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A Review on Stochastic Goal Programming Approach in Production Planning In Manufacturing

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Abstract: *Manufacturing system performance is very important for any manufacturing company and one of the key tools that aid in maintaining and improving its performance is production planning. Manufacturing systems function in an uncertain environment and this affects their system performance in one way or the other. Production planning tactics that don't put into consideration the uncertainties will produce substandard planning decisions linked to the ones that clearly consider uncertainty. Stochastic goal programming is applied in decision-making circumstances with uncertainty using stochastic calculus and therefore the decision-maker isn't in the position to evaluate exactly the several factors but gives certain information regarding the likelihood of the existence of the decision-making factor values. During this paper, existing literature about the application of stochastic goal programming in production planning in manufacturing has been reviewed to provide the reader, optimization practitioners, and researchers with the important matters that arise once dealing with uncertainty modeling in manufacturing systems using stochastic goal programming.*

Keywords: Production planning, uncertainty, manufacturing, Goal programming, Stochastic programming

1. Introduction

Manufacturing is a vital aspect of the global economy and prosperity. There's always an issue of the supply chain within the manufacturing domain, and production planning is one of its stages. Many industries have manufacturing systems characterized as large and sophisticated and operate in an uncertain environment. There are several different methods by which the complexity within the manufacturing system can be reduced and one of them is by modeling uncertainties within the production planning problem [1], [2]. With manufacturing systems functioning in uncertain environments, production planning is a significant element in refining its performance [3]. The production planning process becomes more difficult and complicated concerning product demand uncertainty [4]. Making the production planning process well-organized and enhanced (having minimum expenses and meeting the market demand) is the desire of any manufacturing company.

Optimizing the production planning process is very essential in the production of high-quality products (while maximizing profit), especially given the competitive nature of the market globally.

Examining the decision-making process (to get an optimal alternative possible solution to a specific problem) within the production planning process, the application of mathematical modeling is essential.

One of the objectives in production planning is maximizing profit with the production of products at minimum cost [5]. The process of defining the modest way that proficiently utilizes resources necessary for production (manpower, materials, and equipment) is the production planning process. The usual decisions in Production planning are affected by compromises between productivity efficiency and financial objectives.

Financial targets are precisely linked to cumulative profits or decreasing costs, (including production costs, labor costs, material costs, and inventory costs).

Concerning production efficiency, production planning must reveal the capability to supply products & the distinct effects of extra concerns all through the operation (inventory levels, overtime, and backorders) [1]. Ali Cheraghalikhani, Farid Khoshalhan, and Hadi Mokhtari in their paper characterized the production planning models as shown in Table 1 [6].

Table 1: Model characterization by type of data and number of the objective function

Type of data	Model	Objective function
Deterministic		Single
		Multiple
Uncertain	Fuzzy	Single
		Multiple
	Stochastic	Single
		Multiple

Mula et al.'s research demonstrates the factors of uncertainty within the production system (as demand, environment, system resource, lead time, and yield) and further amalgamate common methods to uncertainty (including stochastic model, dynamic

programming, fuzzy theory, and simulation-based approaches) [2]. Many times uncertainty in production planning is perceived as demand uncertainty (fluctuations) within the production process (production times or material loss). As observed in Bakir & Byrne's research, the variation in the solutions given by the deterministic model & stochastic model is analyzed and the uncertainty factor is market demand (the analytical results showing that the difference relies on the variance of uncertain demand) [1].
Considering the summarized fundamental concerns in table 2 [6], the purpose of the production planning models is to determine an optimum rate of production and labor force, minimizing the costs associated with satisfying the known demand

Table 2: Fundamental concerns in production planning

Fundamental concerns	**Definition**
Market demand	Demand per period satisfied by product, inventory or backorder
Inventory	Products held in stock per period
Backorder	Part of demand not satisfied per period
Production capacity	Maximum amount of products that can be produced per period by system
Warehouse space	Capacity of the warehouse for the holding inventory
Costs of production	Regular time & overtime production and costs of inventory carrying & backorders
Subcontracting	Hiring capacity of other firms temporarily to make component parts
Labor level	Number of workers per period (regular & overtime workers)
Hiring and Layoff cost	Additional workers were recruited to handle extra production loading and redundant workers laid-off to reduce overheads.
Product Price	Selling price of products

Given today's industrial competitiveness, and the uncertain environment these manufacturing companies operate in, it's crucial for the decision makers to maintain optimal strategies or solutions to such problems hence stochastic goal programming method because it proposes a logical structural guide in modeling and resolving such problems.

2. Goal Programming

Goal programming (GP), is one of the well-known multi-objective optimization models and has recurrently been cultivated by both theoretical advances and new applications through categorical success. Abraham Charnes and William W Cooper introduced the first formulation of goal programming spreading its attractiveness to current periods [7], [8], [9], [10], [11]. Having been introduced in the early 1960s, and subsequently, significant additions and several applications have been recommended, one of them being the stochastic goal programming model. This is where the result of the best negotiation reduces total deviances between the achievement $f_i(x)$ and aspiration levels g_i [12]. Goal programming, generally a linear programming tool (useful tool to balance conflicting aspects of the competing criteria), attempts to achieve predefined targets for a set of goals (satisficing philosophy) other than an optimal result subject to stringent constraints (optimizing philosophy).
Stochastic programming must be applied to proficiently assimilate information concerning an aspect of uncertainty. Goals are governed by the decision-makers' perspective (and vary with time due to related factors) [13] , follows a sustaining logic conveyed by means of targets and he appreciates the notion of setting targets & thus being directly involved in the development of other solutions [14]. Goal programming combines several objectives to get the result that minimizes in totality the deviations between achievement & the aspiration levels of the goals. It is essential to specify for each goal g_i, the aspiration level or target $G_i \in R$, with i = 1; 2; : : : ; q introducing positive & negative deviation auxiliary variables to associate goal achievement and targets [15].
goal programming purposes to reconcile the achievement of a set of goals other than optimizing each goal done by instituting an achievement objective function. In terms of fundamental distance metric, the goal programming types are lexicographic, weighted [15], [16], & Chebyshev (min-max) goal programming [17] and in terms of the mathematical nature of the decision variables or goals used are fuzzy, integer, binary, and fractional goal programming [10]. In weighted goal programming, each objective is multiplied by a weight assigned to it, and the overall objective function (archimedian sum of all these), is minimized. In lexicographic goal programming, the objectives are assigned priorities, then ranked by priority from highest to lowest, then the first objective is minimized by itself, and a constraint is set after the optimization to prevent the next optimization from obtaining a worse result, and lastly, this procedure is repeated for all of the objectives. In min-max goal programming, the maximum difference between any goal and its objective is minimized [17]. similar to that of a linear programming model, problem is modelled into a goal programming model in the same way, but, the goal programming model has several & frequently contradicting incommensurable goals, in a specific priority hierarchy (established by ranking or weighing various goals in accordance with their importance) [18]. GP defines the resources needed to attain a preferred set of objectives, determines the point of achievement of the goals per the available resources, and delivers the best sufficient result with a changing resources & priorities of the goals. For every objective, a goal is set and the deviancy concerning every objective & its goal are minimized. The general formulation of goal programming consists in transforming multi-objective programming as [19]:

$$Optimize\ f_i(x) \tag{1}$$

Subject to P1

$$x \in A \tag{2}$$

In the following form:

$$\min \sum_{i=1}^{n} w_i(\delta_i^+ + \delta_i^+) \tag{3}$$

Subject to

$$f_i(x) + \delta_i^- - \delta_i^+ = \hat{f}_i \quad i = 1,\dots,n \tag{4}$$

$$x \in A \tag{5}$$

$$\delta_i^- \text{ and } \delta_i^+ \geq 0 \quad i = 1,\dots,n$$

Where $f_i(x)$ is the goal function i; $\hat{f}_i$ is the target level of objective i; δ_i^- and δ_i^+ are the negative and positive deviations respectively associated with the objective i from its target; w_i is the weight assigned to the objective i, and A is the set of feasible solutions or system constraints.

Pre-emptive and Non Pre-emptive goal programming are the basic types of goal programming formulations, with Non Pre-emptive [20] having the weighted sum of all the undesirable deviations is minimized (no goal is said to dominate any other goal).

$$Max\ Profit\ Z_1 = 2x_1 + 3x_2 \tag{6}$$

$$Min\ Cost\ Z_2 = x_1 + 5x_2 \tag{7}$$

Subject to:

$$x_1 + x_2 \leq 10 \tag{8}$$

$$x_1 - x_2 \leq 4$$

$$x_1, x_2 \geq 0 \tag{9}$$

Supposing that the decision maker needs to have at least 40,000 profit and the cost should not exceed the limit of 20,000, the above problem can be converted into a goal programming problem as follows ($GP1$):

$$Min\ d_1^- + d_2^+ \tag{10}$$

Subject to:

$$2x_1 + 3x_2 + d_1^- = 40{,}000 \tag{11}$$

$$x_1 + 5x_2 + d_2^+ = 20{,}000 \tag{12}$$

$$x_1 + x_2 \leq 10 \tag{13}$$

$$x_1 - x_2 \leq 4 \tag{14}$$

$$x_1, x_2 \geq 0 \tag{15}$$

$$d_1^-, d_2^+ \geq 0 \tag{16}$$

Rajendran demonstrates Pre-emptive Goal Programming as below;

Assuming in the problem above, having known the fact that the multi-objective situation limit to have any such result that satisfies both goals concurrently, the decision makers states the priorities for both the goals. Assuming in problem $GP1$ the first goal has the higher priority, say $P1$, and the second goal has a lower priority, say $P2$, that is $P1 > P2$. In this condition, the problem $GP1$ is written as follows ($GP2$):

$$Min\{P_1 d_1^-, P_2 d_2^+\} \tag{17}$$

Subject to:

$$2x_1 + 3x_2 + d_1^- = 40{,}000 \tag{18}$$

$$x_1 + 5x_2 + d_2^+ = 20{,}000 \tag{19}$$

$$x_1 + x_2 \leq 10 \tag{20}$$

$$x_1 - x_2 \leq 4 \tag{21}$$

$x_1, x_2 \geq 0$ (22)
$d_1^-, d_2^+ \geq 0$ (23)
$P_1 > P_2$ (24)

3. Stochastic programming (SP)

SP is a method aimed at modeling optimization problems involving uncertainty [21] ("find an optimal decision in problems involving uncertain data" [22]). Stochastic programming ([22]) conveys a useful tool within which a huge range of sources of uncertainty is integrated into the development of the production plans [14]. Some of the applications of stochastic programming include, production planning, manufacturing design, financial planning and control [22], portfolio management [23]. As deterministic optimization problems are expressed with known parameters, real world problems comprise unknown parameters at the time a decision is made. Stochastic programming may be applied in a very setting during which a one-off decisions must be made.

The top broadly applied & studied stochastic programming models are two-stage (linear) programs where the decision maker acts within the first stage, after which a random event occurs affecting the result of the first-stage decision [21]. The basic stochastic programming problem is:

$$minimize\ F_O(X) = Ef_o(x, w) \quad (25)$$

Subject to: $F_i(X) = Ef_i(x, w) \leq 0, i = 1, \dots\dots\dots, m$ (26)

Where the variable is x, problem data are f_i , distribution of w
If $f_i(x, w)$ are convex in x for each w, F_i are convex hence stochastic programming problem is convex

4. Stochastic Goal Programming (SGP)

Stochastic Goal Programming is a "multi-criteria decision support" model that has "satisficing" results to a linear structure under an uncertainty situation from the usually predictable utility perspective [24], [25]. Because many real-world optimization problems have got numerous erroneous information estimates & goals and conflicting criteria [26], the stochastic goal programming technique proposes a logical physical aid in modeling and resolving these problems.

SGP addresses intrinsic uncertainty & is being applied in numerous areas like economic development, portfolio selection, project selection, resource allocation, healthcare management, transportation, marketing [12], cash management [15], wealth management [27], energy consumption, workforce allocation, greenhouse gas emissions [11], forest planning [14]. Contini, introduced the first formulation of SGP in 1968, considering goals as random variables having statistical distribution & and suggested a model taking into account that the maximization of the probability that the decision belongs to a region surrounding the random goal. This model induces a solution that is near the random goal as much as possible [28]. The conventional formulation of the SGP model is as follows:

$$\max f(x) \quad (27)$$

Subject to:

$$\sum_{j=1}^{n} a_{ij} x_j \leq \tilde{b}i\ (for\ i = 1, 2, \dots\dots, p) \quad (28)$$

$$\underline{x} \geq 0$$

Where $\underline{x}$ represents an "n-dimensional random vector" of the decision variables, a_{ij} symbolizes a mxn matrix A of "deterministic coefficients" and $\tilde{b}i$ represents an "m-dimensional vector" $\underline{b}$ "(stochastic) resource limitations".

Applications of SGP

Numerous studies have revealed the usefulness of stochastic goal programming formulations being supportive in quiet a number of different areas (marketing, transportation [29], portfolio selection [10], health care management [30], [31], [32], resource allocation, project selection,) [12], "cash management" [15], "wealth management" [27], pharmaceutical [20], "economic development, energy consumption, workforce allocation, & greenhouse emission emissions" [11], "forest planning" [14], Coal-fired power stations, Water management [33], data communication networks, Market share scheme, Investments, Blends, Hot Desking, Advertising [34], [25].

Table 3: Applications of stochastic goal programming

Application	Author (s)	Uncertainty	Conclusion
Textile industry	Wang et al., 2021	Demand	Developed "a stochastic multi-objective mixed-integer programming model for global sustainable multi-product production planning".
Water use planning	Bravo & Gonzalez, 2009	Demand	SGP especially designed for water use planning was developed.
Portfolio management	Ji et al., 2005	Asset returns	Presented "a stochastic linear goal programming model for multistage portfolio management emphasizing the investor's goal & risk preference".

Sustainable development	Jayaraman et al., 2017	Electricity demand	presented "a scenario-based stochastic goal programming model with satisfaction function for optimal employee allocation across various economic sectors".
Cash management	Salas-Molina et al., 2020	Cash flows	Developed "a generalized stochastic goal programming model to derive stable policies within cash management systems with multiple bank accounts using cash flow forecasts as a key input"
Groundwater remediation management	Li et al., 2014	Human health-risk	"Stochastic analysis & goal programming were introduced into the framework to handle uncertainties in real-world groundwater remediation systems"
Pharmaceutical	Rajendran et al., 2019	No. "of customers lost due to side effects"	Developed "a multiple criteria stochastic mixed integer programming model, which serves as a decision support system to pharmaceutical companies".
Forest planning	Eyvindson & Kangas, 2014	Forest inventory	Developed "three stochastic goal programming formulations & highlighted the usefulness of the approach on a small forest holding".

Table 4: (Continued)

Application	**Author (s)**	**Uncertainty**	**Conclusion**
Industrial production (textile blending)	Ballestero, 2005	Blends	"Choice of fibers to make blends in yam production was developed from empirical information & numerically solved"
Wealth management	Kim et al., 2020	Assets	Proposed "a GBI framework that finds the optimal financial plan for an individual to achieve multiple consumption goals with various priority levels", (automated financial advising services)
Health care system (blood collection and distribution)	Attari & Jami, 2018	Demand	Developed "a novel hybrid approach based on stochastic programming, MCGP and robust optimization".
Transportation	Yang, 2007	"direct cost, transportation time, supply abilities, demands"	Three "models were constructed for stochastic solid transportation problem with different modeling Ideas (expected value, chance-constrained & dependent-chance goal programming)".

5. Conclusion

Having scrutinized through a number of papers published in field of stochastic goal programming both theoretical and applied contributions, the following conclusions are drawn:

- Throughout numerous decades, the goal programming model has demonstrated to be powerful instrument and remains to be "an attractive and flexible" model dealing with "decision-making situations" where numerous "conflicting" and "incommensurable" objectives are to be optimized concurrently.
- Given its "simplicity and satisficing philosophy", the goal programming model is suitable for aiding the decision marker to advance towards the best recommendations and help in getting to know more about the "decision-making context".
- SGP is one of greatest widespread applied tools in the "multi-criteria decision aid paradigm" and its acceptance is based on to its being easily "understood and applied".
- The information in this paper can be used as a guide for "academicians and optimization practitioners" to resolve "specific decision-making" situations.

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