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Enhancing Product Quality Using Six Sigma Concepts to Multi-Objective Production Planning

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Abstract

Achieving success in manufacturing over the long term requires dedicated production planning and the development of outstanding products. This study presents an optimization model incorporating Six Sigma concepts to tackle the industrial sector's complex production planning problems. The objective is to develop a comprehensive framework that optimizes production planning while maintaining high-quality standards. The research utilizes Six Sigma approaches to provide a systematic framework for decision-making, ensuring a comprehensive approach to quality engineering in manufacturing processes.

Keywords
Goal programming, Six Sigma, Multi-Objective Optimization Model, Planning.

1. Introduction
Companies must continuously strive for operational excellence to stay competitive in today's rapidly evolving market. One approach gaining significant traction in the manufacturing sector is the implementation of Six Sigma principles to improve product quality. Six Sigma methodology minimizes defects and process variations to ensure consistent, high-quality output. Six Sigma, a well-designed program, is widely used across several industries to achieve targeted performance levels via continuous improvement (Douglas & Erwin, 2000). It is a statistical metric representing six standard deviations from the mean, with the term 'Sigma' 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 (Vote & Huston, 2005). It is important to note that as the degree of quality grows, the process undergoes improvement, reinforcing the value of Six Sigma. Six Sigma is a methodology used in the field of industrial engineering. It is used in industrial businesses to enhance operations. Six Sigma employs various approaches, techniques, and tools from industrial engineering, quality management, and statistical analysis. Six Sigma applies in the manufacturing sector and many industries, such as administrative procedures. Six Sigma is primarily used to address complex issues that are not simply solvable (to put it in simpler terms). Attaining the predetermined objective is challenging (McAdam et al., 2014). In addition, the primary objective of the service-oriented production planning process is to enhance the company's competitiveness by considering customers' viewpoints or operational plans and then prioritizing the horizontal procedure and quality. Six Sigma is a quality improvement methodology known for the features mentioned by (Chen et al. 2009; Cheng et al., 2009).

This study investigates the integration of Six Sigma into multi-objective production planning to improve the overall quality of products. By aligning production goals with quality improvement initiatives, companies can achieve optimal efficiency while meeting customer expectations for superior products. This study provides insights into the potential benefits and challenges of integrating Six Sigma into multi-objective production planning using 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 goal programming is recommended. Goal programming has gained popularity across various fields due to its significant impact on decision-making processes. However, this study focuses on the theories and applications of production planning techniques, specifically goal programming.

Furthermore, Monim's extensive research on the aggregate production planning model, with a specific focus on multi-plant production, serves as a testament to the success of the preemptive goal programming (P.G.P.) approach. By exploring various scenarios, Monim effectively addressed the APP model (Monim A., 2013). The versatility of the goal programming 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 consider conflicting objectives simultaneously, has proven to be a game-changer (Adeyeye & Charles, 2008). Similarly, Kanakana-Katumba et al.'s in-depth analysis of optimal production plans using a goal-programming approach has significantly benefited bottled water manufacturing enterprises (Kanakana-Katumba et al.; O. A., 2018).

Nabendu and Manish delved into the intricacies of mathematical programming models for management systems, exploring the practical applications of the goal programming model. This model is a crucial tool for examining different facets of management systems. Goal Programming is a highly effective and versatile technique for decision-makers in today's complex environment (Nabendu et al., 2015). Jyoti and Himani Mannan conducted a study on applying goal programming in the distribution of operating costs within an organization. They used St. Brother's Public School in Haryana, India, as a case study to analyze the economic and financial implications (Jyoti & Himani, 2013). A hierarchical approach is used to develop a goal programming model to maximize profit, minimize repair costs, and maximize machine utilization (S.C.H. et al., 2009).

There is a significant research gap on the relevance of goal programming to industrial enterprises, particularly in the fridge sector. This research uses Goal programming in the fridge industry to optimize cost and demands. Decision-makers and corporate managers can leverage this study's findings to create thriving organizational plans and policies. This approach considers two performance criteria: demand objective and total production costs, thereby addressing a crucial need in the industrial sector.

The task aims to increase output and income for manufacturing enterprises by lowering obstacles to cost and inefficient resource management. The research will also assist Saudi Arabia in increasing its non-oil exports by obtaining the targeted sales income needed for large-scale manufacturing and production.

2. Goal programming (GP) model

Production planning is a complicated task requiring cooperation between multiple functional units in any organization—planning results from a hierarchy of decisions that deal with different issues in the manufacturing environment. Goal programming, particularly pre-emptive, has become one of the most popular methodologies for multi-objective mathematical programming. The goal programming (GP) model, as defined by Charnes and Cooper (Charnes and Cooper, 1957), can be addressed as:

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

Subject to,

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

$x_j\,, d_i^-, d_i^+ \geq 0\,,\ \forall\, i, j;\ i = 1,2,\ldots,n \ and\ j = 1,2,\ldots.,m$

Where, n represents number of goal constraints, τ_i represents the target level of the ith goal, x_j represents the vector of m-decision variables, a_{ij} represents the Coefficients of decision variables and d_i^- & d_i^+ represents the under-and over-deviational variables. As a goal is unsatisfied or over satisfied, the deviations d_i^- and d_i^+ are added to the constraints. Finally, the deviation variables are used to determine whether each goal is underachieved or overachieved (Winston and Goldberg, 2004).

Performance measures are selected to achieve goals and are provided with the intent to monitor, guide and to communicate to all the business functions in an effective way between the top and the bottom level managers of the manufacturing firm under consideration.

The details of variables, and the objective functions representing the various performance criteria are presented as follows.

The problem considered here involves the production planning of three different product types, Fridge A, Fridge, and Fridge C using the existing manufacturing facilities.
The following performance criteria are incorporated in the model:
(i) Production demand goal;
(ii) Production cost goal;

2.1 Production demand goal

For maximizing production volume, the market requirements concerning aggregate product volumes of product 1, product 2, and product 3 are to be met. Here, exact achievement of the product volumes is desired, and hence both negative and positive goal deviations must be considered in the objective function.
This goal can be represented as
Min $d_1^+ + d_1^- + d_2^+ + d_2^- + d_3^+ + d_3^-$
subject to
$x_1 + d_1^- - d_1^+ = \gamma_1$
$x_2 + d_2^- - d_2^+ = \gamma_2$
$x_3 + d_3^- - d_3^+ = \gamma_3$
where;
x_i= Production volume of type i (i= 1,2,3) to be produce per period
d_i^+ =over achievement of product i (i=1,2,3) volume goal
d_i^-= under achievement of product i (i=1,2,3) volume goal
γ_i = market goal on product i (i=1,2,3) volume (aggregate) as per prediction (goal)
Here, minimization of $d_i^+ + d_i^-$ will minimize the absolute value of $x_i - \gamma_i$. In other words, minimization of both negative and positive deviations of product volume will tend to search for the x_1 , x_2, and x_3 which achieves the goal $x_i = y_i$ exactly.

2.2 Production cost goal

The manufacturers' goal of minimizing the production cost for the product volumes of product 1, product 2, and product 3 can be represented as
Min d_4^+
subject to
$\sum c_i x_i + d_4^- - d_4^+ = C$
where;
c_i = Production cost of ith (i=1,2,3) product
C = Production cost goal fixed by the management
d_4^- = under achievement in production cost goal
d_4^+ = over achievement in production cost goal
The solution set will consist of all x's such that $\sum c_i x_i \geq C$ by minimizing d_4^+ to zero, if such solutions are possible in the model.

3. A case study

This article presents a case study of a prominent industry. Tables 1-2 and Figure 1 concisely summarize the particulars for each item. The current version of our Goal Programming (GP) model integrates Six Sigma with the provided data. Following are the data collected. We developed a model for analysis and conclusion after gathered all information.

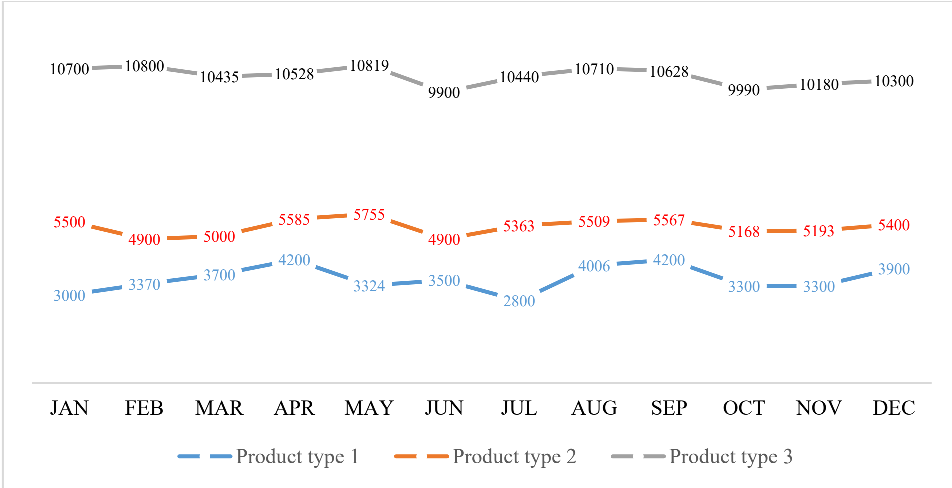

Figure 1. Demand of the products per month in the previous year

Table 1. Yearly average demand and Six Sigma restrictions

i	Product Type	Average demand	Sigma	Average demand-Six Sigma	Average demand+ Six Sigma
1	Fridge A	3550	455	820	6280
2	Fridge B	5320	285	3610	7030
3	Fridge C	10452	307	8610	12294

Table 1 outlines the average demand for each product type, accompanied by their upper and lower Six Sigma restrictions and standard deviations. The average demand reflects the yearly demand for each product type derived from historical data. The upper and lower Six Sigma restrictions indicate the expected range of demand fluctuations for each product type, offering high confidence. The standard deviation quantifies the variability of demand data around the mean, shedding light on the consistency and predictability of demand patterns for each product type. This firm targets a cost of production per total of three units (each unit of these three products) below 6000 SAR. Table 2 shows the number of productions and production costs.

3.1 Production Demand Goal

This goal can be represented as

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

subject to,

$3550x_1 + d_1^+ - d_1^- = 820$

$3550x_1 - d_1^+ + d_1^- = 6280$

$5320x_2 + d_2^+ - d_2^- = 3610$

$5320x_2 - d_2^+ + d_2^- = 7030$

$10452x_3 + d_3^+ - d_3^- = 8610$

$10452x_3 - d_3^+ + d_3^- = 12294$

and,

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

Table 2. Cost of production per unit

Product	Product Type	Production Cost (SAR)
X1	Fridge A	1500
X2	Fridge B	2000
X3	Fridge C	3000

3.2 Production cost goal

The manufacturers' goal of minimizing the production cost for the product volumes of product 1, product 2, and product 3 can be represented as.

Min d_4^+

subject to

$$\sum c_i\ x_i\ +\ d_4^-\ -\ d_4^+\ = C$$

Min d_4^+

subject to,

$1500x_1\ +\ 2000x_2 +\ 3000x_3 +\ d_4^-\ -\ d_4^+\ = 6000$

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

Now we may write the GP as:

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

Subject to,

$3550x_1\ +\ d_1^+ -\ d_1^-\ = 820$

$3550x_1 -\ d_1^+ +\ d_1^-\ = 6280$

$5320x_2\ +\ d_2^+ -\ d_2^-\ = 3610$

$5320x_2 -\ d_2^+ +\ d_2^-\ = 7030$

$10452x_3\ +\ d_3^+ -\ d_3^-\ = 8610$

$10452x_3 -\ d_3^+ +\ d_3^-\ = 12294$

$1500x_1\ +\ 2000x_2 +\ 3000x_3 +\ d_4^-\ -\ d_4^+\ = 6000$

and

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

4. Results and Discussion

Table 3 shows the potential improvement to the desired value based on the best solution of the GP model. It suggests that specific goals can be improved. The initial step involves searching for variables that show positive deviations when looking for potential increases or reductions. One way to determine the increment is by using a positive deviation variable for a maximization problem. On the other hand, when tackling a minimization problem, the reduction can be calculated by employing a negative deviation variable.

Table 3. Outcomes of deviational variables

Goal	Negative deviational variables	Positive deviational variables
G1	$d_1^- = 2730$	$d_1^+ = 0$
	$d_2^- = 1710$	$d_2^+ = 0$
	$d_3^- = 1842$	$d_3^+ = 0$
G2	$d_4^- = 0$	$d_4^+ = 500$

As a result, the decrement can be determined by using a negative deviation variable. Finally, we interpreted these points according to their priority goals:

- The firm's production demand objective is not entirely met due to the presence of non-zero negative deviational variables; thus, the company must formulate a plan to fulfill the demands.
- The value of overachievement for goal two is 500, while the value of underachievement is zero. Consequently, the goal of minimizing production costs was achieved, and the firm will reduce its costs by SAR 500 per total of three units (each unit of these three products) for the following year.

5. Conclusion

Goal programming models and their applications to real-life manufacturing problems have become increasingly popular as a reliable decision-making tool for handling multiple conflicting objectives. Modern manufacturing has become increasingly complex due to customer demand uncertainty, competitive markets, and rapid technological developments.

An effective production plan is pivotal in helping decision-makers achieve the organization's objectives. By optimizing resource utilization in a given situation, it can significantly contribute to the organization's success. This study presents a goal programming model that incorporates Six Sigma, a model that has proven successful in determining the most efficient production plan for industries. The model's optimal solution demonstrates its effectiveness, as it enables the industry to fully achieve all the goals identified in this study, instilling confidence in its potential.

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