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RESEARCH PAPER

An Integrated Model for Continuous and Simultaneous Performance Improvement: A SCOR-Based Supply Chain Decision Alignment

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ABSTRACT

This study develops an integrated model of Strategic and operational activities to enhance the efficiency of supply chain management. Furthermore, this paper aims to improve supply chain performance management (SCPM) by employing proper decision-making approaches. For this purpose, a new framework is developed that integrates strategic decisions based on human intelligence with operational decisions that are based on machine intelligence which leads to continuous improvement at different levels of the supply chain. The proposed model optimizes the performance indicator based on SCOR metrics. A process-based method is utilized for high-level decisions, while a mathematical programming method is proposed for low-level decisions. The suggested operational model takes some major supply chain properties such as multiple suppliers, multiple plants, multiple materials, and multiple produced items over several periods into account. To solve the operational multi-objective optimization model, a goal programming approach is applied. The computational results are explained in terms of a numerical example, and a sensitivity analysis is performed to investigate how the performance of the supply chain is influenced by strategic scenario planning.

KEYWORDS: *Decision alignment; Supply chain management; Performance measurement; Goal programing; SCOR model; Decision alignment; Multi objective.*

1. Introduction

Based on the classical definition, supply chain management (SCM) involves three types of decisions, including strategic, operational, and tactical ones [1]. Hence, the alignment of the mentioned decisions as an important issue must be investigated from both academic and scientific viewpoints [2]. Note that, the efficiency of one component of a supply chain (SC) does not guarantee the optimum effectiveness of its overall performance [3]. In addition, taking into account the occurred events in the process which leads to changes in conditions is one of the most important necessities of supply chain management and a requirement for continuous improvement [4]. Performance management is essential for successful organizational competitiveness [5]. It specifies what should be sustained as the company's strength and what requires to be overcome as the weakness [6]. Reliable performance indices are key factors that significantly affect the efficiency of mathematical programming models. In this regards, a variety of indicators are provided to evaluate performance [7]. With the development of digital technology and the emergence of industry 4, researchers focused on the development of evaluation indicators that can quickly and accurately measure performance improvement in the new digital space [8]. In this regard, the supply chain operations reference (SCOR) approach is known as the most common reference model in the literature for evaluating performance management and effective efforts have been made to use it in the industry 4 [9]. It has five major indicators at its highest level, which are partitioned into some partial ones at lower levels C Such structure helps researchers and practitioners to formulate

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comprehensive and effective multi-objective optimization models [10].

This article focuses on two major goals: (1) transmitting the strategic decisions into operational ones by aligning different decision levels to promote supply chain performance management (SCPM), and (2) employing appropriate decision-making models in each level to enhance the competitiveness of the supply chain. Based on the aforementioned explanations, the following characteristics should be considered for better evaluation and optimization of a supply chain: (1) taking conflicting indicators into account; (2) recognizing external and internal factors affecting supply chain performance; (3) continuous improvement of supply chain performance based on the latest changes in external and internal factors; (4) simultaneous use of human intelligence and machine intelligence in decision making; (5) coordination between decisions based on human intelligence and machine intelligence; and (6) determining steps to improve supply chain targets based on industry benchmarks. This study aims to provide a performance evaluation framework by taking all mentioned characteristics into account. To accomplish that, SCM decisions are divided into two basic levels due to their nature: human-intelligence and machine-intelligence-based decisions. This study develops a process-based method and a multi-objective technique to identify high-level and low-level decisions, respectively. Then, a novel intermediate multi-objective method is utilized to align high-level decisions with low-level ones. For handling the SCM resource constraints, which are equivalent to assigning high priorities to only a small number of objective functions, the proposed method employs a prioritization approach to solve the multi-objective model at the strategic level because we can [11]. The operational aspects in the proposed mathematical model take some important SC features, including multi-echelons, several materials, multiple suppliers, multiple plants, and several products during multiple periods into account. To solve the operational multi-objective optimization problem, a GP technique is employed. The proposed model optimizes the performance indicator based on SCOR metrics. The proposed conceptual framework is summarized in Figure 1:

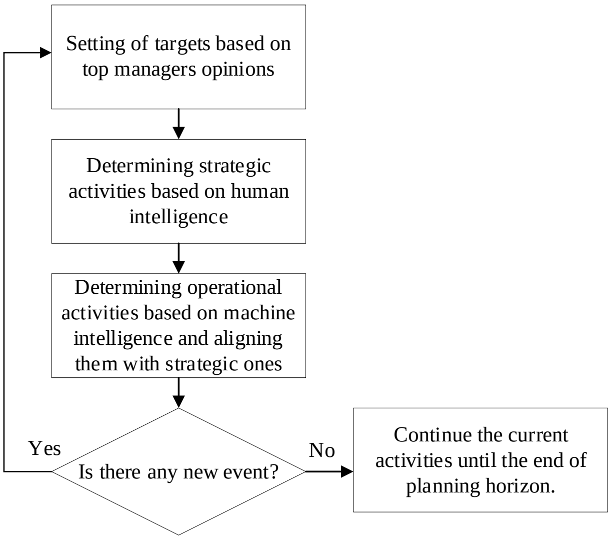

Fig. 1. Conceptual framework

The rest of this article is structured as follows. In Section 2, a review of the recently published studies on SCPM is presented. In Section 3, the proposed SCPM framework is presented. In Section 4, a mathematical programming model for SC is illustrated. In Section 5, the computational results are explained in terms of a numerical example. Then, the sensitivity of the proposed model on the strategic scenario planning is analyzed. Finally, Section 6 is dedicated to concluding remarks and recommendations for further research.

2. Literature Review

Due to the complexity of supply chain performance management, numerous attempts have been undertaken in this domain by researchers over the past years [12-14]. In this regard, Estampe *et al*. [15] proposed a survey to classify and analyze the most important characteristics of performance management. To accomplish that, first, they defined five levels for the SC maturity grid. Afterward, they compared

16 frameworks, including conditions, constraints, indicators, usage, type, and conceptualization degree. Finally, they discussed the limitations and efficacy of the selected frameworks. Najmi *et al*. [16] studied the existing literature by taking indicators, procedures, and techniques for performance evaluation into account. Singh and Acharya [17] studied the critical factors that affected the supply chain's performance and discussed the popular performance management tools among researchers. Using a two-stage framework, Schaltegger *et al* [18] first employed the neighborhood rough set theory to determine the key performance indicators (KPI) for supply chain performance evaluation. Then, based on the KPI identified in the first stage, they benchmarked and investigated the relative performance using data envelopment analysis (DEA). Abou-Eleaz *et al*. [19] provided a critical review in the context of evaluating supply chain performance by considering the quality factors, type of flows, human capital, type of benchmarking, maturity level of the supply chain, decision level, and sustainability.

2.1. Decision alignment

Extensive studies have been conducted to integrate decisions in the supply chain [4]. In this context, some researchers have investigated the impact of integrating decisions on supply chain performance. For example, some studies have studied the mentioned effect on the sustainability of the supply chain [20]. Supply chain management is a complex process in which decisions should be made via an integrated system [21-23]. The efficient optimization method and continuous improvement of the entire supply chain are the major concerns that must be addressed at various levels of the supply network [24]. The major objectives of SCPM models are deployed at the strategic level, while the operational level involves actions that produce value-added items [25-28]. All decisions which are made at strategic, operational, and tactical levels must be well-optimized in line with the main objectives of supply chain management. The issue is to formulate strategic and operational goals and connect them properly [29]. Although decision alignment is a basic factor involved in SCM, most existing studies in this context have considered the decisions at different levels of SC independently. Note that some of such decisions are related to the organization, while some are associated with the facilities. As mentioned, decisions should be integrated for aligning the supply chain strategies. Generally, the decisions are integrated based on comprehensive mathematical models while some researchers have used simulation-based methods [30].

2.2. Performance management

Performance management involves the techniques and principles to enhance the performance of organizations/companies, while performance measurement focuses on the establishment of performance indicators and their applications. Performance measurement provides some useful measures and tools for analyzing the outputs and which leads to a sustained improvement in supply chain performance [18]. One of the key aspects of successful supply chain management is to utilize an efficient performance evaluation method [10]. In this regard, Kocaoğlu *et al*. [29] pointed out the necessity of integrating model quantification and performance measurement to select proper supply chain strategies.

To the best of the authors' knowledge, significant attention over the past several years has been paid by the researchers to establishing different frameworks for performance measurement, categorizing the existing indicators, and designing the conceptual models for performance management [31, 32]. However, their capabilities are not adequate due to some shortcomings in the SCPM frameworks [29, 33]. In addition, most of the existing studies are not comprehensive enough in performance evaluation based on performance indicators [34]. Data envelopment analysis is an efficient tool for analyzing supply chain performance [35]. On the other hand, available quantitative models in the literature have mainly relied on individual factors such as financial metrics to investigate the supply network's efficiency [36].

The mathematical formulations to optimize performance management should support exact quantitative measures. SCOR approach is known as the most applicable and common model in the literature of SCPM. This model has been extensively employed in different industries and services [37]. The hierarchical structure of SCOR improves the efficiency of the entire SC because target values for performance indicators are obtained at different levels [38]. Zhang and Reimann (2014) believe that the development of mathematical programming models for performance management affects SC outputs significantly, and SCOR can present appropriate indicators in this research area [39]. This model involves 250 SCOR metrics that are structured in a hierarchical (and codified) way from organization level 1 to process level 2 to diagnostic level 3. The metrics are classified into five performance categories of costs, asset management efficiency, reliability, responsiveness, and agility. The first two attributes are internally focused, while the latter three are considered customer-focused. The basic challenge is to define, rank, and align the competitive requirements for each attribute, knowing that it will have to choose where it will be best in class and where it is acceptable to perform at an average level.

2.3. Process-based models

Some of the existing studies have presented step-by-step and administrative approaches for strategic performance improvement. For example, Cai *et al.* [40] suggested a novel method to recognize key performance indicators (KPIs) for performance management at a strategic level. A performance measurement procedure using a financial approach based on the SCOR model and Analytic Hierarchy Process (AHP) was recommended by Elgazzar *et al*. [41]. Agami *et al*. [42] introduced a successive five-step performance enhancement model to determine the bottleneck of KPIs.

2.4. Mathematical models

Many studies present multi-objective methods for performance improvement. Blanco [43] presented a solution approach to solve an optimization problem with three objective functions. He modeled the problem in terms of linear integer programming and extended a solution approach for it. Two main approaches have been used to solve multi-objective optimization problems consisting of (1) prior approaches, such as the weighting sum technique [44]; and (2) progressive approaches, such as the ϵ-constraint method [45]. A multi-period multi-product mixed integer linear programming model for maximizing profit and minimizing carbon dioxide emissions during the cement production and transportation process has been developed by Hajisoltani et al. [46].

A multi-objective mathematical programming to optimize a multi-period supply chain by considering production, distribution, and capacity planning was introduced by Liu and Papageorgiou [47]. Their proposed model optimizes responsiveness, total cost, and service level as key objectives. Two methods, as solution approaches, were used to tackle the proposed multi-objective problem, i.e., ε-constraint and lexicographic minimax methods. Based on SCOR indicators, Cai *et al.* [48] proposed a multi-objective mathematical programming model and then solved it by PSO algorithm. Zhang and Reimann [39] optimized the SC performance through the concurrent use of five SCOR indicators. Using the SCOR framework, Kocaoğlu *et al*. [29] introduced multiple objective formulations based on establishing a relationship between strategic and operational decisions.

2.5. Goal programing

The structure of the existing GP models in the literature can be generally categorized into two classes: (1) crisp decision-making problems and (2) fuzzy goal programming models. Most studies in this context, such as [10, 39, 49, 50] have focused on the former one. In this regard, an interactive goal programming framework to optimize production processes with virtual manufacturing cells was established by Slomp *et al*. [51]. Mahdavi *et al*. [52] proposed a fuzzy GP approach to optimize a multi-objective model of production planning in a virtual production process. GP is recommended for decision-making problems wherein targets are assigned to all of the attributes, and the decision-maker aims to minimize the deviations between the aspiration levels and the achievement of goals. This optimization method consists of two sets of constraints, including system constraints and goal constraints. The system constraints are formulated following linear programming models, while the goal constraints are auxiliary ones that determine the best solution concerning a set of favorite targets. The mathematical formulation of the GP is given according to the following equation:

$$\text{Minimize} \quad \sum_{i=1}^{n}\left(d_i^+ + d_i^-\right)$$

Subject to:

$$S_j(x) = (\le \text{ or } \ge) \quad (for\ j = 1,2,\dots,m)$$

$$F_i(x) - d_i^+ + d_i^- = G_i \quad (for\ j = 1,2,\dots,m)$$

$$x \in X$$

$$d_i^+ \text{ and } d_i^- \ge 0 \quad (for\ j = 1,2,\dots,m)$$

where $S_j(x)$ denotes the j^{th} system constraint, $F_i(x)$ is the i^{th} goal constraint; and G_i represents the aspiration level of the i^{th} goal. Furthermore, d_i^+ and d_i^- are the positive and negative deviations from the target value of the i^{th} goal, respectively.

$$d_i^+ = \begin{cases} F_i(x) - G_i & if\ F_i(x) \succ G_i \\ 0 & otherwise \end{cases} \quad d_i^- = \begin{cases} G_i - F_i(x) & if\ F_i(x) \prec G_i \\ 0 & otherwise \end{cases} .$$

The most extensively employed achievement functions in goal programming are preemptive GP, Weighted GP, and the Chebyshev structure in which the maximum deviation is minimized. The Weighted GP formulation is given as follows:

$$\begin{aligned} &Minimize\ \ \textstyle\sum_{i=1}^{n} w_i(d_i^+ + d_i^-) \\ &Subject\ to\ \ S_j(x) = (\leq or \geq) 0 \quad (for\ j = 1,2 \ldots, m) \\ &F_i(x) - d_i^+ + d_i^- = G_i \ \ (for\ \mathrm{i} = 1,2 \ldots, n) \\ &x \in X \\ &d_i^+ \text{ and } d_i^- \geq 0 \qquad (for\ \mathrm{i} = 1,2 \ldots, n)\ , \end{aligned}$$

where W_i is the respective positive weight attached to the negative and positive deviations from the target value of the i^{th} objective.

3. SCPM Framework

To establish a sustainable, flexible, adaptable, efficient, responsive, competitive, and robust supply chain network, it is necessary to utilize efficient models and techniques that ascertain profitability and stability. Due to the necessity of supply chain performance management and the mentioned deficiencies, more research should be conducted to fill knowledge gaps in this domain.

To fill the existing research gaps, this study introduces a SCOR-based method to measure, analyze, and enhance the SCPM. In this regard, the structure of the SC is formulated by a multi-objective decision-making model. Then, a goal programming optimization model is developed to solve the mathematical model. The proposed SCPM framework is illustrated in Figure 2. This figure indicates how the proposed SCPM framework considers the six features mentioned in the introduction section, simultaneously. Furthermore, an event detection mechanism is provided to detect external and internal changes in the supply chain based on which new decisions should be updated. It means that, the developed SCPM framework is a dynamic one that makes optimal decisions based on the latest data. Ideally, the three steps of event detection, decision-making, and new action should be performed in real-time.

According to the nature of activities, the proposed method classifies the decisions into two groups: (1) human-intelligence-based decisions and (2) machine-intelligence-based ones. Human-intelligence-based decisions are unstructured, broad, and vague and consider various objectives during each period. These types of decisions are made at the highest level of supply chain performance management and affect all the lower levels. Making human-intelligence-based decisions requires considerable creativity, analysis capability, as well as innovation in different areas where only human intelligence can be utilized. In general, strategy planning problems are addressed at this level. Machine-intelligence-based decisions usually pursue fixed targets during different periods. Such decisions do not often need creativity, considerable ability to analyze and innovation. However, it may require high computing power. At this level, the decisions related to three problems of distribution management, inventory planning, and production scheduling are made.

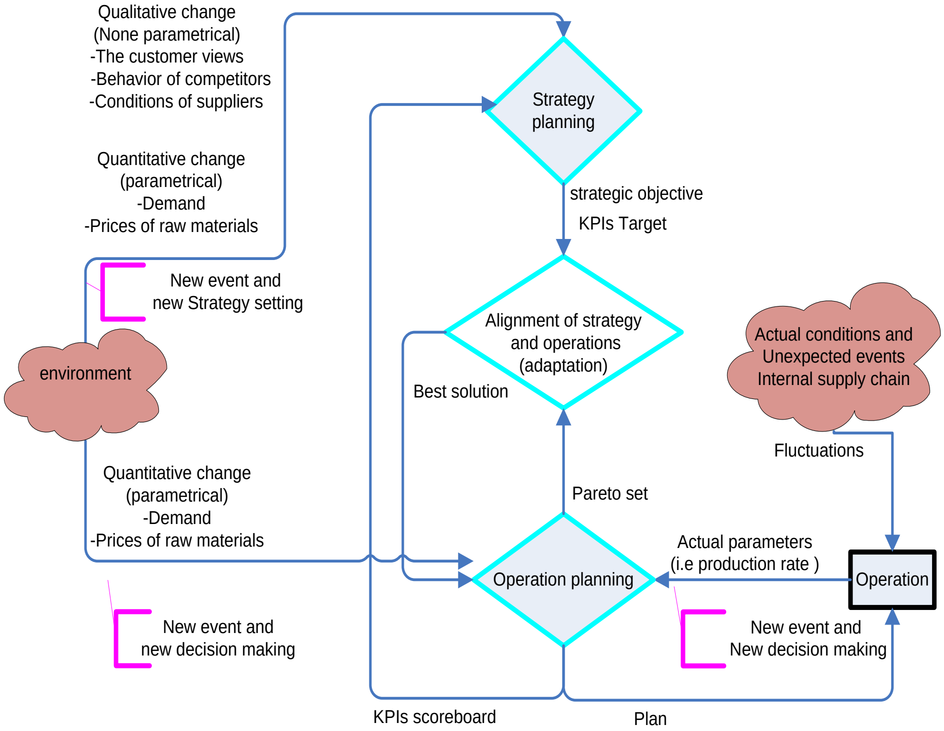

Fig. 2. The proposed IT-based framework for supply chain performance management

A human-intelligence-based has been usually employed for making decisions related to strategic planning. A novel human-intelligence-based decision-making model is proposed in this article which contains the following phases: As seen in Figure 3, strategic objectives are defined in the first phase, denoted by P1 and a prioritization approach is utilized to handle the multi-objective nature of the problem in this phase.

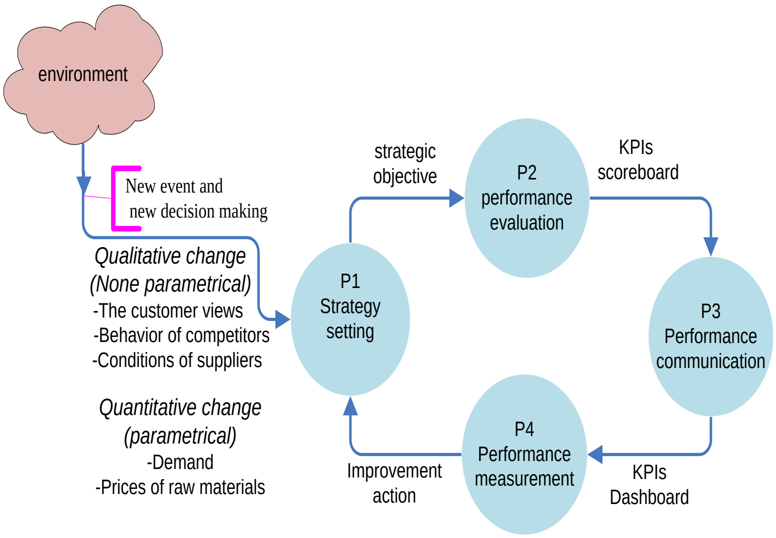

Fig. 3. Decision-making procedure based on human intelligence

The SCOR model, along with its 5 main metrics, is employed to determine objective functions and their characteristics, including priorities, targets, and proper performance benchmarks. According to Table 1, the difference between the actual and target values for each is calculated in the second phase (P2). Afterward, based on the obtained results, a dashboard is used to specify the metrics which are far from their pre-specified expectations during phase three (P3). The recognized metrics are considered performance bottlenecks. Finally, according to the obtained results, the management takes appropriate measures in the fourth phase (P4) to enhance and attain performance indicators of higher levels in subsequent activities.

The information related to SCOR's indicators at the first level involving the current situation, the strategy setting, the objectives priorities, and the difference between the actual and target values is shown in Table 1. Such structure provides a comparative evaluation for decision-makers. The third column represents the observed situation of the supply chain performance management, while columns 4-6 indicate the benchmark quantities of indicators under parity, advantage, and superior levels [40]. Note that the grey cells show the objective priorities. Finally, the difference between the target and current conditions is indicated in the last column. Based on Table 1, reliability holds the first priority, while both responsiveness and assets have the average priority. Finally, flexibility and costs take the lowest priority. To eliminate the obtained gap values, strategic planning is designed by considering the objective priorities.

Tab. 1. Specifying the objectives and strategies of SCOR [53].

Attribute	Metric (level 1)	You	Benchmark			Gap
			Parity	Advantage	Superior	
Reliability	Perfect order fulfillment	95%	92%	95%	98%	3%
Responsiveness	Order fulfillment cycle time	14 Days	8 Days	6 Days	4 Days	8 Days
Flexibility	Supply chain flexibility	62 Days	80 Days	60 Days	40 Days	0 Days
Cost	Supply chain management Cost	12.2%	10.8%	10.4%	10.2%	1.4%
Assets	Cash-to-cash cycle time	35 Days	45 Days	33 Days	20 Days	2 Days

We can develop DSSs using machine intelligence to tackle operational planning problems. In general, the mathematical programming model of operational planning is a multi-objective model. Such models can be automated to a large extent. However, based on the structure and targets of the SC, various types of DSSs should be proposed. In this regard, different quantitative models, such as linear programming (LP), non-linear programming (NLP), deterministic, stochastic, fuzzy, simulation, and meta-heuristic algorithms, can be employed at the machine-intelligence level. Moreover, various types of objectives are precisely defined according to the SCOR metrics. We aim to optimize SC decisions to obtain the highest values of SCOR metrics (Figure 4).

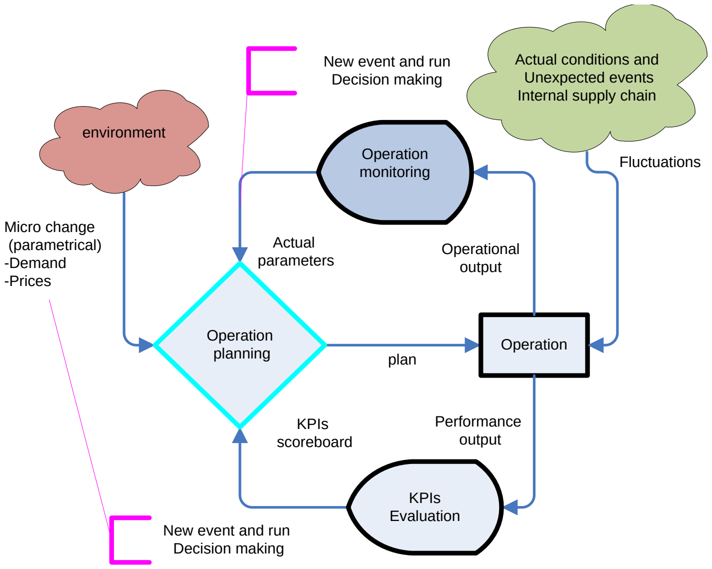

Fig. 4. Decision-making process based on machine-intelligence

4. Problem Formulation

A numerical example is presented in this section to highlight the efficiency of the developed method by considering a two-echelon supply chain that involves several suppliers and plants. A multi-objective optimization formulation for the mentioned supply chain is established. In this example, several products within a family are produced along the supply network, while the planning is done during several periods.

As will be seen in subsection 4.1.1, parameter *T* indicates the number of periods in the planning horizon. In this study, the periods can be different since the demand and production capacity parameters for various periods are not necessarily the same. Note that, the process is executed based on the obtained values of decision variables through optimizing the developed mathematical programming. According to Figure 2, the process run continues until the occurrence of the first change in the process condition and reoptimizing the developed model.

Other features of this two-echelon SC are listed:

- Demands are known and determined during each period.
- Transportation cost from suppliers to plants consists of both variable and fixed terms.
- The parameters are known values and remain constant during each period.
- The developed mathematical formulation aims to (1) reduce the total logistics cost, (2) increase the network's agility, and (3) maximize the supply chain's reliability concurrently.

4.1. Notations

4.1.1. Indices

$i = 1, \dots, I$	Index of suppliers
$j = 1, \dots, J$	Index of plants
$l = 1, \dots, L$	Index of products
$n = 1, \dots, N$	Index of materials
$t = 1, \dots, T$	Index of periods

4.1.2. Parameters

α_{ljt}	Maximum allowance percentage of backordered demand for l^{th} product in j^{th} plant at t^{th} time period
Bsm_{ni}	The batch size that i^{th} supplier provides the n^{th} material
$Capp_{ljt}$	The capacity of the j^{th} plant to manufacture l^{th} produced item during the t^{th} time period
$Caps_{nit}$	The capacity of the i^{th} supplier to provide the n^{th} type of material during t^{th} time period
Cbl_{lj}	The backorder unit cost for l^{th} product in j^{th} plant
D_{ljt}	The demand of the l^{th} product from plant j during the t^{th} time period
Fcr_{nij}	Fixed transfer cost of n^{th} material from i^{th} supplier to j^{th} plant
Hmp_{lj}	Holding cost of l^{th} product in j^{th} plant
Hmr_{nj}	Holding cost of n^{th} material in j^{th} plant
Pc_{lj}	The Production cost of the l^{th} product (except for raw material) in j^{th} plant
Pr_{ni}	Supply price of n^{th} material by the i^{th} supplier
Qp_{l}	The required space for storing per unit of l^{th} product
Qr_{n}	The required space for storing per unit of n^{th} material
SSm_{njt}	Safety stock of n^{th} material in the warehouse of j^{th} plant j at t^{th} time period
Tdr_{nijt}	The time for delivering per batch of n^{th} material from i^{th} supplier to j^{th} plant at t^{th} time period
$Trmax_{nijt}$	Due date of delivering per batch of n^{th} material from i^{th} supplier to j^{th} plant at t^{th} time period
Ur_{nl}	The required volume of n^{th} material to produce per unit of l^{th} product
Vcr_{nij}	Variable transfer cost per unit of n^{th} material from i^{th} supplier to j^{th} plant
Vmp_{j}	The available amount of the finished items in the warehouse of the j^{th} plant
Vmr_{j}	The available amount of raw materials in the warehouse of the j^{th} plant

4.1.3. Decision variables

A_p *(Agility)*	Flexibility: Plant surplus capacity
A_s *(Agility)*	Flexibility: Supplier surplus capacity
C	Supply chain cost
C_s *(Cost)*	Suppliers cost
C_p *(Cost)*	Plants costs
R *(Reliability)*	Perfect order fulfillment

BLg_{lt}	Backorder level of the l^{th} product in j^{th} plant at t^{th} time period
Ipm_{ljt}	Inventory level of l^{th} product in j^{th} plant at the end of t^{th} time period
IRm_{njt}	Inventory level of n^{th} material in j^{th} plant at the end of t^{th} time period
Q_{ljt}	Sale quantity of l^{th} product by j^{th} plant at t^{th} time period
TR_{nijt}	Arrival time of n^{th} material from i^{th} supplier to j^{th} plant at t^{th} time period
W_{nijt}	1; If j^{th} plant orders n^{th} material to i^{th} supplier at t^{th} time period, 0; otherwise

X_{nijt}	The volume of the nth material provided by ith supplier to jth plant at tth time period
Y_{ljt}	The volume of lth item produced by jth plant at tth time period

4.2. The mathematical model

Here, an endeavor is made to employ the proposed SCOR model to design decision models. Without loss of generality, only three indicators of cost, agility, and reliability are considered to implement the model.

4.2.1. Minimize *C* (Cost)

$$C = C_s + C_p \tag{1}$$

$$C_s = \sum_t \sum_n \sum_i \sum_j X_{nijt} \times Pr_{ni} + \sum_t \sum_n \sum_i \sum_j W_{nijt} \times Fcr_{nij} + \sum_t \sum_n \sum_i \sum_j X_{nijt} \times Vcr_{nij} + \sum_t \sum_n \sum_j Hmr_{nj} \times IRm_{njt} \tag{2}$$

$$C_p = \sum_t \sum_l \sum_j \mathrm{Y}_{ljt} \times \mathrm{Pc}_{lj} + \sum_t \sum_l \sum_j Hmp_{lj} \times Imp_{ljt} + \sum_t \sum_l \sum_j Cbl_{lj} \times BLg_{ljt} \tag{3}$$

4.2.2. Maximize *A* (agility)

$$A = A_s + A_p \tag{4}$$

$$A_s = \sum_t \sum_n \sum_i \left(Cap_{nit} - \sum_j X_{nijt} \right) \tag{5}$$

$$A_p = \sum_t \sum_l \sum_j \; Cap_{ljt} - Y_{ljt} \tag{6}$$

4.2.3. Maximize *R* (reliability)

$$R = \sum_t \sum_l \sum_j R_{tlj} \tag{7}$$

$$R_{tlj} \le Y_{ljt} + Ipm_{ljt} \quad \forall l, j \text{ and } \forall t \in [1, T] \tag{8}$$

$$R_{tlj} \le D_{ljt} \quad \forall l, j \text{ and } \forall t \in [1, T] \tag{9}$$

As the first objective, the total cost of the supply chain consists of supplier's costs ($\boldsymbol{C_s}$) and plant's costs (C_p) are minimized according to Eq. (1). It is remarkable from Eq. (2) that supplier's costs include four terms of raw material costs, both variable and fixed transfer costs of raw materials to plants, and raw materials holding costs in warehouses at each time period. According to Eq. (3), C_p includes the production costs, backlogged costs at each time period, and holding costs of produced items in plants.

According to Eq. 4, Eq. 5, and Eq. 6, the system's agility is maximized through the second objective function. The most important indicator to measure the agility of the supply chain is flexibility which is defined as the capability of the system to react to external factors. As mentioned by Sabri and Beamon [54], this metric can be evaluated by surplus capacity. To evaluate the system flexibility, the current article uses the maximum extra demand that is fulfilled by the surplus capacity. Finally, the third objective function aims to maximize the system's reliability, which is defined as the capability of fulfilling customer needs on time in the right quantity. According to Eq. 7, perfect order fulfillment (POF) can be equivalent to reliability as one of the first-level metrics. According to Eq. 8 and Eq. 9, the POF relies on the minimum value of the produced items and the number of demands at a given time period. The mathematical limitations of the mentioned supply chain are presented as follows:

4.2.4. Inventory level

Note: It is assumed that the inventory level at the start time is zero.

$$IRm_{njt} = IRm_{nj,t-1} + \sum_i X_{nijt} - \sum_l Ur_{nl} \cdot Y_{ljt} \qquad \forall n\, j\, t \tag{10}$$

$$IPm_{ljt} = IPm_{lj,t-1} + Y_{ljt} - Q_{ljt} \qquad \forall l\, j\, t \tag{11}$$

$$IRm_{njt} \ge SSm_{njt} \qquad \forall n\, j\, t \tag{12}$$

4.2.5. Volume warehouse

$$\sum_n Qr_n \times IRm_{njt} \le Vmr_j \qquad \forall t\, j \tag{13}$$

$$\sum_l Qp_l \times Ipm_{ljt} \le Vmp_j \qquad \forall t\, j \tag{14}$$

4.2.6. Product capacity

$$\sum_j X_{nijt} \le Cap_{nit} \qquad \forall n\, i\, j\, t \tag{15}$$

$$Y_{ljt} \leq Cap_{ljt} \qquad \forall l\ j\ t \qquad (16)$$

4.2.7. Delivery time

$$Tdr_{nijt} \times (X_{nijt} / Bsm_{ni}) \leq Tr\max_{nijt}\ , \qquad \forall n\ i\ j\ t \qquad (17)$$

where

$$Tdr_{nijt} \times \frac{X_{nijt}}{Bsm_{ni}=TR_{nijt}} \qquad \forall t\ l\ j \qquad (18)$$

4.2.8. Backordered demand

$$BLg_{ljt} = BLg_{lj,t-1} + D_{ljt} - Q_{ljt} \qquad \forall t\ l\ j \qquad (19)$$

$$BLg_{ljt} \leq \alpha_{ljt}.D_{ljt} \qquad \forall t\ l\ j \qquad (20)$$

$$D_{ljt} - Q_{ljt} \leq BLg_{ljt} \qquad \forall t\ l\ j \qquad (21)$$

4.2.9. Logical

$$W_{nijt} \times M_1 \geq X_{nij} \qquad M_{1;}\ \textit{A very big number} \qquad (22)$$

$$W_{nijt} \in \{1,0\} \qquad \forall n\ i\ j \qquad (23)$$

$$X_{nijt}, Y_{ljt}, IRm_{njt}, Ipm_{ljt}, TR_{nijt}, W_{nijt}, BLg_{lt}, Q_{ljt} \geq 0 \qquad \forall n\ l\ i\ j \qquad (24)$$

Constraints (10) and (11) balance the inventory level of raw materials and finished items at plant warehouses, respectively, while Eq. (12) guarantees the balance of safety stock of raw materials at the plant warehouse. Moreover, Eq. (13) and Eq. (14) ensure that the required space for storing raw materials and finished items doesn't exceed the warehouse space, respectively. Eq. (15) guarantees the capacity of raw material for each type of material provided by suppliers during each time period, while Eq. (16) ensures that the amount of produced items doesn't exceed the production capacity of each plant during a given time period. Eqs. (17) and (18) ensure that the arrival time of materials from *i*th supplier to *j*th plant at *t*th time period is less than its due date. The balance of the backordered amount of produced items in any two successive periods is indicated by Eq. (19). In addition, constraints (20) and (21) represent the boundary of back-ordered volumes of each produced item considering its demand in plants. Besides, Eq. (22)-(24) are extra constraints that must be considered. The delivery of the *n*th raw material to the *j*th plant from the *i*th supplier is guaranteed by Eq. (22) when the mentioned supplier is established. Ultimately, condition (23) indicates that W_{nijt} is a binary variable, while condition (24) ensures that the other decision variables are continuous and non-negative ones.

4.3. Solution methodology

To handle the multiple objectives, an aggregation method with the two following characteristics is required:

1- Considering different weights for objective functions,

2- Any requirement for matching the objective functions with their corresponding goal values.

As an aggregation approach with both mentioned features, the weighted GP method is used for the joint optimization of multiple objectives. This approach, by considering constraints (10)–(24), the objective functions given by Eqs. (1)- (9), and using the deviation variables can be written as:

$$\begin{aligned}
&Minimize \quad \textstyle\sum_{i=1}^{n} w_c d_c + \\
&w_a d_a + w_r d_r \\
&Subject\ to \quad C - d_c \leq G_c \\
&A + d_a \geq G_a \\
&R + d_r \geq G_r \\
&d_c\ d_a\ d_r \geq 0 \\
&X \in FS\ ,
\end{aligned} \qquad (25)$$

where w_c, w_a, and w_r denote the weights of the goals, G_c, G_a, and G_r are the aspiration level of the goals. Moreover, the positive deviations from the target values of the goals are expressed by d_c, d_a, and d_r. Recall that *c*, *a*, and *r* represent the indices of the SC cost, agility, and reliability, respectively.

5. Results

The suggested mathematical programming model is solved by a CPLEX solver in GAMS 24.1.2.

5.1. Computational results

The process of decision-making by aligning them using the top-down method and the obtained results are discussed in this subsection. As mentioned before, the priorities of the model objectives at the highest level of the SCPM are specified through SCOR indicators. Then, the strategies are implemented by such priorities in the next time period. Moreover, low levels programs are established according to such priorities. The non-numerical rows in Tables 3 and 4 represent the multi-level model structure, while columns A-L indicate the concept of each quantity in rows. Columns A-C express a strategic scenario while the optimum values of model objectives for the strategic scenario are reported in columns D-F.

Furthermore, columns G-L contain objective values for the supplier and plant, including the supply cost (C_s), production cost (C_p), supply agility (A_s), production agility (A_p), supply reliability (R_s), and production reliability (R_p). It is worth mentioning that the products cannot be manufactured without components. Consequently, supplier reliability remains constant across all scenarios and is not taken into account in our computations. The numerical rows indicate decision-making scenarios consisting of strategies that are aligned with the operational plan. Translating strategic goals to operational planning is understandable by taking various strategic scenarios and operational plans into account. Each record at the operational level is related to a given operational production and supply planning. For the sake of brevity, only X_{nijt} values from Scenario 15 are shown. Table 2 gives the optimal volume of n^{th} raw material that is transferred from i^{th} supplier to j^{th} plant at t^{th} time period. For example, $X_{3324} = 8$ indicates that plant 3 should purchase 8 units of type 3 raw material from the second supplier in the fourth time period. Notably, merely non-zero decision variables are reported in Table 2.

Tab. 2. Optimum values of n^{th} material transported from i^{th} supplier *to* j^{th} plant *at* t^{th} time period (X_{nijt} of scenario 15)

Variable	X_{1113}	X_{1122}	X_{1122}	X_{1124}	X_{1211}	X_{1212}	X_{1214}	X_{1223}	X_{2122}
Value	3	6	2	5	8	8	5	7	3
Variable	X_{2123}	X_{2211}	X_{2312}	X_{2313}	X_{2314}	X_{2321}	X_{2324}	X_{3111}	X_{3112}
Value	6	6	4	3	3	5	2	3	4
Variable	X_{3113}	X_{3114}	X_{3221}	X_{3222}	X_{3224}	X_{3311}	X_{3312}	X_{3322}	X_{3324}
Value	6	6	8	3	6	5	6	3	8

The proposed multi-objective programming model is divided into three separate single-objective mathematical models, according to Table 3.

Tab. 3. Target values of strategic objectives

			Supply chain decision alignment											
		Row sign	A	B	C	D	E	F	G	H	I	J	K	L
			Human decision level			Intermediate decision level			Machine decision level					
Tools	Strategy planning method	Scenario number	Cost: setup, inventory, backorder	Flexibility: supply chain flexibility	Reliability: minimum demand and products	(Best for each objective)		Ideal point	Best for each echelon S (Supplier), P (Plant)					
			Goals setting (Strategy level)			Cost-Min C	Flexibility-Max A	Reliability-Max R	Min (sum)		MaxMin		Max	
									C_s	C_p	A_s	A_p	R_s	R_p
GAMS-CPLEX	Single objective		W1	W2	W3									Exact solution
		1	1	0	0	349	120	25	230	119	45	75		25
		2	0	1	0	479	176	17	161	318	91	85		17
		3	0	0	1	409	120	30	237	172	45	75		30
Cost			S=Superior (best aspiration levels)			349	176	30						
Flexibility		Target setting (Strategy level)	A=Advantage (aspiration levels)			388	159	26						
Reliability			P=Parity (aspiration levels)			427	142	22						

That is to say, as displayed in Table 3, the objective functions are separately optimized to achieve the best possible values (best aspiration levels) for each objective [55]. The first, second and third rows of Table 3 report the optimum scenarios under optimizing each objective function individually. Here, the first row is expressed for more clarification. Since the purpose is to design a scenario by minimizing the cost function, the weight of the first function will be equal to 1 while other weight values are zero. Then, the minimum cost will be obtained as 349 when the proposed multi-objective model is solved under these weights. In this scenario, agility and reliability functions are obtained as 120 and 25, respectively. As can be seen by individual optimization of the reliability function, the cost of the third scenario is obtained as 409, which is 60 units larger than the first scenario's cost. Moreover, the optimum value of the reliability function in this scenario is obtained as 30, which is larger than those of the first and second scenarios.

Table 4 presents the obtained values for production planning and objective function (i.e., performance measurement indices). In this table, from the fourth scenario, the strategies optimize the objectives subject to the benchmark levels selected as targets for the objectives. This target determines the aspiration levels G_m, $m=c,a,r$ in Constraint (25). The value of w_i in Constraint (25) can be specified based on decision-maker's preferences. Without loss of generality, the weights are assumed to be equal, and the objective functions are expressed by free-scale values. The levels of indicators are categorized into three benchmark levels according to Table 1. The methods of setting performance targets include theoretical targets, internal benchmarks, external benchmarks, and historical-based ones [56, 57]. The optimum values of the objective function in scenarios 1-3 are employed to specify superior, advantage, and parity levels. According to Table 3, it is supposed that such a set leads to a proper internal range for specifying three levels of superior, advantage, and parity levels.

Tab. 4. Strategic scenarios for performance, values of objectives, and operational plans

				Supply chain decision alignment														
			Row sign	A		B		C		D	E	F	G	H	I	J	K	L
SCOR based approach	Tools	Strategy planning method	Scenario number	Human decision level Goals setting (Strategy level)							Supply chain objective		Machine decision level Best for each echelon S (Supplier), P (Plant)					
				Cost Min		Flexibility Max		Reliability Max		Cost Min	Flexibility Max	Reliability Max	Min (sum)		MaxMin			Max
										C	A	R	C_s	C_p	A_s	A_p	R_s	R_p
				Benchmark- objective target														
				Goals														Best solution
	GAMS-CPLEX	Goal programming	4	S	349	S	176	S	30	406	150	23	197	209	70	80		23
			5	S	349	S	176	A	26	406	150	23	197	209	70	80		23
			6	S	349	S	176	P	22	388	148	22	196	192	68	80		22
			7	S	349	A	159	S	30	406	150	23	197	209	70	80		23
			8	S	349	P	142	S	30	376	137	24	212	164	59	78		24
			9	A	388	S	176	S	30	406	150	23	197	209	70	80		23
			10	P	427	S	176	S	30	429	149	25	207	222	69	80		25
			11	A	388	A	159	A	26	406	150	23	197	209	70	80		23
			12	A	388	A	159	S	30	406	150	23	197	209	70	80		23
			13	A	388	A	159	P	22	388	148	22	196	192	68	80		22
			14	A	388	S	176	A	26	406	150	23	197	209	70	80		23
			15	A	388	P	142	A	26	392	138	25	208	184	60	78		25
			16	S	349	A	159	A	26	406	150	23	197	209	70	80		23
			17	P	427	A	159	A	26	429	149	25	207	222	69	80		25
			18	P	427	P	142	P	22	426	142	22	222	205	63	79		22
			19	P	427	P	142	S	30	430	137	28	219	211	59	78		28
			20	P	427	P	142	A	26	427	143	26	208	219	64	97		26
			21	P	427	S	176	P	20	439	166	20	178	261	83	83		20
			22	P	427	A	159	P	22	431	160	22	189	242	77	82		22
			23	S	349	P	142	P	22	376	143	27	202	175	63	79		22
			24	A	388	P	142	P	22	383	142	22	217	171	63	79		22

25	S	349	A	159	P	22	388	148	22	196	192	68	80	22
26	S	349	P	142	A	26	376	137	24	212	164	59	78	24
27	A	388	S	176	P	22	388	148	22	196	192	68	80	22
28	A	388	P	142	S	30	393	138	25	209	184	60	78	25
29	P	427	S	176	A	26	429	149	25	207	222	69	80	25
30	P	427	A	159	S	22	431	160	22	189	242	77	82	22

5.2. Discussion

The sensitivity of the proposed model on some important parameters is analyzed in this subsection. To accomplish this, the impact of various benchmark structures on the obtained results is evaluated for the GP method. Various benchmark levels are supposed for the objective functions. A total of 30 different scenarios are tested to illustrate the behavior of the aspiration levels and their effects on the results. However, based on the priorities of strategists for the objective functions, various scenarios will be designed. In these scenarios, the decisions are optimized, subject to superior, advantage, and parity targets for tree objectives. As an example, in Scenario 26, the superior, parity, and advantage targets are considered for cost, agility, and reliability objectives, respectively.

The results in Table 4 reveal that:

- Given the conditions of the problem, certain scenarios (i.e., strategies) result in the same operational programs. Thus, it is derived that both the proposed model and solution approach are relatively robust under minor changes in the strategy.
- Concerning Scenario 18, for which all of the targets are set on the parity level, the operational objective satisfied all of the targets. This is because the scenario is overly conservative. The 18m scenario is dominant by the 13m scenario because the agility and reliability are equal, while the cost of the 13m scenario is as much as 38 units.
- Most scenarios cannot dominate others since each one has its distinct advantages.
- Scenario 24 is dominated by Scenario 23 in terms of cost, agility, and reliability. Although Scenario 23 is overall better than Scenario 24, strategy 24 has the lowest production cost and is thus better than Scenario 23.
- The agility of scenario 22 is 160, which is better than the agility target.
- Aspiration levels and weights, subject to Constraint 25, depend on the strategist's insight: different levels and weights lead to different scenarios. This illustrates how decisions at the human intelligence level impact those at the machine level at the operational level.
- By analyzing different scenarios obtained from machine intelligence as well as the operational results, strategists' opinions may be influenced; this represents how decisions at the machine intelligence level impact those at the human level.
- Heuristic and meta-heuristic techniques can be used for solving large-scale examples since the proposed model is NP-hard mathematical programming.

6. Conclusion

Based on the dynamic alignment of strategic and operational decisions, a multi-objective mathematical formulation for improving the performance management of the supply chain was proposed. Considering a two-echelon supply chain involving suppliers and manufacturers, the proposed framework integrates theories, tools, techniques, multi-objective optimization, SCOR model, and GP method into a novel SCPM. The main aspects of a supply chain, such as multiple plants, multiple suppliers, multiple products, and multiple materials in multiple periods of time, were considered in the proposed operational model. The proposed model minimizes the total supply cost and production cost while maximizing supply agility, production agility, and the reliability of the supply network. Then, based on the SCOR model, a GP method to align different decisions was employed. A case study was presented to highlight the efficiency of the proposed solution approach. Besides, the sensitivity of the proposed model on some important parameters and scenarios was analyzed. The significant novelties of this paper can be summarized in the following aspects:

- Presenting improved performance indicators by aligning different decisions.
- Taking both quantitative and qualitative parameters into account for strategy planning.
- Employing the SCOR model to develop a hybrid framework for evaluating and

improving the supply chain's performance at all SCM levels.

- Presenting decision-making procedure based on human intelligence for strategic planning.
- Presenting decision-making procedure based on machine intelligence for quantitative formulation at low levels.

Furthermore, the important novelties of the operational model are summarized as follows:

- Developing mathematical programming that integrates the designing of a supply chain with dynamic performance improvement in an industrial system.
- Proposing a mixed-integer multi-objective GP method for performance management in a two-echelon supply chain.
- Using SCOR indicators of total cost, agility, and reliability objective functions.
- Investigating the behaviour of the proposed method through a sensitivity analysis of different scenarios.

In summary, two characteristics of the presented framework are the main contributions of this study from the point of view of managers:

1. Updating decisions based on the occurrence of both strategic and operational events.
2. Alignment between strategic and operational activities from two sides the bottom-up and the top-down.

7. Research Implications, Limitations and Future Works

The most important benefit of using the developed framework is the alignment of the strategic activities with operational ones in the supply chain such that all organization resources are coordinated. The limitation or requirement of implementing such a framework is the ability to quickly detect changes, make up-to-date decisions and modify the plan based on the current condition. These shortcomings are being resolved with recent advantages in information technology and the progress of industry 4.

According to the mentioned novelties, the following recommendations are made for future directions:

- Developing the proposed mathematical model based on stochastic programming or fuzzy set theory.
- Integrating other characteristics of the supply chain, such as distribution, into the developed model.
- Using other solution methods, such as meta-heuristic algorithms to solve the model in large-scale instances.

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