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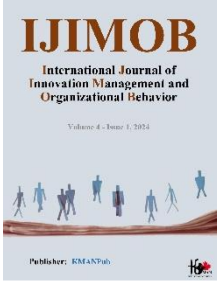

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Identification and Analysis of Supply Chain and Supplier Risks Using Frog-Leaping and Genetic Algorithms (A Case Study in the Automotive Industry)

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A B S T R A C T

Objective: The increasing complexity of the production process, the use of machines with advanced and modern capabilities, and the growing demand for products compel industry owners to maximize their capabilities at minimal costs towards production, reduce the risk of product manufacturing, and also improve the quality of their manufactured products to access broader markets. One of the most important factors in achieving this goal is the assessment of risk in product manufacturing. Given the financial difficulties in the automotive industry, supply chain management is of high importance because employing high-risk suppliers increases the possibility of rework and is economically detrimental to the automotive industry.

Methodology: To examine the risks in the automotive supply chain, mathematical modeling was used, and the model was executed with two metaheuristic algorithms.

Findings: Comparing the results, it is evident that the research model was analyzed with both exact solution methods and a metaheuristic approach, where in the metaheuristic method, it was solved using genetic and frog-leaping algorithms. By comparing the research outcomes, it can be said that the exact solution method shows better and more optimal results.

Conclusion: However, due to the NP-HARD nature of the problem, this method does not reach a solution in a logical time frame for larger dimensions of the problem. Therefore, the problem was solved with metaheuristic algorithms. Comparing the algorithms, it can be seen that the frog-leaping algorithm has provided more optimal results, but the solving time was less in the genetic algorithm compared to the frog-leaping algorithm.

Keywords: *Risk, Supply Chain, Suppliers, Frog-Leaping Algorithm, Genetic Algorithm, Automotive Industry.*

1 Introduction

Nowadays, the use of supply chain risk assessment methods is expanding across various industries. The reason behind this expansion is the pervasive and ubiquitous nature of the industry in human daily life to meet their needs. The growing population increases the need for various industrial products, energy, food, etc., more and more each moment. While the available resources become more limited every moment, meeting these needs undoubtedly relies on the use of today's advanced industries, which have increasingly attracted attention due to their optimal and economical use. The increasing complexity of the production process, the use of machines with advanced and modern capabilities, and the growing demand for products compel industry owners to utilize their maximum capabilities with the minimum cost in the direction of production, reduce the risk of product manufacturing, and also to increase the quality of their manufactured products to access broader markets. One of the most important factors for achieving this goal is risk assessment in product manufacturing (Costantino et al., 2015). Currently, there are over 70 different qualitative and quantitative risk assessment methods worldwide. These methods are usually used to identify, control, and reduce the consequences of risks. The existing risk assessment methods are suitable for assessing hazards, and their results can be used for management and decision-making regarding control and reduction of their consequences without concern. Each industry can benefit from these methods according to its needs. These methods have various advantages and disadvantages relative to each other. Organizations usually need a system that, in addition to assessing their activities and processes, can guide them regarding risk status, determine risk tolerance criteria, and precisely identify the risks of their processes, etc., depending on the complexity of each industry's activities, the type of system that can achieve this goal differs (Akman, 2015; Atashsooz et al., 2016; Badurdeen et al., 2014; Che, 2012; Chen, 2011; Costantino et al., 2015; Dahel, 2003; Ha & Krishnan, 2008; Hong et al., 2005; Khaleie et al., 2012; Kilincci & Onal, 2011; Mirghafoori et al., 2012; Omurca, 2013; Punniyamoorthy et al., 2013; Shieh et al., 2010; Walters, 2006; Weber et al., 1991; Wu & Lee, 2007). This research also addresses the risk of suppliers, which is one of the most important issues related to risk in the supply chain. This topic will be detailed further.

The need for customization has made the supply chain a complex phenomenon that requires a lot of information, parallel activities, and controlled operations to increase the level of service to customers, which in turn raises the level of risk and uncertainty (Chopra & Meindl, 2007; Chopra & Sodhi, 2004; Costantino et al., 2015). The extent of risk in the supply chain imposes complexity and numerous problems, making having an appropriate strategy for managing this risk essential. Moreover, cooperation and coordination between different sections of the supply chain in any area and activity are necessary as it reduces risk and increases the level of service to customers (Atashsooz et al., 2016; Azar et al., 2021; Bouchery, 2012). The goal is to reduce the negative impact of external disruptions and strive to manage certain risks in the supply chain. The global automotive industry, with a turnover of more than 2790 billion dollars and employing more than 48 million people directly and indirectly, would be equivalent to the seventh largest economy in the world if considered a country. Therefore, all governments support this industry in times of crisis. The importance of this industry is such that during the imposition of illegal Western sanctions related to the peaceful use of nuclear energy against our country, the automotive industry, alongside the oil industry, due to its prominent role in the country's macroeconomy, faced international restrictions. On the other hand, Iran's automotive industry, as the locomotive of the country's industry, has the potential to produce about 2 million vehicles and produce over 10 million parts and 6000 vehicles daily in the country, which promotes 60 major and minor industrial fields such as steel, petrochemicals, rubber, aluminum, glass, textiles, paints and coatings, chemicals, etc. (Azar et al., 2021; Pooya & Qorban Poor, 2015).

Despite the fact that in recent years in Iran, the trend of car production, having a high added value in the production chain and holding about 1.2 percent of the global share, has undergone significant growth; however, the high competition in this industry, along with environmental pressures and the requirements of domestic automakers to reduce prices and delivery times, increase quality, and the suppliers' ability to produce diverse and new parts in a shorter time, as well as Iran's accession to the World Trade Organization and the possibility of foreign competitors entering Iran's automotive industry arena, necessitates a more desirable performance compared to other competitors in this industry, which has provided a good basis for conducting the present research. Additionally, research has shown that the most important reasons for the success of Japanese automakers are the efficiency and effectiveness of their parts supply and assembly system and the entire supply

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chain, indicating the importance of the supply chain network in the automotive industry, causing American companies to also try to employ similar systems to those of Japan in their supply chains. Companies like Toyota have significantly benefited from appropriate supply chain management methods, outpacing their American competitors by reducing production costs. Hence, the strategy of supply chain management in the automotive industry currently holds a special position worldwide, and the world's automotive industries are pioneers in employing modern supply chain managements. Many successful automotive companies have significantly reduced their production costs with appropriate supply chain management, gaining more competitive ability in the global market (Atashsooz et al., 2016; Mirghafoori et al., 2012).

In our country, the automotive industry currently holds a special place in terms of intersectoral linkages in the country's economy. For this reason, many efforts have been made towards the localization and development of the automotive industry in Iran over the past few decades; however, on a global scale, the country's automotive industry has not made significant progress in this area. On the other hand, the emergence of new processes, the state's political relations, sanctions, and the global integrated development in the country's automotive industry cause the supply chains of this industry to face new and diverse risks every day. In such an environment, managing automotive companies without considering the strategic risks ahead of their supply chain is not possible, and administration and management require the identification and monitoring of supply chain risks. Achieving such a goal necessitates the integrated and cohesive identification of supply chain risks in the automotive industry for managing the related risks.

Iran Khodro, as the country's largest automaker, plays a very important and determining role in the prosperity of this industry in the country. Iran Khodro is indeed the leader and pioneer of the automotive industry, whose active and forward movement can stimulate the prosperity of this industry; therefore, factors related to Iran Khodro are of special importance, one of the most important of which is the assessment of supplier risks. Given the financial problems in the automotive industry, supply chain management is very important because using high-risk suppliers can increase the possibility of rework and financially harm the automotive industry. For example, automotive parts production is based on standards given to parts manufacturers, but in recent years, due to sanctions, some parts manufacturers have been unable to procure high-quality raw materials and have produced parts that do not meet the required standards after initial controls due to the use of alternative materials, which itself, non-compliance with standards by parts manufacturers, late supply, increased prices, etc., pose risks for Iran Khodro companies. Therefore, examining and clustering supplier risks can provide a solution for better supplier selection for Iran Khodro managers

2 Methods and Materials

This research is analytical-descriptive in nature, and its methodology is based on survey data collection. Considering that it aims to assist company managers in improving the company's situation, it is applied-developmental in purpose and descriptive in its execution approach. Initially, this study identifies decision-making criteria in the field of risk management through a review of previous research. In the next phase, these criteria are evaluated using separate applications of frog-leaping and genetic metaheuristic algorithms, and the impact of reducing these risks on the cost and performance of Iran Khodro in both algorithms is examined and compared to determine the main criteria for the next phase of the research. The subsequent phase involves identifying the primary supply chain risks for Iran Khodro, with suppliers being clustered based on risk criteria, enabling the classification of suppliers based on risks.

The research steps are as follows: analysis and review of research history and extraction of supply chain risk factors; prioritization and ranking of supply chain risks; collecting information related to suppliers; clustering suppliers based on the main supply chain risk factors using Matlab software.

In this research, the company under study is Iran Khodro, with data from 35 of its suppliers evaluated as a sample. The large number of suppliers for Iran Khodro enables detailed clustering in this study. Respondents to the research questions are managers and experts of this company, chosen for their knowledge and mastery of issues related to parts supply. Given the research title and methodology, two perspectives exist regarding the population and sample. According to the first perspective, the population consists of all Iran Khodro suppliers, and the sample comprises those suppliers being studied. This approach aims to specify the status of Iran Khodro suppliers concerning detailed indices, requiring random selection of suppliers to generalize the findings to all suppliers. The other perspective relates to the company's employees and those participating in this research, where participants should be selected to represent a general view of all employees and cover other factory

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sections. The current study considers both perspectives, hence selecting a number of suppliers randomly and employing experts from various departments.

This research utilized literature review (library research) for theoretical discussions and research history, while real data from Iran Khodro were used in the main and operational parts, applying them in a mathematical model to identify the most significant risks separately using genetic and frog-leaping algorithms. Additionally, 35 active suppliers at Iran Khodro were evaluated as a sample for supplier risk assessment.

The objective function of the problem consists of four parts. The first part is the total production preparation cost for each product. The second is the total inventory holding cost for each product at the supplier's warehouse. The third is the total inventory holding cost for each product at the retailers' warehouses. The fourth is the routing cost of the vehicle.

In this section, we presented the results of implementing each algorithm for six problems. Table 1 shows the average distance as one of the comparison criteria between the algorithms.

3 Findings and Results

Table 1

Measurement of Average Distance from the Ideal Point

Problem Size	Dimensions	Genetic Algorithm	Frog-Leaping Algorithm
Small	6x4x3	21,345	29,054
	6x5x3	24,597	31,200
	8x4x3	27,459	34,590
	8x5x3	30,891	37,405
	10x4x3	35,195	38,925
	10x5x3	39,120	39,909
Medium	26x8x6	436,490	459,001
	26x10x6	489,120	498,021
	28x8x6	490,543	560,004
	28x10x6	521,030	590,648
	30x8x6	530,197	621,500
	30x10x6	570,034	640,912
Large	46x14x9	584,002	698,250
	46x15x9	587,020	712,505
	48x14x9	596,100	761,290
	48x15x9	601,806	793,015
	50x14x9	615,049	810,230
	50x15x9	630,492	819,302

Table 2 calculates and presents the criteria for the maximum expansion on average for both selected algorithms.

Table 2

Maximum Spread Criterion in Both Genetic and Frog-Leaping Algorithms

Problem Size	Dimensions	Genetic Algorithm	Frog-Leaping Algorithm
Small	6x4x3	4,371	10,402
	6x5x3	4,725	13,165
	8x4x3	4,964	15,060
	8x5x3	4,974	15,946
	10x4x3	5,223	18,395
	10x5x3	5,560	20,071
Medium	26x8x6	6,271	22,038
	26x10x6	7,003	24,060
	28x8x6	7,263	26,662

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	28x10x6	8,164	29,159
	30x8x6	8,381	36,062
	30x10x6	8,973	49,940
Large	46x14x9	11,005	87,693
	46x15x9	12,005	98,794
	48x14x9	13,166	100,001
	48x15x9	15,366	109,360
	50x14x9	18,496	128,381
	50x15x9	21,165	187,736

Table 3 reports the uniformity criterion for the performance of both the genetic algorithm and the frog-leaping algorithm.

Table 3

Uniformity Criterion for Genetic and Frog-Leaping Algorithms

Problem Size	Dimensions	Genetic Algorithm	Frog-Leaping Algorithm
Small	6x4x3	498.21	1208.87
	6x5x3	876.64	1652.87
	8x4x3	992.87	857.89
	8x5x3	318.87	1397.98
	10x4x3	59.86	1653.98
	10x5x3	95.87	872.23
Medium	26x8x6	543.78	2810.87
	26x10x6	644.87	3143.21
	28x8x6	765.98	3719.32
	28x10x6	932.87	2769.13
	30x8x6	658.98	3871.32
	30x10x6	745.89	3912.32
Large	46x14x9	376.87	18763.65
	46x15x9	432.87	13287.12
	48x14x9	642.98	12376.87
	48x15x9	425.87	17879.87
	50x14x9	613.09	21065.82
	50x15x9	1094.90	24809.59

Subsequently, Table 4 reports the Pareto points number criteria for both the genetic and frog-leaping algorithms.

Table 4

Pareto Front Points Number Criterion for Genetic and Frog-Leaping Algorithms

Problem Size	Dimensions	Genetic Algorithm	Frog-Leaping Algorithm
Small	6x4x3	67.87	31.98
	6x5x3	61.87	39.87
	8x4x3	56.12	20.43
	8x5x3	50.63	22.98
	10x4x3	69.21	27.19
	10x5x3	58.12	30.32
Medium	26x8x6	58.21	38.44
	26x10x6	52.87	37.42
	28x8x6	53.21	30.21
	28x10x6	50.12	44.12
	30x8x6	49.23	45.32
	30x10x6	48.12	50

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Large	46x14x9	53.87	52
	46x15x9	59.31	51
	48x14x9	50.87	59
	48x15x9	61.43	56
	50x14x9	68.79	42
	50x15x9	60.12	57

Table 5 reports the set coverage criterion for both algorithms in problems of varying dimensions.

Table 5

Set Coverage Criterion in Frog-Leaping and Genetic Algorithms

Problem Size	Dimensions	Genetic Algorithm	Frog-Leaping Algorithm
Small	6x4x3	0.80	0.19
	6x5x3	0.71	0.03
	8x4x3	0.61	0.39
	8x5x3	0.88	0.27
	10x4x3	0.58	0.37
	10x5x3	0.69	0.09
Medium	26x8x6	1	0
	26x10x6	1	0
	28x8x6	1	0
	28x10x6	1	0
	30x8x6	1	0
	30x10x6	1	0
Large	46x14x9	1	0
	46x15x9	1	0
	48x14x9	1	0
	48x15x9	1	0
	50x14x9	1	0
	50x15x9	1	0

Furthermore, the results of solving the problem using the GAMS method and both the frog-leaping and genetic algorithms, which represent the model presented in the research, are provided and compared. Coding and solving the problem using GAMS were feasible for small and medium-sized problems, but no solution was obtained within a reasonable time for larger dimensions. However, the optimal solution for the first objective function and for the second objective function are as follows: The results from the genetic algorithm implemented in MATLAB environment yielded the best answer obtained throughout all generations with ZOPT = 217508.76, and the optimal chromosome in phase two, which corresponds to the order quantity at each of the intermediate and retail warehouses, was used. However, the response from the first linear programming method of the genetic algorithm, which corresponds to the minimum total inventory system cost for the existing risks, is as follows: Min z1 = 257051, Min z2 = 24543.

Also, the result from solving the problem using the second method, the frog-leaping algorithm, is as follows: Min z1 = 236505, Min z2 = 21098.

The results from solving the problem using the three methods are presented in Table 6.

Table 6

Results of Solving the Two-Level Supply Chain Inventory System Problem Using Two Methods

Method	Result
Genetic Algorithm	Z1=257051
Frog-Leaping Algorithm	Z1=236505
GAMS (Optimal)	Zopt=249809, 224534, 221098, 19928

4 Discussion and Conclusion

By comparing the results obtained, it becomes clear that the model presented in this research was analyzed using both exact solution methods and a metaheuristic approach, where it was solved in the metaheuristic method using two metaheuristic algorithms: genetic and frog-leaping. The comparison of the research outcomes suggests that the exact solution method provides better and more optimal results. However, due to the NP-HARD nature of the problem, this method does not yield a solution within a reasonable time frame for larger problem sizes, which is why the problem was solved using metaheuristic algorithms. Among these algorithms, the frog-leaping algorithm presented more optimal results, but the solution time in the genetic algorithm was less compared to the frog-leaping algorithm. Considering this, the second approach of linear programming with the genetic algorithm, selected in this research for problem-solving and aiming at simplifying the issue and ease of resolution, does not significantly focus on the objective function coefficients related to the potential demand volatility. Given all these points, if the goal is to account for the uncertainty in determining system parameters due to the existing uncertainty in today's business environment, aiming to achieve more practically applicable outcomes, it can be claimed that the model presented in this research has shown considerable efficiency in terms of the results provided and cost reduction, which is the most critical determinant in inventory system performance. In other words, by incorporating uncertainty into the model with both the frog-leaping and genetic algorithms and aligning the problem conditions closer to the real-world system operations, it has been possible to achieve better outcomes using this model. Thus, the main hypothesis of the thesis, which posits that reducing inventory system costs and carbon dioxide emissions and improving its performance can be achieved using a metaheuristic algorithm, is confirmed.

In analyzing the complexities and risks associated with supply chain management, especially in the selection and evaluation of suppliers, several studies have emphasized the significance of incorporating risk assessment models to enhance decision-making processes. The research by Atashsooz et al. (2016) on modeling the structural interpretation of supply chain risks in the petrochemical industry underscores the intricate nature of supply chain vulnerabilities and the necessity for robust risk management frameworks (Atashsooz et al., 2016). This is in line with the findings of Azar et al. (2011), who developed a mathematical model for multi-objective, robust-fuzzy sourcing, illustrating the importance of considering risk management in supply chain decisions related to the automotive industry (Azar et al., 2021). Further, the work of Pouya and Ghorbanpour (2015) on clustering industries in terms of supply chain 'greenness' for environmental management presents a novel approach towards incorporating sustainability and risk considerations into supply chain management. This perspective is critical as companies strive to balance operational efficiency with environmental responsibilities (Pooya & Qorban Poor, 2015).

In conclusion, the body of literature (Atashsooz et al., 2016; Azar et al., 2021; Badurdeen et al., 2014; Li & Zabinsky, 2011; Mirghafoori et al., 2012; Punniyamoorthy et al., 2013) consistently advocates for the integration of sophisticated risk assessment and management strategies within the supply chain. These strategies encompass a broad spectrum of methodologies, from mathematical modeling and fuzzy logic to clustering and environmental sustainability considerations. Adopting such comprehensive approaches enables organizations to not only mitigate risks but also to optimize their supply chain operations in alignment with both operational and environmental objectives, thereby achieving a competitive edge in today's volatile market landscape.

This study, while providing significant insights into the evaluation and management of supply chain risks, particularly in supplier selection, is not without its limitations. One of the primary constraints is the reliance on quantitative models and algorithms that may not fully capture the complexity and dynamism of real-world supply chains. These models often require simplifications and assumptions that might not accurately reflect the uncertainty and variability inherent in supply chain operations. Additionally, the focus on specific algorithms, such as the genetic algorithm and the frog-leaping algorithm, may overlook other potentially effective heuristic or metaheuristic approaches that could offer better or more robust solutions under different circumstances. Moreover, the study's applicability might be limited by its context-specific nature, deriving mainly from the automotive and steel production industries, which may not be directly transferable to other sectors with different operational dynamics and risk profiles. Finally, the study predominantly addresses the quantitative aspects of risk management, leaving room for further exploration into qualitative factors

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such as supplier reliability, reputation, and the strategic fit that are equally critical in supplier selection and overall supply chain resilience.

Recommendations:

Designing the supply chain considering risk factors and exploring efficient approaches for quantifying risk and implementing risk management and its application in the supply chain.

Companies should ensure they receive accurate and timely data from all manufacturers. This challenge is significant and requires substantial effort, supported through motivating suppliers and engaging in the process.

Building strong relationships with your colleagues and understanding their motivations and challenges.

Sharing a compelling vision of success with them.

Simplifying data submission.

Providing suppliers with transparent and documented feedback to be aware of their performance.

Offering solutions to reduce critical risks, considering their interconnections and the network among them.

Authors' Contributions

All authors have contributed significantly to the research process and the development of the manuscript.

Declaration

In order to correct and improve the academic writing of our paper, we have used the language model ChatGPT.

Transparency Statement

Data are available for research purposes upon reasonable request to the corresponding author.

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Declaration of Interest

The authors report no conflict of interest.

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Ethical Considerations

In this research, ethical standards including obtaining informed consent, ensuring privacy and confidentiality were observed.

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