Identification of Root Causes of Supply Chain and Supplier Risks in the Automotive Industry

Mohsen Khosravian[1], Mohammad Ebrahim Pourzarandi[2,*] and Seyyed Jalal Haghighat Monfared[3]

[1] Department of Industrial Management, Tehran Markaz Branch, Islamic Azad University, Tehran, Iran;
[2] Department of Industrial Management, Tehran Markaz Branch, Islamic Azad University, Tehran, Iran;
[3] Department of Industrial Management, Tehran Markaz Branch, Islamic Azad University, Tehran, Iran;

* Correspondence: pourzarandi@yahoo.com

Citation: Khosravian, M., Pourzarandi, M. E., & Haghighat Monfared, S. J. (2025). Identification of Root Causes of Supply Chain and Supplier Risks in the Automotive Industry. *Business, Marketing, and Finance Open*, 2(1), 89-103.

Received: 21 August 2024
Revised: 12 October 2024
Accepted: 06 December 2024
Published: 01 January 2025

Abstract: This study aimed to identify, analyze, and prioritize the root causes of supply chain and supplier risks in the automotive industry, focusing on Iran Khodro Company and its suppliers. This research employed a descriptive-analytical method with data collected from Iran Khodro Company and 35 of its suppliers through random sampling and expert surveys. Root causes were identified through extensive literature review and expert consultations, followed by a two-round Delphi method for validation. The findings were weighted and prioritized based on expert consensus, using risk assessment indices and statistical analysis. The study identified key risk factors including lack of safety actuator systems, inadequate safety supervision, insufficient job competency, and absence of safety training as the most critical root causes. Additional significant risks were work-related stress, inadequate preventive maintenance, and failure to use personal protective equipment. Design inefficiencies, absence of safety sensors and ventilation systems, and hidden psychological factors also contributed to supply chain vulnerabilities. The results highlight systemic issues within the automotive supply chain that increase operational risks and disrupt supply chain continuity. Addressing root causes such as safety system inadequacies, employee competency, and preventive maintenance is essential for enhancing supply chain resilience in the automotive industry. Implementing advanced safety measures, fostering employee training, and adopting digital tools can mitigate supply chain risks and improve operational efficiency. The study underscores the need for comprehensive risk management strategies to ensure sustainable and resilient supply chain operations.

Keywords: Supply chain risk, automotive industry, supplier risk, root cause analysis, supply chain resilience, risk management, Iran Khodro Company.

1. Introduction

The automotive industry is a complex and highly integrated network of suppliers, manufacturers, and logistics providers, where supply chain efficiency and resilience play a crucial role in operational success. The rapid globalization of markets, increased demand volatility, and recent global crises have amplified the risks associated with supply chain disruptions. Supply chain management (SCM) in the automotive industry has been increasingly scrutinized for its ability to withstand unforeseen events, such as the COVID-19 pandemic, geopolitical conflicts, and technological disruptions [1-3]. Given the industry's reliance on just-in-time (JIT) manufacturing and lean supply chain principles, even minor disruptions can cascade through the entire value chain, leading to significant financial and operational consequences [4, 5].

The automotive sector faces a myriad of risks, including supplier failures, logistical bottlenecks, quality issues, and regulatory changes, which can all impact supply chain performance [6, 7]. The increasing interconnectedness of supply chains has led to a greater emphasis on supply chain risk management (SCRM) as a strategic imperative for automotive companies. SCRM involves identifying, assessing, and mitigating risks through proactive strategies, such as diversifying suppliers, implementing robust monitoring systems, and enhancing digitalization efforts [8, 9]. Global crises, such as the COVID-19 pandemic, exposed the vulnerabilities of automotive supply chains, particularly in terms of sourcing flexibility and production capacity [10, 11]. During the pandemic, supply chains suffered from reduced labor availability, semiconductor shortages, and transportation restrictions, leading to production halts and financial losses [12, 13]. Additionally, geopolitical conflicts, such as the war in Ukraine, have further exacerbated supply chain instability, impacting the procurement of essential raw materials and automotive components [2].

One of the most significant risks in automotive supply chains is supplier dependency. Many automakers rely on a limited number of suppliers for critical components, such as semiconductors, lithium-ion batteries, and advanced electronic systems [6]. Disruptions in these upstream suppliers can have a domino effect, delaying production schedules and increasing costs [14]. Research suggests that companies with a more flexible sourcing strategy and diversified supplier base exhibit higher resilience during crises [10, 15]. Logistical risks also present substantial challenges in the automotive supply chain. Delays in transportation, port congestion, and disruptions in global shipping routes can lead to increased lead times and inventory shortages [1, 16]. The rise of inter-organizational information systems has facilitated real-time visibility and improved coordination among supply chain stakeholders, helping mitigate logistical disruptions [17]. However, the reliance on traditional transportation infrastructure remains a vulnerability, particularly when unexpected events, such as natural disasters, strike [18].

Quality control and compliance risks further complicate supply chain management in the automotive sector. With stringent regulatory requirements and high consumer expectations, any defects or quality lapses can result in costly recalls and reputational damage [19]. Ensuring supplier compliance with safety standards, environmental regulations, and ethical labor practices has become increasingly important [20]. Companies that integrate proactive quality risk management strategies into their supply chains are better equipped to minimize disruptions and maintain customer trust [21]. In response to increasing supply chain risks, many automotive firms are leveraging digital technologies to enhance their resilience. Digital transformation, including the adoption of blockchain, artificial intelligence (AI), and Internet of Things (IoT) solutions, has been identified as a key enabler of efficient supply chain operations [12, 22]. Blockchain technology, for example, enables secure and transparent tracking of supply chain transactions, reducing fraud and improving traceability [8]. AI-driven predictive analytics can help companies anticipate potential disruptions and optimize inventory management in real time [1].

Supply chain flexibility has also emerged as a crucial factor in mitigating risks. Companies that maintain a diversified supplier portfolio, implement dual-sourcing strategies, and invest in regionalized production hubs have demonstrated greater resilience in the face of global disruptions [9]. Additionally, collaborative risk management approaches that involve close coordination with suppliers, logistics partners, and policymakers can help enhance overall supply chain stability [7]. Despite extensive research on supply chain risks in the automotive industry, there remains a need for a more comprehensive analysis of the root causes of these risks. Existing studies primarily focus on risk mitigation strategies but often overlook the underlying factors that contribute to supply chain vulnerabilities [4, 23]. Identifying the root causes of supply chain and supplier risks is essential for developing targeted interventions that address systemic issues rather than just mitigating surface-level disruptions. This study aims to fill this research gap by systematically identifying, analyzing, and prioritizing the root causes of supply chain risks in the automotive industry. In another word, this study seeks to identify and analyze the root causes of supply chain and supplier risks in the automotive sector.

2. Methodology

The study employs a descriptive-analytical design aimed at identifying and analyzing the root causes of supply chain and supplier risks in the automotive industry, with Iran Khodro Company as the focal case. The temporal scope of the research spans from February 2019 to June 2021. The research population includes all suppliers of Iran Khodro Company, while the sample comprises 35 randomly selected suppliers from this population, ensuring that the results can be generalized across the entire supplier base. Additionally, participants include managers and experts from various departments within Iran Khodro, selected based on their in-depth knowledge of supply chain challenges and risks. This dual perspective ensures comprehensive coverage of both supplier-related risks and internal company assessments, with respondents representing different operational sections to capture diverse viewpoints.

Data collection is carried out in two stages. Initially, an extensive literature review is conducted to extract potential supply chain risk factors. Subsequently, structured surveys and checklists are employed to gather data from participants. The survey design incorporates criteria such as clarity, relevance, simplicity, and necessity, with ambiguous or irrelevant responses being replaced by clear, pertinent, and essential data through iterative validation by expert panels comprising five to seven members. The validated risk factors are then subjected to a rating process through expert consensus, conducted in two rounds spaced 15 days apart. In both rounds, experts rate the significance of identified risks, with response options including "strongly agree" (4 points), "agree" (3 points), "disagree" (2 points), and "strongly disagree" (1 point). Risk importance is also rated on a scale of 1 to 3, with 3 indicating high importance, 2 indicating moderate importance, and 1 indicating low importance.

Data analysis involves prioritizing and ranking the identified supply chain risks using statistical methods and expert consensus techniques. The first phase of analysis focuses on identifying root causes by examining detailed case reports of past supply chain disruptions, aligning findings with legal and operational documentation, and extracting underlying risk factors. Expert validation is then conducted, with validated risk factors subjected to reliability testing using the consensus-based rating system. Statistical tools are employed to calculate reliability coefficients and assess the consistency of expert ratings. Final risk rankings are determined based on weighted scores assigned by experts, ensuring that the most critical risks are prioritized for further analysis and mitigation planning.

3. Findings and Results

Findings that, first, attract seventy percent approval from experts and, second, for which each expert's responses in the second round are identical to his or her responses in the first round are considered reliable and accurate. After applying the agreement and importance coefficients, the weight of these findings is determined, and the prioritized as well as fundamental items are identified as the final findings.

After posing various questions, the manner and rationale behind each incident were clarified, and the initial data necessary for determining the root causes were obtained, as described in the table below.

Table 1. Root Cause Analysis in Automotive Industry Factories

Activity	Type of Risk	Risk Outcome	Affected Scope	Severity	Causes of Risk Occurrence	Probability of Occurrence	Detection Method	Control Number	RPN	Standard/ Law	Acceptable Risk	Unacceptable Risk	Recommended Action
Tire Molding	Mold falling during replacement onto the foot	Crushing/fracture of foot bones	A	6	Lack of a suitable support fixture	5	Regular periodic inspection	5	150		√		Use a mobile workstation with adjustable height
Tire Molding	Transporting the mold	Back pain, lumbar disc issues	B	6	Lack of a proper carrying device	5	Regular periodic inspection	5	150		√		Use a mobile workstation with adjustable height
Tire Molding	Exposure to noise	Hearing loss	B	6	Machine operating conditions/failure to use ear protection	5	Regular periodic inspection	5	150	√			Measure and take action in case of exceeding permissible limits
Tire Molding	Hand getting stuck in the funnel area of the machine	Crushing/fracture of hand bones	A	6	Insufficient care during material loading	5	Regular periodic inspection	5	150	√			Install a guard to prevent hand entry
Tire Molding	Performing work in a standing position	Varicose veins and joint pain in the legs	B	6	Failure to take breaks during work	7	Regular periodic inspection	5	210			√	Requiring temporary seated work and avoiding continuous operation
Tire Molding	Bursting of the air hose	Injury to body parts	A	5	Hose wear, excessive air pressure beyond the specified limit, and malfunction of the cutoff system	5	Regular periodic inspection	5	125		√		—
Tire Molding	Separating adhered tire layers	Back pain, lumbar disc issues, etc.	B	7	Excessive weight of adhered layers and applying too much force	5	Regular periodic inspection	5	175		√		—
Tire Molding	Contact with the hot part of the machine	Hand burn	A	5	Failure to use appropriate gloves	5	Regular periodic inspection	5	125		√		—
Tire Molding	Hand caught between rollers/dryer of the machine	Finger injuries	A	5	Using gloves while working with rollers/dryer	5	Regular periodic inspection	5	125		√		—
Tire Molding	Using soap for lubrication	Skin disease	B	4	Failure to use suitable gloves during contact	5	Regular periodic inspection	5	100		√		—
Tire Molding	Tire compound fumes	Air pollution	Z	7	Increased tire curing temperature	3	None	10	210				—

Tire Molding	Pushing the sidewall collection stand	Back pain, lumbar disc issues, etc.	B	7	Unsuitable wheels on the stand and contact with the floor covering	6	Regular periodic inspection	5	210		√	Use hard (bone) wheels instead of rubber wheels
Tire Molding	Electric shock	Risk of burns to body parts and physical injury	A	7	Inefficiency of the PM system and inadequate grounding performance	6	Regular periodic inspection	5	210		√	Execute scheduled PM actions on time and periodically check the grounding system
Tire Molding	Water leakage	Wastewater pollution	Z	4	Leakage from O-rings and pipes	4	None	10	160			—
Tire Molding	Collision with the overhead crane during inspection of the cooling conveyor area	Death	A	10	Insufficient platform height at the inspection site in relation to the overhead crane boom and no crane horn for warning	8	Regular periodic inspection	5	400		√	Install a warning horn on the crane and ensure no worker is on the platform before crane movement to carry heavy loads
Tire Molding	Risk of a worker falling during movement in the base thread area	Physical injury	A	5	Slippery stairs and wearing improper footwear	7	Regular periodic inspection	5	175	√		Clean the walking area of slippery factors periodically and use footwear free from oil residue
Layer Manufacturing	Collision with the machine during operation	Physical injury	A	5	Malfunctioning cutoff sensor	5	Regular periodic inspection	5	125	√		—
Layer Manufacturing	Pushing the thread stand	Back pain, lumbar disc issues, etc.	B	7	Unsuitable wheels on the stand and contact with the floor covering	6	Regular periodic inspection	5	210		√	Use hard (bone) wheels instead of rubber wheels
Layer Manufacturing	Electric shock	Risk of burns to body parts and physical injury	A	7	Inefficiency of the PM system and inadequate grounding performance	6	Regular periodic inspection	5	210		√	Execute scheduled PM actions on time and periodically check the grounding system
Layer Pressing	Collision with the bladder, press machine,	Physical injury	A	5	Malfunctioning cutoff sensor	5	Regular periodic inspection	5	125	√		—

	and building												
Layer Manufacturing	Bladder falling onto the foot during replacement	Crushing/fracture of foot bones	A	6	Lack of a suitable support fixture	7	Regular periodic inspection	5	210			√	Use a suitable support fixture during installation
Using the air intake capsule for dehumidifying	Explosion of the air capsule	Death	A	10	Wear on the capsule wall and malfunction of the safety valve	5	Regular periodic inspection	5	250			√	Scheduled testing (thickness measurement of the capsule and the intake cutoff system)
Layer Manufacturing	Rubber waste	Soil pollution	Z	8	Improper disposal	3	Instruction	6	144				Collect and transfer for recycling
Gluing to prevent sticking to the bladder	Slipping during work	Physical injury	A	5	Failure to clean paint from the floor at the work area during spraying	6	Regular periodic inspection	5	150		√		—
Gluing to prevent sticking to the bladder	Explosion of the paint and air tank	Death	A	10	Wear on the capsule wall and malfunction of the safety valve	5	Regular periodic inspection	5	250			√	Scheduled testing (thickness measurement of the capsule and the intake cutoff system)
Gluing to prevent sticking to the bladder	Exposure to noise	Hearing loss	B	6	Machine operating conditions/failure to use ear protection	5	Regular periodic inspection	5	150	√			Measure and take action in case of exceeding permissible limits
Gluing to prevent sticking to the bladder	Hand caught in the conveyor belt	Finger injuries	A	5	Using gloves while working with the conveyor and wearing loose work clothes	5	Regular periodic inspection	5	125		√		—
Gluing to prevent sticking to the bladder	Head collision with the chuck (three-jaw)	Physical injury	A	5	Entering the chuck area while it is rotating	5	Regular periodic inspection	5	125		√		—
Gluing to prevent sticking to the bladder	Contact of the hand with paint during work	Skin disease	B	5	Failure to use proper gloves and apron	7	Regular periodic inspection	5	175		√		Prevent work if gloves and an apron are not used
Bead Manufacturing	Pushing the spool stand	Back pain, lumbar disc issues, etc.	B	7	Unsuitable wheels on the stand and contact	6	Regular periodic inspection	5	210			√	Use hard (bone) wheels instead of

					with the floor covering							rubber wheels
Bead Manufacturing	Contact with the hot part of the machine	Hand burn	A	5	Failure to use appropriate gloves	5	Regular periodic inspection	5	125		√	—
Bead Manufacturing	Electricity consumption	Energy waste	Z	3	Using a heater for warming	7	None	10	210			Turn off the machine when idle
Bead Manufacturing	Hand entrapment while operating the machine	Finger injuries	A	5	Using gloves while working with the machine and wearing loose work clothing	5	Regular periodic inspection	5	125		√	—
Bead Manufacturing	Steam leakage	Energy waste	Z	6	Wear on pipes and connections	3	Periodic inspection	3	54			Replace pipes and connections
Apexing	Hand entrapment while operating the machine	Finger injuries	A	5	Using gloves while operating the machine and wearing loose work clothing	5	Regular periodic inspection	5	125		√	—
Apexing	Hand collision with scissors	Finger lacerations	A	5	Lack of a guard	5	Regular periodic inspection	5	125		√	—
STEEL BELT Manufacturing	Pulley falling onto individuals	Physical injury	A	4	Inattention when placing the pulley	5	Regular periodic inspection	5	100		√	—
STEEL BELT Manufacturing	Hand collision with wire	Finger cuts	A	4	Failure to use gloves	5	Regular periodic inspection	5	100		√	—
STEEL BELT Manufacturing	Moving the wire roll	Musculoskeletal disorders	B	6	Manually carrying a heavy wire roll	8	Visual check	5	240			Use an overhead crane or arm
Cooling the Belt	Hand caught between rollers	Finger injuries	A	5	Belt sticking to the roller and separating it	5	Regular periodic inspection	5	125		√	—
Cooling the Belt	Contact with the hot part of the machine	Hand burn	A	5	Failure to use appropriate gloves	5	Regular periodic inspection	5	125		√	—
STEEL BELT Cutting	Hand entrapment while operating the machine	Finger amputation	A	7	Failure to use a warning sensor	5	Regular periodic inspection	5	175		√	Operator training - sensor installation
STEEL BELT Cutting	Exposure to noise	Hearing loss	B	6	Machine operating conditions/failure to use ear protection	5	Regular periodic inspection	5	150	√		Measure and take action in case of exceeding permissible limits

STEEL BELT Cutting	Electric shock	Risk of burns to body parts and physical injury	A	7	Inefficiency of the PM system and inadequate grounding performance	6	Regular periodic inspection	5	210		√	Execute scheduled PM actions on time and periodically check the grounding system
Tire Curing	Bladder rupture	Burns to body parts	A	6	Steam valve failure	4	Regular periodic inspection	5	120	√		—
Tire Curing	Mold falling onto the foot during replacement	Crushing/fracture of foot bones	A	6	Lack of a suitable support fixture	7	Regular periodic inspection	5	210		√	Use a suitable support fixture during installation
Tire Curing	Carbon black particles in the environment	Air pollution	Z	7	Airflow in the environment	6	None	10	420			Build and install a closed automatic ventilation system
Tire Curing	Contact with steam from curing	Hand burn	A	5	Failure to use appropriate gloves	5	Regular periodic inspection	5	125	√		—
Tire Curing	Electric shock	Risk of burns to body parts and physical injury	A	7	Inefficiency of the PM system and inadequate grounding performance	6	Regular periodic inspection	5	210		√	Execute scheduled PM actions on time and periodically check the grounding system
Tire Curing	Green tire falling from the hook during operation	Physical injury	A	5	Tire not secured in position and the person moving around during work	5	Regular periodic inspection	5	125	√		—
Rubber Strip Cutting	Moving the spool stand	Back pain, lumbar disc issues, etc.	B	7	Moving it manually without lifting equipment	6	Regular periodic inspection	5	210		√	Use an overhead crane and a holder
Rubber Strip Cutting	Hand entrapment while operating the machine	Finger amputation	A	7	Failure to use a warning sensor	5	Regular periodic inspection	5	175	√		Operator training - sensor installation
Rubber Strip Cutting	Working in a standing position	Varicose veins and joint pain in the legs	B	6	Failure to take breaks during work	7	Regular periodic inspection	5	210		√	Requiring temporary seated work and avoiding continuous operation
Rubber Strip Cutting	Moving blade	Finger amputation	A	8	Lack of a fixed guard	4	Visual check	5	160			Safety training for operating the machine/

												Installation of a transparent plastic guard
Rubber Strip Cutting	Hand collision with the adjusting pins (the "Needles of Zaram" during cutting)	Finger injuries	A	5	Failure to observe safety points when adjusting the cord	5	Regular periodic inspection	5	125	√		—
Rubber Strip Cutting	Load falling during transportation	Death	A	10	Inappropriate roll holding hook, no horn, and no safety catch on the crane hook	7	Regular periodic inspection	5	350		√	Design a suitable hook for carrying loads and prevent people from walking in the load path, install a horn, and ensure the crane hook has a safety catch
Cord Collector	Wheels and chain	Clothing entrapment	A	5	Lack of a fixed guard	4	Regular periodic inspection	5	100		√	Install a guard
Steam Generation for Production Halls	Explosion of the steam tank	Death	A	10	Wear on the tank walls and malfunction of the safety valve	5	Regular periodic inspection	5	250		√	Scheduled testing (thickness measurement of tanks and the cutoff system)
Water Hardness Testing	Hand contact with chemicals during work	Skin disease	B	5	Failure to use proper gloves and apron	7	Regular periodic inspection	5	175	√		Prevent work if gloves and an apron are not used
Steam Generation for Production Halls	Inhaling chemical vapors	Respiratory disease	B	7	Failure to use an appropriate mask	7	Regular periodic inspection	5	245		√	Prevent work if a proper mask is not used when adding materials
Steam Generation for Production Halls	Splashing of chemicals when pouring them into the tank	Burns to the face and body parts	A	6	Failure to use a face shield, gloves, and appropriate apron while working	7	Regular periodic inspection	5	210			Prevent work if a face shield, gloves, and apron are not used when adding chemicals and install an eyewash station in the area
Steam Generation	Contact with the	Hand burn	A	5	Failure to use	5	Regular periodic	5	125	√		—

for Production Halls	hot part of the machine				appropriate gloves		inspection						
Steam Generation for Production Halls	Chemicals present in the environment	Wastewater pollution	Z	8	Spillage during weighing and leakage from connections	7	Instruction	5	280				Wash using a scrubber and vacuum device
Condenser Station	Slipping from a ladder while moving around	Physical injury	A	5	Slippery stairs and wearing improper footwear	5	Regular periodic inspection	5	125		√		—
Compressed Air Production	Tank explosion	Death	A	10	Wear on the tank walls and malfunction of the safety valve	5	Regular periodic inspection	5	250			√	Scheduled testing (thickness measurement of tanks and the cutoff system)
Compressed Air Production	Exposure to noise	Hearing loss	B	6	Machine operating conditions/failure to use ear protection	5	Regular periodic inspection	5	150	√			Measure and take action in case of exceeding permissible limits
Repairing Air Handling Units – Air pipes and water pipes at height	Operator fall	Fatality	A	10	Failure to use equipment	5	Supervision and control	4	200				Obtain a work-at-height permit and use personal protective equipment for working at heights

Findings that, first, received seventy percent approval from experts and, second, had responses in the second round that matched each expert's initial responses were considered reliable and precise findings. Subsequently, after applying agreement and importance coefficients, their weight was determined, and the prioritized and essential items were identified as the final findings. These findings were ranked in descending order of importance, as presented below in 25 items.

Table 2. Final Coded Findings with Prioritization

Factor	Value
Lack of safety actuator systems	213
Lack of safety supervision	210
Lack of job competency	204
Lack of safety training	204
Lack of relevant work experience	201
Failure to use personal protective equipment	201
Stress (thermal, auditory, etc.) affecting concentration	198
Lack of preventive maintenance requirements	198
Lack of safety requirements	198
Lack of technical inspection requirements	198
Lack of productivity requirements	198
Failure to conduct periodic inspections	198

Work pressure	195
Negligence	195
Haste in work	195
Failure to use safe lifting equipment	195
Lack of physical fitness	195
Inappropriate design (low crane boom height relative to operator position)	195
Lack of ventilation system	195
Inappropriate design (wheels of the stand)	192
Lack of suitable support fixture	192
Absence of safety sensors	192
Absence of safety warning systems	189
Lack of auxiliary equipment to facilitate work	189
Hidden factors (mental and psychological issues due to family problems)	186

The results of this study revealed and prioritized the root causes of supply chain and supplier risks in the automotive industry, focusing on Iran Khodro Company and its suppliers. The most critical factor identified was the lack of safety actuator systems, with a value of 213, indicating its significant impact on supply chain disruptions. This was closely followed by the lack of safety supervision, which scored 210, highlighting the importance of oversight in maintaining operational stability. Insufficient job competency and lack of safety training, both with values of 204, were also identified as major risks, reflecting the need for well-trained and competent personnel in mitigating supply chain vulnerabilities. The absence of relevant work experience and failure to use personal protective equipment, each with a value of 201, further compounded the risks, particularly in high-risk operational environments.

Stress factors, including thermal and auditory stress affecting concentration, along with the lack of preventive maintenance, safety requirements, technical inspections, and productivity standards, each scored 198, demonstrating their equal and substantial influence on supply chain performance. Work pressure, negligence, and haste in work, each with a value of 195, were identified as critical human-related risks that can lead to operational errors and disruptions. Design-related issues, such as low crane boom height relative to operator position and unsuitable stand wheels, also scored 195, indicating the need for ergonomic and safe infrastructure design. Additional significant factors included the lack of ventilation systems, suitable support fixtures, safety sensors, and warning systems, with values ranging from 192 to 189. Finally, hidden factors, such as mental and psychological issues due to family problems, scored 186, emphasizing the importance of addressing employee well-being as part of comprehensive supply chain risk management.

4. Discussion and Conclusion

The findings of this study identified and prioritized key root causes of supply chain and supplier risks in the automotive industry, with a focus on Iran Khodro Company and its suppliers. The most critical factors included the lack of safety actuator systems, inadequate safety supervision, insufficient job competency, and the absence of comprehensive safety training. Additional significant risks were related to work-related stress, inadequate preventive maintenance, and insufficient use of personal protective equipment. These findings reflect systemic challenges within the automotive supply chain that contribute to operational disruptions and increased vulnerabilities.

The lack of safety actuator systems was identified as the most critical root cause, with a weight of 213. This aligns with previous research by Huang, Wang, and Zhang (2023), who highlighted that technological inadequacies, particularly in safety and monitoring systems, exacerbate supply chain risks in the automotive industry [1]. The absence of automated safety mechanisms increases the likelihood of operational failures, as manual oversight often fails to detect risks in real time [6]. Similarly, Carpitella (2024) emphasized the importance of digital transformation and the integration of advanced safety systems in mitigating operational risks, particularly in high-risk environments such as automotive manufacturing [22].

Inadequate safety supervision, ranked second with a weight of 210, further compounds supply chain vulnerabilities. Gebauer and Tangour (2023) argued that effective safety supervision is essential for maintaining operational efficiency and preventing disruptions, particularly in complex supply chains [10]. Their study on resilience during pandemics demonstrated that companies with robust safety oversight were better able to maintain production continuity and manage supply chain disruptions. Jum'a, Qamardin, and Ikram (2024) also highlighted that safety supervision, along with stakeholder collaboration, is a critical component of supply chain resilience strategies in the automotive industry [8].

The study also found that insufficient job competency and lack of safety training, both weighted at 204, are significant risk factors. Irsyadillah and Dadang (2020) noted that employee competency and training directly impact supply chain performance, as well-trained employees are better equipped to manage operational risks and respond to disruptions effectively [23]. This finding is supported by Kayouh and Dkhiss (2024), who identified that proactive risk management, including employee training, enhances supply chain performance in the Moroccan automotive industry [9].

Another critical factor identified was work-related stress, including thermal and auditory stress, with a weight of 198. This finding aligns with Dias, Hernández, and Oliveira (2020), who noted that high-stress environments in automotive manufacturing can lead to decreased employee concentration and increased error rates, thereby heightening supply chain risks [7]. Pató, Herczeg, and Csiszárik-Kocsír (2022) similarly found that stress induced by the COVID-19 pandemic disrupted automotive supply chains, as employees faced heightened workloads and operational pressures [3].

Preventive maintenance emerged as another significant risk factor, with its absence contributing to operational failures and supply chain disruptions. Liang et al. (2022) emphasized that preventive maintenance is crucial for maintaining supply chain health, particularly in high-demand industries like automotive manufacturing [4]. Their study utilized the SIR epidemic model to demonstrate how preventive maintenance can mitigate the propagation of risks within supply chains. Similarly, Zhang (2024) highlighted that regular maintenance and monitoring are essential for achieving green supply chain management and reducing operational risks [16].

The failure to use personal protective equipment (PPE), weighted at 201, also posed a significant risk. Ayra (2025) highlighted that the adoption of PPE is essential for ensuring employee safety and minimizing operational disruptions in supply chains [15]. The study emphasized that organizations with strong risk management cultures, including strict adherence to safety protocols, exhibited better operational performance and resilience during disruptions.

The study's findings on the importance of safety requirements, technical inspections, and productivity standards align with research by Ishida (2020), who highlighted that comprehensive safety and quality standards are critical for managing supply chain risks in the post-COVID-19 era. Ishida's study demonstrated that automotive companies with stringent safety and quality controls were better able to navigate the complexities of global supply chains during the pandemic [5]. Prashar and Aggarwal (2019) further supported this, noting that quality risk management is essential for ensuring supply chain resilience, particularly in high-precision industries like automotive manufacturing [19].

The identification of work pressure, negligence, and haste in work as significant risk factors reflects systemic issues within supply chain management practices. Surjandy et al. (2020) highlighted that high work pressure and operational inefficiencies often lead to increased error rates and supply chain disruptions. Their study on blockchain technology in the automotive component industry suggested that digital tools can help alleviate work pressures by streamlining operations and improving supply chain visibility [12].

Inappropriate design elements, such as low crane boom height and unsuitable stand wheels, were also identified as critical risk factors. Zhou (2024) highlighted that design inefficiencies in supply chain infrastructure contribute to operational delays and increased risk exposure. Their case study on supply chain resilience in the automotive industry emphasized that infrastructure improvements and ergonomic designs are essential for enhancing operational efficiency and reducing risks [14].

The absence of ventilation systems, safety sensors, and warning systems further exacerbates supply chain risks. Jones, Cai, and Kamaşak (2024) emphasized that environmental controls, such as proper ventilation and safety sensors, are critical for maintaining safe working conditions and ensuring operational continuity. Their study on sustainable packaging designs in the automotive industry highlighted that environmental and safety considerations are integral to supply chain management [20].

Finally, hidden factors such as mental and psychological issues due to family problems, weighted at 186, were identified as significant risks. Srivastava and Rogers (2021) highlighted that employee well-being directly impacts supply chain performance, as psychological stress can lead to decreased productivity and increased error rates. Their study on managing global supply chain risks emphasized the importance of employee support systems in enhancing supply chain resilience [11].

This study, while comprehensive, is limited by its focus on a single company and its suppliers within the Iranian automotive industry. The findings may not be fully generalizable to other regions or industries due to differences in regulatory environments, market dynamics, and operational practices. Additionally, the study relied on expert opinions for risk assessment and prioritization, which may introduce subjective biases despite efforts to ensure reliability and accuracy.

Future research should explore supply chain risk management in other regions and industries to provide a broader understanding of risk factors and mitigation strategies. Comparative studies between different automotive manufacturers can offer insights into best practices and highlight industry-wide challenges. Additionally, future studies could leverage advanced analytical tools, such as machine learning and big data analytics, to identify and predict supply chain risks more accurately.

Automotive companies should invest in advanced safety systems and preventive maintenance programs to mitigate supply chain risks. Enhancing employee training and competency is essential for managing operational challenges and ensuring supply chain resilience. Companies should also adopt digital tools, such as blockchain and IoT, to improve supply chain visibility and operational efficiency. Moreover, fostering a supportive work environment and addressing employee well-being can significantly enhance supply chain performance and reduce operational risks.

Authors' Contributions

Authors equally contributed to this article.

Ethical Considerations

All procedures performed in this study were under the ethical standards.

Acknowledgments

Authors thank all participants who participate in this study.

Conflict of Interest

The authors report no conflict of interest.

Funding/Financial Support

According to the authors, this article has no financial support.

References

[1] K. Huang, J. Wang, and J. Zhang, "Automotive Supply Chain Disruption Risk Management: A Visualization Analysis Based on Bibliometric," *Processes,* vol. 11, no. 3, p. 710, 2023, doi: 10.3390/pr11030710.

[2] A. Milenković and G. Milovanović, "Automotive Supply Chain Disruptions Caused by Crisis in Ukraine," *Ekonomika,* vol. 70, no. 1, pp. 95-110, 2024, doi: 10.5937/ekonomika2401095m.

[3] B. S. G. Pató, M. Herczeg, and Á. Csiszárik-Kocsír, "The COVID-19 Impact on Supply Chains, Focusing on the Automotive Segment During the Second and Third Wave of the Pandemic," *Risks,* vol. 10, no. 10, p. 189, 2022, doi: 10.3390/risks10100189.

[4] D. Liang, R. Bhamra, Z. Liu, and Y. Pan, "Risk Propagation and Supply Chain Health Control Based on the SIR Epidemic Model," *Mathematics,* vol. 10, no. 16, p. 3008, 2022, doi: 10.3390/math10163008.

[5] S. Ishida, "Perspectives on Supply Chain Management in a Pandemic and the Post-Covid-19 Era," *Ieee Engineering Management Review,* vol. 48, no. 3, pp. 146-152, 2020, doi: 10.1109/emr.2020.3016350.

[6] Y. Chen, Y. Guo, and S. Liu, "Research on Supply Chain Risk Assessment Index System and Risk Countermeasures of Automobile Manufacturing Industry," pp. 551-558, 2023, doi: 10.2991/978-94-6463-256-9_57.

[7] G. C. Dias, C. T. Hernández, and U. R. d. Oliveira, "Supply Chain Risk Management and Risk Ranking in the Automotive Industry," *Gestão & Produção,* vol. 27, no. 1, 2020, doi: 10.1590/0104-530x3800-20.

[8] L. Jum'a, S. Qamardin, and M. Ikram, "Developing Resilience Strategies Amid Supply Chain Risks in the Automotive Industry: A Stakeholder Theory Perspective," *Business Strategy and the Environment,* vol. 33, no. 8, pp. 9197-9213, 2024, doi: 10.1002/bse.3977.

[9] N. Kayouh and B. Dkhiss, "The Impact of Proactive Risk Management, Collaboration, and Digital Tools on Supply Chain Performance in the Moroccan Automotive Industr," *Uncertain Supply Chain Management,* vol. 13, no. 4, pp. 763-772, 2024, doi: 10.5267/j.uscm.2024.12.100.

[10] M. Gebauer and C. Tangour, "Resilience to Pandemics Through Flexibility in Sourcing, in Order Fulfillment, and Production Capacity of the Automotive Supply Chain," pp. 365-375, 2023, doi: 10.1007/978-3-031-27933-1_34.

[11] M. Srivastava and H. Rogers, "Managing Global Supply Chain Risks: Effects of the Industry Sector," *International Journal of Logistics Research and Applications,* vol. 25, no. 7, pp. 1091-1114, 2021, doi: 10.1080/13675567.2021.1873925.

[12] S. Surjandy, M. Meyliana, W. Harco Leslie Hendric Spits, and E. Abdurachman, "A Proposed Supply Chain Model of Blockchain Technology-Based in Automotive Component Industry," *International Journal of Recent Technology and Engineering,* vol. 8, no. 5, pp. 3110-3114, 2020, doi: 10.35940/ijrte.e6440.018520.

[13] J. Ye, "Risk Management Strategies for Chip Supply Chain Disruption: Case Study of R Automotive Manufacturing Company," *Advances in Economics Management and Political Sciences,* vol. 52, no. 1, pp. 278-282, 2023, doi: 10.54254/2754-1169/52/20230755.

[14] Y. Zhou, "Examining Supply Chain Resilience in the Automotive Industry: A Case Study," *Frontiers in Management Science,* vol. 3, no. 4, pp. 36-38, 2024, doi: 10.56397/fms.2024.08.04.

[15] A. D. Ayra, "Peran Resiliensi Dalam Memediasi Pengaruh Budaya Manajemen Risiko Rantai Pasok Terhadap Kinerja Organisasi," *Akademik Jurnal Mahasiswa Ekonomi & Bisnis,* vol. 5, no. 1, pp. 332-346, 2025, doi: 10.37481/jmeb.v5i1.1200.

[16] R. Zhang, "Methods for Carbon Reduction Through Green Supply Chain Management in the Automotive Industry," *Frontiers in Business Economics and Management,* vol. 17, no. 3, pp. 301-303, 2024, doi: 10.54097/s5vaf884.

[17] S. Abrighach and Y. A. Meriouh, "Empirical Investigation Into the Impact of Inter- Organisational Information Systems on Supply Chain Performance," *Economics and Finance,* pp. 34-44, 2024, doi: 10.51586/2754-6209.2024.12.1.34.44.

[18] S.-H. Shin and S.-Y. Shin, "A Study on the Reinforcement of Supply Chains Corresponding to Global Value Chain Reforms in the Automobile Parts and Component Industry," *Journal of International Logistics and Trade,* vol. 19, no. 3, pp. 163-179, 2021, doi: 10.24006/jilt.2021.19.3.163.

[19] A. Prashar and S. Aggarwal, "Modeling Enablers of Supply Chain Quality Risk Management: A Grey-Dematel Approach," *The TQM Journal,* vol. 32, no. 5, pp. 1059-1076, 2019, doi: 10.1108/tqm-05-2019-0132.

[20] A. Jones, Y. Cai, and R. Kamaşak, "Examining Sustainable Packaging Designs in the Automotive Industry," pp. 206-227, 2024, doi: 10.4018/979-8-3693-0669-7.ch010.

[21] J. Rohit and A. Vivek, "Operations and Supply Chain in Automobile Industry," *International Journal for Multidisciplinary Research,* vol. 6, no. 2, 2024, doi: 10.36948/ijfmr.2024.v06i02.17071.

[22] S. Carpitella, "Overcoming Barriers to Digital Transformation Towards Greener Supply Chains in Automotive Paint Shop Operations," *Sustainability,* vol. 16, no. 5, p. 1948, 2024, doi: 10.3390/su16051948.

[23] N. Y. Irsyadillah and S. Dadang, "A Literature Review of Supply Chain Risk Management in Automotive Industry," *Journal of Modern Manufacturing Systems and Technology,* vol. 4, no. 2, pp. 12-22, 2020, doi: 10.15282/jmmst.v4i2.5020.