Assessing the vulnerability of supply chain using Analytic Network Process approach

Safar Fazli¹, Azam Masoumi²

¹Assistant Professor of Industrial Management, Department Of Social Sciences, Imam Khomeini International University, Iran
²MS student of Industrial Management, Faculty of Social Sciences, Imam Khomeini International University, Iran

*Corresponding Author email: a.masoumi.623@gmail.com

ABSTRACT: In today's business environment, harsher and more frequent natural and man-made disasters make supply chains more vulnerable. Increased number of supply chain disruptions and risks that Organization faced reduce the organization's revenue and increase their costs. The importance of these cases imply that if supply chain managers were more capable of measuring and managing supply chain vulnerability, they could reduce the number of disruptions and their impact. Recognizing its drivers, perceiving its importance and the effect of each of them on the organization make possible the vulnerability management. In this research an approach based on Analytic Network Process for prioritizing vulnerability's drivers is applied. The empirical evidence is based on 136 questionnaires which were distributed among executives and experts of supply chain and logistic in the automotive industry and spare parts of the existing companies and analyzed by using Factor Analysis method. The results showed that in this industry, supply (supplier) side is the main driver of supply chain vulnerability. Also suppliers' dependence was identified as the main supply chain vulnerability drivers, this result found by investigating of 18 vulnerability drivers in areas of supply, demand, and structure of supply chain. Identifying the main supply chain vulnerability drivers to the managers in supply chain vulnerability assessment and utilization of appropriate strategy helps them to reduce risk.

Keywords: Analytic Network Process; Automotive industry and spare parts; Supply chain risk management; Supply chain vulnerability; Vulnerability drivers

INTRODUCTION

Today firms are facing risks since the business and economical environments are dynamic and changing. Because there is an extensive communication between any firm with other parts of supply chain (suppliers, suppliers' suppliers, customers, and customers' customers) many of these risks are imposed by the supply chain itself. Supply chain risk management (SCRM) is an important issue in the field of supply chain management. This may be the consequence of "outsourcing", "emerging of global markets", "dependence on suppliers and customers" and "fast developing of information technology" (Narasimhan and Talluri, 2009). We can say the greater imposed risk is, so is the vulnerability of associations. In addition today firms are more vulnerable than before affected by several reasons.

First, disasters have increased in number and in intensity during the last decades. Natural disasters such as droughts, floods, windstorms, hurricanes, earthquakes or tsunamis strike more often and have a great economic impact. At the same time, the number of man-made disasters such as accidents, wars, terrorist attacks, strikes, or sabotage that affect supply chain has increased. Figure 1 shows this increasing trend (Wagner and Neshat, 2010).

Second, today's supply chains are more complex than they used to be. There are various reasons for supply chain complexity, such as higher levels of R&D and manufacturing outsourcing, supplier–supplier relationships in supplier networks, increased dependence on supplier capabilities, new technologies, regulatory requirements, and shorter product life-cycles due to rapidly changing customer preferences, and international market and production expansion.

Third, supply chain executives have strived to improve their financial performance, which is measured with ratios such as return on assets (ROA).
Fourth, with competition becoming fiercer, competitive pressures often force companies to assume more “calculated risks”. Risks that managers must accept in order to improve competitiveness reduce costs and improve profitability. However, the downside potential of the “calculated risks” could have adverse consequences that jeopardize the whole supply chain’s ability to serve the final customers, thus affecting firms’ long-term goal accomplishment (Wagner and Neshat, 2010).

The widespread disruptions cited in the literature, underline that vulnerability of modern supply chains can subsequently result in supply chain disruptions and detrimental effects for firms (Hendricks and Singhal, 2005; Wagner and Bode, 2008).

In line with the frequently cited business wisdom “you can’t manage, what you don’t measure” supply chain managers should consider quantifying the risks in order to reduce them. Chen and Paulraj (2004, p. 136) also believe that “the scientific development of a coherent supply chain management discipline requires that advances be made in the development of measurement instruments”. Along these lines, supply chain vulnerability also has to be measured and quantified (Kleindorfer and Saad, 2005). Measurement of supply chain vulnerability is by and large regarded as difficult because it is multi-dimensional and there are no well-developed metrics for evaluating the factors on which vulnerability depends (Wagner and Bode, 2006). Despite these obvious reasons for higher supply chain vulnerability and its impact on firm performance, the understanding of the supply chain vulnerability concept still remains on a conceptual and normative level. Since the practicality of vulnerable recognition can strengthen the managers against risks, this research aims to fill the gap between theoretical and practical levels by using statistics model and decision making techniques.

The remainder of the article is organized as follows. Second part of this research is specified to literature review, theoretical foundations of supply chain risk management and its driver survey which helps us to come to a general understanding of the subject. It reviews previous researches in the field of vulnerability and enlightens the need of Analytic Network Process approach (ANP) for ranking the drivers of vulnerability as well. In the third part research methodology, explanation of Analytic Network Process and collecting data are presented. Data analysis is presented in the fourth part and fifth part is specified to conclusion and comments for future studies.

**Literature review and the background of previous researches related to vulnerability of supply chain and its drivers**

Beside the advantages and attractions of supply chains, they face many risks. To improve the function and effective management of supply chain, it is essential to identify the supply chain risks for making them manageable (Wagner and Bode, 2008). Failure of supply chain can have long-term adverse effects on financial function of associations. Therefore it is widely accepted that supply chain risk management is a necessity for today business (Hendricks and Singhal, 2003, 2005). Other experts acknowledge that increased risks exist in the field of supply chain and their management is urgent (Christopher and Lee, 2004; Tang, 2006a).

Figure 2 depicts the relationship between supply chain disruption and supply chain vulnerability.
The failure to understand the potential vulnerabilities can compromises the supply chain’s ability to handle supply chain disruptions. As a result vulnerability should be managed through applying different approaches of supply chain risk management and implementing proper strategies towards risks. Associations cannot keep their competitive advantages to confront the vulnerability without a proper supply chain risk management approach.

**Supply chain vulnerability concept**

Supply chain vulnerability has been defined broadly by Christopher and Peck (2004, p. 3) as “an exposure to serious disturbance”. Wagner and Bode (2006, p. 304) state that “supply chain vulnerability is a function of certain supply chain characteristics and that the loss a firm incurs is a result of its supply chain vulnerability to a given supply chain disruption”. Since then, Wagner and Bode (2009, p. 278) defined the concept of vulnerability in a supply chain context more precisely: “While a supply chain disruption is the trigger that leads to the occurrence of risk, it is not the sole determinant of the final loss. It seems consequential that also the susceptibility of the supply chain to the harm of this situation is of significant relevance. This leads to the concept of supply chain vulnerability. The basic premise is that supply chain characteristics are antecedents of supply chain vulnerability and impact both the probability of occurrence as well as the severity of supply chain disruptions”.

If supply chain managers can alleviate these supply chain characteristics, they can reduce its vulnerability and the detrimental effects for the focal firm and the supply chain as a whole (Wagner and Neshat, 2010).

**Supply chain vulnerability drivers**

According to definitions, vulnerability of supply chain is the consequence of some drivers related to features or records of supply chain. Vulnerability is not invisible but there are some variables that determine the level of vulnerability.

Due to the reasons of vulnerability increase which were introduced before, supply chain vulnerable drivers (SCVD) are subcategorized into three groups: supply side, demand side, and supply chain structure vulnerabilities (Wagner and Neshat, 2010).

Vulnerability drivers on the demand side reside in the downstream supply chain operation. This includes the customer (e.g., customer dependence, financial situation of the customer), the product and its characteristics (e.g., its complexity and life-cycle), the outboundsupplychain(e.g.,thephysicaldistributionof productstothecustomer),thedistributionandtransportation operationrequiredforservingthecustomer(Christopher and Lee, 2004; Erhunetal,2007). Further,demandsidevulnerabilitydriverscan residetheneeruncertaintysurroundingtherandomdemandsofthecustomers(Nagurneyetal.,2005).

Vulnerability drivers on the supply side can reside in the supply base, the supplier portfolio or the supplier network (e.g., supplier—supplier relationships, supply base complexity, supply base structure) (Choi and Krause, 2006; Hallikas et al., 2004). When a supplier in the supplier network is vertically integrated by a direct competitor, forcing the termination of the relationship with the buying firm can also increase vulnerability of the supply chain for the buying firm(ChopraandSodhi,2004). The inability of suppliers to adapt to technological or product design changes may have detrimental effects on the customer’s costs and competitiveness (Zsidisin and Ellram, 2003). Vulnerability drivers in the supply chain structure stem to a large degree from the dynamics of the supply chain and the globalization (and off-shoring) of value-adding activities.
and Gregor, 2008). Because globalization requires a highly coordinated flow of goods, information, and cash within and across national boundaries, disruptions can have severe impacts on supply chain performance (Wagner and Neshat, 2010). Whensupply chains have to cover a large number of international markets and regions of the world, they are more susceptible to natural and man-made disasters (Manuj and Mentzer, 2008). Furthermore, modern supply chains contain “slack,” with lower inventories, fewer buffers, and leaner logistics operations, making supply chains more fragile. Likewise, Tang and Tomlin (2008, p. 12) observed that “long and complex global supply chains are usually slow to respond to changes, and hence, they are more vulnerable to business disruptions.”

Several publications mention how certain supply chain characteristics might increase or decrease the vulnerability of the supply chain. We found assumptions that supply chain vulnerability is increased by customer dependence, supplier dependence, supplier concentration, single sourcing, and global sourcing (Wagner and Bode, 2006). In sum, the structure of the supply chain, the parties involved on the supply side, and the parties involved on the demand side of the supply chain can all be considered major drivers of supply chain vulnerability.

Supply chain vulnerability at different levels of analysis

Supply chain vulnerability can be measured and managed at different levels, principally an entire economy, an industry, an entire supply chain, or only the focal firm (Wagner and Neshat, 2010). Likewise, decision makers at these different levels can define measures to reduce supply chain vulnerability. The higher the level, the more difficult it is for an individual firm to influence supply chain vulnerability.

It can be worthwhile to measure the vulnerability on the level of an economy. McKinnon (2006) provides a qualitative analysis of the vulnerability of the UK economy to the temporary disruption of the country’s road freight system. He concludes that individual firms can do little to reduce the vulnerability stemming from a temporary shut-down of road freight transportation. Instead, public policy makers would have to understand the vulnerability of supply chains to such a source of risk and take emergency measures in case a disruption occurs. In sum, a measure and a better understanding of supply chain vulnerability for a national economy can result in better informed decisions of policymakers with respect to an economy’s supply chain vulnerability (Wagner and Neshat, 2010). The next level is the application of the concept of supply chain vulnerability to an industry. Supply chain vulnerability can vary among industries. Their study of the impact of supply chain disruptions on operating performance, Hendricks andSinghal (2005) show that industries are affected differently by supply chain disruptions. Other industry-specific examples include the high number of vulnerable suppliers in the automotive industry (Hannon, 2008; Wagner et al., 2009) or the shortages of certain commodities (e.g., electronic components, steel) on the supply market (Carbone, 2000; Stundza, 2005). Supply chain vulnerability can also be assessed on the level of the focal firm—not taking the consequences of supply chain risks for the other firms involved in the supply chain into account. Many business continuity plans take this perspective (e.g., what should a firm do in case of fire in its production plant?). The firm level of analysis is narrower and fails to consider the risks stemming from a firm’s involvement in networks of production and supply (Wagner and Neshat, 2010).

Applying quantitative approach for supply chain vulnerable drivers

Conducted researches in the field of supply chain vulnerability emphasize the importance of vulnerability. For example, a research was conducted by Wagner and Bode on vulnerability of supply chain. They believed that their research is the first comprehensive survey on vulnerability. In their research they investigated supply chain’s risks, risks sources and failures of supply chain. They also argued that failures are the consequences of several internal and external resources of supply chain. Vulnerability of supply chain and its drivers have been studied in their study.

The main aim of their study was to investigate the relation among supply chain’s features and its risks and to have a practical survey on the factors that cause vulnerability in supply chain. Through statistics researches (multiple regression, variance and etc.) and questionnaire they showed that associations should consider the customer and supplier’s dependence. They handed the questionnaires to 760 chief managers of logistic and supply chain in German associations. The results indicated that single and global resourcing is one of the main aspects of creating vulnerability.

In 2010, Wagner and Neshat have estimated the vulnerability of supply chain with the help of Graph theory. In their study they referred to an essay written by Wagner and Bode in 2006. They argued that it is the first time that the graph theory had been used to estimate and quantify the indices of vulnerability in supply chain however the theory had been applied for supply chain's issues.

Wagner and Neshat classified vulnerability drivers into 3 subcategories “demand side, supply side and supply chain structure side”. We have followed the same category as well. Through questionnaires given to 760
chief managers of logistic and supply chain of 8 different industries in Germany they collected the data. According to intense dependence of drivers and application of graph theory they came to a conclusion useful for managers to recognize the drivers and their omitting influence on risk decrease which helped them to apply a proper strategy to cope with risks.

Previous researches haven't used multi-criteria decision-making methods to prioritize the drivers of supply chain's vulnerability. In this study supply chain vulnerability drives are identified for Automotive Industry and Spare Parts and then with the help of factor analysis and Analytic Network Process (ANP) most important drives are introduced.

**RESEARCH METHODOLOGY**

Analytic network process method is used in this research. Although this method hasn't been used for vulnerability issues of supply chain, it has been applied to solve supply chain's problems especially in the field of performance evaluation. For example Bayazit offers an ANP model to solve the problems of supply chain which has 10 criteria of evaluation classified based on performance and suppliers' abilities. To formalize the interactions among the criteria, they must be compared in pair as a control agent.

Gencer and Gurpinar apply a proposed ANP model in an electronic factory to choose the best supplier. In this model the interactions among criteria are taken into account (Ho et al.,2010). Because of the ANP application in prioritizing different criteria and non-hierarchal interactions of vulnerability drives discussed in this study, Analytic network process technique seems the most proper method to be used.

**Analytic network process approach (ANP)**

ANP is an innovative theory developed by hierarchical analysis process proposed by Saaty (1996) for issues with mediating relation among criteria. While hierarchical analysis method models the decision making framework with the help of one-way hierarchical relation among criteria, ANP method models decision making framework with the help of network system which licenses the more complex interactions among criteria. Therefore hierarchical analysis has been developed into ANP to solve the problems with the dependence of criteria. To achieve the effect and relative importance in this framework, judgment and rationality were used. To have a better understanding of ANP method following stages can be helpful.

All the components that influence the decision must be determined and classified into clusters. The decision making network should be delineated clearly, in other word it has to present a clear delineation and decomposes into relation network framework.

Then the interactions among components must be done by pair comparison. After that experts are wanted to compare clusters, components and answers pair by pair. This is done with the question “how much influence can a criterion have on another one according to interests and preference?” The rate of relative importance of each component is determined by scale 1-9 which indicates equal preference to complete preferred.

With the result of previous stage the super matrix is achieved which is shown by equation (1).

\[
W = \begin{pmatrix}
\mathbf{e}_{11} & \cdots & \mathbf{e}_{1n_1} \\
\mathbf{e}_{21} & \cdots & \mathbf{e}_{2n_2} \\
\vdots & \ddots & \vdots \\
\mathbf{e}_{m1} & \cdots & \mathbf{e}_{mn_m} \\
\mathbf{c}_1 & \cdots & \mathbf{c}_m
\end{pmatrix}
\]

\[
\mathbf{w}_{ij} = \begin{pmatrix}
\mathbf{w}_{11} & \cdots & \mathbf{w}_{1m} \\
\mathbf{w}_{21} & \cdots & \mathbf{w}_{2m} \\
\vdots & \ddots & \vdots \\
\mathbf{w}_{m1} & \cdots & \mathbf{w}_{mn_m}
\end{pmatrix}
\]
In which $C_n$ indicates the $n$th cluster, $e_{nm}$ indicates element $m$th in $n$th cluster and $W_i$ indicates special and main vector of elements’ effect in $j^{th}$ cluster in comparison with $i^{th}$ cluster. The super matrix form is dependent on problem’s structure. Clusters are usually dependent on each other in a network and the sums of columns are more than one. The obtained matrix is called weighted matrix. According to equation (2), weighted super matrix is multiplied by itself and becomes into a static matrix which is limited super matrix. The final weight vector and priorities are observable.

$$W = \lim_{k \to \infty} W^{2k+1}$$

(2)

**Data collecting in the automotive industry and spare parts**

According to previous studies and existed literature in the field of vulnerability of supply chain, 26 criteria have been recognized as vulnerability drivers of supply chain. Other required data were achieved from other several industrial companies. The collected data were obtained through questionnaire and gathering experts’ opinion related to vulnerability drivers.

Questionnaires were distributed in two levels. In first level, questionnaires were distributed among 250 experts of automotive industry which 136 of them were filled. (Response rate 54.4%). The experts were asked to give score to 26 identified drives from previous studies using Likert range of five options. (Very low = 1, low = 2, medium = 3, high = 4, very high = 5). The achieved data were entered to SPSS.

In the second level with the help of ANP, questionnaires were distributed among experts of automotive industry. The experts were chosen according to their educational and experimental features. The input of ANP is paired comparisons. Considering the network structure of research model, the ANP questionnaire is designed in the frame of several matrices. The questionnaire of this research includes 7 matrices of paired comparisons.

Experts determined the preference rate of each criterion in comparison with other criterion according to Saaty’s scale (equal preference = 1, rather poor = 3, relatively little = 5, very little = 7, very little = 9).

After collecting questionnaires, the corresponding elements of each matrix were multiplied by each other, and the $5^{th}$ root of the result (according to number of the experts) was obtained from the achieved result. Then inconsistency rate was calculated. If inconsistency rate is more than 0.1 the matrix must be returned to the expert till the inconsistency is obviated in pair comparisons. All the stages introduced of ANP in part 1.3 of this research were done to obtain limited super matrix. In this super matrix, all the numbers in the row are indicating the weight of any criterion and sub-criterion of corresponding row.

**Data and findings analysis**

Identification of main drivers of supply chain obtained by “Factor Analysis” is the first findings of this research put into three principal groups. These groups of main drivers were named based on Wagner and Neshat's research in 2010 under the title "Vulnerability Drivers from demand side, supply side and supply chain structure side ". Table (1) shows the summery of these results.

<table>
<thead>
<tr>
<th>Table 1. Result of using Factor Analysis in SPSS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Component</td>
</tr>
<tr>
<td>VAR00001</td>
</tr>
<tr>
<td>VAR00002</td>
</tr>
<tr>
<td>VAR00003</td>
</tr>
<tr>
<td>VAR00004</td>
</tr>
<tr>
<td>VAR00005</td>
</tr>
<tr>
<td>VAR00006</td>
</tr>
<tr>
<td>VAR00007</td>
</tr>
<tr>
<td>VAR00008</td>
</tr>
<tr>
<td>VAR00009</td>
</tr>
<tr>
<td>VAR00010</td>
</tr>
<tr>
<td>VAR00011</td>
</tr>
<tr>
<td>VAR00012</td>
</tr>
<tr>
<td>VAR00013</td>
</tr>
<tr>
<td>VAR00014</td>
</tr>
<tr>
<td>VAR00015</td>
</tr>
<tr>
<td>VAR00016</td>
</tr>
<tr>
<td>VAR00017</td>
</tr>
<tr>
<td>VAR00018</td>
</tr>
</tbody>
</table>

2768
The structure of network model for vulnerability of supply chain is the second finding. Figure (3) shows that vulnerability drivers have interactions. Also subsidiary criteria have interactions among themselves. This result is achieved based on review of literature and surveying previous researches.

![Network Model Diagram]

Figure 3. Network model
Determination the weight of main and minor drivers is the last result. Based on determined weight, ranking is done. After applying ANP and trough super matrix, the weight of each driver is achieved. The results are shown in table 2. These results are achieved based on applying ANP and the use of Super Decisions software.

Table 2. Importance of main and minor Supply chain vulnerability drivers in automotive industry and spare parts

<table>
<thead>
<tr>
<th>Main criteria</th>
<th>Weight</th>
<th>Rank</th>
<th>subsidiary criteria</th>
<th>Weight</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demand side</td>
<td>0.01647</td>
<td>3</td>
<td>Customers' dependency</td>
<td>0.08671</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Product complexity</td>
<td>0.27666</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Short products’ life cycles</td>
<td>0.63663</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Suppliers’ dependency</td>
<td>0.32475</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Low quality of supplier</td>
<td>0.05754</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Selection or change the supplier cost</td>
<td>0.04788</td>
<td>5</td>
</tr>
<tr>
<td>Supply side</td>
<td>0.79052</td>
<td>1</td>
<td>Uncertainty of deliver time</td>
<td>0.03962</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Logistics and transportation base</td>
<td>0.04343</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Flexibility constrain</td>
<td>0.04792</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Risk transfer on the side of supplier</td>
<td>0.21943</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Merge</td>
<td>0.21943</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Lean inventory</td>
<td>0.24389</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Global sourcing network</td>
<td>0.27850</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Supply chain complexity</td>
<td>0.06399</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Increase the layers of supply chains</td>
<td>0.05784</td>
<td>5</td>
</tr>
<tr>
<td>Supply chain structure</td>
<td>0.019301</td>
<td>2</td>
<td>Agility of supply chains</td>
<td>0.05496</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Logistic systems</td>
<td>0.05496</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>technology</td>
<td>0.24584</td>
<td>2</td>
</tr>
</tbody>
</table>

According to the obtained results, the main vulnerability driver from supply side with the first rank, and the main vulnerability driver from demand side with the last rank, and minor drivers related to each main driver are shown in the table.

**DISCUSSION AND CONCLUSION**

In this study we showed that it is possible to rank the main vulnerability drivers with ANP technique. Ranking can help the supply chain risk management significantly. When estimating the weights and priorities of each vulnerability drivers are done by supply chain managers of supply chain, they can easily make decision to decrease or omit the most important drivers. This is introduced as an approach to confront the supply chain risk.

Since supply chain risk management is costly, managers are forced to search for efficient resources to manage the risk and by "cost and benefit oriented investigating" they specify the resources to essential activities. According to limitation of resources accessible for managers (time, money and etc.,) the ranking of vulnerability drivers of supply chain which was done through ANP technique can help the managers with their decision making and specifying the proper resources to vulnerability drivers. Managers can identify a supply chain with fewer vulnerability drivers and better suppliers.

With the help of ANP the results show that Automotive Industry is more vulnerable from its demand side. Therefore managers should seek for reduction of risks. The achieved result is in compliance with Wagner and Neshat's study in 2010. In their study Automotive Industry was more vulnerable than other industries, and the vulnerability was from its demand side (Wagner and Neshat, 2010).

The analysis also showed that from demand side, the biggest rate of association's vulnerability is caused by dependence on suppliers. After "demand side", "supply chain structure" has the biggest vulnerability which is caused by "global resourcing network". According to Wagner and Bode "dependence on customer", "dependence on suppliers", "single resourcing" and "global resourcing network" are the most important drivers in three levels of main drivers (Wagner and Bode, 2006). In their research they proved that although minor drivers from demand and supply side of supply chain vulnerability are corresponding, the vulnerability driver from supply chain structure has a different result.

We have tried to quantify the theoretical concept of supply chain's vulnerability and prioritized the identified drivers based on experts' opinions. Findings approve the offered theoretical model for supply chain in 2010 (Wagner and Neshat, 2010), therefore "considering this model as a conceptual framework" and "ranking the vulnerability drivers of supply chain" have meaning and consistency.
Despite all the advantages of decision making in supply chain risk management for this research to benefit from, we can't forget the flaws and limitations. One of the flaws that this research suffered from was the dependence of approaches on experts' opinions and qualitative data. Vulnerability drivers and ranking are specified to automotive industry and can't be applied to any other one.

As it is possible to investigate the vulnerability drivers for a special industry, then researchers can compare the vulnerability drivers of other industry as well. Vulnerability drivers can be compared in a chain, or among several chains or in different times. We hope that managers can use and apply the result to find the best strategy of reducing or omitting the identified driver to reduce the risk of supply chain and have a better Supply chain risk management.

REFERENCES


