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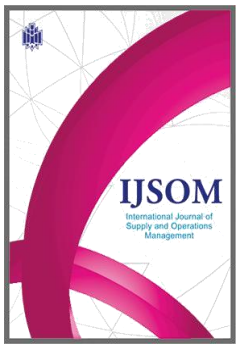

Optimizing Sustainability and Risk Management in Intelligent Supply Chains: A Case Study from Thailand

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Abstract

In this study, an exploration is undertaken to contribute significantly to the sustainable development of intelligent supply chains by investigating the optimization of the supply chain network within the realm of risk management, with specific attention devoted to resource reliability. The formalization of risk management and its integration into intelligent supply chain optimization is evaluated through an online survey involving leaders of enterprises in Thailand. A novel mathematical model aimed at enhancing risk mitigation while considering the availability of requisite resources is introduced and subsequently optimized utilizing GAMS software. To address the multi-objective nature inherent in the proposed model, an approach grounded in fuzzy theory is applied. The research outcomes illuminate the evolving role of risk mitigation within Thai enterprises, emphasizing its responsibility to provide assurances against potential risks. Despite notable strides in risk management, persistent challenges are underscored. Furthermore, emphasis is placed on the capacity of intelligent supply chains to adapt and efficaciously address dynamic risk factors in an ever-evolving world, aligning seamlessly with the principles of sustainable development.

Keywords: Sustainable development; Risk mitigation; Mathematical modeling; Fuzzy theory; Intelligent supply chain.

1. Introduction

In an era marked by dynamic changes in the economic and legal landscape, coupled with the complexities of modern business operations, the imperative for effective response and comprehensive financial disclosure has never been more critical. These transformations call for a meticulous examination of audit quality, a concern at the forefront of auditors' minds (Churilova et al., 2020; Bykova et al., 2019). High-quality auditing, as substantiated in the literature (Dudin et al., 2016; Goli et al., 2019a), plays a pivotal role in instilling confidence among investors and stakeholders. It serves as the bedrock upon which the reliability of financial statements rests, providing an accurate reflection of a company's financial standing.

In the realm of auditing, the approach adopted by audit firms for each assignment assumes paramount importance. An audit firm's choice of methodology can significantly influence the audit's outcomes. An erroneous approach may heighten the risk of audit failure, precipitating reputational damage and potentially costly legal repercussions (Pahlevan et al., 2021). Given the unique nature of each audit assignment, no universal approach exists that guarantees flawless results.

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However, a ray of hope shines through the adoption of a risk-based approach to auditing, particularly for large enterprises (Gerasimova et al., 2019). This methodology strategically directs audit resources towards areas within the financial statements that are susceptible to distortion, either inadvertently or intentionally, due to the inherent risks faced by the business.

It is noteworthy that contemporary corporate governance practices seamlessly integrate risk management as an indispensable facet (Goli et al., 2021a). Organizations are obligated to identify and elucidate their business risks, concurrently articulating their management strategies. Amidst the broader spectrum of business and organizational risks, a distinctive category pertains to auditors, encompassing the potential for oversight errors or deliberate misstatements when scrutinizing the financial records of entities, be they corporate or individual. The essence of high-quality auditing lies in the mitigation of audit risks, thereby reducing the likelihood of a misleading audit report issued by the audit firm. However, regulatory examinations often expose shortcomings in auditing practices, as evidenced by Anderson et al. (2017).

Simultaneously, the combination of ineffective auditing and a lack of diligence from management and stakeholders in identifying and addressing significant misstatements or financial control weaknesses poses a severe threat to the overall viability of a business. Within this complex landscape, our study assumes significance as it endeavors to delineate critical areas for enhancing the quality of internal audits—an essential component for efficient risk management within enterprises in Thailand. In the context of intelligent supply chains and the application of novel solution techniques, our investigation aims to unveil strategies that can fortify audit quality and contribute to the sustainable development of modern, dynamic supply chain systems.

The remaining sections of the paper are structured as follows: Section 2 comprehensively reviews the relevant literature. Section 3 delineates the proposed methodology. In Section 4, the solution method is expounded. Subsequently, Section 5 presents the numerical results, and finally, the paper is concluded in Section 6.

2. Literature Review

Supply chain management assumes a pivotal role in fortifying organizations against potential risks, as underscored by pertinent research (Shen, 2017; Drogalas et al., 2017). Shin and Park (2017) undertook a comprehensive examination delving into the integration of enterprise risk management and control systems, illuminating the paramount importance of establishing a robust relationship between enterprise risk management and management control systems to augment the value derived from supply chain operations.

In the domain of supply chain management and auditing, continuous vigilance is warranted to monitor two primary categories of risks: business risks and audit risks, as elucidated in academic literature (Zwaan et al., 2011). Business risks encompass potential losses and unforeseen events that could exert adverse impacts on supply chain operations (Swanson, 2019). It is imperative to conduct regular assessments of supply chain risks, given their recurrent nature. However, it is pertinent to acknowledge that the onus of managing business risks rests with supply chain management. Nevertheless, when formulating supply chain strategies, the management team should diligently assess the relative significance of supply chain risks. This assessment entails a comprehensive evaluation, considering both quantitative and qualitative potential consequences (Se Msi et al., 2018).

The delineation between audit risk and business risk pivots primarily on the inherent nature of each risk category. Supply chain risks emanate from inefficiencies in internal and external processes, whereas business risks can materialize due to an array of factors encompassing strategic, financial, operational, reputational, and industry-specific dimensions (Cascarino, 2017).

Recently, Oliveira et al. (2019) reviewed the optimization approach for risk mitigation in supply chains. The results indicated a fundamental methodological disconnection involving risk mitigation, simulation and optimization methods.

Hansen (2020) evaluated the effect of risk in finding a practical solution for newly emerged vehicles. In this research, it was revealed that when performing risk assessments for land planning purposes, bunkering assessments or passenger and crew safety, these aspects must be reflected.

Zhang and Alipour (2021) provided a framework for mitigating the risk of flood and investigated the role of this strategy on transportation networks. They used a real transportation system as a testbed to develop a framework to evaluate flood-related risks and implement a specific risk reduction strategy.

Suryawanshi and Dutta (2022) presented the standard mathematical models for optimizing the supply chain while considering the risks and uncertainty in this research. They investigated several real cases and indicated that the resiliency of the supply chain could handle and mitigate most supply chain risks.

Jin and Gao (2023) proposed a hybrid optimization approach for green supply chain networks and the scheduling of a distributed 3D printing intelligent factory. Initially, they constructed a cost-minimization model based on the green supply chain network architecture of the distributed 3D printing intelligent factory. Subsequently, mathematical software was employed to solve the model, facilitating the development of a scheduling plan. In another study, Kamran et al. (2023) introduced a novel stochastic multi-objective, multi-period, and multi-commodity simulation-optimization model for decision-making in the production, distribution, location, allocation, and inventory control of COVID-19 vaccines. The proposed model was solved using Variable Neighborhood Search (VNS) and Whale Optimization Algorithm (WOA) algorithms. Notably, the simulation model incorporated unique features, such as accounting for the impact of virtual education and imposed quarantine on estimating vaccine quantities.

Additionally, Hao and Demir (2024) conducted a comprehensive exploration of the AI supply chain journey, employing a systematic literature review and empirical interviews with supply chain experts. Their research integrated empirical data within a Technology-Organization-Environment (TOE) framework, revealing intricate interactions among technological, organizational, and environmental factors. Through thematic analysis, six axial themes for the pre-development stage and one theme for the deployment and post-development stages emerged, providing valuable insights into factors influencing successful AI integration.

This research makes a significant contribution to the field by offering a meticulously crafted business continuity and post-disaster recovery plan tailored specifically for intelligent supply chains in Thai enterprises. This research establishes a foundational framework for future studies, providing valuable insights for enhancing the resilience and sustainability of business operations in a dynamically evolving landscape. In summary, the main contributions of this research are as follows:

- Meticulously crafted business continuity and post-disaster recovery plan for intelligent supply chains in Thai enterprises.
- Introduction of a specialized mathematical model for resource allocation during catastrophic incidents.
- Identification of pivotal actions for internal audit functions to elevate their quality and align with evolving stakeholder expectations in risk management.
- Exploration of the growing divergence between risk management and supply chain performance within Thai enterprises.
- Emphasis on the potential for optimizing risk management efficiency through advanced collaborations and integrated models.

3. Methodology

The descriptive phase of this study was founded upon an online survey conducted among senior executives from 34 enterprises in Thailand. The respondent sample was curated utilizing the Register of Enterprises of Thailand as a basis. Invitations were disseminated via direct mail to solicit the participation of potential respondents. During the data processing phase, three questionnaires were excluded from consideration. The principal objective of this survey was to scrutinize the state of internal audits in Thailand through the lens of a risk-based approach. The primary research methodology employed was a concise questionnaire grounded in the Global Internal Audit Common Body of Knowledge questionnaire, which was developed as part of a comprehensive global practitioner survey. Upon the completion of the survey, an assessment of the structure of the risk mitigation approach was undertaken, with the subsequent intention to formulate a mathematical model aimed at optimizing the supply chain network and facilitating risk mitigation throughout the entirety of the supply chain.

The model specifically focused on the evaluation of the flexibility of an organization while considering unlimited resources and the possibility of using the resources by the organization (Goli et al., 2019b; Goli et al., 2021b; Goli et al., 2020). The organization feeds on a series of unlimited resources, and all resources, facilities, human resources and energy are available infinitely. The organization determines how much of the resource depends on its goal. On the other hand, the more the organization can use resources to improve, the sooner it can return to its normal state and the shorter the recovery period will be. Therefore, the cost of resources and time should be balanced. In addition, higher use of resources leads to a shorter recovery time. There are several sources of each type that have different reliability. Evidently, the increased cost of resources increases their reliability, and according to the functions, these two values

are in conflict and must reach a value of their equilibrium. On the other hand, given the nature of the model, attempts were made to minimize the recovery period of the organization and not allow the organizational level to decrease below a certain level after an accident.
An organization is considered to have several critical products. S shows the series of critical products. Each critical operation at the L level requires a certain amount of J resources. Every low-level operation requires fewer resources than a high level. A destructive accident damages resources, decreasing the operation level of various processes. In addition, each destructive accident is recognized with three components of β_d (the probability of an accident), κ_{jdt} (impact of the d accident on j internal resource at t time) and η_{jdt} (impact of d accident on j external resource at t time). A destructive accident results in a decrease in various operations at the Minimum Business Continuity Objective ($MBCO$) level, and the objective is to return the operations to their normal state at a Maximum Tolerable Period of Disruption ($MTPD$) time. The number of resources required and the recovery time depend on the severity of the accident and its impact on the process. In this section, we present a multi-objective mixed integer linear programming (MOMILP) used to allocate resources to critical operations in a way that minimal reduction in the level of operation and minimum cost and maximum reliability of resources occurs, and the obtained solution is optimized.

3.1. Model assumptions

The main modeling assumptions are as follows:

- The organization is considered in two critical and normal situations.
- Different accidents can occur concomitantly.
- The organization produces various key products.
- Each key product has its own level of importance, the priority of which shows the process for recovery.
- Each accident exerts its own specific impacts and may destroy the resources required for a process completely or partially.
- The amount of use of different levels of operations from different sources is different and known.
- Minimum Business Continuity Objective (MBCO) and Maximum Tolerable Period of Disruption (MTPD) are given for each key product and related critical operation based on the organization's situation. As a result, MBCO and MTPD act as low and high limits.
- In a normal situation, each of the processes is at its highest level of performance.
- Resources are always available indefinitely.
- In a critical situation, the average cost of using resources is given.
- Recovery of each product requires allocating a minimum of a series of pre-determined resources.
- Each accident reduces the level of reliability of internal and external resources.
- A multi-periodic time horizon is required to recover from critical processes. Therefore, the time horizon should be at least equal to the maximum MTPD among key products.
- The operations depend on each other.
- The reliability of resources decreases after an accident.
- The cost of using the resources increases after an accident.
- Time, reliability, and cost must reach a balance.

Indices

D	Index of destructive accident $(d = 1,2,\dots,D)$
S	Index of key products/services $(s = 1,2,\dots,S)$
L	Index of level of operations $(l = 1,2,\dots,L)$
J	Index of resources $(j = 1,2,\dots,J)$
T	Index of time period $(t = 1,2,..,T)$

Parameters

γ_s	*The MTPD amount for the* key product s
λ_s	The MBCO amount for the key product s

R_{sjl}	Minimum resources j required for product s at level l
C_j	Average cost of resource j
β_d	Possibility of occurrence of accident d
κ_{jdt}	Effect of accident d on the reliability of resource j at time t
η_{jdt}	Impact of accident d on price of resource j at time t
ω_s	Relative importance of key product s
ρ_j	Minimum reliability of resource j

Variables

x_{slt}	If the key product s is at level l at time t, it is equal to one; otherwise, it is zero.
RE_{jt}	The amount of resource j consumed for the recovery process at time t.
RR_{sjl}	The amount of resource j consumed to recover product s at level l
ϖ_s^t	Level of operations for key products s at time t
ϑ_s	Recovery time for key product s

3.2. Mathematical Model Constraints

$$Min\ f_1 = \sum_{s=1}^{S} \sum_{t=1}^{T} \omega_s \,.\, (L - \varpi_s^t) \tag{1}$$

The objective function (1) minimizes the relative decrease in the level of key products.

$$Min\ f_2 = \sum_{s=1}^{S} \omega_s \vartheta_s \tag{2}$$

The objective function (2) minimizes the relative time required to recover key products.

$$Max\ f_3 = \sum_{j=1}^{J} \sum_{t=1}^{T} \sum_{d=1}^{D} \rho_j \,.\, RE_{jt} . \kappa_{jdt} . \beta_d \tag{3}$$

The objective function (3) maximizes the total resource usability.

$$Max\ f_4 = \sum_{j=1}^{J} \sum_{t=1}^{T} \sum_{d=1}^{D} C_j \,.\, RE_{jt} . \eta_{jdt} . \beta_d \tag{4}$$

The objective function (4) minimizes the cost of using resources.

$$\sum_{l=1}^{L} x_{slt} = 1 \qquad \forall s, t \tag{5}$$

Constraint (5) expresses that each operation can be only at one level at each time.

$$\sum_{l=1}^{L} l . x_{slt} \geq \lambda_s \qquad \forall s, t \geq \lambda_s \tag{6}$$

Constraint (6) shows that the operational level of each s at each time should be larger than the minimum level of recovery.

$$\sum_{l=1}^{L} l . x_{slt} - \sum_{l=1}^{L} l . x_{sl(t-1)} \geq 0 \qquad \forall s, t \geq 2 \tag{7}$$

Constraint (7) reveals that the level of operation does not decline over time.

$$RR_{sjl} \geq R_{sjl} \qquad \forall\ s, j, l \tag{8}$$

Constraint (8) demonstrates that the amount used by each source for each product must be greater than the minimum product needed for that resource at that time.

$$\sum_{s=1}^{S}\sum_{l=1}^{L} RR_{sjl}\, x_{sjl} \leq RE_{jt} \qquad \forall j,t \tag{9}$$

Given the decrease in resources after an accident, constraint (9) guarantees that the number of resources required is less than the available domestic and foreign resources.

$$\left(T - \sum_{t=1}^{T} x_{sLt} + 1\right) \leq \vartheta_s \qquad \forall s \tag{10}$$

Constraint (10) states that the recovery time of each operation must be less than the defined time.

$$\vartheta_s \leq \gamma_s \qquad \forall s \tag{11}$$

Constraint (11) guarantees that the recovery time should be less than the maximum tolerable time.

$$x_{slt} \in \{0,1\} \qquad \forall s,l,t \tag{12}$$

Constraint (12) shows the binary variable.

$$\varpi_s^t\,, RR_{slj}, RE_{jt}, \vartheta_s \geq 0 \qquad \forall s,j,t \tag{13}$$

Constraint (13) shows the non-negative variables.

4. Solution Method

In contemporary times, optimization challenges manifest across a multitude of domains, encompassing transportation, investments, location analysis, network design, and planning and scheduling. Typically, these practical problems are initially described through a series of logical propositions, which are subsequently embedded into a mathematical model. Consequently, formulating the problem as a mathematical model constitutes a pivotal phase in the practical application of optimization principles. This paper endeavors to elucidate the process of model creation and assessment, offering a deliberate explanation of the requisite rules and guidelines. The aim is to empower readers with the ability to utilize mathematical logic for generalization and adapt concepts to address a spectrum of issues. The effective utilization of optimization software hinges on constructing a precise and suitable model that not only adheres to the problem's constraints but also takes into account algorithmic limitations as a critical factor.

Complex and extensive problems necessitate the collaboration of multidisciplinary teams equipped with a diverse array of expertise to tackle them. Many organizational challenges, for instance, encompass economic, social, political, engineering, natural, biological, and psychological facets. While it is impractical for an individual to be well-versed in all these domains, the presence of a collaborative team facilitates the examination and analysis of the problem from various perspectives by experts from distinct fields. This multidisciplinary approach enhances the likelihood of finding optimal solutions to complex problems.

The formulated model is addressed through a fuzzy solution approach, which entails the transformation of a multi-objective problem into a single-objective one by establishing membership functions for each objective function. This method consists of the following sequential steps.

Step 1: obtaining the positive ideal solution (PIS) and negative ideal solution (NIS) for each objective function

$$Z_1^{PIS} = minZ_1, Z_1^{NIS} = maxZ_1 \tag{14}$$

$$Z_2^{PIS} = minZ_2, Z_2^{NIS} = maxZ_2 \tag{15}$$

$$Z_3^{PIS} = maxZ_3, Z_3^{NIS} = minZ_1 \tag{16}$$

Step 2: Determining the membership function of each objective function

$$\mu_1(f) = \begin{cases} 1 & if\ Z_1 \le Z_1^{PIS} \\ \dfrac{Z_1^{NIS} - Z_1}{Z_1^{NIS} - Z_1^{PIS}} & Z_1^{PIS} \le Z_1 \le Z_1^{NIS} \\ 0 & Z_1 \ge Z_1^{PIS} \end{cases} \tag{17}$$

$$\mu_2(f) = \begin{cases} 1 & if\ Z_2 \le Z_2^{PIS} \\ \dfrac{Z_2^{NIS} - Z_2}{Z_2^{NIS} - Z_2^{PIS}} & Z_2^{PIS} \le Z_2 \le Z_2^{NIS} \\ 0 & Z_2 \ge Z_2^{PIS} \end{cases} \tag{18}$$

$$\mu_3(f) = \begin{cases} 1 & if\ Z_3^{PIS} \le Z_3 \\ \dfrac{Z_3 - Z_3^{NIS}}{Z_3^{PIS} - Z_3^{NIS}} & Z_3^{NIS} \le Z_3 \le Z_3^{PIS} \\ 0 & Z_3^{PIS} \ge Z_3 \end{cases} \tag{19}$$

Step 3: Integrating the objective functions based on the following model

$$max\lambda(f) = \gamma\lambda_e + (1-\gamma)\sum_n w_n\,\mu_n(f) \tag{20}$$

$$\lambda_e \le \mu_n(f)\ n = 1,2,3 \tag{21}$$

$$f \in F(f), \lambda_e \& \gamma \in [0,1] \tag{22}$$

In these equations, $\mu_n(f)$ is the membership degree of each objective function, λ_e is the minimum membership degree of the objective function, w_n is the relative weight of each objective function, and γ is the compensation coefficient. The above problem is solved by determining the compensation coefficient γ and the relative weights w_n for each objective function.

4. Numerical Results

This section presents the results obtained by solving the model with GAMS. The model was solved for three problems of different sizes, which are shown in Table 1. It should be noted that these problems were generated by picking random values from reasonable ranges for the parameters.

Table 1. Problem instances generated with the relative weights (0.3, 0.35, 0.35) and the compensation coefficient γ = 0.3

Test Problem	$\lvert W\rvert$	$\lvert J\rvert$	$\lvert K\rvert$	$\lvert M\rvert$	$\lvert D\rvert$	$\lvert T\rvert$	$\lvert DR\rvert$	f_1	f_2	f_3
1	2	3	3	3	3	2	2	3331070.791	366046.322	544114.278
2	3	3	4	3	2	2	2	2153713.759	314595.168	444037.839
3	5	3	3	3	5	2	2	2480187.750	294428.624	439279.720

Figure 1 displays the set of Pareto solutions corresponding to Problem No.3, as delineated in Table 1. This illustration has been generated by varying γ for Problem No.3. Within this visual representation; it is observable that the point denoting the maximum job opportunities provided by the current supply chain also exhibits the highest levels of cost and environmental pollution. This observation underscores the impossibility of maximizing job opportunities in isolation from the considerations of the other two functions, aligning seamlessly with the fundamental tenets of the Pareto optimal solution concept.

The escalation in the overall cost can be attributed to the requisites for job opportunity creation, entailing infrastructure development, facility expansion, and meticulous production capacity enhancement planning. These actions inevitably result in heightened costs and concurrently escalate environmental impact. In a broader context, the outcomes depicted in the figure substantiate the feasibility of generating additional job opportunities without concomitant environmental pollution escalation through augmented investment in advanced technologies. However, it is imperative to acknowledge that the procurement of sophisticated technologies, while conducive to job creation, entails an inevitable increase in capital costs, which inherently conflicts with the overarching objective of minimizing the cost component within the objective function.

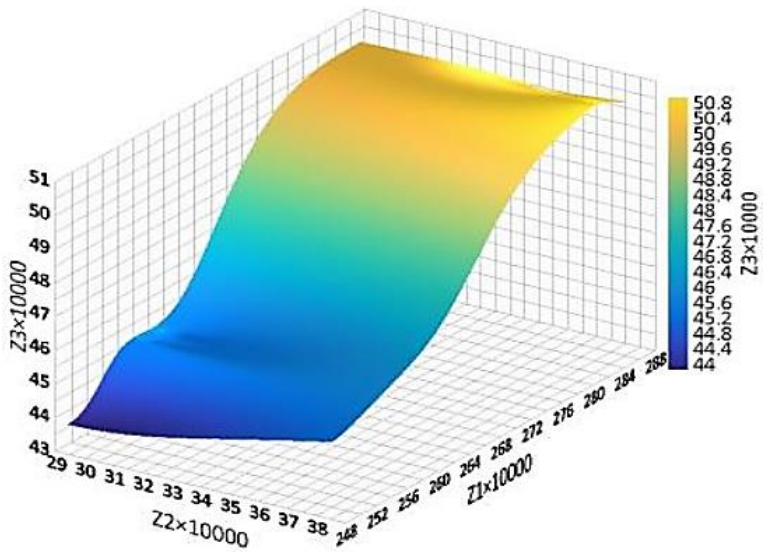

Figure 1. Pareto optimal front

Table 2 shows the changes in the objective function values following a change in relative weights at γ=0.3. From Table 2, it can be concluded that any change in the values assigned to relative weights will have a great impact on the objective function and solution. Therefore, these values must be chosen with great care.

Table 2. Changes in the objective function values following a change in relative weights at γ=0.3

w_n	f_1	f_2	f_3	$\mu_1(f)$	$\mu_2(f)$	$\mu_3(f)$
(0.9, 0.05, 0.05)	2191124.038	363669.621	410153.958	0.580	0.708	0.197
(0.7, 0.2, 0.1)	2393345.645	306007.572	433490.246	0.519	0.960	0.242
(0.45, 0.25, 0.3)	2480187.750	294428.624	439279.720	0.492	1	0.253

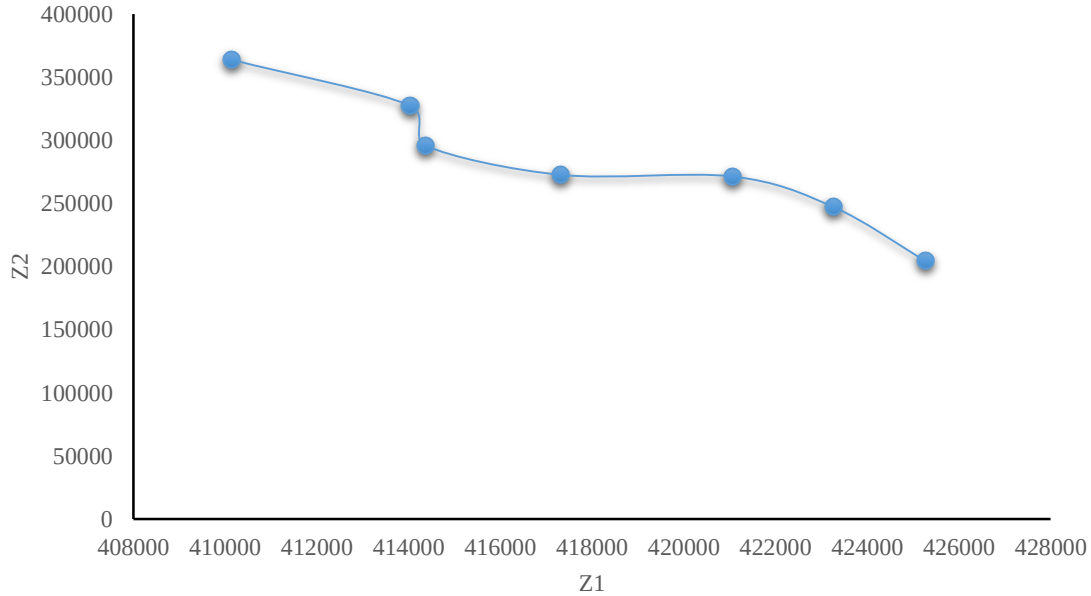

Figure 2. Comparison of values of the first and second objective functions in Pareto solutions

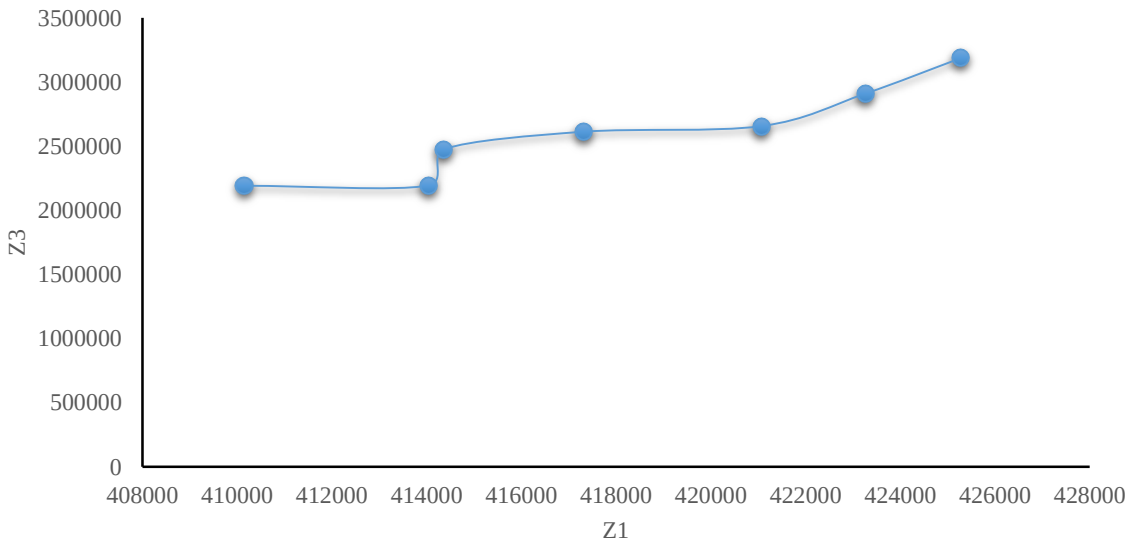

Figure 3. Comparison of values of the first and third objective functions in Pareto solutions

Figure 2 demonstrates an inverse relationship between the value of the first objective function and that of the second objective function. In essence, to enhance outcomes pertaining to the second objective, a certain degree of sub-optimization in terms of the first objective must be tolerated. Likewise, as illustrated in Figure 3, a comparable relationship holds for the first and third objectives, implying that the pursuit of the first objective is at odds with the third objective and vice versa. Consequently, these figures provide evidence that the stipulated objective functions are inherently conflicting and necessitate optimization through multi-objective optimization methodologies, akin to the approach employed within this research.

4. Objective Function Analysis

In order to analyze the results obtained from the optimization of the mathematical model, we analyzed sensitivity in three scenarios: optimistic, realistic and pessimistic. Each scenario assessed the possibility of the occurrence of a destructive accident as well as the amount and severity of the damage, where the more the perspective toward the issue is pessimistic, the more damage will occur. These three scenarios are designed to use one of them at the time of the accident according to the initial prediction of the severity of the accident and to estimate the damage to the organization at the first moment of the accident. The mathematical model was run in GAMS win 64 24.8.5 to solve the proposed model.

The model was solved based on the objective function's multi-objective nature to prevent an objective's superiority over another objective function using the ideal planning method. In this process, we minimized deviation between objectives and the optimal solution. Results related to objective functions are presented in Table 3 and Figure 4.

Objective functions (3) and (4), which are related to cost and reliability, showed that the more pessimistic we are about the probability of occurrence and the damage caused by accident, the worse the values will be. The objective function (1) represents the sum of the relative reduction of the product level that has taken its minimum value, and its value is the same in all three scenarios according to functions (3) and (4). The objective function (2) also represents the minimum time required for the organization to recover from an accident, the value of which in all three scenarios is 3.685. Moreover, Table 4 shows the time required to recover products after an accident (in realistic conditions), which shows that product 3 is more sensitive to accidents than other products and has more time to reach its initial conditions.

Table 3. Optimal values of objective functions

Scenario	f_1	f_2	f_3	f_4
Realistic	1485.000	3.685	7321249.310	1.376877×10^{9}
Optimistic	1485.000	3.685	4477142.049	9.369919×10^{8}
Pessimistic	1485.000	3.685	1.030476×10^{7}	1.924052×10^{9}

Table 4. Minimum time required to recover products

Product	1	2	3	4
Time required for product recovery	1	1	3	4

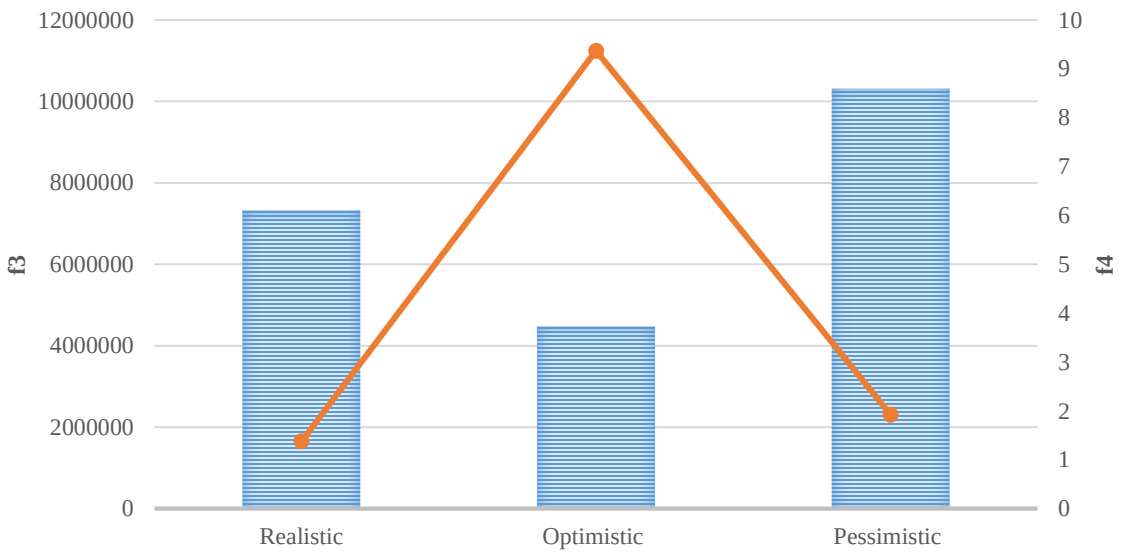

Figure 4. The difference between the third and fourth objectives in each state of uncertainty

As depicted in Figure 4, the outcomes are presented across three scenarios: realistic, optimistic, and pessimistic. The maximum value of the objective function is attained when the model adopts a pessimistic stance, while the minimum value is achieved under the optimistic scenario. Nevertheless, the results under the realistic scenario, situated in the mid-range (neither exceptionally high nor low), are considered to be the most reliable for informed interpretation.

4. Discussion

This discussion centers on the current state of intelligent supply chain planning within companies operating in Thailand, particularly in the context of risk mitigation and the application of innovative solution techniques. Despite some notable efforts, the adoption of new-generation supply chain capabilities in Thailand remains at its nascent stage. Thai companies grapple with challenges such as elevated investment risks and diminished service quality. Many companies have come to recognize the imperative of aligning their internal audit functions with the evolving business landscape.

This underscores the escalating significance of intelligent supply chain planning in risk management and innovation facilitation. Contemporary internal audit functions are expected to furnish analytical insights, offer professional counsel, and proactively predict potential risks. To effectively meet these demands, supply chain planners must possess specialized competencies in domains such as information technology, data analysis, risk modeling, and fraud prevention. In addressing this skills gap, experts advocate for innovative talent acquisition models, including co-sourcing and the intelligence approach. These models usher in specialized skills without necessitating substantial investments, fostering knowledge exchange across various segments of the supply chain.

Furthermore, the discussion underscores the underutilization of advanced data management and synthesis techniques in the realm of supply chain planning despite the tangible advantages they offer in risk assessment and resource optimization.

5. Conclusion

This study delivers a comprehensive overview of a business continuity and post-disaster recovery plan meticulously crafted to minimize costs and maximize resource reliability within the realm of intelligent supply chains. Additionally, a mathematical model is introduced for resource allocation, particularly tailored to address catastrophic incidents. This model ensures organizational flexibility throughout and following such events minimizes capital utilization, and expedites the return to normalcy. Within the domain of risk management, key actions that internal audit functions can take to elevate their quality and align with the evolving expectations of stakeholders are identified through our research.

The study's findings illuminate a noteworthy trend within Thai enterprises, indicative of an increasing divergence between risk management and supply chain performance. Although intelligent supply chain engenders heightened confidence in risk management, formal risk management processes still maintain an edge. Furthermore, the adoption of an integrated model within Thai enterprises remains at a relatively nascent stage, implying untapped potential for optimizing risk management efficiency. Nevertheless, our results suggest opportunities for fostering closer collaboration with key stakeholders to fortify risk management practices. Additionally, risk management can enhance coordination in their risk assessment activities, ensuring the mutually beneficial utilization of each other's knowledge and expertise. Finally, our study corroborates our initial assumptions and furnishes valuable insights that can serve as a cornerstone for assessing the quality of intelligent supply chains.

Future research should focus on refining integrated models, assessing their long-term effectiveness, and exploring advanced collaborations with stakeholders in the context of Thai enterprises. Investigating novel approaches for risk assessment coordination and understanding the sustained impacts of integrated risk management on intelligent supply chains would provide valuable insights. These efforts aim to advance strategies that align risk management with the evolving dynamics of intelligent supply chains in the contemporary business landscape.

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