Construction of Index System for Risk Assessment in Supply Chains of Automotive Industry

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Abstract— **Automotive industry plays an important role in the economy and is exposed to a variety of supply chain risks but is underprivileged in terms of research. Therefore, to inform the effective and efficient development of the automotive industry, this paper analyses the key risk sources for supply chains of automotive firms using three primary sources, six secondary sources and 35 risks established from the existing literature on supply chain risk. To testify the proposed index system, data of 101 questionnaires were employed to SPSS 25 to perform reliability and validity checks. Afterwards, factors analysis was performed to get the final risk assessment index system, which confirmed that supply chain risks in the automotive industry are classified in three primary sources, internal risks, external risks and stream risks. Six secondary sources, macro risks, industry risks, organizational risks, operational risks, upstream risks and downstream risks, and 35 risks in total. This research fulfils the gap in the literature by providing a risk assessment index system to automotive firms, which can use this index system to analyse risk in their supply chain and then take risk mitigation measures accordingly.**

Keywords— *Index system for risk assessment, risk assessment, supply chain risk, automotive industry, Pakistan*

1. Introduction

Due to the turbulent changing environment like innovation, improvement in technology, outsourcing, globalization and unforeseen events, the risk is inherent in almost all the aspects of life. Uncertainty is the reason behind the occurrence of risk because we don't know what is going to happen in the future. Risk can be forecasted but can't be measured entirely, and there is uncertainty what will happen in the future, which leaves a gap between what we have already planned and what happens [1]. Whatever the situation it is risk has the severe potential of harm and loss to the organizations, and they must assess that potential. Risk management involves two crucial steps, risk identification and risk assessment, which consists in understanding those conditions which create problems and then evaluate their likelihood of occurrence and their negative impact [2]. Since the mid-twentieth century organizations have broadened their approach of risk management from issues like insurance, safety, public relations, finance to supply chains. This is because of severe disruptions in the supply chains on a regular basis [3]. Supply chain disruptions are the unplanned events that affect the normal flow of the material in supply chains, and it not only halts the operations but also takes a long recovery time if not prepared already [4]. Zsidisin defined Supply chain risk as "probability of an incident associated with inbound supply from an individual supplier failure or the supply market occurring, in which its outcomes result in the inability of, the purchasing firm to meet the customers demand or causes threats to the customers life and safety" [5].

In the past decades, ways of doing business are changed, and supply chains of the automotive sector are facing more severe risks than it has ever faced. Significant reasons of risk arising in automotive supply chains are complexity, efficiency and uncertainty [6]. Multiple product variants and supplier dependencies also create problems because, in case of supplier defaults, the flow of material stops [7]. Automotive firms supply chains are exposed to different kinds of risks with low probability and high impact. Low probability but high impact risks are difficult to predict because of the uncertainty, and they are even difficult to manage when they occur. This is the reason why managers leave some of these risks and don't take necessary measures which exposes firms to these kinds of risks more often [8]. The supply chain consists of a complex structure of sharing information, material, goods, finance and other resources from an internal department to an outside company till the final customer. However, the supply chains are prone to different risk factors like globalization, multiple product variants, dependency on suppliers, outsourcing and environmental damage prevailing inside and outside the supply chain which cause

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supply chain disruptions [9]. Supply chain disruption put a significant impact on the firm's financial, operational, short term and long-term performance. The more complex business activities are more open to supply chain risks. To maintain supply chain performance, companies must respond to the risk quickly, whether they are internal or external. It requires that supply chains must be deeply understood and supply chain managers must know how to manage risks in their supply chains. When it particularly comes to the automotive industry, it is considered as one of the advanced industries which consists of multiple small and complex steps in the manufacturing process. Multiple tier suppliers base sometimes threaten the flow of material [10].

For that reason, there is an increase in supply chain risks in the automotive industry and a decrease in financial and operational performance is observed in recent years. According to the automotive supply chain disruption report published by JLT insurance in 2018. A rise of 30% in supply chain disruptions was observed in automotive industry in America alone [11]. The report tells that supply chains is the automotive industry are facing risks like never before. Automotive companies are indulged in identification, assessment, measurement and management of risk in their supply chains. In managing supply chain risks, the most critical step is risk identification, which is a process of discovering and defining the risk [12]. There are different methods of identifying risk and organizations use their own methods to identify the risks. Once the risks are identified they are categorized according to their nature. The second most crucial step is risk measurement or risk assessment, in which different risks are measured, assessed according to their probability of occurrence and prioritizes according to their level of severity [13].

Review on supply chain risk literature indicated that there is limited research on this area, particularly and automotive industry specifically. Moreover, to the author's knowledge, there is no research already available that has tried to provide a risk assessment index system for supply chains of the automotive industry. Thus, the objective of this paper is to analyse the risk factors in supply chains of the automotive industry in Pakistan and construct an index system for risk assessment in supply chains of automotive industry. Therefore, this research aims at filling the research gap in the literature and is helpful for supply chain managers in understanding risks in their supply chains accordingly.

The rest of the paper is organized as follows; the next section provides the supply chain risk sources and proposed index system. Section 3 provides the methods for evaluation of the index system. Section 4 provides the results, and finally, the conclusion is presented in section 5.

2. Supply Chain Risk Sources

Time to time, different researchers have presented the definition of supply chain risk according to its nature, impact, and severity. Due to the divergence, different terminologies, approaches, and practices their applicability is limited to a specific context which depends on the location, context and nature of firm's business. However, the definition of supply chain risk presented by Zsidisin is considered comprehensive; he defined Supply chain risk as "probability of an incident associated with inbound supply from an individual supplier failure or the supply market occurring, in which its outcomes result in the inability of, the purchasing firm to meet the customers demand or causes threats to the customers life and safety" [5]. He has focused on the fundamental aspects of the risk which are related to possible outcomes, probability of occurrence, and subjective values [5].

Various authors have focused more on the flow of variability and said risk as variability in the distribution of material and information flow in various interfaces of the supply chain. This change in risk perception highlighted the need for analysing and assessment of risks. Lavastre et al. defined supply chain risk as: "Those small events and incidents that happen to one or several parts in the supply chain and affect the whole supply chain negatively and restricts in achieving organizational goals" [14]. Previous researchers have classified supply chain risk into many different categories based on earlier studies on supply chain risk. But the classification is not to one point, and every researcher has tried to classify it according to its perceptions and situations. Despite the differences among supply chain risk classification, many agreed that supply chain risk could be classified into two categories, internal supply chain risk, and external supply chain risk [15]. According to others, it can be classified into three categories, risk internal to supply chain, risk external to supply chain, risk internal to firm but external to supply chain [16-18].

Supply chain risks could arise from different sources. There are various sources of risk, which are uncountable in numbers and can have an impact on firms supply chain [19,20]. Classification of risk also depends on the researcher's scope of study that which risks should be included in the research and which risk should not [21]. Christopher and Peck classified risk into two significant categories internal and external, which are quite broader classification and is not specific to some point [22]. On the other hand, Sodhi et al. [23] proposed nine sources of risk, such as disruptions, forecast, delays, intellectual property, systems, receivables, capacity, inventory, and procurement. The classification of Chopra and Sodhi is more comprehensive as it involves all the operational levels in nine categories, and elaborates the internal risks in more specific aspects [23].

Moreover, Thun and Hoenig [6] classified internal supply chain risks into two categories, which are internal company risks and cross-company-based risks. According to him, internal risks are those which arise due to the internal settings of a company while cross-company risks occur due to the non-cooperation of supply chain partners outside the control of the focal company. It is also empirically proven [24] that internal risks in the supply chain occur more frequently and affects the firm's day to day operations. While external risks don't happen more regularly, but their impact on firm is more severe compared to internal supply chain risks. Internal supply chain risks should gain primary attention of the supply chain managers to mitigate these risks and avoid supply chain disruption in time [25].

Furthermore, economic, technological, environmental, socio-political, and geographic changing are the sources of external supply chain risks, which are beyond the control of the supply chain [24]. External risks defined by most of the researcher are supply-side risks or demand-side risks [6,21,25,26]. Both supply-driven and demand-driven risks effect/disturb firms general business processes and are considered as significant risks in almost every company [7].

Due to the turbulent changing environment like innovation, improvement in technology, outsourcing, globalization and unforeseen events, risk is inherent in almost all the aspects of life and companies are facing severe competition which requires them to operate supply chains efficiently and effectively [19]. Risk of different categories could affect supply chain directly and indirectly and in turn, can affect firms in achieving their goals. Thus, keeping in view of our research objective, this research aims at focusing on all the risks which could have the potential to harm/disrupt the supply chains of the automotive industry.

The importance of no single source of risk can be overdriven when previous researchers have elaborated the significance of all the described risk sources. Therefore, to achieve the research objective, the classification of supply chain risks according to earlier studies is summarized in Table 1.

2.1 Macro Risks Associated with Supply Chain

Macroeconomic risk and environmental risks are caused by uncertain events and have the potential to disrupt the supply chains of companies. According to Thun et al. [24], macro risks are the high probability and high impact risks which portray severe impact on firm performance. According to researcher macro events such as natural disasters, terrorist attacks and labour disputes are the events which cause disruptions in the normal operations of organizations and affect the supply chains, which ultimately distracts firms from achieving their goals [6,22,23,27]. On the other hand, researchers suggest that economic events/trends and governmental decisions can affect the supply chains of companies. Political unrest, government restrictions on import/export or other regulatory changes, and economic instability of the country either it's in the shape of currency fluctuations, inflations, unemployment, etc., creates disruptions in firms normal supply chain operations [8,9,19,28-34].

2.2 Industry Risks Associated with Supply Chain

Industry risks are the risks associated with specific industrial factors such as input risk, product risk, and competitor risk [35]. Input risks are the risks associated with the acquisition of not accurate and good quality and quantity inputs during the production process [36]. If firms fail in the purchase of the right quality of material at the right time, then the firms might remain backward in the industry and troubles in carrying out their businesses [37]. Moreover, those risks which arise due to change in customer taste, change in demand, availability of substitute goods and scarce complementary goods are the risk associated with the product itself [28]. Firms should implement proper demand estimation techniques and judge customer preferences to avoid supply chain disruptions. Managing competitor risk is vital for firm supply chain performance. Firms should be aware of technology, human resources, and products of their competitors to perform better than them [35].

2.3 Organizational Risks Associated with Supply Chain

There are certain risks within the organizations which are often responsible for the disruptions in the supply chain. Researchers have explored in previous studies that internal risks such as organizational and operational risks are more often to occur and disrupt supply chains compared to external risks (supply-driven and demand-driven) [24]. Christopher and Peck described organizational risks as the most critical factors to the success of the supply chain and whole company [22]. Liability risks are defined as risks arise due to the consumption or production of the product like product liability and emission of the pollutants [23].

The study [26] described organizational risks as the risks which are inside the organization and have potential to terminate or delay the day to day operations of the firm, which in turn creates disruptions in the whole supply chain. So, it is necessary to analyze the risks prevailing within the organization, and proper mitigation measures should be implemented. The study [39] suggests a few of the organizational risks, such as financial risks, liability risks,

Table 1. Classification of Supply Chain Risks

Risk factors/Sub-factors	Description	References
Environmental/Macro		[6-9,19-23,26-34,39]
Natural disasters	Risk arises due to events like earthquake, fire, floods, hurricanes, etc.	
Political unrest	Risks associated with the political crisis that affects the businesses.	
Economic instability	Risks related to issues such as currency fluctuations, inflation, oil crises which cause supply disruptions.	
Government restrictions	Changing governmental policies like trade barriers, import restrictions, increase in customs duty, and change in law arises risks to supply chains.	
Terrorist attacks	Attacks like 9/11, which results in stopping the supply of Toyota, resulting in loss of million dollars.	
Labor disputes	The risk associated with labour such as strikes, payments, staff reduction, and downsizing and governmental wage rate change.	
Industry Risks		[6-9,19-23,26-34,39]
Input risk	The risk associated with the acquisition of not accurate and good quality and quantity inputs during the production.	
Product risk	Risk arises due to change in customer taste, change in demand, availability of substitute goods and scarce complementary goods.	
Competitor risk	The risk associated with the rival firm, its technology, products, human capital, and techniques.	
Organizational Risks		[6-9,19,21-34,39]
Liability risk	Risk arises due to the consumption or production of the product like product liability and emission of the pollutants.	
Financial risk	Risk arises due to the poor financial conditions, less cash at hand, collectable problems.	
Behavioral risk	Risk arises due to the conflicts of managers and employees, corporate governance issues, and agency problems.	
Research & Development risk	Risk arises due to issues in a new product, its design, its features, etc.	
Technological risk	Risk arises due to change in technology, misuse of technology, using outdated technology, or using labour, which is not skilled how to use equipment or having a supplier with obsolete technology.	
Communication risk	Risk arises due to the failure of communication within and outside the organization. This communication can be company goals, strategies, and relationships.	
Operational Risks		[6-9,19,21-29,31-34]
Machine breakdown	The risk associated with machine breakdown, which can reduce production and increase the cost.	
Malfunction of IT system	Risk arises due to the failure of the company IT system and a breakdown of communication within or outside the organization.	
Underutilized capacity	Risk arises due to not using the organizational resources completely and not producing the goods to the highest capacity.	
Lead times	Risk arises due to taking more idle time and more spare times during the manufacturing process.	
Troubling third-party logistics	Not receiving material and raw goods on time can stop organizations production, so having a logistic problem handler raises the risk.	
Human error	Errors caused by humans in the earlier stages of production can lead to bigger problems.	
Labor unrest	Labor strikes, labor sitting idle and labor communication.	
Upstream (supply side) risks		[14,19,21,24-29,31-34,37,43]
Supplier quality problem	When the supplier provides low-quality products and then compromises over high-quality equipment, risk arises in supply chains.	
Supplier delivery failure	Risk arises due to not on-time delivery by the supplier; it creates problems in production.	
Insolvency of supplier	Risk arises due to suppliers becomes insolvent and has insufficient funds to operate.	
Single Sourcing	Having a single supplier is a risk itself if the supplier fails in delivering the product the company faces.	
Increase in raw material prices	Increase in raw material prices causes problems in procurement, and this kind of situations arise risk for the supply chain.	
Supplier communication failure	If the supplier fails in the communication of delivery failure, quality problem or any problem at his side, it creates damage to the organization.	
Upstream cargo damage	Sometimes cargo damages create huge problems, operating on risky routes by logistics companies is a risk.	
Downstream (demand side) risks		[14,19,21,24-26, 29,31-34,37,43]
Demand fluctuations	Change in demand due to seasonality, volatility, change in fashion and trends uplift the demand fluctuation risk.	
Inventory shortage	Organizations try to cut of inventory cost and use lean inventory technique, which rises inventory shortage risk.	
Delivery chain disruptions	Delivery chain disruptions result in late deliveries to the customers, which creates a harmful impact and is a risk to company reputation.	
Forecasting error	This risk arises while forecasting the demand for a product. Error in forecasting leads to organizational loss.	
Decline in market prices	The decline in market prices exposes supply chains to risk as the company will not be covering production cost.	
Inflexibility	Risk of losing market share in high demand due to production inflexibility.	
Poor customer relationship	Poor customer relationship is the most significant risk to the company because spreading bad word of mouth can ruin the business	

and research, and development risk. These risks are associated with the financial aspects of the company, means company is not good at managing its financial issues and is exposed to variety of risks.

The study [25] elaborated some non-financial organizational risks in the company, such as communication risks, technological risks, and behavioral risks. If a company is unable to communicate within or outside the company with its partners, it is exposed to the communication risk, which has the power to disrupt companies supply chains. Similarly, if the organization doesn't focus on changing technology and remains constant in this term, it is exposed to technological risks. Furthermore, behavioral risks are associated with the attitude and commitment of the employees towards their task, if they are not committed to the job that's ultimately a threat to the supply chain of the company [29].

2.4 Operational Risks Associated with Supply Chain

According to Thun et al. [24], most of the disruptions in the supply chain are caused by the firm's operational risks. In his study, he has mentioned some high probability and high impact operational risks which cause disruptions in the supply chain on regular intervals. Mitigating operational risks inside the firm are necessary for a smooth and resilient supply chain. In the previous studies, researchers have used different operational risk factors such as machine breakdown, malfunction of IT system, lead times, troubling third-party logistics, underutilized capacity, and human error and labour unrest. The results of the research have shown a material effect of these risks on disruptions and negative impact on firm financial and operational performance [15].

Operational risks are the risks which arise due to negligence in firm's day to day operations [25]. If a firm manages its operations continuously and designs a proper risk mitigation structure for the operational risks, then they are less likely to occur [29]. Firms are more likely to react to the events caused by the outside forces and neglect what is happening inside which is the biggest reason behind arising such kind of risks, which creates negative impact on supply chain and performance due to no or less managing criteria [26].

The study [35] have taken both operational and organizational risk in this study supply chain risk, and firm performance is measured. Impact of both have been found negative on firms' financial performance. Researchers have thrown light on the effects of operational risk on supply chains and explained the importance of managing and mitigation of these risks [23-26,29,38,39].

2.5 Upstream Risks (supply-driven risks)

Upstream risks are associated with the activities of the supply side of the firm supply chain, which can be driven from the firm supply network and multiple suppliers [21] which in turn could disrupt firm operations [26]. Firms face severe difficulties in selecting suppliers as the right supplier selection is necessary for the firm's undisrupted supply and operations. There are uncountable numbers of supply-driven risks, but researchers have focused on the most disruptive upstream risks such as supplier quality problems, delivery delays, communication failure, increase in price, etc. Thun and Hoenig [6] elaborated in their study about supply chain risk in the automotive industry that supplier quality problems are the most disruptive risks and their both probability and impact are high on the scale which creates a high level of severity in disruptions.

According to study [43], supply-driven risk is positively associated with operational risks, which means when supply chain faces supply risks due to whatever reasons, it trigs the operational risks too and affects the firm's operations, which could lead to decrease in firm financial performance. Furthermore, delays in delivery from the supplier, poor logistics handling, and late shipments affect firms' operations [40]. Firms should create a proper analysis system to know whether the delivery was delayed due to the supplier, or it was because of the weak third-party logistic system [44]. Some firms do believe in single sourcing, maybe because of close relationships with the suppliers or low costs, but single sourcing is a real threat to the continuity of firm operations. Supply chain issues of Toyota and Siemens are the best examples of how single sourcing is severe disrupting to the firm's operations [23]. So, it is suggested by the researchers that firms should have multiple tiers of suppliers so that if the delivery delays or fails from one supplier there should be back up for the continuity of the business [26].

2.6 Downstream Risks (demand-driven risks)

On the one side, firms have to manage its upstream risks, and on the other side, they should be aware of the downstream risks associated with demand-side of the supply chain [41]. The demand side of the supply is associated with the accurate forecasting of the demand, distributions of finished goods to the final customers, and managing customer relationship [42]. Any ambiguity during the operations of demand-side could lead to supply chain disruptions [45]. The primary issue is mismatching of demand or not accurate predictions of the demand, which creates uncertainties and disruptions in the supply chain [43]. When a firm mismatches its demand for the particular products, it creates a bad impression on customers resulting in poor customer relationships, low sales, huge inventory storage costs, more supply chain disruptions and more financial losses [6].

It is evident that there are fluctuations depending on different factors such as economic situation, product life cycle and seasonal demand [19] but there are specific supply chain techniques which could have led to demand-driven risks, such as lean inventory technique in which inventory is not stored at massive amounts, which could lead to errors in actual and forecasted demand [46]. Inflexibility is another crucial aspect which could lead to supply chain disruptions. Not meeting customers demand and not providing finished goods on time creates problems for firms supply chain operations. Delivery chain disruptions lead to poor customer relationship, which in turn affects the supply chains and firm's performance. Above discussed classification of supply chain risks is summarized in Figure 1.

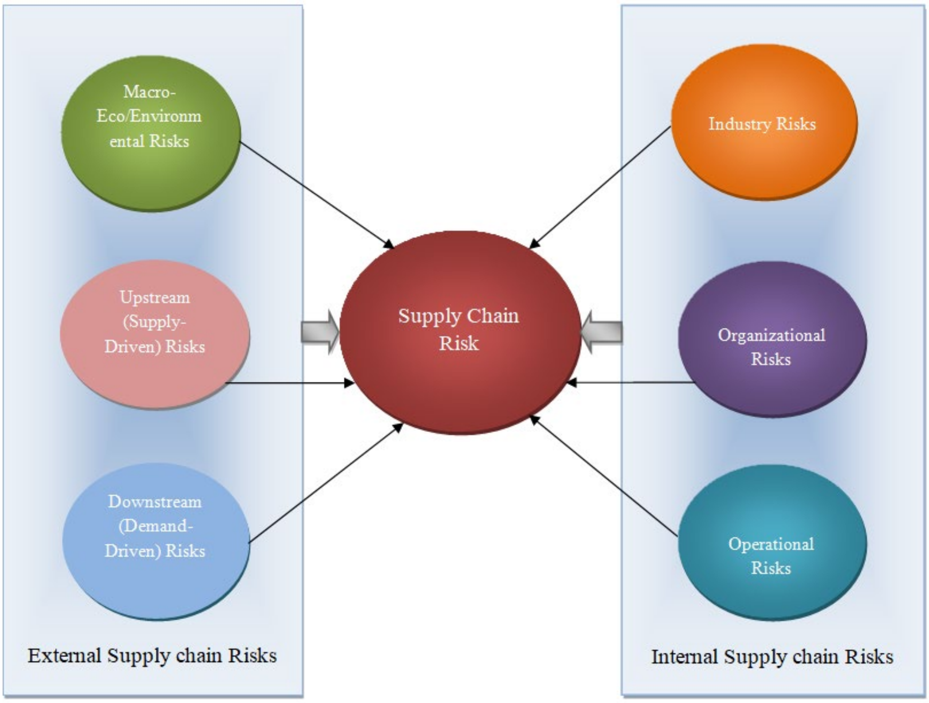

Figure 1. Supply Chain Risk Classification (*Source: Own*)

3. Empirical Settings and Measurements

To achieve the research objectives, a five-point Likert scale questionnaire was developed and sent to the automotive companies in Pakistan to evaluate the risks in their supply chains. We used the multiple questionnaire approach from one firm, and the target respondents were supply chain managers/logistic managers/production managers. Out of 150 questionnaires we received 101 questionnaires with a response rate of 67 %, which is considered very good in such kind of studies. Moreover, all the respondents have more than five years' experience in the field of the supply chain.

3.1 Reliability and Validity

We have checked the reliability of the questionnaire through Cronbach's alpha. There are multiple methods to check the reliability of the survey, but Cronbach's alpha is considered as the most efficient and reliable technique. The value of the coefficient should fall between 0 and 1. Reliability of 0.90 is considered as excellent and above 0.80 is considered as good. If the reliability of the scale is 0.70, it is still accepted but if the reliability of the scale is less than 0.70 than some of the items on the questionnaire have low reliability and the overall reliability can be increased by eliminating those questions. The formula of Cronbach's alpha technique for measuring reliability is as follows:

$$\alpha = \frac{k}{k-1}\left(1 - \frac{\sum_{i=1}^{k}\sigma_i^2}{\sigma_T^2}\right) \quad (1)$$

Where, k is the number of samples, σ_i^2 is the variance of total observed sample, σ_T^2 is the variance of the current sample. Results of reliability analysis are provided in Table 2.

We checked the constructs validity through two steps to get stable factor solutions. At first, we performed the exploratory factor analysis (EFA) and checked the convergent validity of the constructs through standardized factor loadings and Composite reliability (CR). All the factor loadings range between 0.55 and 0.95, which are high factor loadings and are significant at $p < 0.001$, suggesting that convergent validity exists for the current measurement model. According to Harrington [47], high factor loading suggests, factors are convergent on the same point, which shows high convergent validity. Similarly, CR of the constructs are computed by the sum of squared factor loadings, divided by the sum of squared factor loadings plus the sum of errors extracted, which tells that the measurement of the constructs has consistency. The obtained CRs for the factors are 0.85, 0.75, 0.87, 0.88, 0.95, 0.96 which are greater than 0.60, a threshold value determined by the Kline [48] and Lee [49].

Table 2. Reliability Analysis

Factors	Risks	Cronbach's alpha if item deleted	Cronbach's Alpha
			0.97
Environmental/Macro	Natural disasters (ER1)	0.742	0.826
	Political unrest (ER2)	0.731	
	Economic instability (ER3)	0.803	
	Governmental restrictions (ER4)	0.795	
	Terrorist attacks (ER5)	0.805	
Industry Risks	Input risks (IR1)	0.539	0.65
	Product risk (IR2)	0.494	
	Competitor risk (IR3)	0.497	
Organizational Risks	Liability risk (OR1)	0.846	0.896
	Financial risk (OR2)	0.891	
	Behavioral risk (OR3)	0.871	
	R&D risk (OR4)	0.841	
	Technological risk (OR5)	0.871	
	Communication risk (OR6)	0.893	
Operational Risks	Machine breakdown (OPR1)	0.825	0.814
	Malfunction of IT system (OPR2)	0.753	
	Underutilized capacity (OPR3)	0.789	
	Lead times (OPR4)	0.765	
	Troubling third-party logistics (OPR5)	0.788	
	Human error (OPR6)	0.787	
	Labor unrest (OPR7)	0.772	
Upstream risks	Supplier quality problems (UR1)	0.787	0.816
	Supplier delivery failure (UR2)	0.810	
	Insolvency of the supplier (UR3)	0.760	
	Single Sourcing (UR4)	0.807	
	Increase in raw material price (UR5)	0.803	
	Supplier communication failure (UR6)	0.763	
	Upstream cargo damage (UR7)	0.774	
Downstream risks	Demand fluctuations (DR1)	0.922	0.932
	Inventory shortage (DR2)	0.910	
	Delivery chain disruptions (DR3)	0.912	
	Forecasting error (DR4)	0.904	
	Decline in market price (DR5)	0.926	
	Inflexibility (DR6)	0.921	
	Poor customer relationship (DR7)	0.907	

To check the discriminant validity, we have calculated average variance extracted (AVE), which suggests how much a construct is distinct from the other construct. The AVEs for the factors in the measurement model are 0.54, 0.51, 0.52, 0.52, 0.75 and 0.76, which are higher than the threshold value of 0.50 described by [49,50]. Therefore, the results of factor analysis in our study are satisfactory and meet the thresholds value, which means reliability and validity is proven for this study.

3.2 Multicollinearity Diagnostic

Multicollinearity analysis is conducted before conducting the factor analysis, to examine whether the issue of perfect multicollinearity exists or not. If multicollinearity exists, then some remedies can be taken to check the robustness of the analysis results. We tested the multicollinearity through variance inflation factor (VIF), which was performed through SPSS 25. The results of multicollinearity analysis are presented in Table 3, which shows that VIF of all the variables is less than 6, and tolerance is less than 0.60.

3.3. Factor Analysis

Factor analysis is a statistical technique which is used to extract similar factors from the group of variables. Moreover, it can find out the hidden factors in a set of multiple variables. It classifies variables of similar nature under one factor, which reduced the total number of variables, and the relationship among constructs can be verified through different techniques. Supply chain risks are usually divided into two or three major categories, such as internal risks, external risks, and stream risks (upstream and downstream risks). Furthermore, according to the supply chain risk classification presented in Table 1, there are six subordinates to these three major categories such as

Economical/Environmental risks, Industry risks, organizational risks, operational risks, upstream risks (supply-driven risks) and downstream risks (demand-driven risks). There is a total of 35 risks which are classified into these six sub-categories; therefore, factor analysis is required to testify the assumptions of this classification.

Table 3. Results of VIF Test

Risks	Tolerance	VIF
Natural disasters (ER1)	0.169	5.904
Political unrest (ER2)	0.195	5.133
Economic instability (ER3)	0.315	3.175
Governmental restrictions (ER4)	0.314	3.184
Terrorist attacks (ER5)	0.507	1.970
Input risks (IR1)	0.114	5.777
Product risk (IR2)	0.313	3.198
Competitor risk (IR3)	0.365	2.741
Liability risk (OR1)	0.602	1.660
Financial risk (OR2)	0.506	1.978
Behavioral risk (OR3)	0.593	1.687
R&D risk (OR4)	0.507	1.971
Technological risk (OR5)	0.548	1.337
Communication risk (OR6)	0.551	1.814
Machine breakdown (OPR1)	0.427	2.340
Malfunction of IT system (OPR2)	0.179	5.573
Underutilized capacity (OPR3)	0.170	5.873
Lead times (OPR4)	0.173	5.766
Troubling third-party logistics (OPR5)	0.513	1.948
Human error (OPR6)	0.284	3.525
Labor unrest (OPR7)	0.376	2.658
Supplier quality problems (UR1)	0.366	2.733
Supplier delivery failure (UR2)	0.157	6.370
Insolvency of the supplier (UR3)	0.314	3.182
Single Sourcing (UR4)	0.529	1.889
Increase in raw material price (UR5)	0.188	5.313
Supplier communication failure (UR6)	0.245	4.089
Upstream cargo damage (UR7)	0.338	2.958
Demand fluctuations (DR1)	0.584	1.463
Inventory shortage (DR2)	0.501	1.994
Delivery chain disruptions (DR3)	0.519	1.928
Forecasting error (DR4)	0.264	3.782
Decline in market price (DR5)	0.338	2.958
Inflexibility (DR6)	0.458	2.183
Poor customer relationship (DR7)	0.450	2.180

The two possible tests in the factor analysis tell whether the factor analysis is suitable for the data collected or not. These two tests are Kaiser-Meyer-Olkin (KMO) measure and Bartlett's Test of Sphericity. The KMO ranges between 0 and 1, and if the KMO value is greater than 0.70 only than factor analysis is suitable for the study. If the KMO is less than 0.70, it is generalized that the correlations among the variables are small and don't explain the relationship between them; in this case, factor analysis is not suitable. Generally, principal component analysis is used, and for the rotation purpose Varimax technique is used, and if the factor has eigenvalue less than one than factor analysis is terminated. We have followed the same rule in our study and have used Principal component analysis and Varimax technique for the rotation purpose.

On the other hand, Bartlett's test tells whether the data obtained represent the assumptions of standard multivariate analysis or not. It has value 0 and 1, 0 means elements are not on the diagonal line, and 1 suggests elements are on the diagonal line. Which is in accordance with the null hypothesis that, the correlation matrix is a unit matrix. If the value of F is significant, then the matrix is not a unit matrix. The following steps are taken while conducting a factor analysis, which were explained in the study [51].

3.3.1 Standardize the data

Suppose there is m number of indicating variables in a principal component analysis (PCA) method such as x_1, x_2, x_3, ... x_m, and there are n number of objects to be evaluated. In this case, we can represent each value of the j^{th} index in the ith evaluation construct as x_{ij}. Each value of x_{ij} is converted in the standardized format such as $\tilde{x}_{ij}$.

$$\tilde{x}_{ij} = \frac{x_{ij} \times \tilde{x}_j}{s_j} \tag{2}$$

where, $i = 1,2, 3, \ldots\ldots, n$ and $j = 1,2,3, \ldots. m$. $\tilde{x}_j$ represents the mean of the sample and s_j represents the standard deviation. Therefore, the $\tilde{x}_j$ and s_j are represented in the shape of formula as $\tilde{x}_j = \frac{\sum_{i=1}^{n} x_{ij}}{n}$, $s_j = \frac{\sum_{i=1}^{n}(x_{ij} - \tilde{x}_j)}{n-1}$.

3.3.2 Calculating the correlation coefficient matrix in factor analysis

The correlation coefficient matrix is calculated through the following formula in the Principal component analysis (PCA).

$$R = [r_{ij}]_{mxm} \tag{3}$$

Where, r_{ij} represents the correlation between the indexes of the jth and ith terms. Therefore, r_{ij} is represented in the shape of formula as $r_{ij} = \frac{\sum_{k=1}^{n}(\tilde{x}_{ki} \times \tilde{x}_{kj})}{n-1}$, where $i, j = 1,2,3, \ldots\ldots m$, $r_{ij} = 1$ and $r_{ij} = r_{ji}$.

3.3.3 Calculating the elementary load matrix through PCA

The eigenvalues of the represented R correlation matrix should satisfy the general thumb of the rule, which is, $\lambda_1 \geq \lambda_2 \geq \lambda_3 \geq \ldots. \geq \lambda_m \geq 0$. Corresponding vectors of eigenvalues are represented as u_1, u_2, u_3, …., u_m, where, $u_j = (u_{1j}, u_{2j}, u_{3j}, \ldots., u_{nj})^T$. the general elementary load matrix formula is

$$A = \left(\sqrt{\lambda_1}\eta_1, \sqrt{\lambda_2}\eta_2, \sqrt{\lambda_3}\eta_3, \ldots., \sqrt{\lambda_m}\eta_m\right) \tag{4}$$

3.3.4 Selection of principal components for the rotation of factors

m factors are chosen in order to calculate the overall contribution rate of each factor in the elementary load matrix. The obtained original matrix is called matrix A, and the obtained rotated matrix is called B. So, $A = \hat{A}T$ where, $\hat{A}$ is the top of the column p of A and T is the orthogonal matrix. The contribution rates either singular or cumulative for eigenvalues λ_j are calculated through the following formula:

$$b_j = \frac{\lambda_j}{\sum_{k=1}^{m} \lambda_k}, \quad (5)$$

$$\alpha_j = \frac{\sum_{k=1}^{p} \lambda_k}{\sum_{k=1}^{m} \lambda_k}, \quad (6)$$

Where, j = 1,2,3, …... m, α_j represents cumulative contribution rate and b_j represents the single contribution rate.

The above-explained method is the general method for the extraction of variables in the factor analysis through the principal component method. Rotation of the constructs is also an essential part in factor analysis, and without discussing the rotation method, factor analysis is incomplete. There are different methods of rotation in factor analysis, such as Equamax, Quartimax, Promax, Direct Oblimin, and Varimax. Each of them has its own uses, advantages, and disadvantages. We have used the Varimax rotation method in this study. Therefore, we discuss the process of Varimax in this section. The followings are the steps of the Varimax rotation method.

3.3.5 Two-factor plane orthogonal rotation method

If there a is factor loading matrix called A = (a_{ij}), i = 1, 2, ……, p, j = 1,2 then the orthogonal matrix Q will be $\begin{pmatrix} cos\emptyset & -sin\emptyset \\ sin\emptyset & cos\emptyset \end{pmatrix}$. That's known as the counter-clockwise rotation of the factors. According to the formula if the rotation is clockwise, then it needs to interchange two elements from the secondary base.

$$B = AQ = (b_{ij}),\ i = 1, 2, \ldots, p, j = 1,2, \quad (7)$$

Where, B is the rotated factor matrix.

$$V_j = \frac{1}{p}\sum_{i=1}^{p}\left(\frac{b_{ij}^2}{h_{ij}^2}\right)^2 - \left(\frac{1}{p}\sum_{i=1}^{p}\left(\frac{b_{ij}^2}{h_{ij}^2}\right)\right)^2, j = 1,2 \quad (8)$$

In order to maximize the total variance explained in the factor analysis, the orthogonal rotation method is used. Which suggests $V = V_1 + V_2$, $\frac{dv}{d\emptyset} = 0$ and should satisfy the following conditions:

$$tan4\emptyset = \frac{D_0 - 2A_0B_0/p}{c_0 - (A_0^2 - B_0^2)/p} \quad (9)$$

Where,

$$\begin{cases} A_0 = \sum_{i=1}^{p} u_i, B_0 = \sum_{i=1}^{p} v_i \\ C_0 = \sum_{i=1}^{p} u_i - v_i, D_0 = 2\sum_{i=1}^{p} u_i v_i, \\ u_i = (\frac{a_{i1}}{h_i})^2 - = (\frac{a_{i2}}{h_i})^2, v_i = \frac{2a_{i1}a_{i2}}{h_i^2} \end{cases} \quad (10)$$

3.3.6 In the situation where m > 2, which is a public factor number

When there are two factors in the rotation matrix of different kinds then m (m-1)/2 is basically the rotation function. In this scenario, the rotation cycle is completed at m(m-1)/2, and after it completes the second section of the rotation begins. In this way, the extracted variance of the constructs is checked and increased based on their matrices. The rotation stops there, where the last rotation cycle time is too short, and the variance is increasing very slow or not at all such as, $V^{(k)}$, where k is the k^{th} cycle time.

4. Results and Analysis

The analysis results of reliability, validity and VIF meet the requirements; therefore, all the risk factors are included in the factor analysis, and results of the explanatory factory analysis are presented in this section.

4.1 Factor Analysis of External Risk Factors

Table 4 presents the results of KMO and Bartlett's test of sphericity for external risk factors. The results showed that the value of KMO is 0.77, which is greater than the required value of 0.70 and F value is 0.000. Therefore, further analysis is suitable for this scale.

Table 5 presents the results of factor analysis, which shows that there is only one factor extracted, and the eigenvalue is 2.803, which is greater than 1. The factor loadings of the extracted components are 0.868, 0.920, 0.770 and 0.782. Factor extracted explains 70% of the total variance. All the four variables under the external risk factor can be explained through the one factor extracted. Therefore, external risk factor doesn't require the orthogonal rotation and should be directly explained as an external risk ability factor.

Table 4. KMO and Bartlett's Test of External Risk Factors

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.770
Bartlett's Test of Sphericity	Approx. Chi-Square	206.959
	df	6
	Sig.	.000

Table 5. Total Variance Explained by External Risk Factors

	Initial Eigenvalues			Extraction Sums of Squared Loadings		
Component	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	2.803	70.086	70.086	2.803	70.086	70.086
2	.615	15.379	85.465			
3	.374	9.360	94.826			
4	.207	5.174	100.000			

4.2 Factor Analysis of Internal Risk Factors

Table 6 presents the results of KMO and Bartlett's test of sphericity for internal risk factors. According to the results that value of KMO is 0.87, which is greater than the required value of 0.70 and Bartlett's test of sphericity *F* value is 0.000. Therefore, further analysis is suitable for this scale. Hence, we have conducted a factor analysis of the internal risks through Principal Component Analysis (PCA) method. Table 7 presents the extraction results of the factor analysis using Principal Component Analysis (PCA). According to the results, the internal risk variables can be divided into three factors, namely, industry risks, organizational risks and operational risks. The extraction results show that the eigenvalue of all the three are factors are greater than 1 and the all factors shows a total variance of 71% in which the first factor only shows 34% of the total variance, which is less than the threshold value of 50%.

Table 6. KMO and Bartlett's Test of External Risk Factors

Kaiser-Meyer-Olkin Measure of Sampling adequacy.		.870
Bartlett's Test of Sphericity	Approx. Chi-Square	1708.853
	df	120
	Sig.	.000

Table 7. Total Variance Explained by Internal Risk Factors

	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
Component	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	8.336	52.100	52.100	8.336	52.100	52.100	5.495	34.341	34.341
2	1.814	11.339	63.439	1.814	11.339	63.439	3.095	19.342	53.683
3	1.206	7.540	70.979	1.206	7.540	70.979	2.767	17.297	70.979

Table 8. Factor Rotation Matrix of Internal Risk Factors

	Component 1	**Component 2**	**Component 3**
IR1	.290	.053	.565
IR2	.806	.398	.230
IR3	.073	.693	.410
OR1	.753	.442	.386
OR2	.136	.570	.156
OR3	.249	.592	.663
OR4	.742	.450	.400
OR5	.936	.011	.102
OR6	.627	.581	.134
OPR1	.210	.730	-.156
OPR2	.562	.314	.552
OPR3	.261	.084	.833
OPR4	.816	.036	.331
OPR5	-.025	.517	.474
OPR6	.725	-.027	.274
OPR7	.817	.365	.011

Table 8 presents the results of the factor loading matrix, which were acquired through the Varimax orthogonal rotation method. All the variables with high coefficients are classified under one category because they have a greater influence on the variables.

4.3 Factor Analysis of Stream Risk Factors

Table 9 presents the results of KMO and Bartlett's test of sphericity for stream risk factors. According to the results that value of KMO is 0.877, which is greater than the required value of 0.70 and Bartlett's test of sphericity *F* value is 0.000. Therefore, further analysis is suitable for this scale.

Table 9. KMO and Bartlett's Test of Stream Risk Factors

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.877
Bartlett's Test of Sphericity	Approx. Chi-Square	1513.36
	df	91
	Sig.	.000

Table 10 presents the extraction results of the factor analysis using Principal Component Analysis (PCA). According to the results, the stream risk variables can be divided into two factors, namely, Supply risks and demand risks. The extraction results show that the eigenvalue of the all the three are factors are greater than 1 and the all factors shows a total variance of 67% in which the first factor only shows 37% of the total variance.

Table 10. Total Variance Explained by Stream Risk Factors

	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
Component	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	8.237	58.833	58.833	8.237	58.833	58.833	5.205	37.176	37.176
2	1.130	8.075	66.908	1.130	8.075	66.908	4.162	29.732	66.908

Table 11 presents the results of the factor loading matrix, which were acquired through the Varimax orthogonal rotation method. All the variables with high coefficients are classified under one category because they have a greater influence on the variables.

Table 11. Factor Rotation Matrix of Stream Risk Factors

	Component 1	Component 2
SR1	.607	.319
SR2	.310	.459
SR3	.686	.539
SR4	-.047	.882
SR5	.672	-.178
SR6	.552	.616
SR7	.569	.570
DR1	.554	.703
DR2	.803	.501
DR3	.804	.486
DR4	.223	.609
DR5	.653	.492
DR6	.754	.289
DR7	.737	.608

4.4 Factor Analysis of Overall Risk Factors

Table 11 presents the results of KMO and Bartlett's test of sphericity for internal risk factors. According to the results that value of KMO is 0.909, which is greater than the required value of 0.70 and Bartlett's test of sphericity *F* value is 0.000. Therefore, further analysis is suitable for this scale.

Table 11. KMO and Bartlett's Test of Overall Risk Factors

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.909
Bartlett's Test of Sphericity	Approx. Chi-Square	4665.315
	df	595
	Sig.	.000

Table 12 presents the extraction results of the factor analysis using Principal Component Analysis (PCA). According to the results, the stream risk variables can be divided into two factors, namely, Supply risks and demand risks. The extraction results show that the eigenvalue of the all the three are factors are greater than 1 and the all factors shows a total variance of 75% in which the first factor only shows 26% of the total variance. Table 13 presents the results of factor rotation matrix for all the risk components. All the components were rotated through the varimax rotation method, and the results suggest a stable factor solution for all the described risks.

Table 12. Total Variance Explained by All Risk Factors

	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
Component	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	18.275	52.215	52.215	18.275	52.215	52.215	9.133	26.096	26.096
2	2.746	7.845	60.061	2.746	7.845	60.061	6.547	18.707	44.802
3	1.566	4.475	64.535	1.566	4.475	64.535	5.946	16.988	61.791
4	1.276	3.647	68.183	1.276	3.647	68.183	1.651	4.717	66.507
5	1.212	3.463	71.645	1.212	3.463	71.645	1.496	4.275	70.782
6	1.117	3.192	74.838	1.117	3.192	74.838	1.419	4.056	74.838

Table 13. Factor Rotation Matrix of All Risk Factors

	1	**2**	**3**	**4**	**5**	**6**
Natural disasters (ER1)	0.143	0.248	0.388	0.402	0.109	-0.387
Political unrest (ER2)	0.483	0.733	0.303	0.143	0.109	0.007
Economic instability (ER3)	-0.124	0.361	0.542	0.381	0.292	0.286
Governmental restrictions (ER4)	0.125	0.209	0.249	0.109	0.031	0.761
Terrorist attacks (ER5)	0.403	0.396	0.594	0.048	0.122	-0.111
Input risks (IR1)	0.344	-0.021	0.753	0.010	0.166	-0.180
Product risk (IR2)	0.724	0.278	0.221	0.224	0.244	0.014
Competitor risk (IR3)	-0.045	0.130	0.660	0.030	0.051	0.231
Liability risk (OR1)	0.699	0.169	0.213	0.214	-0.026	-0.020
Financial risk (OR2)	0.570	0.692	0.129	-0.086	0.068	0.200
Behavioral risk (OR3)	0.340	0.508	0.401	0.332	0.314	0.020
R&D risk (OR4)	0.417	0.582	0.318	0.148	0.160	-0.119
Technological risk (OR5)	0.616	0.283	0.261	-0.021	0.217	-0.218
Communication risk (OR6)	0.236	0.463	0.295	0.195	0.185	0.061
Machine breakdown (OPR1)	0.328	0.159	0.110	0.696	-0.076	0.133
Malfunction of IT system (OPR2)	0.385	0.305	0.528	0.016	-0.100	-0.067
Underutilized capacity (OPR3)	0.477	0.197	0.115	0.169	0.143	-0.268
Lead times (OPR4)	0.686	0.357	0.407	0.094	0.045	0.003
Troubling third-party logistics (OPR5)	0.764	-0.009	-0.105	0.196	-0.094	0.248
Human error (OPR6)	0.137	0.219	0.265	-0.110	0.752	0.012
Labor unrest (OPR7)	0.661	0.306	0.391	-0.041	-0.021	-0.025
Supplier quality problems (UR1)	0.584	0.312	0.418	0.165	0.073	0.288
Supplier delivery failure (UR2)	0.569	0.527	0.467	0.239	0.199	0.114
Insolvency of the supplier (UR3)	0.049	0.381	0.544	-0.224	-0.500	0.082
Single Sourcing (UR4)	0.162	0.275	0.830	0.217	0.133	0.157
Increase in raw material price (UR5)	0.576	0.496	0.500	0.214	0.202	0.137
Supplier communication failure (UR6)	0.867	0.392	0.081	0.053	0.013	-0.034
Upstream cargo damage (UR7)	0.848	0.423	0.090	0.028	0.022	-0.066
Demand fluctuations (DR1)	0.606	0.421	0.598	0.156	0.082	0.035
Inventory shortage (DR2)	0.579	0.437	0.610	0.138	0.029	0.030
Delivery chain disruptions (DR3)	0.621	0.160	0.035	-0.411	0.247	0.212
Forecasting error (DR4)	0.549	0.707	0.067	0.040	-0.059	0.127
Decline in market price (DR5)	0.696	0.404	0.499	0.031	0.170	0.157
Inflexibility (DR6)	0.315	0.846	0.218	0.047	0.044	0.023
Poor customer relationship (DR7)	0.198	0.867	0.295	0.109	0.043	0.092

5. Discussion and Conclusion

This research aims to provide a useful index system for risk assessment for supply chains of the automotive industry to the mangers of automotive firms, which will help them in managing risks in their supply chains. Therefore, employing data of 101 questionnaires, reliability, validity, multicollinearity and factor analyses were performed, and key risk factors supply chains of the automotive industry in Pakistan are identified. At first, factors analysis for each construct was performed, and finally, a combined analysis of all the factors was performed through Principal Component Analysis (PCA) and Varimax rotation method. Finally, the final index system for risk assessment of supply chains of the automotive industry is developed and presented in Table 14. Which confirmed that supply chain risks in the automotive industry are classified into three primary sources such as, internal risks, external risks and stream risks. Six secondary sources such as macro risks, industry risks, organizational risks, operational risks, upstream risks and downstream risks; and 35 risks in total. This paper has important practical implications as risks of supply chains in the automotive industry are evaluated for investigating the further impact on firms' operational activities.

Moreover, countermeasures are presented, and the practical importance of risk management problems is discussed in this paper. Furthermore, this paper establishes the importance of risk management in supply chains of the automotive industry and provides a useful index system for supply chain managers for assessing and mitigating risks in their supply chains. Supply chain managers of automotive firms can use this index system to evaluate risks in their supply chains. After evaluations, risk mitigation strategies based on supply chain practices such as resilience, flexibility and robustness can be developed. By looking at the severity of risk in the index, these practices can be used accordingly to manage risks.

This study is prone to a few limitations which could be dealt with in future studies. First, this study only explained the importance of casual supply chain risks and green/sustainable supply chain risks were excluded from this study. Further studies, including green/sustainable risks and sustainable firms, could provide another side of the story. Second, this research only deals with the automotive firm; therefore, its applicability is limited to automotive firms. There is a potential to establish a study on IT and electronics industry to deal with risk arising in their supply chains. Finally, this study explains the context of only one country and its applicability to other countries is limited due to different behavioural and business peculiarities. Therefore, a cross country comparison is suggested for future studies to establish more general and reliable results.

Table 14. Final Index System for Risk Assessment in Supply Chains of Automotive Industry

Primary Risk Factors	Secondary Risk Factors	Risks
External risks	**Environmental/Macro**	Natural disasters (ER1)
		Political unrest (ER2)
		Economic instability (ER3)
		Governmental restrictions (ER4)
		Terrorist attacks (ER5)
Internal risks	**Industry Risks**	Input risks (IR1)
		Product risk (IR2)
		Competitor risk (IR3)
	Organizational Risks	Liability risk (OR1)
		Financial risk (OR2)
		Behavioral risk (OR3)
		R&D risk (OR4)
		Technological risk (OR5)
		Communication risk (OR6)
	Operational Risks	Machine breakdown (OPR1)
		Malfunction of IT system (OPR2)
		Underutilized capacity (OPR3)
		Lead times (OPR4)
		Troubling third-party logistics (OPR5)
		Human error (OPR6)
		Labor unrest (OPR7)
Stream risks	**Upstream (supply side) risks**	Supplier quality problems (UR1)
		Supplier delivery failure (UR2)
		Insolvency of the supplier (UR3)
		Single Sourcing (UR4)
		Increase in raw material price (UR5)
		Supplier communication failure (UR6)
		Upstream cargo damage (UR7)
	Downstream (demand side) risks	Demand fluctuations (DR1)
		Inventory shortage (DR2)
		Delivery chain disruptions (DR3)
		Forecasting error (DR4)
		Decline in market price (DR5)
		Inflexibility (DR6)
		Poor customer relationship (DR7)

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