the production of jeans pants generates more profit than the other products. In the literature, the researchers [2, 25, 33, 34] focused only on a single objective, i.e., whether to minimize cost, maximize profit, optimize the utilization of resources, or capacity plan, ignoring other important aspects of production planning, while the present study focused on a number of objectives important to production planning, in addition to maximizing profit.

A sensitivity analysis is performed to examine the impact of preferential weights on a meta-goal programming problem, and how far the optimum solutions and values of goals vary when the preferential weights are also changed. Accordingly, the LINGO software was used to generate the solutions of meta-goal programming problems for different preferential weights, as shown in Tables 6 and 7.

The findings of this sensitivity analysis reveal that the meta-goal programming model can provide a wide variety of optimal solutions. The sensitivity analysis, as shown in Tables 6 and 7, is used to assess the influence of preferential weights on the solution to the meta-goal programming problem. Changes in the preferential weights parameters (f_k^+, f_k^-), which represent the relevance of the degree of satisfaction of the goals based on the decision-maker's preferences, result in varying degrees of satisfaction in the optimization problem.

To summarize, the current findings reveal that the meta-GP technique offers decision-makers an acceptable and effective model for handling various emerging production planning challenges in their textile production process. This meta-GP technique is broad enough to suit the competing economic and operational objectives of a wide range of industries.

Table 6. Results of an analysis of the sensitivity to preferential weights parameters (f_k^+, f_k^-).

$\sum(f_k^+, f_k^-)$	**Goal 1**	**Goal 2**	**Goal 3**	**Goal 4**	**Goal 5**	**Goal 6**	**Goal 7**
1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1	843650.91	1303500	5339366.96	212797.04	1636987.76	379493.67	233496.22
0.9, 0.8, 0.7, 0.6, 0.5, 0.4, 0.3, 0.2, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7	843661.6	1303516.08	5339424.93	212799.41	1636994.74	379498.83	233499.35
0.7, 0.6, 0.5, 0.4, 0.3, 0.2, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.2, 0.9	843652.32	1303500	5339363.29	212797.04	1636972.91	379494.08	233496.70
0.8, 0.7, 0.6, 0.5, 0.9, 0.4, 0.3, 0.2, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7	843661.93	1303516.48	5339426.43	212795.28	1637000	379498.95	233499.41
0.6, 0.7, 0.8, 0.9, 0.8, 0.7, 0.6, 0.5, 0.4, 0.3, 0.2, 0.1, 0.6, 0.3, 0.4	843663.32	1303519.09	5339436.39	212799.86	1636999.38	379499.72	233499.82
0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.9, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8	843663.14	1303518.53	5339434.37	212799.78	1636998.02	379499.56	233499.75
0.9, 0.8, 0.7, 0.6, 0.5, 0.4, 0.3, 0.2, 0.2, 0.1, 0.5, 0.4, 0.3, 0.2, 0.1	844664	1292520	5223640	207175	1521375	370500	231000
0.4, 0.9, 0.8, 0.7, 0.6, 0.5, 0.4, 0.3, 0.2, 0.1, 0.2, 0.3, 0.4, 0.5, 0.7	821479.94	1315354.23	5315163.71	210196.10	1637000	374461.05	229096.10
0.2, 0.4, 0.5, 0.9, 0.7, 0.8, 0.7, 0.1, 0.2, 0.7, 0.4, 0.3, 0.2, 0.1, 0.5	785887.08	1237120	5077687.2	203911.53	1637000	3771076.92	218988.46
0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 0.8, 0.7, 0.6, 0.5, 0.4, 0.3	843600	1303434.70	5339105.46	212787.17	1636918.76	379472.84	233483.87
0.7, 0.8, 0.9, 0.8, 0.7, 0.6, 0.5, 0.4, 0.3, 0.2, 0.1, 0.2, 0.3, 0.4, 0.5	826208.15	1232812.86	5205610.7	205220.87	1637000	353309.57	223132.28
0.3, 0.4, 0.4, 0.4, 0.3, 0.2, 0.5, 0.4, 0.3, 0.1, 0.5, 0.3, 0.3, 0.3, 0.4	833241.36	1256369.95	5163347	205107.09	1491517.3	368084.73	228847.03
0.6, 0.5, 0.4, 0.3, 0.2, 0.1, 0.9, 0.3, 0.7, 0.6, 0.5, 0.4, 0.3, 0.2, 0.1	843600	1278244.72	5243336.21	209969.25	1584499.43	364519.79	230067.65
0.5, 0.4, 0.3, 0.2, 0.1, 0.9, 0.8, 0.7, 0.6, 0.5, 0.4, 0.3, 0.2, 0.1, 0.2	831598.64	1303444.23	5250249.82	208473.18	1592234.21	378422.25	230443.20
0.3, 0.2, 0.1, 0.9, 0.8, 0.7, 0.6, 0.5, 0.4, 0.3, 0.2, 0.1, 0.2, 0.3, 0.4	824857	1280687.35	5272010.72	211935.33	1637000	381651.31	231962.36

Table 7. Results of an analysis of the sensitivity to preferential weights parameters (f_k^+, f_k^-)

$\sum (f_k^+, f_k^-)$	Goal 8								**Meta-Goal 1**	**Meta-Goal 2**	**Meta-Goal 3**
	y_1	y_2	y_3	y_4	y_5	y_6	y_7	y_8			
1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1	15000	12000	10000	19998.96	14000	7999.58	17999.07	15000	0.00016	0.00006	3
0.9, 0.8, 0.7, 0.6, 0.5, 0.4, 0.3, 0.2, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7	15000	12000	10000	20000	14000	7999.84	18000	14999.78	0.000026	0.0000099	3
0.7, 0.6, 0.5, 0.4, 0.3, 0.2, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.2, 0.9	15000	12000	10000	20000	14000	7999.86	18000	15000	0.0000205	0.0000103	2
0.8, 0.7, 0.6, 0.5, 0.9, 0.4, 0.3, 0.2, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7	15000	12000	10000	20000	14000	7999.85	18000	14999.81	0.000266	0.000089	3
0.6, 0.7, 0.8, 0.9, 0.8, 0.7, 0.6, 0.5, 0.4, 0.3, 0.2, 0.1, 0.6, 0.3, 0.4	15000	12000	10000	20000	14000	7999.86	18000	15000	0.0000205	0.0000103	2
0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.9, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8	15000	12000	10000	20000	14000	7999.94	18000	14999.92	0.0000128	0.0000043	3
0.9, 0.8, 0.7, 0.6, 0.5, 0.4, 0.3, 0.2, 0.2, 0.1, 0.5, 0.4, 0.3, 0.2, 0.1	15000	12000	10000	30000	5250	8000	18000	15000	0.5	0.25	2
0.4, 0.9, 0.8, 0.7, 0.6, 0.5, 0.4, 0.3, 0.2, 0.1, 0.2, 0.3, 0.4, 0.5, 0.7	20176.9	7332.76	10000	20000	14000	7400	18000	15000	0.5	0.3	5
0.2, 0.4, 0.5, 0.9, 0.7, 0.8, 0.7, 0.1, 0.2, 0.7, 0.4, 0.3, 0.2, 0.1, 0.5	15000	12000	10000	5000	13269.23	8000	18000	19500	0.47934187	0.3	4
0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 0.8, 0.7, 0.6, 0.5, 0.4, 0.3	15000	11996.7	10003	19993.13	14000	7996.15	18000	15000	0.0009616	0.0002404	4
0.7, 0.8, 0.9, 0.8, 0.7, 0.6, 0.5, 0.4, 0.3, 0.2, 0.1, 0.2, 0.3, 0.4, 0.5	15000	12000	2469.45	20000	13755.95	8000	4500	15000	0.5	0.3	4
0.3, 0.4, 0.4, 0.4, 0.3, 0.2, 0.5, 0.4, 0.3, 0.1, 0.5, 0.3, 0.3, 0.3, 0.4	15000	12000	10000	10073.67	14000	8000	18000	5,694.07	0.5	0.24815814	3
0.6, 0.5, 0.4, 0.3, 0.2, 0.1, 0.9, 0.3, 0.7, 0.6, 0.5, 0.4, 0.3, 0.2, 0.1	15000	15824.7	10896.39	20000	6191.21	8000	18000	15000	0.5	0.22310828	3
0.5, 0.4, 0.3, 0.2, 0.1, 0.9, 0.8, 0.7, 0.6, 0.5, 0.4, 0.3, 0.2, 0.1, 0.2	15222.6	12000	4350.08	20000	14000	16000	18000	15000	0.5	0.28249583	4
0.3, 0.2, 0.1, 0.9, 0.8, 0.7, 0.6, 0.5, 0.4, 0.3, 0.2, 0.1, 0.2, 0.3, 0.4	12848.6	12000	7609.64	12828.94	21911.149	10868.42	22302.635	12310.85	0.5	0.0717106	6

5. Conclusions

The main objective of this study was to develop a mathematical technique applicable to real-life production problems, and the obtained solution set can be implemented as a decision support instrument for production planning in the textile manufacturing industry. The meta-goal programming model is formulated and its applicability is illustrated by using an industrial case. The solutions are derived by the standard LINGO software package. Most researchers have emphasized a single objective. In this study, the meta goal programming technique has been applied to attain a solution that meets all three meta-goals, with some original goals being partially met. An analysis of sensitivity to the preferential weights was conducted. Thus, one clear advantage of meta-goal programming is that it can be seen as providing a new dimension to programming by allowing the decision-maker to state appropriate requirements according to different explicit goals. Therefore, it provides a promising, acceptable optimal solution to the decision-maker. The proposed approach is much more flexible than standard goal programming approaches, as it gives more freedom to decision-makers in expressing their preferences by allowing them to create a meta goal i.e., cross GP-variant, and hence is applicable to more realistic problems with non-linear goals and/or non-continuous variables. As a result, the current findings provide a potential model for industrialists to overcome various problems arising in the manufacturing process. The current work is likely to pique the interest of many additional scholars and production managers who are interested in dealing with multi-objective issues in production planning.

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