Decision Support for Supply Chain Risk Management in Automotive Industry

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Abstract
This study aimed to identify the types of risks that arise in the automotive industry supply chain. Due to the increase in production volume today, there are many problems in the quality of the auto parts from the substandard production, which are consequently followed by many risks. Currently, there are many accident-related deaths each year around the world and most accidents are caused by cars that are produced without analyzing the risks in the supply chain. Moreover, the domestic automotive parts companies themselves are not yet aware which factors can affect the risks at most. Therefore, this research aimed to understand the risk factors in the automotive supply chain in order to contribute to the development of guidelines on various aspects of decisions. In general, the risks consist of internal and external risks, including the impact of economics, natural disasters, terrorism, or even the risks of production. This research was conducted by questionnaire and interview data obtained from automotive parts manufacturers in Thailand, a total of 170 people and experts in the automotive parts industry. The statistical analysis was performed using SPSS and the level of risks was determined by calculating the probability of occurrence and severity of risk factors. The results showed that the types of risks that arise in the automotive supply chain in a very high level (E-Extreme risk) that must be urgently resolved are the risk factors of production technology and the risk factors of quality control. These can be defined as decision-making guidelines for managing the risks in the automotive industry supply chain for the risks of production technology.
Keywords: Supply chain risk management, Decision-making, Automotive industry

1. Introduction

The automotive industry is a major industry in Thailand and generate high economic value for the country. Thailand Automotive Institute Ministry of Industrial (2012) In 2012, ratio of the domestic product value in the production industry is about 10 percent with direct employments of more than 500, 000 skilled workers. This excludes the value created by other relevant industries, such as upstream and service industries in respect of finance, insurance and after-sales service. Thailand could have also stepped up to lead the region and the world with a total production of cars as the first rank in Asia and the fifteenth car manufacturer in the world in 2011. In addition, it has served as a production base of auto parts in the region. Moreover, there is an expectation in the growth of the automotive industry in Thailand until 2050, which tends to have a higher production rate continuously. Thailand Automotive Institute Ministry of Industrial (2012)

According to its high production today, there are problems and risks in the quality of auto parts that have not met the standards. Thailand Automotive Institute. (2014) In October 2012, it recalled 7.43 million cars worldwide because of the risk of fire, and in February in the same year it recalled 1.9 million Prius hybrid cars. In 2014, Toyota, one of Japan's major car manufacturers, recalled 6.39 million cars worldwide because it found many different problems, such as driver's seat, steering column, and ignition system. Moreover, Toyota paid US$ 1,200 million to make a settlement in a criminal case because of the accelerator problem that could not be controlled and did not respond to the brake system, causing the deaths of over 10 people. Furthermore, Ford Motor, the second largest car manufacturer in the US, also announced a recall of approximately 434,700 cars because of two problems, firstly, a potential corrosion problem causing the sub-frame of the car separated from the lower arm that can affect the steering control and increase the risk of accidents, and secondly, the problem of rear seat frame made of substandard material that may increase the risk of injury if an accident occurs. Currently, there are 1.3 million deaths and more than 50 million injured people caused by road accidents each year around the world. Thailand Automotive Institute. (2014) If no corrective action is taken, in 2030 the number of deaths will increase to 2.4 million people per year. Most road accidents are caused by the vehicles that do not meet safety standards because there is now no analysis of risk factors that affect vehicles that do not meet safety standards as well as the impacts within the automotive industry supply chain.

It is therefore necessary to consider the risks that may occur in the automotive industry supply chain, which consists of three major parts, i.e. suppliers of raw materials or parts, manufacturers of parts, and car assemblers, in order to study the factors in the automotive industry supply chain that can have an impact on the risks at the highest level based on a risk assessment of four aspects: 1) supplier, 2) production process, 3) quality control, and 4) automotive assembly need. The study found that there are many factors that affect the risks in the supply chain. It is needed to analyze different factors in order to determine the factors that affect the risks by analyzing the risks that may result from these factors in terms of chances and the impacts that may occur when such risks occur. In addition, this research consider the factors that are common among all three groups of entrepreneurs and how those factors are linked together in order to lead to the development of a decision-making practice to support these risks and a risk management system for the automotive industry. Thitivadee. (2009)

According to the above-mentioned problems, automotive parts companies in the country have still not been aware of which factors that significantly affect the risks well as there are no decision-making practice and risk management system as an alternative to their own production of parts with minimal risk. Therefore, this research aims to understand the risk factors in the automotive industry supply chain that can affect at most and to develop a decision-making practice in various related aspects for those involved in the production of automotive parts to use in their decision-making in order to enhance the ability of their own production process as well as to prevent a impact on the flow of raw materials and parts and to prevent the disruption of production and assembly processes so that they can produce automotive parts with standard, quality and safety for all users.

2. Literature Review

Risk management is a plan and process of defining the strategy, conducting systematically to identify events that pose a risk, assessing the damage occurred that may affect individuals or organization, and selecting a method for risk management to reduce and eliminate or maintain the risks to a level acceptable to the individuals or organization. Thitivadee (2009)

The process of risk management can be divided into three major steps, i.e. (1) risk identification, (2) risk assessment, and (3) risk control. Liping et al. (2006)

Risk identification is to find whether there is any risk that can result in a negative effect on the organization. This includes externally-driven risks, such as political and economic conditions, and internally-driven risks, such as performance of automotive parts companies.

In this research, the researcher used the theoretical framework of Christopher and Peck due to its various components corresponding to the automotive industry. This framework consists of supplier risk, production process risk, quality control risk, and automotive risk, which is related to the automotive industry supply chain.

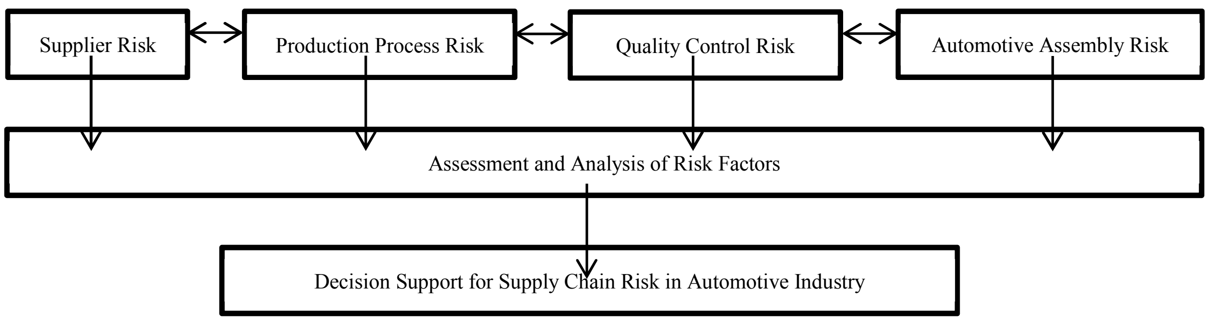

Figure 1. Diagram of the risk assessment in the automotive industry supply chain. Olson & Wu (2010)

In addition, according to the literature review, the risks can be classified as shown in Table 1.

Table 1. Examples of risk types obtained from the synthesis of articles and research papers to prepare a questionnaire within the supply chain

Relevant research papers/articles	Types of risks																
	1.Environment	2. Policy	3.Competition	4. Marketing	5. Production	6. Transportation	7. Disruptions	*8. Delay*	*9. System*	10. Forecast	*11. Intellectual Property*	*12. Procurement*	*13. Receivables*	*14. Inventory*	*15. Capacity*	*16. Macro*	*17. Security*
Olson & Wu (2010)				✓	✓												
Pujawan & Geraldin (2007)	✓					✓											
Kersten et al. (2007)					✓												
Tuncl & Alpand (2010)	✓				✓												
Chirstopher & Peck *(2004)*					✓		✓	✓	✓	✓	✓	✓	✓	✓	✓		
Vilko & Hallikas (2012)	✓	✓			✓							✓				✓	✓
Tang & Tomlin (2008)					✓						✓	✓					
Jennifer et al. (2008)						✓	✓		✓	✓	✓	✓	✓	✓	✓		✓
George et al. (2004)	✓																
Rachmat (2011)	✓				✓							✓					

According to the research related to risk assessment, many researchers studied and divided different types of risks based on their research purposes. The research has summarized and categorized the types of risks into 17 categories as shown in the table above. This research aimed to study and evaluate the risks in the automotive industry supply chain, and the researcher selected the study of Christopher and Peck (2004). It was found that they considered many aspects of risks throughout the entire supply chain, which is consistent with this research. The researcher therefore chose to adapt it to evaluate the automotive industry supply chain.

Risk assessment is to assess each risk factor identified for their likelihood as shown in Table 2 and to assess their severity or impact as shown in Table 3 in order to reveal different levels of risks and therefore to determine the risk control measures appropriately. This will allow the organization to plan and allocate the resources properly under its limited budget, manpower or time. The results indicate the levels of risks.

Table 2. Likelihood ranking, Suphannika & Damrong (2007), Molak (1996)

Rank	Likelihood	Explanation
1	Very low	May occur every 1-3 years
2	Low	May occur every 6 months - 1 year
3	Medium	May occur every 6 months
4	High	May occur every 3 months
5	Very high	May occur every 1 month or more

Table 3. Consequences ranking. Suphannika & Damrong (2007)

Rank	Likelihood	Explanation
1	Very low	Damage the workpiece in terms of appearance
2	Low	Damage and cause an unnecessary waiting in the workflow
3	Medium	Damage and cause a delayed production
4	High	Damage and stop the production line
5	Very high	Damage and harm the end users

After the likelihood of risks and the severity of impacts are analyzed, these scores are multiplied to get the scores of such risks, which can indicate the levels or degrees of risks that mean the status of the risks obtained by an assessment of likelihood of risks and severity of impacts of each risk factor. There are four levels of criteria as follows:

E – Extreme Risk ($\bar{x}$ = 2.56-4.00) A risk that needs to be urgently solved
H – High Risk ($\bar{x}$ = 1.60-2.40) A risk that must be highly taken care of and solved
M – Medium Risk ($\bar{x}$ = 0.64-1.44) A risk that a management plan may be established for but needs not to be immediately solved
L – Low Risk ($\bar{x}$ = 0.16-0.64) Most are acceptable. Suphannika & Damrong (2007), Molak (1996)

Table 4. Risk matrix. *Molak (1996)*

		Consequences				
		Very low (0.40)	*Low (0.80)*	*Medium (1.20)*	*High (1.60)*	*Very high (2.00)*
Likelihood	*Very high (2.00)*	M 0.80	H 1.60	*H* 2.40	*E* 3.20	*E* 4.00
	High (1.60)	M 0.64	M 1.28	H 1.92	E 2.56	E 3.20
	Medium (1.20)	L 0.48	M 0.96	M 1.44	H 1.92	H 2.40
	Low (0.80)	L 0.32	L 0.64	M 0.96	M 1.28	H 1.60
	Very low (0.40)	L 0.16	L 0.32	L 0.48	M 0.64	*M* 0.80

After assessing the risks, risk control measures are determined to reduce the likelihood of the risks and the impacts of the events to a level acceptable to the organization.

The overall reviews revealed that it has never been used in the automotive industry in Thailand. Therefore, it is necessary to develop the method mentioned above to be adapted for use in the automotive industry supply chain.

3. Methodology

3.1 Research process

According to the related theories and research, there were twelve risk factors that would affect the automotive industry supply chain. These risk factors could be used to determine the risk likelihood to assess the risks and to create a questionnaire to interview the relevant respondents. The levels of risk likelihood were then set by dividing the severity into five levels, i.e. 5 (very high), 4 (high), 3 (medium), 2 (low), and 1 (very low) as specified in the questionnaire. This questionnaire was submitted to 129 experts in the automotive industry supply chain, including Tiers 1, 2 and 3 and OEMs. Three-hundred sets of questionnaire were sent out and the researcher received 170 sets back regarding the factors that would affect the risks in the automotive industry supply chain. The data were then collected and analyzed using the ANOVA program. The results were divided based on the severity of risk impacts into 4 levels, i.e. E (Extreme Risk), H (High Risk), M (Medium Risk), and L (Low Risk) in the Risk Matrix. After the levels of risks were assessed and determined, the researcher first selected and improved the factors that affected the risks at most in order to determine the decision-making practice for risk management in the automotive industry supply chain by reviewing and working with experts in the automotive industry, providing to those involved to use in their decision-making in the automotive industry, and following up the implementation for further improvement and development.

Based on the related research as mentioned above, the researcher has therefore developed a methodology for use in this study by referring to George et al. (2004) and this can be summarized in Figure 2.

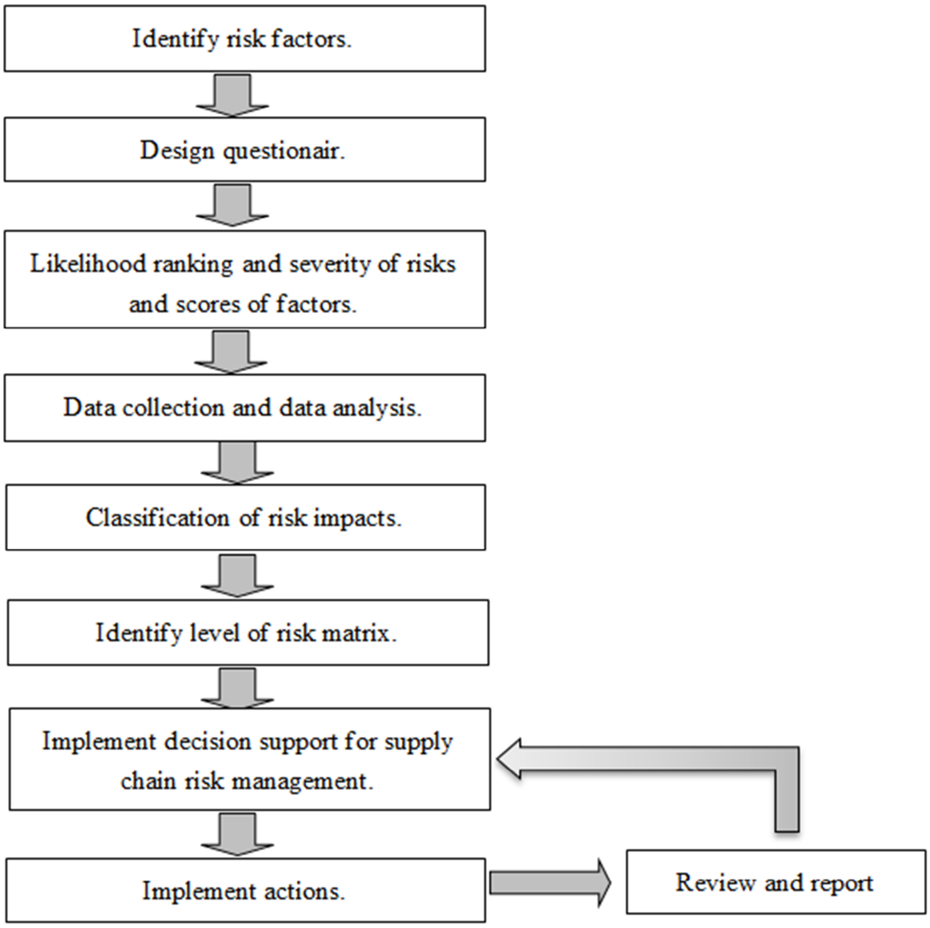

Figure 2. Research Methodology

3.2 Population and sample

The researcher determined and used the following three groups of automotive parts companies in the automotive industry supply chain as the sample of this research. MMTh Supplier Forum (2014)

1) Auto parts suppliers in Tier 3
2) Auto parts manufacturers in Tiers 1 and 2
3) OEMs

In this research, there were 129 auto parts manufacturing and assembling companies in Bangkok and its surrounding provinces

Companies in this group are auto parts and assembly companies in the automotive industry supply chain in Thailand and have participated in the meeting. In addition, they have market share, talent and high production capacity. As a result, these companies have seen the importance of risks that may affect them. The researcher therefore selected these companies as the sample used in the study for this research.

3.3 Questionnaire's reliability test

This research employed a statistical analysis technique to analyze its data obtained from the questionnaire's reliability test. Cronbach's Alpha was used to measure the questionnaire's internal consistency, and this value obtained from thirty sets of questionnaire was 0.89. This means the questionnaire used in this research was reliable and could be used in this research.

Determination of the relationship between the independent variables and the dependent variables

The independent variables and the dependent variables were configured to find the relationship between them as follows:

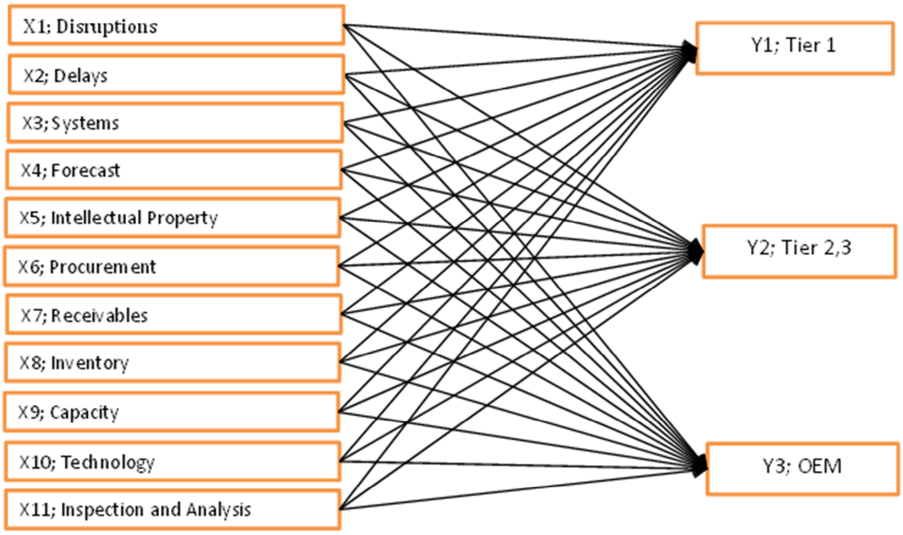

Figure 3. Relationship between the independent variables and the dependent variables

4. Results of data analysis

As the tool for data collection, 170 of 300 sets of questionnaire sent out were returned (56%) by allowing a sampling error of 5%. The results were consistent with those of the ANOVA analysis using the SPSS program. The respondents focused on the technology and quality risks that can affect the automotive industry at the highest level. The data were obtained from the survey using the questionnaire and interviews with 170 manufacturers of automotive parts and experts in the automotive business. The statistical analysis was performed using the SPSS software and the levels of risks were ranked by calculating the likelihood of occurrence and the severity of risk factors. The results showed that the first two types of risks that arise in the supply chain of the automotive industry and can affect or damage the end users are technology and quality risks, which can pose a risk in the automotive industry supply chain.

This research used ANOVA, in which F was given by the ratio of the variance between groups (SS_R) divided by the variance within groups (SS_W). df = K – 1 represents the degree of freedom for the numerator and df = N - K represents the degree of freedom for the denominator. Determination of the F – test value can be summarized in the following table. Kitisak (2005)

Table 5. ANOVA

Source of variation	SS	df	MS	F
Between groups	SS_B	K – 1	SS / K – 1	MS / MS
Within groups	SS_W	N -K	SS /N - K	
Total	SS + SS	N – 1		

Meanings of symbols

T^{i} = Sum of n values in each group
T = Sum of all scores

n^{j} = Number of data in each group
K = Number of groups

X^{ij} = Data ordered i in group j

$\bar{X}_j$ **= Average of group j**

$\bar{X}$ **= Total average**

$\sum_{j=1}^{K} \sum_{i=1}^{n_j} X_{ij}^2$ = **Sum of each score squared in every group**

The experimental results are shown in Tables 6 - 9.

Table 6. Means and standard deviations of the technology risks by the types of automotive industry

Technology	x̄	N	S.D.
Tier 1	*4.11*	*62*	*.42*
Tier 2	*4.23*	*64*	*.39*
OEM	*4.10*	*44*	*.50*
Total	*4.15*	*170*	*.43*

Table 6 shows the technology risks from all 170 respondents. Tier 2 focuses on the technology risks that can affect the automotive industry at the highest level.

The results showed that the auto parts and assembly companies have focused on technology risks as their first priority. These risks can have the highest impact towards the companies in the automotive industry supply chain. These sample companies argued that all departments in their companies have used primarily the technology to help improve their performance, working speed, accuracy of inspection, and analysis of designs in order to meet the needs of their customers. So, technology is important and can help prevent the risks from happening within their companies.

Table 7. Means and standard deviations of the quality risks by the types of automotive industry

Quality	x̄	N	S.D.
Tier 1	*4.24*	*62*	*.39*
Tier 2	*4.36*	*64*	*.43*
OEM	*4.23*	*44*	*.39*
Total	*4.28*	*170*	*.41*

Table 7 shows the quality risks from all 170 respondents. Tier 2 focuses on the quality risks that can affect the automotive industry at the highest level.

Table 8. ANOVA test for technology risks

Risks	*Sources of variance*	*SS.*	*df.*	*MS.*	*F*	*Sig.*
Technology	*Between groups*	*1.454*	*2*	*.727*	*3.085*	*.048***
	Within groups	*39.350*	*167*	*.236*		
	Total	*29.633*	*169*			

***Sig < .05*

According to Table 8, different technology risks have an impact on different types of automotive industry with a statistical significance of .05 (based on Sig. < .05).

Table 9. ANOVA test for quality control risks

Risks	*Sources of variance*	*SS.*	*df.*	*MS.*	*F*	*Sig.*
Quality control	*Between groups*	*1.141*	*2*	*.570*	*3.343*	*.038***
	Within groups	*28.492*	*167*	*.171*		
	Total	*29.633*	*169*			

***Sig < .05*

According to Table 9, different quality control risks have an impact on different types of automotive industry with a statistical significance of .05 (based on Sig. < .05).

Table 10. Scores of each type of risk factors. Chopra & Sodhi (2004)

Risk factors	x̄
Disruptions	
A1 No measures to prevent natural disasters, such as flood and earthquake, which can pose a risk	*3.49*
A2 No plans to block the employees' protest, which can have an impact on the risk	*3.36*
A3 No plans to support the bankruptcy of suppliers, which can become a risk	*3.41*
A4 No plans to support the war and terrorism, which can become a risk	*3.35*
A5 Dependence on only one supplier, which can have an impact on the risk	*3.48*
Delays	
B1 Use of production capacity that exceeds its real capacity, which can become a risk	*3.41*
B2 Suppliers have no flexibility in terms of delivery, which can have an impact on the risk	*3.48*
B3 Poor quality or products, which can become a risk	*3.58*
B4 Suppliers have a variety of deliveries, which can become a risk	*3.22*
Systems	
C1 Disruption of infrastructure, which can have an impact on the risk	*3.62*
C2 Intensive combination of systems or networks, which can have an impact on the risk	*3.29*
C3 Transactions through electronic media, which can become a risk	*3.57*
Forecast	
D1 Mistaken forecasting of demands, which can become a risk	*3.40*
D2 Suppliers use an excessive lead time, which can have an impact on the risk	*3.44*
D3 Change of seasons will affect the forecasting, which can become a risk	*3.34*
D4 Diverse products will affect the forecasting of demands, which can become a risk	*3.39*
D5 You see that the short life-cycle of the product can have a faster deterioration, which can have an impact on the risk	*3.53*
D6 Many retail customers pose a risk towards the forecasting of demands	*3.30*
D7 Reporting the false demands can affect the risk of supply	*3.40*
D8 No clarity on the actual demands, which can have an impact on the risk	*3.54*
Intellectual property	
E1 Counterfeit products of competitors, which can become a risk	*3.68*
E2 Lack of possession patent for self-produced products, which can become a risk	*3.70*
Procurement	
F1 Fluctuation in currency exchange rates, which can have an impact on the risk	*3.75*
F2 Purchase of raw materials or parts from the same source, which can become a risk	*3.63*
F3 Procurement process by purchasing from multiple sources, which can become a risk	*3.35*
F4 Lack of process to make both a short-term and long-term procurement contract with suppliers, which can become a risk	*3.63*
Receivables	
G1 Uncertain number of customers, which can have an impact on the risk	*3.65*
G2 Financial instability of customers, which can have an impact on the risk	*3.81*
Inventory	
H1 Rapid rate of deterioration for products in the inventory stock, which can become a risk	*3.67*
H2 Excessive storage of inventory, which can have an impact on the risk	*3.70*
H3 Reduced value of products, which can have an impact on the risk	*3.75*
H4 Uncertainty of demands and supply, which can become a risk	*3.72*
Capacity	
I1 Costs incurred by the process's inability, which can become a risk	*3.84*
I2 Rigor of production process, which can have an impact on the risk	*3.82*
Technology	
J1 No flexible machines in the production process, which can become a risk	*4.34*
J2 No design software, which can become a risk	*4.44*
J3 No continuous improvements in the production process, which can become a risk	*4.27*
J4 No applications of tooling technologies, which can become a risk	*4.21*
J5 No applications of just-in-time system, which can become a risk	*3.94*
J6 No automated or robotic machines assisted in the production, which can have an impact on the risk	*3.90*
J7 No use of statistical process to aid in the design of components and production process, which can become a risk	*4.14*
J8 No analysis of process's ability, which can pose a risk	*4.14*
J9 No use of process of experimental design, which can pose a risk	*4.05*
Inspection and analysis	
K1 No use of statistics to help in examining the quality of the parts, which can become a risk	*4.07*
K2 No use of measurement system, which can have an impact on the risk	*4.22*
K3 No use of FMEA to assess the impacts, which can become a risk	*4.26*
K4 No use of *QC 7 Tools*, which can become a risk	*4.44*
K5 No use of *why why why analysis technique*, which can become a risk	*4.43*
K6 Lack of modern measurement tools, which can become a risk	*4.29*

The analysis results shown in Table 10 found that the risk with the highest average score of 4.44 is the risk of technology, "J2: No design software, which can become a risk", which means that the automotive parts manufacturers see that a lack of design software is likely to affect the risks in the production process. In addition, the risk of inspection and analysis, "K4: No use of QC 7 tools, which can become a risk", has also an average of 4.44, which means that the automotive parts manufacturers see that a lack of application of QC7 tools is likely to encounter the risks as well.

After the average scores of the analysis have been known, they will be graded into 4 orders, i.e. E -

Extreme Risk, H - High Risk, M - Medium Risk, and L - Low Risk, in order to determine the severity of its effects. Risk factors and topics with a higher level of severity will be considered as the first ranks.

According to the classification and ranking of risk factors as shown in Table 10, it can be seen that the first five risk factors from the perspective of the manufacturers of automotive parts are as follows:

The levels of risks are shown in Table 11.

Table 11. Scores of each type of risk factors

Symbols	Risk factors	x̄	Levels of risks
J1	No flexible machines in the production process, which can become a risk	*4.34*	*Extreme Risk*
J2	No design software, which can become a risk	*4.44*	*Extreme Risk*
J3	No continuous improvements in the production process, which can become a risk	*4.27*	*Extreme Risk*
J4	No applications of tooling technologies, which can become a risk	*4.21*	*Extreme Risk*
K2	No use of measurement system, which can have an impact on the risk	*4.22*	*Extreme Risk*
K3	No use of FMEA to assess the impacts, which can become a risk	*4.26*	*Extreme Risk*
K4	No use of *QC 7 Tools*, which can become a risk	*4.44*	*Extreme Risk*
K5	No use of *why why why analysis technique*, which can become a risk	*4.43*	*Extreme Risk*
K6	Lack of modern measurement tools, which can become a risk	*4.29*	*Extreme Risk*
J7	No use of statistical process to aid in the design of components and production process, which can become a risk	*4.14*	*Extreme Risk*
J8	No analysis of process's ability, which can pose a risk	*4.14*	*Extreme Risk*
J9	No use of process of experimental design, which can pose a risk	*4.05*	*Extreme Risk*
K1	No use of statistics to help in examining the quality of the parts, which can become a risk	*4.07*	*Extreme Risk*
J5	No applications of just-in-time system, which can become a risk	*3.94*	*High Risk*
J6	No automated or robotic machines assisted in the production, which can have an impact on the risk	*3.90*	*High Risk*
B3	Poor quality or products, which can become a risk	*3.58*	*High Risk*
C1	Disruption of infrastructure, which can have an impact on the risk	*3.62*	*High Risk*
C3	Transactions through electronic media, which can become a risk	*3.57*	*High Risk*
D8	No clarity on the actual demands, which can have an impact on the risk	*3.54*	*High Risk*
E1	Counterfeit products of competitors, which can become a risk	*3.68*	*High Risk*
E2	Lack of possession patent for self-produced products, which can become a risk	*3.70*	*High Risk*
F1	Fluctuation in currency exchange rates, which can have an impact on the risk	*3.75*	*High Risk*
F2	Purchase of raw materials or parts from the same source, which can become a risk	*3.63*	*High Risk*
F4	Lack of process to make both a short-term and long-term procurement contract with suppliers, which can become a risk	*3.63*	*High Risk*
G1	Uncertain number of customers, which can have an impact on the risk	*3.65*	*High Risk*
G2	Financial instability of customers, which can have an impact on the risk	*3.81*	*High Risk*
H1	Rapid rate of deterioration for products in the inventory stock, which can become a risk	*3.67*	*High Risk*
H2	Excessive storage of inventory, which can have an impact on the risk	*3.70*	*High Risk*
H3	Reduced value of products, which can have an impact on the risk	*3.75*	*High Risk*
H4	Uncertainty of demands and supply, which can become a risk	*3.72*	*High Risk*
I1	Costs incurred by the process's inability, which can become a risk	*3.84*	*High Risk*
I2	Rigor of production process, which can have an impact on the risk	*3.82*	*High Risk*
A1	No measures to prevent natural disasters, such as flood and earthquake, which can pose a risk	*3.49*	*High Risk*
A2	No plans to block the employees' protest, which can have an impact on the risk	*3.36*	*High Risk*
A3	No plans to support the bankruptcy of suppliers, which can become a risk	*3.41*	*High Risk*
A4	No plans to support the war and terrorism, which can become a risk	*3.35*	*High Risk*
A5	Dependence on only one supplier, which can have an impact on the risk	3.48	*High Risk*
B1	Use of production capacity that exceeds its real capacity, which can become a risk	3.41	*High Risk*
B2	Suppliers have no flexibility in terms of delivery, which can have an impact on the risk	3.48	*High Risk*
B4	Suppliers have a variety of deliveries, which can become a risk	3.22	*High Risk*
C2	Intensive combination of systems or networks, which can have an impact on the risk	3.29	*High Risk*
D1	Mistaken forecasting of demands, which can become a risk	3.40	*High Risk*
D2	Suppliers use an excessive lead time, which can have an impact on the risk	*3.44*	*High Risk*
D3	Change of seasons will affect the forecasting, which can become a risk	*3.34*	*High Risk*
D4	Diverse products will affect the forecasting of demands, which can become a risk	*3.39*	*High Risk*
D5	You see that the short life-cycle of the product can have a faster deterioration, which can have an impact on the risk	*3.53*	*High Risk*
D6	Many retail customers pose a risk towards the forecasting of demands	*3.30*	*High Risk*
D7	Reporting the false demands can affect the risk of supply	*3.40*	*High Risk*
F3	Procurement process by purchasing from multiple sources, which can become a risk	*3.35*	*High Risk*

According to the average scores graded based on the severity of the risks as shown in Table 11, the severity of the risks can be classified into only 2 groups, i.e. Extreme Risk and High Risk, which can be described as follows:

Group 1 is designated for E-Extreme risks that must be urgently solved, i.e. red risk factors. These risk factors that are mostly prioritized by the manufacturers of automotive parts include: technology risk factors (J) that consist of No flexible machines in the production process (J1), No design software (J2), No continuous improvements in the production process (J3), No applications of tooling technologies (J4), No use of statistical process to aid in the design of components and production process (J7), No analysis of process's ability (J8), and No use of process of experimental design, which can pose a risk (J9), and quality control risk factors that consist of No use of statistics to help in examining the quality of the parts (K1), No use of measurement system (K2), No use of FMEA to assess the impacts (K3), No use of *QC 7 tools (K4),* No use of *why why why analysis technique* (K5), and Lack of modern measurement tools (K6).

Group 2 is designated for H-High risks that must be highly taken care of and solved, i.e. red risk factors. They include Disruptions (A), Delays (B), Systems (C), Forecast (D), Intellectual property (E), Procurement (F), Receivables (G), Inventory (H), Capacity (I), and Technology (J).

The researcher therefore suggests that the risk factors with a higher level of severity, i.e. Extreme Risk, should be taken into account to determine the decision-making practice at first, in particular the risk factors of J1, J2, J3 and J4. It they are left with no consideration, it may affect the risks violently and cause negative effects on the companies.

Table 12. Risk matrix from the perspective of manufacturers of automotive parts

		Consequences				
		Very low (0.40)	*Low (0.80)*	*Medium (1.20)*	*High (1.60)*	*Very high (2.00)*
Likelihood	*Very high (2.00)*				A, B, C, D, E, F, G, H, I, J	J, K
	High (1.60)					
	Medium (1.20)					
	Low (0.80)					
	Very low (0.40)					

According to the classification of risk factors in Table 12, it can be seen that most manufacturers of automotive parts agree that most risk factors come with a very high to low level of severity and likelihood. This is a bad sign to indicate that the entire operations throughout the supply chain of the production of automotive parts are accompanied by risk factors which can have an impact on the operations at most under no control. However, these risk factors can be classified into the following three groups:

5. Conclusions and future directions.

The results of the assessment of risk levels in this research can be used to define the practices of decision-making for managing the risks in the supply chain in the automotive industry in terms of technology risks that are E-Extreme risks and must be urgently resolved. Therefore, the researcher used the conceptual framework obtained from the above-mentioned research to define the details of questionnaires and interviews with experts from companies in the automotive industry supply chain in order to determine the practices of decision-making and problem-solving regarding the technology risks as shown in the figure below.

The framework obtained from this research can be adapted to analyze the industries with risks in their supply chains, such as electrical and electronic appliance industry that is one of the main industries and is in Thailand's development master plan. The Office of Industry Economics (2011) Risk matrix can also be applied to determine the severity of risks in the supply chains of other industries, such as electrical and electronic appliance industry, and be used as guidelines in the decision to manage the risks that may arise.

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Appendix 1. *Technology risks*

	Supplier	Production Process	Quality Control	Automotive Assembly
Problem	• Cannot produce the parts to meet the customer's demands • Cannot design the parts to meet the customer's demands • High production cost • Problem of work-piece quality • Long production time	• Cannot produce the parts to meet the customer's demands • Cannot design the parts to meet the customer's demands • High production cost • Problem of work-piece quality • Long production time • Production process affects the environment	• Cannot inspect the complicated parts • High inspection cost • Error of measurement and inspection capability • Long inspection time	• Cannot assemble the cars to meet the customer's demands • Cannot design the systems to meet the customer's demands • High production cost • Problem of assembly and long production time
Effect	• Cannot deliver the work to meet the customer's demands	• Cannot deliver the work to meet the customer's demands	• Error of inspection and long inspection time	• Cannot deliver the work to meet the customer's demands
Cause	• No flexible machines in the production process • No design software • No continuous improvements in the production process • No applications of tooling technologies • No applications of just-in-time system • No automated or robotic machines assisted in the production • No use of statistical process to aid in the design of components and production process • No analysis of process's ability • No use of process of experimental design	• No flexible machines in the production process • No design software • No continuous improvements in the production process • No applications of tooling technologies • No applications of just-in-time system • No automated or robotic machines assisted in the production • No use of statistical process to aid in the design of components and production process • No analysis of process's ability • No use of process of experimental design to design the parts with no environmental impact assessment • No analysis of finite element method and design process • No material and process selection in design	• No flexible machines in the production process • No use of software assisted in measurement and inspection process • No use of statistical process to aid in the measurement and inspection of workpiece • No analysis of ability of measurement and inspection process	• No flexible machines in the production process • No design software • No continuous improvements in the production process • No applications of innovation jig and fixture • No applications of just-in-time system • No automated or robotic machines assisted in the production • No use of statistical process to aid in the design of components and production process • No analysis of process's ability • No use of process of experimental design
Prevention	• Provide machines to form parts with diverse forms • Use the Catia software to design with simulation • Perform a continuous improvement within the organizations • Perform the tooling design by using the Catia software and inspect the tooling's assembly • Establishing the JIT system to reduce MUDA in the production process • Use the robotic system to reduce the working time and to increase the accuracy instead of human labours • Use the MSA statistics to analyze the production process's ability • Use the ANOVA statistical method to determine the relationship between different variables to help make a design-related decision • Use the design of experiment to help consider and select the materials for design	• Provide machines to form parts with diverse forms • Use the Catia software to design with simulation • Perform a continuous improvement within the organizations • Perform the tooling design by using the Catia software and inspect the tooling's assembly • Establishing the JIT system to reduce MUDA in the production process • Use the robotic system to reduce the working time and to increase the accuracy instead of human labours • Use the MSA statistics to analyze the production process's ability • Use the ANOVA statistical method to determine the relationship between different variables to help make a design-related decision • Use the design of experiment to help consider and select the materials for design • Always perform a life cycle assessment (LCA) in the design process • Analyse the material degradation • Perform the failure analysis and design • Consider the design for fracture and fatigue resistance	• Provide flexible machines for measurement and inspection • Provide the software to help in the measurement and inspection process • Perform a continuous improvement within the organizations • Use the MSA statistics to analyze the measurement process's ability	• Provide machines to form parts with diverse forms • Use the Catia software to design with simulation • Perform a continuous improvement within the organizations • Perform the tooling design by using the Catia software and inspect the tooling's assembly • Establishing the JIT system to reduce MUDA in the production process • Use the robotic system to reduce the working time and to increase the accuracy instead of human labours • Use the MSA statistics to analyze the production process's ability • Use the ANOVA statistical method to determine the relationship between different variables to help make a design-related decision • Use the design of experiment to help consider and select the materials for design
Detection	• Perform a technology assessment • Assess the technology capability • Establish a technology management plan • Perform the technology planning • Establish a technology roadmap • Establish the design technology and knowledge management	• Perform a technology assessment • Assess the technology capability • Establish a technology management plan • Perform the technology planning • Establish a technology roadmap • Establish the design technology and knowledge management • Establish the modern manufacturing systems	• Perform a technology assessment • Assess the technology capability • Establish a technology management plan • Perform the technology planning • Establish a technology roadmap	• Perform a technology assessment • Assess the technology capability • Establish a technology management plan • Perform the technology planning • Establish a technology roadmap • Establish the design technology and knowledge management