A Goal Programming Model for Production Planning in a Small and Medium Bottled Water Manufacturing Enterprise

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Abstract

Small and Medium Manufacturing Enterprises are one of the major drivers that stimulates job creation, enhance youth empowerment and improve economic growth of a country. Hence, the development of optimal production plan that will promote business success and maximize profit generation in these enterprises are vital. In light of this, this paper proposed a goal programming model that could be used to optimally plan production operations in a Small and Medium Bottled Water Manufacturing Enterprise. The goal programming model was formulated by taking into consideration the various objectives that this enterprise want to achieve amidst the constraints that the production system of this enterprise is facing. Operations-related data of the enterprise such as customer order data, inventory data, production time and production cost data were used to solve the production planning model of this organisation. The solution to the goal programming model of this enterprise using the LINDO software unveiled the organization objectives that could be achieved and those that cannot be achieved. The deviation values that hindered the unachieved objectives from been met were also unveiled.

Keywords
Goal Programming, Constraint, Small Medium and Manufacturing Enterprise, Bottled Water Product.

1. Introduction

Small and Medium Manufacturing Enterprises (SMME) contribute up to 35% of the Gross Domestic Product of various countries in the global world [1]. This is expected to grow to 60% in 10 to 15 years' times [2]. This is a huge chunk contribution to various nations' economy in the global space. According to Amra *et al.* [3], South Africa has 5.6 million SMMEs'; of which 3.3 million are medium enterprises, 1.7 million are microenterprises and 554 thousand are small enterprises. This sector is expected to create 90% of the jobs in the next 5 to 10 years, therefore it is essential that small business enterprise strategically plan and schedule: (1) their operations and (2) the use of their resources, in order to maximize their productivity and profit. Production planning in SMMEs is a difficult and enormous task because it requires effective interactions and cooperation among various departments in that organisation [4]. Planning operation is a conglomerate of verified and hierarchy decisions that address various issues within a particular manufacturing environment [5].

An in-depth knowledge about the manufacturing and external environments interms of detailed operational processes, products and customer voice are highly important in designing a suitable production planning systems for the SMMEs [6]. Goal programming have been used and recommended by decision makers in evaluating the feasibility of meeting various objectives that a company want to achieve amidst various constraints that the company faces [7 and 8]. Goal programming have been applied in many areas such as bank financial management, crop and nutrient management, stock market portfolio management, student enrollment distribution, funding allocation, bakery production, food product distribution, energy consumption management and tourism management. However, its application in Small and Medium Bottled Water Production Enterprise; that possess scarce resources in meeting the abrupt and fluctuating customer demands, is still in its infancy. In light of this, the purpose of this study is to develop a goal programming model, which will unveil an optimal production plan that could be used to meet the strategic objectives of a Small and Medium Bottled Water Production Enterprise, and ensure that it remain competitive.

2. Literature Review

Goal Programming (GP) model has been used in many industries to optimize the use of their resources. The study by [9], [10], [11], [12] and [13] have used goal programing to improve various operations such as food products distribution, Chilli nutrient management, pineapple nutrient management, student enrollment distribution, and funding allocation. In the research works of [9], [10], [11], [12] and [13], the ability of organizations to achieve various goals such as demand fulfilment to various customers, minimization of product delivery costs, minimization of net profit made by an organization, minimization of fertilizer usage, maximization of nutrients available to the soil for optimum crop growth and maximization of classroom space utilization, under careful consideration of resources available in these organizations were investigated. The results of their studies unveiled the goals that could be achieved and the goals that were underachieved. This application didn't end there, other scholars applied this methodology at tooth paste production factory[14] , bakery production [15], and a general application to all manufacturing industries [16]. The study by [17] outlined how goal programming was used to determine the optimum price for alcohol beverages. The application of GP was also evident to solve products distribution problem found in a dairy company[18] .

A longitudinal literature review by [19] indicated the application of goal programming in engineering, management and social science. In his review, he outlined the revolution of goal programming methodologies and solutions that took place between 2000 and 2010. This sudden increase was attributed to the simplicity of the approach and computerization of the model for easy application. Based on this literature review, it could be inferred that the application of goal programming to improve the operations of Small and Medium Bottled Water Production Enterprise has not been explored. Hence, goal programming approach could be adopted to develop an optimal production plan that could be used by a Small and Medium Bottled Water Production Enterprise.

3. Production System of a Small and Medium Bottled Water Manufacturing Enterprise

Small and Medium Bottled Water Production Enterprise ABC produces three types of bottled water products demanded by the customers. The production process of producing these bottled water products involves: (1) collection and placing of preforms in the preheating machine, (2) pre-heating of the preforms to generate the bottles, (3) removal of the properly formed bottles out of the pre-heating machine, (4) blowing of the bottles in the blowing machine, (5) feeding of the bottles into an integrated washing and filling machine, (6) cleaning of the bottles, (7) filling of the bottles with purified and treated water, (8) capping of the filled bottled water, (9) labelling of the bottled water, (10) shrink wrapping of the bottled water and (11) packaging of bottled water. However, the development of an optimal planning system that will ensure just-in-time production and delivery of these three bottled water products demanded by the customers is essential for the enterprise. Since the main goals of the production planning of an organization involves: (i) the coordination of the production rates with respect to customer orders and (ii) decision making regarding when to order raw materials, inventory levels to be hold by the organization and staff hiring strategies, therefore, goal programming methodology with capability of meeting these aforementioned goals using the available scarce resources of an organization, as stipulated by [20] was utilized in this study to develop an optimal production plan for Small and Medium Bottled Water Production Enterprise ABC.

Hence, the next section of the paper present a goal programming model that could be used to successfully plan the operations of this enterprise with a view to meeting their fluctuating customer demands.

4. Model Development

A. Assumptions of the Model

The assumptions of the model developed in this study were based on: (1) the number of products produced in a Small and Medium Bottled Water Production Enterprise, (2) raw material requirements required to produce these products, (3) inventory holding policy of a Small and Medium Bottled Water Production Enterprise, and (4) the demand pattern for each product produced in a Small and Medium Bottled Water Production Enterprise, which may vary from one organization to the other. These varying aforementioned parameters in different Small and Medium Bottled Water Production Enterprises result into the development of unique production planning systems used in these organizations. In light of this, the assumptions of this model are highlighted as follows:

(i) Three products X, Y *and* Z demanded by the customers at period i, where $i = 1, 2, 3, \ldots\ldots, n$, are produced in a Small and Medium Bottled Water Production Enterprise ABC.
(ii) Raw materials used to produce products X, Y *and* Z at period i are available in a Small and Medium Bottled Water Production Enterprise ABC.
(iii) The inventory holding capacity of products X, Y *and* Z at period $i - 1$ is the same as the inventory held at the last period of production based on the inventory holding policy of the Small and Medium Bottled Water Production Enterprise ABC.
iv) The demand of $X > Y > Z$ in a Small and Medium Bottled Water Production Enterprise ABC.

B. Notations

X_i, Y_i and Z_i: the quantity of products X, Y *and* Z produced in each period i in a Small and Medium Bottled Water Production Enterprise ABC.
IX_i, IY_i and IZ_i: the amount of inventory of products X, Y *and* Z held in each period i in a Small and Medium Bottled Water Production Enterprise ABC.
PT_{i-X}, PT_{i-Y} and PT_{i-Z}: the time required to produce products X, Y *and* Z in each period i in a Small and Medium Bottled Water Production Enterprise ABC.
PC_{i-X}, PC_{i-Y} and PC_{i-Z}: the operating cost required to produce products X, Y *and* Z in each period i in a Small and Medium Bottled Water Production Enterprise ABC.
DX_i, DY_i and DZ_i: customer order for products X, Y *and* Z in each period i in a Small and Medium Bottled Water Production Enterprise ABC.
PTA = production time available for each period i in a Small and Medium Bottled Water Production Enterprise ABC.
PC_i = production cost for each period i in a Small and Medium Bottled Water Production Enterprise ABC.

A, B and C = inventory to be held for products X, Y *and* Z in each period i in a Small and Medium Bottled Water Production Enterprise ABC.
WC_i = Warehouse capacity for each period in a Small and Medium Bottled Water Production Enterprise ABC.

C. Objectives of the Model

The seven key objectives of the Small and Medium Bottled Water Production Enterprise ABC considered by the authors are highlighted as follows:
(i) Priority objective 1: meet the demand of product X in each period i. The flexibility constraint associated with this objective is given as $IX_{i-1} + X_i - IX_i = DX_i$.
(ii) Priority objective 2: meet the demand of product Y in each period i. The flexibility constraint associated with this objective is given as $IY_{i-1} + Y_i - IY_i = DY_i$.

(iii) Priority objective 3: meet the demand of product Y in each period i. The flexibility constraint associated with this objective is given as $IZ_{i-1} + Z_i - IZ_i = DZ_i$.
(iv) Priority objective 4: minimize the production cost incurred in producing products X, Y and Z in each period i. The flexibility constraint associated with this objective is given as $PC_{i-X} + PC_{i-Y} + PC_{i-Z} = PC_i$
(v) Priority objective 5: hold an inventory of A, B and C for products X, Y and Z at the last period of period n of production. The flexibility constraint associated with this objective is given as IX_n = A, IY_n = B and IZ_n = C.
(vi) Priority objective 6: minimize the amount of inventory of products X, Y and Z held in each period i. The flexibility constraint associated with this objective is given as $IX_i + IY_i + IZ_i = WC_i$.
(vii) Priority objective 7: minimize the production time used in producing products X, Y and Z in each period i. The flexibility constraint associated with this objective is given as $PT_{i-X}\, X_i + PT_{i-Y}\, Y_i + PT_{i-Z}\, Z_i = PTA$.

D. Rigid constraints of the Small and Medium Bottled Water Production Enterprise ABC

The various constraints that the system of the Small and Medium Bottled Water Production Enterprise ABC faces in meeting the aforementioned objectives are:
(i) Production system capacity constraint in meeting the demand of products X, Y and Z, which in this case, is determined using PTA in each period i.
(ii) The inventory holding capacity constraint of products X, Y and Z based on the inventory policy of the Small and Medium Bottled Water Production Enterprise ABC i.e. A, B and C.
(iii) The warehouse capacity constraint to hold products X, Y and Z in each period i i.e. WC_i.

E. Goal programming Model Formulation

The goal programming model formulated using the strategic objectives and the rigid constraints of the Small and Medium Bottled Water Production Enterprise ABC is presented using equations (1) to (11).

Minimize $\{d_{i-DX}^- + d_{i-DY}^- + d_{i-DZ}^- + d_{i-PC}^+ + d_{i-A}^- + d_{i-A}^+ + d_{i-B}^- + d_{i-B}^+ + d_{i-C}^- + d_{i-C}^+ + d_{i-WC}^+ + d_{i-PTA}^+\}$ (1)

Subject to:

$IX_{i-1} + X_i - IX_i + d_{i-DX}^- - d_{i-DX}^+ = DX_i$. (2)
$IY_{i-1} + Y_i - IY_i + d_{i-DY}^- - d_{i-DY}^+ = DY_i$. (3)
$IZ_{i-1} + Z_i - IZ_i + d_{i-DZ}^- - d_{i-DZ}^+ = DZ_i$. (4)
$PC_{i-X} + PC_{i-Y} + PC_{i-Z} + d_{i-PC}^- - d_{i-PC}^+ = PC_i$ (5)
$IX_n + d_{i-A}^- - d_{i-A}^+ = A$ (6)
$IY_n + d_{i-B}^- - d_{i-B}^+ = B$ (7)
$IZ_n + d_{i-C}^- - d_{i-C}^+ = C$ (8)
$IX_i + IY_i + IZ_i + d_{i-WC}^- - d_{i-WC}^+ = WC_i$ (9)
$PT_{i-X}\, X_i + PT_{i-Y}\, Y_i + PT_{i-Z}\, Z_i = PTA$ (10)
All decision variables ≥ 0 (11)

5. Production Operations Data of the Small and Medium Bottled Water Manufacturing Enterprise ABC

The production operations data used to solve the goal programming model of this enterprise was obtained through: (1) time and method studies and (2) opinions of the production manager of the Small and Medium Bottled Water Production Enterprise ABC. The data collected in this enterprise include the customer order for three varieties of bottled water products for four weeks, inventory holding capacity of this enterprise at the beginning and last period of production based on their inventory policy, the time required to produce 500ml, 5 litres and 1.5 litres bottled water products, the production time available to produce these bottled water products, the production time available per week to produce these bottled water products, the operating cost required to produce 500ml, 5 litres and 1.5

litres bottled water products, and the production cost available per week to produce these bottled water products demanded by the customers. The summary of the data collected in SMBWPE is presented in Table 1.

Table 1. Demand and Process Operations Data of the Small and Medium Bottled Water Manufacturing Enterprise ABC

	500ml Bottled Water	5 litres Bottled Water	1.5 Bottled Water
Customer Order for week 1	9000	180	24
Customer Order for week 2	11520	50	10
Customer Order for week 3	25920	760	10
Customer Order for week 4	10740	20	20
Production Time (seconds)	285.875	622.26	262.32
Production Cost (Rand)	1.85	9	3.80
Inventory held at the beginning and last period of production	1440	120	20
Production time available to produce the bottled water products	126000 seconds (i.e. 7 hours for work and one (1) hour for launch and tea break).		
Production cost available to produce the bottled water products per week (Rand)	28784		

The goal programming model of the Small and Medium Bottled Water Production Enterprise ABC was parametrized and solved using LINDO software package.

6. Results and Discussion of the Model Solution

The production plan solution output of the model is presented in Table 2.

Table 2. Production Plan Solution Output of the Model

Production Plan / Decision Variables	X	Y	Z	Production Plan/ Decision Variables	IX	IY	IZ
Week 1 Production Plan	11278	870	24	Week 1 Inventory Plan	3718	810	20
Week 2 Production Plan	15559	0	24	Week 2 Inventory Plan	7757	760	10
Week 3 Production Plan	18164	0	0	Week 3 Inventory Plan	0	0	0
Week 4 Production Plan	12180	140	40	Week 4 Inventory Plan	1440	120	20

Based on Table 2, it could be inferred that the production manager of the Small and Medium Bottled Water Production Enterprise ABC need to produce: (1) 11278, 15559, 18164 and 12180, (2) 870, 0, 0 and 140, (3) 24, 24, 0 and 40; units of 500ml, 5 litres and 1.5 litres of bottled water respectively in order to meet their customers demand. Furthermore, during these four weeks, SMBWPE should hold an inventory of: (1) 3718, 7757, 0 and 1440, (2) 810, 760, 0 and 120, (3) 20, 10, 0 and 20; units of 500ml, 5 litres and 1.5 litres of bottled water respectively, in order to support the system production output to meet the customer products demand per week.

The result of the Small and Medium Bottled Water Production Enterprise ABC ability to meet its strategic objectives based on the system constraints is presented in Table 3.

Table 3. Achievability and Non-Attainment Results of the Objectives of the Small and Medium Bottled Water Manufacturing Enterprise ABC

Priority Objective	Goal	Achievable/ Non-achievable	Resource Availability, Demand Targets and System Capacity Constraints	d^+	d^-
Priority Objective 1	Goals 1 - 4	(0, 0, 0, 0)	(7560, 11520, 25920, 10740)	(0, 0, 0, 0)	(0, 0, 0, 0)
Priority Objective 2	Goals 6 - 8	(0, 0, 0, 0)	(60, 50, 760, 20)	(0, 0, 0, 0)	(0, 0, 0, 0)
Priority Objective 3	Goals 9 - 12	(0, 0, 0, 0)	(4, 10, 10, 20)	(0, 0, 0, 0)	(0, 0, 0, 0)
Priority Objective 4	Goals 24 - 27	(0, 0, 4820, 0)	(28784, 28784, 28784, 28784)	(0, 0, 4820, 0)	(0, 0, 0, 4839)
Priority Objective 5	Goals 13 - 15	(0, 0, 0)	(1440, 120, 20)	(0, 0, 0)	(0, 0, 0)
Priority Objective 6	Goals 20 - 23	(0, 0, 0, 0)	(72660, 72660, 72660, 72660)	(0, 0, 0, 0)	(68113, 64134, 72660, 71080)
Priority Objective 7	Goals 16 - 19	(3645530, 4321905, 5066603, 3453567)	(126000, 126000, 126000, 126000)	(3645530, 4321905, 5066603, 3453567)	(0, 0, 0, 0)

Based on Table 3, it could be inferred that objectives 1, 2, 3 and 5 can be achieved with the resources currently available in Small and Medium Bottled Water Production Enterprise ABC, since the deviational variables; d_1^- to d_{12}^-, d_{13}^+, d_{13}^-, d_{14}^+, d_{14}^-, d_{15}^+ and d_{15}^- are equal to zero. Objective 4 can be achieved in the first, second and third weeks, however cannot be achieved in the third week since the value of the deviational variables of d_{24}^+, d_{25}^+, d_{26}^+ and d_{27}^+ are 0, 0, 4820 and 0 respectively. The value of d_{26}^+ = 4820, indicated that the budget of the Small and Medium Bottled Water Production Enterprise ABC for third week operation supposed to be R33604. The value of d_{27}^- = 4839 showed that the production cost available for week 4 will be underutilized by R4839. Therefore, the percentage utilization of the production cost available in this week will be underachieved by 16.81%. Objective 6 can be achieved since the value of the deviational variables; d_{20}^+, d_{21}^+, d_{22}^+ and d_{23}^+ are equal to zero. However, the value of d_{20}^-, d_{21}^-, d_{22}^- and d_{23}^-; which are 68113, 64134, 72660 and 71080, showed that the warehouse space capacity will be underutilized during the four weeks of production. Hence, the percentage utilization of the warehouse space capacity during the four weeks of production will be underachieved by 93.74%, 88.27%, 100% and 97.83% respectively. Objective 7 cannot be achieved since the value of the deviational variables; d_{16}^+, d_{17}^+, d_{18}^+ and d_{19}^+ are 3645530, 4321905, 5066603 and 3453567. In light of this, it could inferred that the production time during each week of production in order to meet the customer demands should be 3771530 seconds, 4447905 seconds, 5192603 seconds and 3579567 seconds respectively.

7. Conclusion

We have successfully formulated a goal programming model that could be used to plan the production of varieties of products demanded by the customers at different time periods in a Small and Medium Bottled Water Production Enterprise ABC. Production operations data of the Small and Medium Bottled Water Production Enterprise ABC, obtained through: (1) time and method studies and (2) opinions of the production manager of this organization was used to solve the model. Based on the results obtained, it was inferred that objectives 1, 2, 3 and 5 of the Small and Medium Bottled Water Production Enterprise ABC can be achieved. Objective 4 of this enterprise can be achieved during the first, second and fourth week of production, however cannot be achieved in the third week of production. Objective 6 of this enterprise can be achieved, however objective 7 cannot be achieved. Inability of the goal programming model to achieve: (1) the fourth objective in the third week of production, and (2) the seventh objective of the company, were due to the deviations of the results of this model from these objectives target. In light of this, it could be inferred that goal programming model could be used to optimally plan the production operations of the Small and Medium Bottled Water Production Enterprise ABC, in order to meet the strategic goals

and targets of this organisation. The development of an integrated production planning and logistic model capable of holistically achieving just-in-time (JIT) production and delivery of varieties of products demanded by the customers at various locations within the required time, using the scarce resources available in Small and Medium Bottled Water Production Enterprise ABC still need to be explored.

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