Integrating Six Sigma Principles towards Multi-Objective Production Planning for Enhanced Quality in the Al Kharj Manufacturing Sector

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ABSTRACT

Effective production planning and creating high-quality items are two of the most critical factors in establishing long-term success in the manufacturing business. This study presents Goal Programming (GP), a Multi-Objective Optimization technique for decision-making issues, incorporating Six Sigma concepts to tackle the industrial sector's complex production planning problems. The aim is to provide a systematic framework for decision-making, ensuring a comprehensive approach to quality engineering in manufacturing processes. The current study entails considerable practical implications regarding the fridge industry in specific practical ways. Production planning was enhanced by evaluating market demand, manufacturing costs, and sales data using LINGO. Deploying Six Sigma to find the limits on demand, helped reduce production costs while making additional revenue from sales. Sensitivity analysis revealed that by the following year, the firm is expected to have decreased manufacturing costs by 13.13% to minimize expenses, while it is also anticipated to have reduced sales by 1.12% to maximize revenue. The GP technique demonstrated that the Al Kharj fridge industry could optimize sales revenue and costs. The suggestions provided based on these findings are actionable and have the potential to be effectively implemented in the industrial sector.

Keywords-quality engineering; six sigma concepts; multi-objective planning; optimization model; production planning

I. INTRODUCTION

Companies must strive for operational excellence to stay competitive in today's rapidly evolving market. Implementing Six Sigma principles to enhance product quality is gaining significant traction in the manufacturing sector. The Six Sigma method minimizes defects and process variations to ensure consistent, high-quality output. It is a well-developed systematic approach extensively deployed in numerous sectors to attain desired performance levels through ongoing progress [1]. It is a statistical metric representing six standard deviations from the mean, with the term 'Sigma' being derived from the Greek alphabet to symbolize statistical variance. The Six Sigma methodology provides a comprehensive range of instruments to optimize performance and minimize faults in any process [2]. It is important to note that as the degree of quality grows, the process undergoes improvement, reinforcing the value of Six Sigma. The latter is utilized in the field of industrial engineering, and particularly in industrial businesses to improve operations. Six Sigma employs various approaches, techniques, and tools from the industrial engineering, quality management, and statistical analysis fields. Its utilization extends beyond industrial engineering to include several other sectors, such as managerial processes and fiscal operations. To put it in simpler terms, Six Sigma is a quality improvement methodology primarily deployed to address complex issues that are not easily solved. The primary objective of the service-oriented production planning process is to enhance the company's competitiveness by considering customer viewpoints or operational plans and then prioritizing the horizontal procedure and quality. However, this objective is challenging to be obtained [3, 4].

This study investigates the integration of Six Sigma into Multi-Objective production planning to improve overall product quality. By aligning production goals with quality improvement initiatives, companies can achieve optimal efficiency while meeting customer expectations for superior quality products. This study provides insights into the potential benefits and challenges of the aforementioned integration by employing a Multi-Objective decision-making approach, ultimately contributing to a more competitive and quality-driven manufacturing environment. To solve Multi-Objective planning problems, a flexible and practical methodology called GP is proposed. GP has become increasingly popular in various fields due to its substantial influence on decision-making processes. Nevertheless, this investigation concentrates on the theories and applications of production planning techniques, particularly GP. The extensive research conducted in [5], on the Aggregate Production Planning model (APP), with a specific focus on multi-plant production, is a testament to the success of the Preemptive Goal Programming (PGP) approach. By exploring various scenarios, authors in [5] effectively addressed the APP model. The versatility of the GP approach is evident in its successful implementation in various fields. For instance, it has been instrumental in the methodology of a toothpaste manufacturing plant, which determined the material blend for each facility at every production stage. This model's adaptability, allowing leaders to simultaneously consider conflicting objectives, has proven to be a game-changer [6]. Furthermore, authors in [7] examined ideal production strategies using a GP method, resulting in substantial advantages for bottled water manufacturing companies.

Authors in [8] extensively studied the complexities of mathematical programming models in the context of management systems, specifically focusing on the practical implementations of the GP model. The specific model is an indispensable instrument for scrutinizing many aspects of management systems. In today's complicated world, GP is a very effective and adaptable strategy for decision-makers [8]. Authors in [9] investigated using GP to allocate operational expenses inside a company. The economic and financial consequences were analyzed employing St. Brother's Public School in Haryana, India, as a case study. A hierarchical method was deployed to construct a GP model to maximize profit and machine usage, while minimizing maintenance expenses [10]. The adoption of Six Sigma principles facilitates not only cost savings, but also an overall increase in product quality and customer satisfaction, as observed in [11], where significant improvements in production rates are revealed through the former's implementation. Ultimately, Six Sigma enhances production planning by establishing robust metrics for continuous improvement, aligning operational goals with quality outcomes. Similarly, at PT XYZ, the framework addressed an excessive defect rate in the Foley catheter assembly line, emphasizing the importance of root cause analysis to devise comprehensive solutions that ultimately elevated product quality and operational efficiency [12]. Similarly, another case study within the packaging sector, illustrated that precise defect categorization, evident through rigorous measurement, resulted in a discernible reduction of defects by homing the operator training and strict material supervision [13]. Integrating Six Sigma with collaborative strategies ensures that organizations are reactive and proactive in maintaining high-quality standards throughout the production lifecycle, eventually enhancing customer satisfaction and loyalty [2, 4, 14-19]. Equivalently to the current research, authors in [20-22] established financial models adopting a GP approach and analyzed financial firm strategies. These methodologies enabled attaining objectives regarding the overall liability, assets, profit, equity, optimal management, revenues, etc. Additionally, authors in [23] investigated the improvement of dynamic stability in wind power production by applying static VAR Compensation integrated with Multi-objective Optimization Algorithms. Lean manufacturing reduces non-value-adding procedures, whereas Six Sigma eliminates waste to meet production planning targets. Quantitative modeling may enhance Lean processes under uncertainty, while Six Sigma and Lean synergize to achieve sustainability [24]. Lean and Circular Economy principles enhance operational frameworks by boosting manufacturing process improvement and reliability, preserving resources, and reducing waste. Six Sigma knowledge is needed to make Multi-Objective production planning choices in this changing environment [25]. Another study discovered industry 4.0 best practices that align with Lean management in real-world industries. These findings suggest companies need Six Sigma and new technologies to reach various production objectives and optimize operations [26]. However, a significant gap exists in the research regarding integrating GP with Six Sigma principles within industrial operations, particularly in the Al Kharj industry sector. This study presents a GP model incorporating Six Sigma principles within the fridge industry to enhance cost efficiency and sales performance. Through the application of Six Sigma, the present study established demand constraints by defining the lower and upper limits for the proposed model. Decision-makers and corporate managers can utilize this study's findings to develop effective organizational plans and policies. The proposed method evaluates three key performance metrics, the demand objective, overall production costs, and sales revenue. The aim is to increase the output and income for the Al Kharj industry by lowering obstacles to cost and inefficient resource management. The research will also assist Al Kharj in increasing its non-oil exports by obtaining the targeted sales income needed for large-scale manufacturing and production.

II. MATERIALS AND METHODS

1) Proposed Multi-Objective Optimization Model

Production planning is a complex endeavor necessitating the collaboration of numerous functional divisions within an organization. Planning is the outcome of a series of decisions that address various aspects of the manufacturing environment. One of the most prevalent methodologies for Multi-Objective programming is GP, particularly PGP. Authors in [27] define the GP model as:

$$\text{Min } \sum_{i=1}^{n}(d_i^- + d_i^+)$$

$$\text{Subject to: } \sum_{j=1}^{m}(a_{ij}\, x_j + d_i^- - d_i^+) = \tau_i \text{ and}$$

$$x_j\, , d_i^-, d_i^+ \geq 0$$

$$\forall\, i, j;\; i = 1,2,\ldots,n \text{ and } j = 1,2,\ldots.,m$$

where n = objective constraints, τ_i = the i^{th} goal's target level, x_j = decision variables, a_{ij}= decision variable coefficients, and d_i^- and d_i^+ = under-and over-deviational variables. The constraints can be augmented with the deviations d_i^- and d_i^+, as an objective can be either oversatisfied or unsatisfied. Subsequently, deviation variables are implemented to ascertain whether each objective has been attained or exceeded [28]. Performance measures are chosen to accomplish objectives and are intended to effectively monitor, guide, and communicate all business functions between the manufacturing firm's top and bottom administrators. The firm plays a pivotal role in the production planning of three distinct product types, Fridge A, Fridge B, and Fridge C, all of which are manufactured within the current facilities. The model incorporates the subsequent performance criteria:

- Demand objective
- Production expense
- Revenue generated

2) Notations

a) Indices

i = item classification (i = 1, 2, ..., n).

b) Parameters

ς_i = Production cost of the i^{th} item.

$\mathcal{C}$ = Objective of production cost set by the decision-maker.

s_i = Sales revenue generated by the ith product.

$\hat{S}$ = Target of sales revenue fixed by the decision-maker.

c) Decision variable

x_i= Required production volume of the item i per period.

3) Target for Manufacturing Demand

The market needs an overall volume of manufacture of items 1, 2, and 3 to optimize the manufacturing capacity. The objective function must consider both positive and negative target deviations to achieve precisely the desired item volumes. The target is denoted as:

$$\text{Min}(d_1^+ + d_1^- + d_2^+ + d_2^- + d_3^+ + d_3^-)$$

subject to: $x_1 + d_1^- - d_1^+ = \gamma_1$, $x_2 + d_2^- - d_2^+ = \gamma_2$ and $x_3 + d_3^- - d_3^+ = \gamma_3$.

where d_1^+ =over attainment of item 1, d_1^-= under attainment of item 1, d_2^+= over attainment of item 2, d_2^-= under attainment of item 2, d_3^+ = over attainment of item 3, d_3^- = under attainment of item 3, γ_1 =demand goal for item 1, γ_2 = demand goal for item 2, γ_3= demand goal for item 3. In this case, reducing the values of $d_i^+ + d_i^-$ will decrease the absolute value of $x_i - \gamma_i$. To achieve the goal of $x_i = \gamma$ precisely, an investigation for x_1 , x_2 , and x_3 will focus on minimizing negative and positive product volume deviations.

4) Manufacturing Goal

The objective of the manufacturers to reduce the manufacturing cost for item 1, item 2, and item 3 may be expressed as:

$$\text{Min } d_4^+$$

subject to: $\sum \varsigma_i \ x_i + d_4^- - d_4^+ = \mathcal{C}$.

where d_4^- = under attainment in manufacturing cost and d_4^+ = over attainment in manufacturing cost. The solution set will consist of all x's, such that $\sum \varsigma_i \ x_i \geq \mathcal{C}$ by minimizing d_4^+ to 0, if such solutions are possible in the model. By reducing d_4^+ to 0, assuming such solutions are feasible in the model, the set of solutions will include all x's, such that $\sum \varsigma_i \ x_i \geq \mathcal{C}$.

5) Revenue Goal

Based on previous revenue data and developing customer interest in industry automation, the management believes that a revenue goal for the upcoming year should be '$\hat{S}$' million riyals. The achievement of the revenue goal, which will be set at $\hat{S}$, depends on the total gross margin of item 1, item 2, and item 3. Here is one way to represent this goal:

$$\text{Min } d_5^-$$

subject to: $\sum s_i \ x_i + d_5^- - d_5^+ = \hat{S}$.

where d_5^- = under attainment in the returns and d_5^+ = over attainment in the returns. In this case, meeting the revenue target is considered satisfactory, so any deviation from the goal is removed from the objective function. The solution set will include all x values that satisfy the condition $\sum s_i \ x_i \geq \hat{S}$. If this condition is acceptable within the approach, it can be achieved by minimizing d_5^- to 0. GP in managerial operations facilitates the balance of several objectives by prioritizing them and determining the optimal solution that minimizes deviations from these goals. As a result, this study chose GP over other optimization methods. Objectives, such as reducing expenditures and enhancing client needs, are integral to the process. The keys to success are:

- Establishing achievable goals for all operational aspects.
- Goals of differing significance are provided to enable comparison.
- Assessing the influence of preferences on each goal.
- Models are used to determine the best solution.
- Operation control is a dynamic domain requiring continual goal assessment to adjust to changing industrial circumstances.

III. CASE STUDY

This article provides a case study of a well-known industry. Tables I-III summarize each item's specifics. Six Sigma is integrated with the data provided in the present modification of the GP model. After collecting all the appropriate data, a model will be constructed and be analyzed for conclusions to be drawn.

Table II presents the average demand for each product type along with their upper and lower 6σ limits and standard deviations. The mean demand ($\bar{x}$) represents the average monthly demand for each product type based on historical data. The upper 6σ limit ($\bar{x} + 6\sigma$) and lower 6σ limit ($\bar{x}$ - 6σ) indicate the range within which the demand for each product type is expected to fluctuate with a high degree of confidence, considering a six-standard deviation range. The standard deviation (σ) measures the dispersion or variability of demand data around the mean, providing insights into the consistency and predictability of demand patterns for each product type. This industry is targeting the cost of production to be below 70,000,000 and the total revenue above. Table III shows the number of productions, revenue, and production price.

TABLE I. DEMAND IN THE PREVIOUS YEAR

Month	**Product type (quantity)**		
	X1	**X2**	**X3**
JAN	4214	6683	11849
FEB	4485	6071	11932
MAR	4816	6158	11550
APR	5413	6700	11643
MAY	4429	6870	11934
JUN	4651	6039	11072
JUL	4113	6478	11555
AUG	5121	6624	11837
SEP	5425	6682	11743
OCT	4437	6283	11108
NOV	4509	6296	11298
DEC	5034	6515	11422

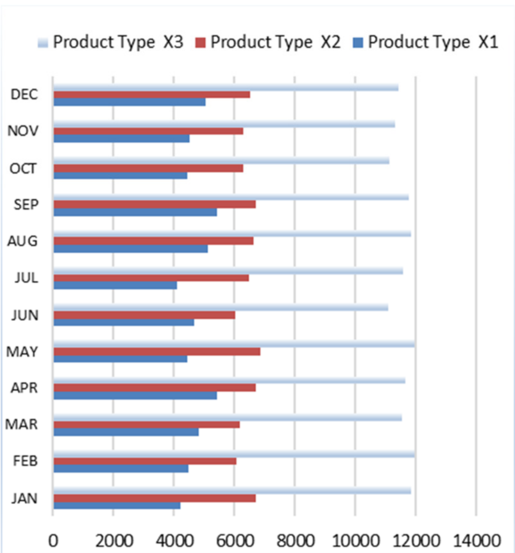

Fig. 1. Demand for the products per month in the previous year.

TABLE II. AVERAGE DEMAND AND 6σ LIMITS

i	**Product type**	$\bar{x}_j$	σ_j	$\bar{x}_j - 6\sigma_j$	$\bar{x}_j + 6\sigma_j$
1	Fridge A	4721	441	2074	7367
2	Fridge B	6450	275	4800	8100
3	Fridge C	11579	302	9765	13392

1) Target for Manufacturing Demand: Entirety Outcome Volumes

A possible formulation of this objective is: Min $d_1^+ + d_1^- + d_2^+ + d_2^- + d_3^+ + d_3^-$

subject to:

$$4721x_1 + d_1^+ - d_1^- = 2074$$

$$4721x_1 - d_1^+ + d_1^- = 7367$$

$$6450x_2 + d_2^+ - d_2^- = 4800$$

$$6450x_2 + d_2^+ - d_2^- = 8100$$

$$11579x_3 + d_3^+ - d_3^- = 9765$$

$$11579x_3 + d_3^+ - d_3^- = 13392$$

$$x_1, x_2, x_3, d_1^+, d_1^-, d_2^+, d_2^-, d_3^+, d_3^- \geq 0$$

TABLE III. COST OF PRODUCTION AND REVENUE

Product	**Product type**	**Cost of production**	**Revenue**
X1	Fridge A	27,200,000	45,000,000
X2	Fridge B	22,000,000	30,500,000
X3	Fridge C	30,000,000	40,900,000

2) Manufacturing Goal

The objective of reducing the production cost for the output quantities of item 1, item 2, and item 3 may be expressed as:

Min d_4^+

subject to:

$$27200000x_1 + 22000000x_2 + 30000000x_3 + d_4^- - d_4^+ = 70000000$$

$$x_1, x_2, x_3, d_4^+, d_4^- \geq 0.$$

3) Revenue Goal

This goal may be written as:

Min d_5^-

subject to:

$$45000000x_1 + 30500000x_2 + 40900000x_3 + d_5^- - d_5^+ = 115000000$$

$$x_1, x_2, x_3, d_5^+, d_5^- \geq 0$$

Now the GP may be written as:

Min $d_1^+ + d_1^- + d_2^+ + d_2^- + d_3^+ + d_3^- + d_4^+ + d_5^-$

Subject to:

$$4721x_1 + d_1^+ - d_1^- = 2074$$

$$4721x_1 - d_1^+ + d_1^- = 7367$$

$$6450x_2 + d_2^+ - d_2^- = 4800$$

$$6450x_2 + d_2^+ - d_2^- = 8100. 11579x_3 + d_3^+ - d_3^- = 9765$$

$$11579x_3 + d_3^+ - d_3^- = 13392$$

$$27200000x_1 + 22000000x_2 + 30000000x_3 + d_4^- - d_4^+ = 70000000$$

$$45000000x_1 + 30500000x_2 + 40900000x_3 + d_5^- - d_5^+ = 115000000$$

$$x_1, x_2, x_3, d_1^+, d_1^-, d_2^+, d_2^-, d_3^+, d_3^-, d_4^+, d_4^-, d_5^+, d_5^- \geq 0$$

IV. ANALYSIS AND RESULT

Table IV and Figure 2 illustrate the potential improvement of the desired value, based on the best solution of the model. It is suggested that specific goals can be improved. The first step involves searching for variables that exhibit positive variations, indicating potential increases or reductions. A positive variable is an effective method for determining the increment in a maximization problem. When dealing with a minimization problem, the reduction can be determined by utilizing a negative variation variable.

TABLE IV. RESULTS OF DEVIATIONAL VARIABLE QUANTITY

Goal	Negative deviational variables	Positive deviational variables
G1	$d_1^- = 2646$	$d_1^+ = 0$
	$d_2^- = 1650$	$d_2^+ = 0$
	$d_3^- = 0$	$d_3^+ = 1813$
G2	$d_4^- = 0$	$d_4^+ = 9195824$
G3	$d_5^- = 0$	$d_5^+ = 1393468$

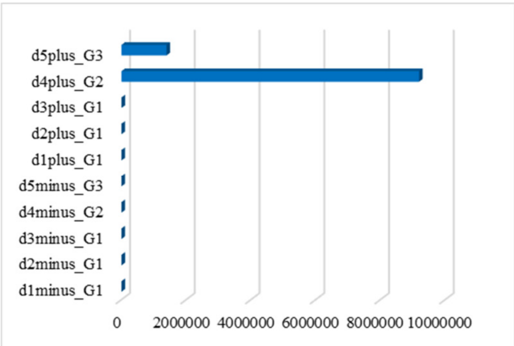

Fig. 2. Negative and positive deviational variables.

Consequently, the decrement may be calculated by using a variable that represents a negative deviation. Finally, these points were evaluated by the key aims that were developed for/as:

1. The company's production demand goal is nearest to being fully achieved because all negative and positive deviational variables are going to zero.
2. The value of d_4^+ for goal 2 is 9195824, while the value of d_4^- is 0. Therefore, the target of minimizing the manufacturing cost was met, and the firm will reduce the cost by 13.13 % for next year.
3. For goal 3, the value d_5^- is zero, while the value of d_5^+ is SR 1393468. Thus, the company's revenue goal was accomplished, and its returns can be eliminated by 1.12% for next year.

V. CONCLUSIONS

Using Goal Programming (GP) models to address real-life manufacturing challenges has gained recognition as a sustainable decision-making tool for managing many competing goals. Due to consumer demand volatility, competitive industries, and quick technological advancements, modern production has become ever more complicated. A well-designed production plan is crucial in assisting decision-makers in attaining the firm's goals. Optimizing resource utilization in each situation can significantly contribute to the success of the organization. This study developed a GP model incorporating Six Sigma to determine the most efficient production plan for the industry. Based on the optimal solution of the GP model, it has been demonstrated that the industry can fully achieve all the goals identified in this study. Integrating technology to optimize processes, inventory management, supply networks, and physical resources may expand production capacity, which presents significant potential. The model exhibits the study's limitations, which are identified as unrealistic goals. The industry must adapt to a dynamic production environment characterized by various industrial structure modifications, user practices, and technological advancements. Subsequent research should investigate alternative dynamic production environment criteria and policy combination criteria. The company's unwavering dedication to conducting comprehensive studies to identify customer demands and gaps certifies its commitment to establishing a robust foundation for potential opportunities in achieving industrial objectives.

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