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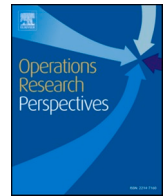
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A GP-AHP approach to Design Responsive Supply Chains for Pareto Customers

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ABSTRACT

This research mainly aims to provide a practical method to (1) rank a firm's customers, (2) determine the *implied* uncertainty for customers' demand, and (3) allocate supply chain (SC) resources for meeting customer demands in an equitable manner in order to provide them with an appropriate/desired level of responsiveness. The suggested methodology utilizes the analytic hierarchy process (AHP) and the Delphi method to (1) assess customers based on their *relative importance* and (2) determine the *implied* demand uncertainty for the product(s) they purchase from the firm. The information obtained from AHP and Delphi is used to construct a goal programming (GP) model to allocate organizational resources among the customers to meet their demands.

1. INTRODUCTION

Customer-focused SC strategies are becoming increasingly popular among practitioners and have recently received considerable attention in the literature. The competition among supply chains is now more concentrated on providing an acceptable level of responsiveness to customers while minimizing cost, i.e., achieving an acceptable efficiency-responsiveness balance [3]. To achieve this balance, a high degree of collaboration and coordination among all SC stages is required to solve challenging issues such as demand and supply uncertainty, risk management, frequent changes in customer orders, lead-time, and quality customer service. Moreover, providing a desired level of responsiveness is quite demanding and can consume abundant resources [28]. This in turn mandates an efficient deployment and the appropriate utilization of organizational resources [29]. Furthermore, providing the same level of responsiveness to all customers may not be possible or economically feasible due to scarce resources. As a result, customer prioritization is inevitable and could offer a practical solution that enable firms to simultaneously improve their SC performance and customer satisfaction.

Customer prioritization requires segmenting customers based on their relative importance to the firm [12]. In fact it has become a common marketing practice [24]. For a SC to apply this strategy and become customer-focused, as suggested by Cohen and Roussel [4], all participating firms' resources and efforts should be primarily focused on the most valuable customers, which are referred to as the *Pareto*

Customers in this paper. This strategy could simultaneously reduce costs and improve customer satisfaction [22].

This paper, using AHP, GP, and the Delphi method proposes a unique methodology to prioritize a firm's customers and determine the implied demand uncertainty for the firm's products. This information is then used to allocate the SC resources to serve customers such that *Pareto Customers* receive a higher priority to satisfy their demand compared to the rest of the customers.

2. LITERATURE REVIEW

The idea of being "customer-focused" has emerged since the late 80s, when organizations became keen to respond to ever-changing customer needs [10, 21]. Among the many customer-focused approaches adopted by organizations, the customer prioritization strategy, where organizational effort is focused on the most valuable customers is perhaps the most widely used approach [33]. In this method, referred to as "customer segmentation," customers with common features are clustered into groups so that organizational resources can be utilized more effectively and efficiently to focus on a specific group with certain needs [11]. Segmentation can improve not only the allocation of the organizational resources but also customer relationship [31].

The Analytic Hierarchy Process (AHP), used in this paper for customer prioritization, has emerged as the most widespread approach for prioritization of criteria and alternatives [26]. AHP has also been extensively used to solve various SC problems. For instance, Alhusain, et

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al [1] utilized AHP to design efficient and responsive supply chains. Kavilal et al. [16] developed a fuzzy AHP model to evaluate various SC designs. Ganguly and Kumar [8] developed a model to prioritize SC risk factors using fuzzy AHP. Zhou et al. [34] applied a hybrid decision model comprised of Delphi and fuzzy AHP to evaluate and prioritize green SC practices on garment manufacturing firms in Pakistan. Khorramshahgol [17] developed an integrated model using AHP and goal programming (GP) for selecting the best suppliers and allocating the procurement funds among them. Tooranloo and Iranpour [32] combined AHP and the interval-valued intuitionistic fuzzy set (IFS) for supplier ranking and selection.

While the idea of customer segmentation is a widely accepted marketing strategy, it is rarely mentioned in SC, so how it may benefit and improve SC performance has been ignored. Even though some researchers argue that a SC strategy should be designed to focus on satisfying customer needs (e.g., Ellinger, et al., [7]) and others suggest that SC performance can be improved by a better utilization of organizational resources (see Sukati et al. [29]) there has been no research that bridges the gap between customer fulfillment and organizational resources. This paper, using three well established methodologies, i.e., AHP, GP and the Delphi method, proposes an integrated approach to (1) rank the customers and (2) measure the implied demand uncertainty and evaluate the extensivity of the resources the firm should commit for customer fulfillment. This latter step (measuring the implied uncertainty of demand) is an important and crucial step. It is similar to the concept of utility in economics, i.e., the marginal utility of one additional dollar is by far higher for a poor man than a millionaire. Similarly, even though all resources are scarce, some resources are scarcer than others and the organization must take adequate care in spending them. Combining the information about customer priority and implied demand uncertainty, the suggested methodology offers practical and easy to implement resource allocation strategies to fulfill customers demand in an equitable manner, considering their relationship with the firm and the degree of resource commitment to fulfill their demand.

The following sections first provide a brief discussion of the analytic hierarch process (AHP), the Delphi method, and goal programming (GP). Next, an outline of the proposed methodology is presented, followed by an illustrative example to demonstrate the ease of use and the extent of its applicability. Then the advantages and shortcomings of the proposed methodology is presented, followed by conclusions.

3. A Brief Discussion of AHP - GP and the Delphi

Since the suggested methodology uses the Delphi, AHP and GP, a brief discussion of each is presented with an emphasis on their merits, as used in this research.

Analytical Hierarchy Process (AHP) is a multicriteria decision making method [26], based on the idea that a complex problem can be set as a hierarchy where its top level reflects the overall objective, the criteria and sub-criteria are at intermediate levels and the lowest level signifies the alternatives. Components at each level are compared to one another with reference to their effects on the higher level. These pair-wise comparisons are structured into n-by-n reciprocal matrices called the pairwise comparison (PWC) matrices. The weights for the criteria and the alternatives can be calculated using Expert Choice®. In addition to the weights, the software also provides a consistency ratio (CR) to capture any bias that may occur in subjective judgements when PWC matrices are constructed. As long as $CR < 10\%$, the inconsistency in judgements (if any) is acceptable. If $CR > 10\%$, then the judgements will have to be revised to remove inconsistencies.

The Delphi Method is an iterative process to reach group consensus. By assuring anonymity and providing feedback, Delphi offers a more refined and comprehensive analysis of the problem [5]. The Delphi, as an alternative to face-to-face meeting, eliminates scheduling problems and location restrictions, thus allowing all the stakeholders to participate and provide feedback [20].

Goal programming (GP) is one of the most widely used techniques for multiple criteria decision-making (MCDM). The main idea in GP is to provide a satisfactory solution, and the basic assumption is that if a satisfactory solution is achieved, then the resources have been allocated as best as possible, according to the decision makers' preferences [2]. GP was initially developed by Charnes and Cooper [2]. Ignizio [13], Romero, et al. [25], Tamiz, et al. [30], Jones, et al [15] and Jones [14] subsequently made major contributions to GP. Khorramshahgol and Ignizio [18] addressed the shortcomings of GP and suggested using AHP to obtain weights and priorities for various goals in GP. The augmented model (AHP-GP) has been used by other researchers, such as Gass [9], Schniederjans [27], Percin [23], for various applications such as supplier selection, facility location, resource allocation and project selection.

Using both the augmented GP-AHP and the Delphi yields special merits for the proposed methodology, which will be discussed in a subsequent section.

4. OVERVIEW OF THE PROPOSED METHODOLOGY

This research seeks to answer a fundamental question: What is the most equitable utilization of organization's SC resources for providing required responsiveness within an acceptable cost/efficiency range, given your organization's competitive strategy and the core strength of its SC drivers (i.e., logistical and cross-functional)? For this purpose, the proposed methodology utilized three well-established planning methods: the Delphi method, the Analytical Hierarchy Process (AHP) and goal programming (GP). Figure 1 shows the proposed methodology.

A detailed explanation of the proposed methodology is presented below. An illustrative example follows.

STEP 1. Determine the SC Strategy: Articulate the firm's competitive strategy and eloquently identify strategic objectives.

There is no doubt that the SC strategy of any firm must be aligned with its overall business strategy [6, 19]. Thus, this is the first logical step in the proposed model and the most important initial activity in formulating an SC strategy.

STEP 2. Conduct the Delphi Inquiry: Select a team of experts to perform the Delphi. This team, called the monitor team, may include the SC managers and experts. The participants (respondents) of the Delphi can be anyone who can provide valuable/pertinent input/feedback. The outcome of the Delphi process will be a set of criteria that can be used to classify the firm's customers into different segments.

STEP 3. Use AHP to Rank the Customers: Utilize the criteria from Step-2 to construct the AHP hierarchy. Apply AHP to determine the weights for various customers and use these weights to rank the customers and situate them in their proper positions on the customer importance spectrum (Figure 2). The spectrum is a continuum ranging from very low (L-) to very high (H+).

STEP 4. Determine the implied Demand Uncertainty: Through the Delphi process (or alternatively, via a face-to-face meeting), determine the implied demand uncertainty for the customers of the firm.

Chopra and Meindl [3] distinguished the demand uncertainty from the implied demand uncertainty. While the former reflects the inherent uncertainty associated with the customer demand, the latter is the uncertainty related to the supply chain as it tries to satisfy a portion of the customer demand with specific attributes the customer requests (e.g., short lead time and frequent changes). The implied demand uncertainty is represented on a continuum ranging from very high (H+) to very low (L-), as shown in Figure 3.

STEP 5. Construct the Customer Priority Index (CPI) Matrix: The CPI matrix is a two-dimensional matrix (Figure 4) whose horizontal axis

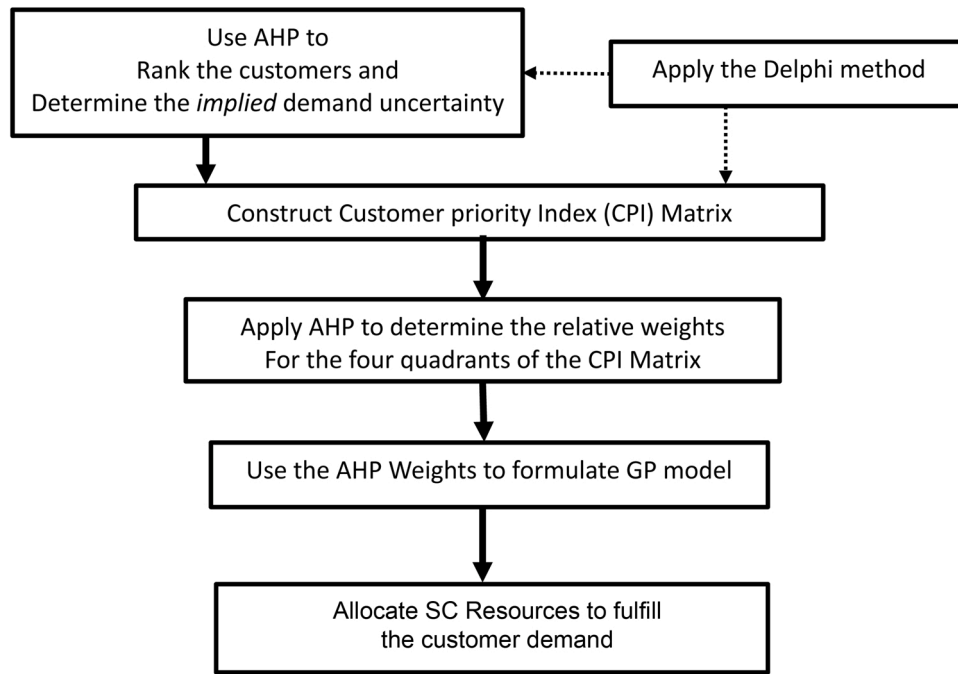


Figure 1. An overview of the proposed model.

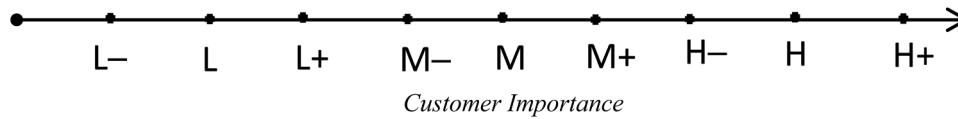


Figure 2. Customer Importance Spectrum.

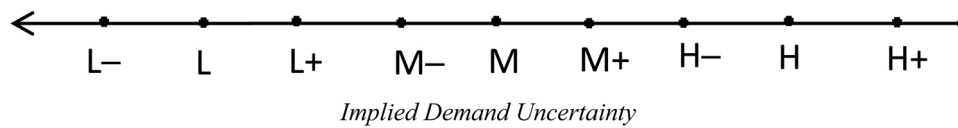


Figure 3. Implied Demand Uncertainty.

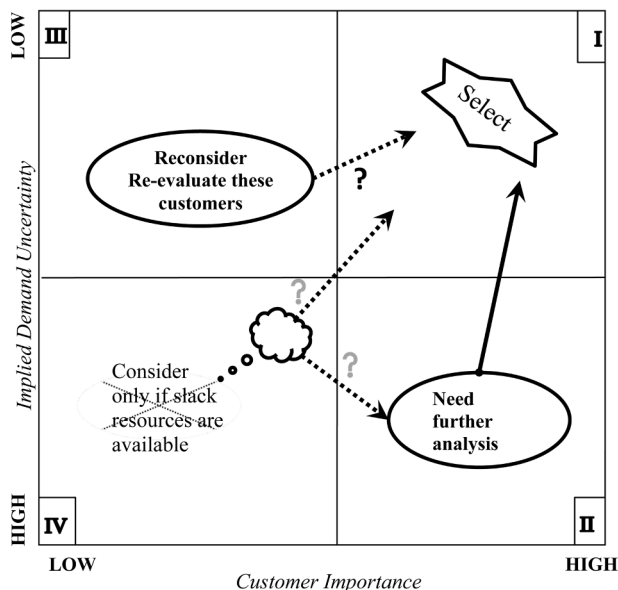


Figure 4. CPI Matrix.

represents customer importance (Step 3) and its vertical axis denotes the implied demand uncertainty (Step 4).

The CPI matrix is further divided into four unique quadrants, each requiring its own distinct SC strategy to provide the required responsiveness. A quadrant can be thought of as a customer segment—a group of customers sharing the same characteristics (e.g., they are the source of high revenue for the firm). The strategy for each quadrant depends on the degree of the customer importance and extensity of the implied demand uncertainty that the customers of that quadrant exhibit.

STEP 6. Position the Customers in the CPI Matrix: For each customer of the firm, considering its priority (Figure 2) and implied demand uncertainty (Figure 3), determine the quadrant to which that particular customer belongs and specify the precise location of the customer in that quadrant.

STEP 7. Use CPI matrix to Determine Customer Fulfilment Strategy: Customer fulfillment (or order fulfillment) is the mainstay of success for any company and, due to limited resources, there is no one-size-fits-all strategy. CPI matrix can help formulate distinct and practical customer fulfillment strategies.

As indicated by the CPI matrix (Figure 4), those customers of the firm that are situated in quadrant I are the most important customers of the

firm and their prospective demands are characterized by relatively low levels of *implied* demand uncertainty. Thus, it makes business sense for the firm to first and foremost select these customers to fulfill their demands in the most satisfactory manner. The choice between quadrants II and III is subject to debate. For instance, although customers in quadrant III are less important than the customers in quadrant II, they exhibit low levels of *implied* demand uncertainty. Thus, it may be easier for the firm to fulfill their demands. On the contrary, the customers in quadrant II are highly important to the firm (compared to customers in quadrant III), and the firm may decide to fulfill their demand, even though they demonstrate a relatively high level of *implied* demand uncertainty. Customers in quadrant IV receive the lowest priority to fulfill their demand since they are characterized as having the lowest importance among all customers with the highest levels of *implied* demand uncertainty.

The next step determines the relative weights for the four quadrants of the CPI matrix.

STEP 8. Allocate SC Resources: Apply AHP to obtain the relative weights of the four quadrants of the CPI matrix and use these weights to formulate the GP model for resource allocation for customer fulfillment. As an initial activity in this step, the criteria for responsiveness of order fulfillment will be identified and, considering these criteria, weights for the four quadrants of the CPI matrix will be determined. These weights, reflecting the relative importance of the four customer segments, will be used to formulate the GP model. Solving the resultant GP-AHP model provides the allocation of the SC resources among customers in various quadrants of the CPI matrix as well as the customers within each quadrant.

To further elaborate on the *implied* demand uncertainty, consider an order placed by a customer (let us say a manufacturer) with ample lead time for MRO (maintenance, repair, operations) parts to be used for a scheduled maintenance. The *implied* demand uncertainty for this order is much less than another order placed by the same customer, ordering the same parts for an emergency repair for a machine that just broke on the assembly line. This brings the entire production line to a standstill. While the firm's SC can most efficiently handle the former situation, it will need a heavy commitment of resources (e.g. the fastest possible transportation mode available) to fulfill the latter demand in a responsive manner.

5. An Illustrative Example

Consider a hypothetical case in which a manufacturer is facing complaints from its customers about delayed deliveries and the inability to handle order changes in a timely manner. This manufacturer's top management decided to follow the methodology suggested in this paper to categorize their customers into four groups and use different SC strategies to fulfill their demands and allocate SC resources among them. This is explained in the following steps:

STEP 1. Determine the SC Strategy: Manufacturer's top management agreed on the following business objectives for the firm:

- 1) Profit
- 2) Productivity and quality
- 3) Growth
- 4) Customer retention
- 5) Social and ethical concerns

To satisfy the above strategic objectives, the manufacturer's VP operations, SC director, and SC managers, agreed on the following SC criteria:

- a) Supplier management
- b) Responsiveness and efficiency
- c) Integration

STEP 2. Conduct the Delphi Inquiry: The SC department selected a team of SC experts to act as the monitor team to conduct the Delphi inquiries to determine the criteria to be used to split the firm's customers into different segments. The monitor team elicited from the following criteria from the respondents:

- a) Annual revenue generated from the customer (C1)
- b) Customer loyalty (C2)
- c) Potential for growth (C3)
- d) Potential for cross sell (C4)

STEP 3. Use AHP to Rank the Customers: After identifying the criteria, AHP was used to obtain their relative weights. Figure 5 shows the AHP hierarchy and Table 1 demonstrates the criteria, the PWC matrix and the relative weights. Unlike its common application for ranking alternatives, AHP was used here only to obtain weights for the criteria. It should be noted that enforcing AHP at this step is intentional since it requires the Delphi participants to critically evaluate the criteria and become more familiar with their tradeoffs when determining the entries for the PWC matrix. Furthermore, filling out PWC matrices coupled with the iterative process of the Delphi establishes a meaningful dialogue among the participants (e.g., SC managers) and helps them describe and refine their thinking, get clarity on the objectives/criteria, and the alternatives.

STEP 4. Determine the Implied Demand Uncertainty: Although the Delphi method can be used at this step, assume that in a face-to-face meeting held by the SC managers (considering the historical information about customer demand) they agreed on the following factors as the indicators of the *implied* demand uncertainty:

- a) Short lead time (D1)
- b) Frequent order changes (D2)
- c) Frequent quantity changes (D3)

Similar to Step 3, AHP was performed here to determine the weights for various indicators of the *implied* demand uncertainty (Table 2).

STEP 5. Construct the Customer Priority Index (CPI) Matrix: This is a straightforward step. Simply construct a matrix (e.g., figure 4), label the axes and on each axis identify various degrees of progression from very low (L-) to very high (H+) and specify the four quadrants.

STEP 6. Position the Customers in the CPI Matrix: Assume the firm has eight customers, A, B, C, D, E, F, G and H. To find the proper position of each customer in its prospective quadrant in the CPI, all customers will be evaluated along the two dimensions of the CPI matrix in the following manner.

- a) The horizontal axis of the CPI matrix represents the composite weight (i.e., the weight considering all criteria) for each customer, and is obtained as follows:

Considering the four criteria determined earlier for customer evaluation (Step 3), construct an AHP hierarchy. Table 3 presents the PWC matrix considering only criterion 1 (annual revenue accrued from a customer). Since there are four criteria, three additional PWC matrices should also be created.

Table 4 presents the weights for all customers, considering all criteria. The last column in table 4 indicates a customer's position on the horizontal axis of the CPI matrix.

- b) The vertical axis in the CPI matrix represents the extensity of *implied* demand uncertainty for customers and will be calculated in a similar manner to the way the customer importance was determined. Table 5 gives the composite weights for the *implied* demand uncertainty for

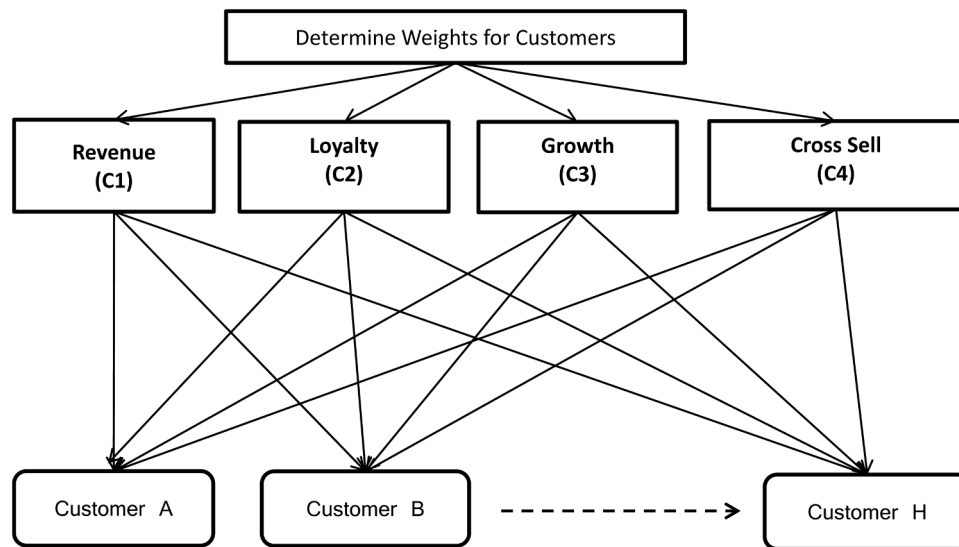


Figure 5. AHP Hierarchy for Customer Ranking.

Table 1
Criteria Weights for Customer Evaluation.

Evaluation Criteria	C1	C2	C3	C4	AHP Weights (CR = 8.3%)
C1	1	4	6	8	0.63
C2	1/4	1	2	4	0.20
C3	1/6	1/2	1	3	0.12
C4	1/8	1/4	1/3	1	0.05

Table 2
Weights for the Elements of the *Implied* Demand Uncertainty.

Indicators of the <i>Implied</i> Demand Uncertainty	D1	D2	D3	AHP Weights (CR = 3.2%)
D1	1	4	6	0.54
D2	1/4	1	2	0.30
D3	1/6	1/2	1	0.16

Table 3
Customer Importance ranking for criterion 1.

C1	A	B	C	D	E	F	G	H	Weights
A	1	1/8	1/3	1/9	1/5	1/9	2	1/4	2.6%
B	8	1	5	1/2	4	1/2	7	4	20%
C	3	1/5	1	1/6	1/2	1/6	3	1/2	4.8%
D	9	2	6	1	4	1	8	3	26.4%
E	5	1/4	2	1/4	1	1/4	5	2	8.9%
F	9	2	6	1	4	1	8	5	28%
G	1/2	1/7	1/3	1/8	1/5	1/8	1	1/4	2.2%
H	4	1/4	2	1/3	1/2	1/5	4	1	7.3%

all customers, considering all criteria. The last column in Table 5 indicates a customer's position on the vertical axis of the CPI matrix.

The capital letters in the last columns of Tables 4 and 5 specify the position of each of the eight customers on the two spectra for customer importance (Figure 2) and *implied* demand uncertainty (Figure 3). Although these letters are subjective judgment(s) of the decision makers, they should reflect and be consistent with the total scores shown in the adjacent columns. Using the information in the last columns of Tables 4 and 5, the firm's customers can be situated in the four quadrants of the CPI matrix (Figure 6).

STEP 7. Use CPI Matrix to Determine Customer Fulfilment Strategy: Referring to the CPI matrix (Figure 6), customers in quadrants I and II (customers D, F, H, B) are the most important to the firm. In addition, customers D, F and H, exhibit a low level of *implied* demand uncertainty. Thus, fulfilling their demand is quite straightforward. Consequently, customers D, F, and H get the highest priority for demand fulfillment. On the contrary, customer A (Quadrant IV), characterized by low importance and high *implied* demand uncertainty, gets the lowest priority for demand fulfillment. Considering customer B (Quadrant III), due to its high importance, the SC managers decided to fulfill its demand before attending to the demands of customers C, E, and G (Quadrant III). These preferences are reflected in the formation of the PWC matrices for the four quadrants (step 8).

To form a composite measure that captures both relative importance and *implied* demand uncertainty for various customer segments, the next step requires using AHP to obtain the weights for the four quadrants taking these two dimensions into consideration.

STEP 8. Allocating SC Resources: In order to allocate organizational resources more justly and equitably, it is imperative to combine the customer importance with the *implied* demand uncertainty. To this end, AHP is used in this step to obtain relative weights for the four quadrants of the CPI matrix. This manufacturer's top management decided that to gain competitive advantage, the firm should focus on responsiveness and manage the *implied* demand uncertainty. In a meeting, the top management determined that the elements of responsiveness important to the firm were those identified for *implied* demand uncertainty, namely, to deal with (1) the short lead time—LT, (2) frequent changes in orders—ORD, and (3) frequent changes in quantity—QNT. Top management firmly believes that handling these three situations would address all Pareto Customers' concerns and greatly improve customer satisfaction, thereby adding to the firm's image. Figure 7 depicts the AHP hierarchy for the 4 quadrants of the CPI matrix.

To obtain the weights for the four quadrants of the CPI matrix (Q1, Q2, Q3 and Q4) using AHP, initially a PWC matrix for the criteria (LT, ORD, QNT) should be constructed (Table 6).

Next, three PWC matrices will be created to compare the four quadrants of the CPI matrix to one another, considering one criterion at a time. Finally, the weights will be augmented to obtain the overall weight for the quadrants of the CPI matrix. Table 7 provides the overall weights for the quadrants of the CPI matrix, considering all the three criteria for responsiveness. These weights, reflecting the relative importance of each quadrant, will be subsequently used in formulating

Table 4
Overall Customer Importance Ranking.

Customer	Criteria/Weights (table 1)				AHP Weights	% of the Largest Weight	Position on the Importance axis
	C1 (0.63)	C2 (0.20)	C3 (0.12)	C4 (0.05)			
A	0.02	0.04	0.03	0.03	0.0257	10	L -
B	0.20	0.23	0.25	0.17	0.2105	83	H +
C	0.05	0.03	0.02	0.03	0.0414	17	L +
D	0.26	0.13	0.07	0.18	0.2072	81	H
E	0.09	0.09	0.05	0.13	0.0872	35	M -
F	0.28	0.19	0.27	0.19	0.2563	100	H ++
G	0.02	0.05	0.01	0.09	0.0283	12	L
H	0.07	0.23	0.29	0.19	0.1339	53	M +

Table 5
Supply Chain Implied Demand Uncertainty.

Customer	Factors/Weights (table 2)			AHP Weights	% of the Largest Weight	Position on the Implied Demand Uncertainty axis
	D1 (0.54)	D2 (0.30)	D3 (0.16)			
A	0.35	0.20	0.21	0.2826	100	H ++
B	0.20	0.19	0.26	0.2066	74	H -
C	0.07	0.01	0.10	0.0568	21	L
D	0.07	0.18	0.10	0.1078	39	L +
E	0.13	0.14	0.05	0.1202	43	M -
F	0.07	0.03	0.09	0.0612	22	L -
G	0.07	0.2	0.05	0.1058	38	L
H	0.04	0.04	0.14	0.0560	20	L -

Table 6
Ranking the Responsiveness Criteria.

CRITERIA	LT	ORD	QNT	Weight (CR = 1.0 %)
LT	1	5	8	54.0
ORD	1/5	1	3	29.7
QNT	1/8	1/3	1	16.3

Table 7
Overall Weights for CPI Quadrants based on all Criteria.

Quadrant	LT (54.0)	ORD (29.7)	QNT (16.3)	Normalized Overall Weights
Q1	56.4	45.4	42.4	0.507
Q2	24.2	23.8	22.7	0.239
Q3	13.9	21.5	22.7	0.177
Q4	5.4	9.2	12.2	0.077

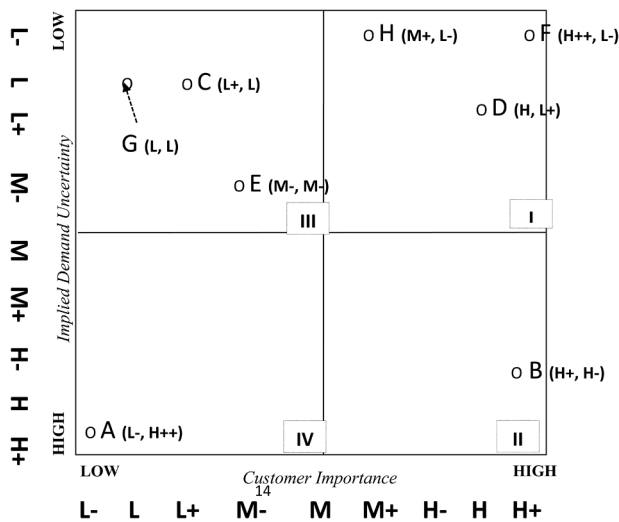


Figure 6. Customers Position in CPI Matrix.

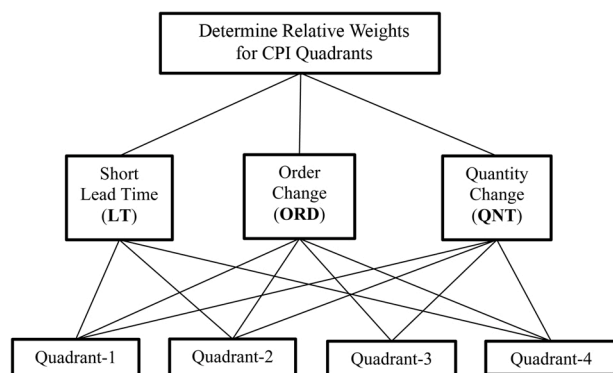


Figure 7. CPI Quadrants Hierarchy Structure.

the GP model for resource allocation.

The next activity in this step is to formulate the GP-AHP model. To demonstrate the applicability of the proposed model, three scenarios are considered. The first two scenarios utilize weighted GP (WGP) while the last uses preemptive GP (PGP). The implicit assumption in using WGP is that the SC managers, considering all the data about all the customers' demand and patterns of their past orders, decided that even though the customers differ in their degree of importance, the differences among them are adequately addressed by the composite weights, i.e., the variances among the weights are not highly significant to justify PGP. However, in the last scenario, PGP is used because the SC managers agree that there is a significant difference among the customers situated in quadrants 1 and 2 of the CPI matrix compared to the customers in quadrants 3 and 4.

5.1. Weighted Goal Programming Formulation:

Decision variables and Parameters

The decision variables and parameters of the GP-AHP model are:

Table 8
Composite Weights.

Customer	AHP Weights Cust. Import. (W_1)	AHP Weights Impl. Demand Uncertainty (W_2)	$\frac{1}{W_2}$ Normalized	Composite Weights $[W_1 + (1/W_2)]/2$
A	0.0257	0.2826	0.039	0.03
B	0.2105	0.2066	0.053	0.13
C	0.0414	0.0568	0.194	0.12
D	0.2072	0.1078	0.102	0.16
E	0.0872	0.1202	0.092	0.09
F	0.2563	0.0612	0.180	0.22
G	0.0283	0.1058	0.104	0.07
H	0.1339	0.0560	0.196	0.17

WC_i^{AHP} AHP weight for Customer i ($i = A, B, \dots, H$). These are the composite weights, shown in table 8.

WQ_j^{AHP} AHP weight for Quadrant j ($j = 1, 2, 3, 4$). These weights are used

in the inter-quadrant comparison of the customers (table 7).

X_i Percent of the SC budget allocated to customer i ($i = A, B, \dots, H$)

d_n^+ Overachievement of goal n

d_n^- Underachievement of goal n

SCENARIO-0

This is considered as the base case. The SC managers are eager to meet the budgetary constraint and assign SC resources among the customers based on their composite weights (table 8). These weights are used in the objective function of the WGP to reflect the relative importance of the customers. Below is a detailed discussion of scenario-0 and its WGP formulation.

1) Resource Allocation Goals

It is desirable to allocate comparatively more of the SC resources to a customer that is relatively more important than other customers and exhibits a relatively lower implied demand uncertainty. The composite weight for each customer (table 8) adequately captures both of these factors and is used, for a customer, as the achievement level for that customer's goal.

2) System constraints

The SC managers decided on the following:

- The entire SC budget must be used.
- Within each quadrant, customers with higher position will be allocated more resources than others. SC managers determined the following preferences for the customers within each quadrant:

Considering the customers in Quadrant I : $X_F > X_D$ and $X_D > X_H$

Considering the customers in Quadrant III : $X_C > X_E$ and $X_E > X_G$

- Resources allocated to the customers in different quadrants of the CPI matrix must be proportional to the weights for those quadrants.

WGP formulation

OBJECTIVE FUNCTION:

$$\text{Min : } WC_A^{AHP} d_1^- + WC_B^{AHP} d_2^- + \dots + WC_H^{AHP} d_8^- \quad (1)$$

1) GOALS

$$\text{Customer A : } X_A + d_1^- - d_1^+ = 0.03 \text{ (minimize } d_1^-) \quad (2)$$

$$\text{Customer B : } X_B + d_2^- - d_2^+ = 0.13 \text{ (minimize } d_2^-) \quad (3)$$

$$\text{Customer C : } X_C + d_3^- - d_3^+ = 0.12 \text{ (minimize } d_3^-) \quad (4)$$

$$\text{Customer D : } X_D + d_4^- - d_4^+ = 0.16 \text{ (minimize } d_4^-) \quad (5)$$

$$\text{Customer E : } X_E + d_5^- - d_5^+ = 0.09 \text{ (minimize } d_5^-) \quad (6)$$

$$\text{Customer F : } X_F + d_6^- - d_6^+ = 0.22 \text{ (minimize } d_6^-) \quad (7)$$

$$\text{Customer G : } X_G + d_7^- - d_7^+ = 0.07 \text{ (minimize } d_7^-) \quad (8)$$

$$\text{Customer H : } X_H + d_8^- - d_8^+ = 0.17 \text{ (minimize } d_8^-) \quad (9)$$

2) SYSTEM CONSTRAINTS

i) Budget Constraint:

$$\sum_{i=A}^H X_i = 1 \quad (10)$$

ii) Intra-Quadrant Constraints:

$$X_F - X_D \geq 0 \quad (11)$$

$$X_D - X_H \geq 0 \quad (12)$$

$$X_C - X_E \geq 0 \quad (13)$$

$$X_E - X_G \geq 0 \quad (14)$$

- Inter-Quadrant Constraints: Considering customer H (quadrant 1) and customer B (quadrant 2), the following relationship is required:

$$\frac{X_H}{0.509} \cong \frac{X_B}{0.239}$$

The constraint related to this equation can be written as:

$$0.239 X_H - 0.509 X_B = 0 \quad (15)$$

The constraint comparing customer B (quadrant 2) to customer C (quadrant 3) can be written as:

$$0.177 X_B - 0.239 X_C = 0 \quad (16)$$

The constraint for comparing customer G to customer A can be written as:

$$0.077 X_G - 0.177 X_A = 0 \quad (17)$$

3) NON-NEGATIVITY CONSTRAINTS:

$$X_i \geq 0, i = A, B, \dots, H$$

$$d_j^+, d_j^- \geq 0, j = 1, 2, 3, 4, 5, 6, 7, 8$$

It is important to note that since the goals are commensurable in this scenario and the subsequent scenarios, normalization is not necessary.

The solution to the above GP-AHP model determines the percent of the resources (e.g. SC budget) that the SC department should allocate to each of its customers. The results are shown below:

Customer:	A	B	C	D	E	F	G	H
Percent Allocation:	2.6	8	5.9	17	5.9	38	5.9	17

SCENARIO-1

Unlike the previous scenario, the SC managers decided to relax the strict intra-quadrant constraints and pursue them as goals, shown below:

$$X_F - X_D + \eta_1^- - \eta_1^+ = 0 \quad (18)$$

$$X_D - X_H + \eta_2^- - \eta_2^+ = 0 \quad (19)$$

$$X_C - X_E + \eta_3^- - \eta_3^+ = 0 \quad (20)$$

$$X_E - X_G + \eta_4^- - \eta_4^+ = 0 \quad (21)$$

In addition, the inter-quadrant constraints were also considered as goals, depicted below:

$$0.239 X_H - 0.509 X_B + \eta_5^- - \eta_5^+ = 0 \quad (22)$$

$$0.177 X_B - 0.239 X_C + \eta_6^- - \eta_6^+ = 0 \quad (23)$$

$$0.077 X_G - 0.177 X_A + \eta_7^- - \eta_7^+ = 0 \quad (24)$$

Equations 18-24 represent the constraints for Scenario-1. The non-negativity constraints are:

$$X_i \geq 0, i = A, B, \dots, H$$

$$\eta_j^+, \eta_j^- \geq 0, j = 1, 2, 3, 4, 5, 6, 7$$

The objective function, assuming equal weights for the goals, would be to minimize the sum of the under-achievements of the goals:

$$\text{Minimize : } \sum_{i=1}^7 \eta_i^- \quad (25)$$

The solution to this scenario yields the following results:

Customer:	A	B	C	D	E	F	G	H
Percent Allocation:	0	10	8	22	8	22	8	22

5.2. Preemptive Goal Programming Formulation

SCENARIO-2

The SC managers, after a lengthy discussion and pondering on the weights they had chosen for PWC matrices, unanimously decided to revise those matrices. Applying AHP once more produced new weights for the four quadrants of the CPI matrix (Table 9).

Examining these weights (Table 9), SC managers agreed on the following priorities for the customers. They also decided to pursue the goals identified in scenario-0.

Priority level 1 (P_1) to denote the highest priority: customers **F, D, H**

Priority level 2 (P_2) to denote the next highest priority: customer **B**

Priority level 3 (P_3) to denote the third level priority: customers **C, E, G**

Priority level 4 (P_4) to denote the lowest priority: customer **A**

Considering the same deviational variables chosen in scenario-0, the objective function would be:

$$\text{Min : } P_1(d_4^- + d_6^- + d_8^-), P_2(d_2^-), P_3(d_3^- + d_5^- + d_7^-), P_4(d_1^-) \quad (26)$$

The constraints and goals would be the same as scenario-0, with the exception of the intra-quadrant constraints which will change to the following, to reflect the updated weights in Table 9.

$$0.30 X_H - 0.51 X_B = 0 \quad (27)$$

The constraint comparing customer B (quadrant 2) to customer C

Table 9

Overall Weights for CPI Quadrants – Revised Weights.

Quadrant	LT (48.5)	ORD (40.0)	QNT (11.5)	Normalized Overall Weights
Q1	58.0	46.4	35.6	0.51
Q2	30.8	30.2	30.0	0.30
Q3	8.2	12.0	20.4	0.11
Q4	3.0	11.4	14.0	0.08

$$(\text{quadrant 3}) \text{ is: } 0.11 X_B - 0.3 X_C = 0 \quad (28)$$

The constraint for comparing customer G to customer A is:

$$0.08 X_G - 0.11 X_A = 0 \quad (29)$$

The solution to the PGP model is presented below:

Customer:	A	B	C	D	E	F	G	H
Percent Allocation:	3	13	12	28	10	28	8	28

6. Discussion of the results

The results of the three scenarios are shown in Table 10.

The results given in Table 10 are consistent with the importance ranking of the customers and their implied demand uncertainties. In scenario-0, the customers within each quadrant receive the same allocation with the exception of customer F in quadrant 1 which has the highest allocation. Customer A gets the smallest resource allocation since it has the lowest composite weight among all the customers. Scenario-1 focuses solely on comparing the customers based on the quadrant in which they are situated. It basically generates the same results: all customers in a particular quadrant are allocated equal resources. Customer A receives zero allocation, mainly due to the very low weight for quadrant 4 in which customer A is situated. Yet, such an extreme solution and whether to attend to at least some "easy to fulfill" portion of the demand by customer A is subject to considerable managerial discussions. Based on the authors' interviews with some large U.S. companies, the decision for them was to leave customers such as A as the last priority and only serve their demands when all other important customers had been adequately attended to and were fully satisfied with the service they received. In other words, the interviewed firms never sacrificed the interest of the more important customers for those that were characterized by very low importance.

The magnitude of the allocation of resources to different customers, determined by WGP or PGP in the suggested methodology is dependent on the relative weights of the quadrants of the CPI matrix and the composite weight for each customer. Thus, the choice between WGP and PGP is also dependent on the aforementioned quantitative factors and qualitative factors for the firm's perception of its customers. Table 11 presents the total allocation to each quadrant of the CPI matrix for each of the three scenarios.

Based on Table 11, Scenario 2 (applying PGP), provides relatively more equitable results and has a reasonably even distribution of the resources compared to the other two scenarios which use WGP. For instance, Scenario-0 (applying WGP) uses almost 75% of the entire resources for the customers of quadrant 1 and leaves only 25% for the rest of the customers. On the contrary, scenario 2 (applying PGP) allocates only 55% of the resources to quadrant 1 customers and assigns 13%, 28%, and 3% to customers of quadrants 2, 3 and 4 respectively.

7. Strength and shortcomings of the proposed model

The proposed methodology integrates the well-established Delphi method with two widely used multi-criteria decision-making models: AHP and GP. It provides a systematic approach to establish customer priority. A unique feature of the proposed methodology is measuring the implied demand uncertainty for each customer and incorporating it in the resource allocation decision. By capturing both the qualitative and

Table 10

Resource Allocation.

Customer	A	B	C	D	E	F	G	H
Scenario 0	2.6	8	5.9	17	5.9	38	5.9	17
Scenario 1	0	10	8	22	8	22	8	22
Scenario 2	3	13	12	28	10	28	8	28

Table 11
Resource Allocation - Quadrants of the CPI Matrix.

Quadrant	1	2	3	4
Scenario 0 WGP	72%	8	17.7	2.6
Scenario 1 WGP	66%	10	24	0
Scenario 2 PGP	55%	13	28	3

quantitative judgements of the decision makers, the suggested methodology can lead to a more equitable allocation of SC resources.

In addition, since the Delphi is anonymous, it provides an environment in which the decision makers and other stakeholders can express their ideas regarding their evaluations of the firm's customers their perceptions of the usage of SC resources. The Delphi facilitates brainstorming and enables reaching consensus. In turn consensus can result in a more agreeable solution and higher cooperation in its implementation.

Another significant benefit of the Delphi, as used in the proposed methodology, is the certainty that it offers in capturing the *implied* demand uncertainty, particularly in this proposed methodology. While demand uncertainty can be more agreeable, *implied* demand uncertainty involves several factors such as lead time, variety and volume, degree of innovation, and customer relationship. It can also be a source of lengthy disputes. The anonymity feature of the Delphi provides a more reasonable and objective look at the *implied* uncertainties of customer demand.

The proposed methodology also benefits from the multi-criteria features of AHP and GP. AHP allows for a systematic way of structuring a complex problem and breaking it down into manageable pieces. Its strong feature is allowing for a pairwise comparison of criteria and alternatives. GP, unlike linear programming, allows for the consideration of multiple objectives and a performance tradeoff among them.

There are some limitations to the proposed methodology. First is the tedious and perhaps time-consuming process of conducting multiple Delphi inquiries. The second is determining the entries for numerous pairwise comparison matrices of the AHP.

8. Conclusions

This research explains a practical and easy-to-use methodology that can enable decision makers in a firm to evaluate their customers on two distinct, yet very important criteria: *relative importance* and *implied demand uncertainty*. Three well-established and widely used methods were adopted, including the Delphi method, analytical hierarchy process (AHP) and goal programming (GP). The Delphi method and the Analytic Hierarchy Process (AHP) were used to rank the firm's customers and assess their *implied* demand uncertainties. Weights obtained from the AHP were used to construct a customer priority index (CPI) matrix and formulate a goal programming (GP) model for supply chain resource allocation. The application of the proposed methodology was demonstrated through an illustrative example, using weighted goal programming and preemptive goal programming.

Declaration of Competing Interest

None' in the template. This statement will be published within the article if accepted.

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