Supply Chain Resilience Assessment: A Grey Systems Theory Approach

Mohamad Amin Kaviani
Department of Industrial Engineering, Shiraz branch, Islamic Azad University, Shiraz, Iran
aminkaviani1366@yahoo.com

Mohammadsadegh Mobin
Industrial Engineering and Engineering Management Department, Western New England University, Springfield, MA01119, USA
mm337076@wne.edu

Eleonora Bottani
Department of Industrial Engineering, University of Parma, Viale G.P. Usberti 181/A, 43124 Parma, Italy
eleonora.bottani@unipr.it

Abstract
Supply chain resilience (SCR) is a crucial property for having efficient supply chain network in any successful enterprise. Due to the increasing uncertainty in the today's business world and the widespread recognition of the grey theory as an effective way to deal with uncertain situations, this study presents a method for measuring SCR based on a grey system theory approach. For this purpose, a case study is carried out in a cement production company, located in Iran. Results revealed that distribution problems and supply limitations are the most serious vulnerabilities threatening the abovementioned company. Therefore, the cement company must make a plan to improve the effectiveness of its SCR by selecting an appropriate set of capabilities including effectiveness, resilience in supply, and flexibility in order fulfillment which are identified as three important capabilities of the case company's supply chain.

Keywords: Supply Chain Resilience (SCR), Grey Systems Theory, Uncertainty, Grey interval numbers, Supply chain vulnerabilities, Supply chain capabilities.

1. Introduction
In the current competitive business environment, efficient supply chain plays an important role for a company to remain among its rivals in the industry (Tavana et al. 2016; Mobin et al., 2016). As it is discussed by Mobin et al. (2015), conditions governing the business environment impose a high uncertainty and unpredictable disruptions on the supply chain networks. This problem causes an increasing possibility of production interruptions and disruptions in meeting the customers' orders (Pettit, Fiksel and Croxton, 2010). These disturbances result from factors such as globalization, growth in work tasks outsourcing, reducing the number of suppliers, increasing demand fluctuations, and a significant decrease in the inventory levels (Pettit et al. 2013). Therefore, the severity and chances, i.e., frequency, of disruptions occurring is on the rise. On the other hand, supply chains are becoming weaker and more prone to disruptions (Wu et al. 2007).

As it is discussed by Schmitt and Singh (2012), a systematic approach is needed to control and reduce supply chain disruptions. Schmitt and Singh also demonstrated several factors, such as: inventory, capacity, and time, have non-linear impact on the supply chain resilience. There are many significant reasons for disruption in the supply chain that can be listed as: unfavorable weather conditions, disruptions in telecom and information and technology (IT) networks, transportation network problems, earthquakes, tsunamis, and failure in outsourcing of activities. In addition to demonstrating the different aspects of the incidents effects on organizations, the abovementioned items show the organizations need to create and expand appropriate capabilities to deal with any eventualities (Smith and Fischbacher, 2009).

Previous management methods, such as one dimensional risk management (Salmon et al., 2015, and Vafadarnikjoo et al., 2015), involved shortcomings have made them weak to be used as efficient tools for managing disruptions in the supply chain (Vafadarnikjoo et al., 2015). Therefore, we need to use more applicable management theories such as resource based view as well as dynamic capabilities view (Yao and Meurier, 2012). In many cases, these incidents have been viewed in a negative light. However, as studies showed, resilient organizations are able to adapt themselves in challenging situations (Sutcliffe and Vogus, 2003).

The important question may be this issue: how to encourage the organization's senior managers to monitoring and evaluating the state of organization resilience especially when there is nothing wrong with the current situations (Sheffi, 2005). Recognizing the current status would be the first step. Managers need a reliable tool to improve the resilience in a way they can plan an organizational strategy for a long term survival and growth (Pettit, 2008).

The aim of this study is to create a foundation for better understanding of the current level of enterprise SCR through a grey systems theory approach. On the basis of a case report, we first use a Delphi method to determine the capabilities and vulnerabilities of Iran cement industry. Then by using the interval grey numbers and applying whitening and degree of grey possibility techniques we would be able to show the SCR of the case company according to the Pettit et al.'s (2013) study about enterprise SCR.

In the next section we present a research background of the study. In the third section the research methodology of the work is discussed in details. The forth section focuses on the result analysis. At the end, the paper finishes with conclusion and future research direction in section 5.

2. Research background

Nowadays, resilience has become a widely used term among managers, researchers, and supply chain advisors. SCR refers to "an organization's ability to survive, adapt, and grow in the face of change and uncertainty" (Pettit et al. 2010). According to another definition, SCR means "the ability of the supply chain to return to its initial state (before the disruption), or to move towards a new state more desirable than the previous one" (Priya Datta et al. 2007). The framework of SCR is based upon the two dimensions of vulnerabilities and capabilities (Pettit et al. 2013). Therefore, in this study we tend to examine these two terms in order to better understand the concept of resilience in supply networks. Many studies have been conducted regarding potential vulnerabilities of the supply chain that are reviewed in Svensson (2004).

There are many examples of vulnerabilities in the literature, including: delays in transportation, worker strikes, terrorist attacks, poor communications, disruptions in IT systems, industrial accidents, natural disasters, government regulations, and even suppliers' opportunism (Sheffi, 2005). According to the previous studies, vulnerabilities can be defined as: "the main factors making an organization susceptible to possible disruptions" (Peck, 2005). Many researches have been carried out regarding supply chain capabilities including flexibility in order implementation, appropriate distribution of production facilities, safety stocks, suitable safety equipment, and sufficient financial reserves (Fiksel, 2006). Some authors have explored concepts such as agility, adaptability, and transparency as the capabilities of the supply chain (Pettit et al. 2013).

Others have pointed to these concepts as important characteristics of a resilient supply chain (Svensson, 2004). Supply chain capabilities can include supply chain features and characteristics which enable a company to predict and deal with possible supply chain disruptions. In the supply chain resilience literature, quantitative approaches have been previously applied by researchers for SCR assessment (i.e. Falasca et al. 2008; Carvalho et al. 2012; Mitra et al. 2009; Vugrin et al. 2011).

Recently, Pettit et al. (2013) introduced a tool for SCR assessment and management (named SCRAM tool). In their study, important links were found between the vulnerabilities and capabilities of the organization's supply chain. Their results indicated a correlation between higher resilience and better supply chain performance. In this study we incorporate the SCARM framework proposed by Pettit et al. (2013) and the fundamentals of the grey systems theory to evaluate and analyze the current state of the enterprise SCR.

3. Research methodology

In this research, we proposed a quantitative approach based on a methodology for SCR assessment and management (SCARM) and the grey theory in an Iranian cement company. We selected the Fars cement producer factory as our case study. First, the capabilities and vulnerabilities of the supply chain in Iran cement industry were identified. The Delphi method, adopted from Mobin et al. (2015) and Saeedpoor et al. (2015), was employed to identify the most important vulnerabilities and capabilities of the cement industry. The expert's community involved academics, cement companies, and policy-making organizations managers, who were familiar with Iran cement industry's supply chain, and had at least ten years of related experience. The experts were selected in three groups of four individuals.

The first group was consisted of Iran cement companies' senior managers. The second group was comprised of the cement factories' employees; and the third group included the academic experts. In the first step, a survey was designed and the Delphi members were asked to rank the identified vulnerabilities based on the research literature in order of importance with regards to Iran cement industry's current conditions. Then, through the review of past studies and research literature, the effective capabilities that could be used to encounter or reduce the negative effects of the supply chain vulnerabilities of Iran cement industry were identified. Later, through a questionnaire, and as it is suggested by Mobin et al. (2015) and Saeedpoor et al. (2015), Delphi members were asked to rate the effectiveness of the capabilities in dealing with the negative effects of cement industry's vulnerabilities from "Very Low" to "Very High".

After that, a questionnaire based on a 5-point Likert Scale, suggested by Skeete et al. (2015) and Mobin et al. (2015), was designed to determine the capabilities and vulnerabilities of Fars Cement Company based on their current state. The survey sample, consisting of 126 individuals was randomly selected from the statistical population including Fars cement company's managers and experts familiar with supply chain issues with at least 3 years of related experience. According to Petti et al.'s (2013) study, SCR can be calculated using the aspects of Vulnerabilities (V) and Capabilities (C) through the following equation: $SCR = (C - V + 4)/8$. In order to quantify the respondents' opinions regarding to both Capability (C) and Vulnerability (V) a grey scale was employed based on a 5-point Likert scale and including grey interval numbers.

The Grey theory is very effective in problem solving, where information is incomplete and ambiguous (Kaviani and Abbasi, 2014; Skeete et al. 2015). As it is mentioned by Mobin et al. (2015), other reasons for using Grey theory include simple calculations and small required sample size. Also, there is no need to sampling distribution (Vafadarnikjoo et al. 2015). Fuzzy sets make great use of inaccurate and vague data by using natural language and linguistic variables (Saeedpoor at al. 2015). Besides Fuzzy logic, grey theory has also been employed as a tool for taking uncertainty into account (Julong, 1989; Mobin et al., 2015; Mobin et al., 2014). Table 1 shows the Grey scale corresponding to the Likert scale adopted from Mobin et al. (2015).

Table1. Likert scale and grey interval numbers

Scale	Grey Number
Very Low	[0,1]
Low	[1,2]
Moderate	[2,3]
High	[3,4]
Very High	[4,5]

Since 126 experts responded to each sub-criterion, experts' opinions needed to be added up for each sub-criterion at first. For this aim, average gray interval numbers, adopted from Skeet et al. (2015), were used.

Assume the interval number related to expert's opinion regarding a criterion is in the form of $\otimes\, \mathrm{G_i} \in [\underline{\mathrm{G}}_\mathrm{i}, \overline{\mathrm{G}}_\mathrm{i}]$. In this case the aggregate interval number of k experts in the given criterion is as follows (Baskaran et al. 2012; Vafadarnikjoo et al. 2015):

$$\otimes\ \mathrm{G} = \frac{1}{\mathrm{k}}\,[\otimes\, \mathrm{G}_1 + \otimes\, \mathrm{G}_2 + \cdots + \otimes\, \mathrm{G}_\mathrm{k}] = [\frac{\sum_{\mathrm{i}=1}^{\mathrm{k}} \underline{\mathrm{G}}}{\mathrm{k}}, \frac{\sum_{\mathrm{i}=1}^{\mathrm{k}} \overline{\mathrm{G}}}{\mathrm{k}}]$$

At this stage it was necessary to combine the grey numbers in each sub-criterion to evaluate the main criteria. For this purpose, the mid-value of grey interval number, adopted from Mobin et al. (2015), was used. Finally obtained interval numbers had to be whitened. As it is discussed by Vafadarnikjoo et al. (2015), it should be noted that unlike fuzzy logic, in grey theory there are limited methods for changing grey numbers to crisp numbers. One of the popular methods for such a changing is whitening, presented in Mobin et al. (2015). If W is considered as the whitened value of ⊗G⊗G interval, we will have (Manzardo et al. 2012):

$$\mathrm{W} = \omega\, \underline{\mathrm{G}}\mathrm{i} + (1 - \omega)\overline{\mathrm{G}}_\mathrm{i};\ \omega \in [0,1]$$

In case ω= 0.5, this is called the mean whitening method. In order to whiten the three grey interval numbers, in addition to the mean method, another innovative method was employed which uses the concept of degree of grey possibility. According to the definition, for two grey numbers $\otimes \mathrm{G}_1 \epsilon \left[\underline{\mathrm{G}}_1, \overline{\mathrm{G}}_1\right]$, $\otimes \mathrm{G}_2 \epsilon \left[\underline{\mathrm{G}}_2, \overline{\mathrm{G}}_2\right]$ $\otimes \mathrm{G}_2 \epsilon \left[\underline{\mathrm{G}}_2, \overline{\mathrm{G}}_2\right]$ and $\mathrm{P}\,\{\otimes\ \mathrm{G}_1 \leq \otimes\ \mathrm{G}_2\}$ are called grey degrees in which (Liu and Forrest, 2010):

$$\mathrm{P}\,(\otimes\ \mathrm{G}_1 \leq \otimes\ \mathrm{G}_2) = \frac{\max\ \left(0, \mathrm{L} - \max\left(0, \overline{\mathrm{G}}_1 - \underline{\mathrm{G}}_2\right)\right)}{\mathrm{L}^*}$$

$$\mathrm{L}^* = \mathrm{L}_1 + \mathrm{L}_2$$

$$\mathrm{L}_i = \overline{\mathrm{G}}_i + \underline{\mathrm{G}}_i$$

In order to compare the grey numbers in this situation, we suggest that the degree of grey possibility would be compared in pair and the mean of each interval number be used as that number's value in comparison to other grey numbers. For example, to compare the main criterion V_5 which involves 4 sub-criteria, we act in the following way ($\mathrm{W}_{\mathrm{V}_{s-i}}$ indicates the whitened value for the sub-criteria i of the criterion V_5).

$$\mathrm{W}_{\mathrm{V}_{5-1}} = \frac{\mathrm{P}(\otimes\ \mathrm{V}_{5-2} \leq \otimes\ \mathrm{V}_{5-1}) + \mathrm{P}(\otimes\ \mathrm{V}_{5-3} \leq \mathrm{V}_{5-1}) + \mathrm{P}(\otimes V_{5-4} \leq \otimes\ \mathrm{V}_{5-1})}{3}$$

$$\mathrm{W}_{\mathrm{V}_{5-2}} = \frac{\mathrm{P}(\otimes\ \mathrm{V}_{5-1} \leq \otimes\ \mathrm{V}_{5-2}) + \mathrm{P}(\otimes\ \mathrm{V}_{5-3} \leq \mathrm{V}_{5-2}) + \mathrm{P}(\otimes V_{5-4} \leq \otimes\ \mathrm{V}_{5-2})}{3}$$

$$\mathrm{W}_{\mathrm{V}_{5-3}} = \frac{\mathrm{P}(\otimes\ \mathrm{V}_{5-1} \leq \otimes\ \mathrm{V}_{5-3}) + \mathrm{P}(\otimes\ \mathrm{V}_{5-2} \leq \mathrm{V}_{5-3}) + \mathrm{P}(\otimes V_{5-4} \leq \otimes\ \mathrm{V}_{5-3})}{3}$$

$$\mathrm{W}_{\mathrm{V}_{5-4}} = \frac{\mathrm{P}(\otimes\ \mathrm{V}_{5-1} \leq \otimes\ \mathrm{V}_{5-4}) + \mathrm{P}(\otimes\ \mathrm{V}_{5-2} \leq \mathrm{V}_{5-4}) + \mathrm{P}(\otimes V_{5-3} \leq \otimes\ \mathrm{V}_{5-4})}{3}$$

These whitened values make it possible to compare the criteria and sub-criteria.

4. Data analysis and results

Using the Delphi method, factors that are challenging Iran's cement industry supply chain were identified and the results of which are displayed in table 2.

Table2. Identifying vulnerabilities of Iran cement industry’s supply chain

Factor	Index code	Index title
Factor 1. External Problems and factors	V 1-1	Natural disasters (earthquake, flood, fire, etc.)
	V 1-2	Fluctuations in currency rates and prices
	V 1-3	The rapidly changing business environment
	V 1-4	Diverse needs of customers
	V 1-5	The rapid development of technology
	V 1-6	International sanctions
Factor 2. Supply limitations	V 2-1	Irregular delivery of orders by the suppliers
	V 2-2	Single consumer sources
	V 2-3	Interruptions in suppliers operations
Factor 3. Production system problems	V 3-1	exhausted equipment in the main production line
	V 3-2	Weakness in production technology
	V 3-3	Lack of relations between quality of products and international standards
	V 3-4	Low diversity
Factor 4. Distribution Problems	V 4-1	Poor after-sales service
	V 4-2	Long waiting time for receiving the ordered product
	V 4-3	Lack of adequate access to spare parts of some products

	V 4-4	Poor customer relationship skills at different centers
Factor 5. Poor communication	V 5-1	Lack of desirable access and poor information (between supply chain members and customers)
	V 5-2	Disproportionate and poor distribution of suppliers
	V 5-3	Disproportionate and poor distribution of production sites
	V 5-4	Disproportionate and poor distribution of distribution sectors

After consensus was reached among experts, 46 capabilities of Iran's cement industry supply chain were identified. The final results are presented in Table 3.

Table3. Identifying capabilities of Iran cement industry's supply chain

Factor	**Index code**	**Index title**
Factor 1. Compatibility	C 1-1	Reduction of Response Time
	C 1-2	Learning from the past events
	C 1-3	Consideration of early warning signs
	C 1-4	Identification of opportunities generated by interruption
	C 1-5	variation in terms of customer / product / market
	C 1-6	Data collection in various areas of business
Factor 2. Effectiveness	C 2-1	Optimal Use of assets
	C 2-2	appropriate Maintenance
	C 2-3	Quality Control System
	C 2-4	Elimination of non-value added activities
	C 2-5	The use of information technology tools to make processes more effective
	C 2-6	Efficient evaluation system for the selection of contractors (suppliers, agents, etc.)
Factor 3. Resilience in supply	C 3-1	Multiple sourcing
	C 3-2	Flexible contracts with suppliers
	C 3-3	Development of buying Strategy
	C 3-4	Requiring providers to have a variety of customer / markets
	C 3-5	Redesign of imported components based on domestic capabilities
Factor 4. Flexibility in order fulfillment	C 4-1	Redesign of imported components based on domestic capabilities
	C 4-2	The use of substitutes for critical equipment
	C 4-3	Demand aggregation
	C 4-4	Common parts
	C 4-5	The modular product design
Factor 5. The development of production technology	C 5-1	The postponement of orders
	C 5-2	The use of modern technology in the production process
	C 5-3	development and expansion of research and development (R & D)
	C 5-4	Localization and adaptation of imported technology with the domestic conditions
Factor 6. human resources	C 6-1	Staff specialized training
	C 6-2	Multi-skilled staff
	C 6-3	Teamwork

To quantitatively measure the vulnerabilities (V1 to V5) the indices of each factor are utilized. For instance, indices V1-1 to V1-6 are measured using the mid-value of their grey interval numbers and assigned as the value of factor V1. We apply the same procedure to measure the values of capability (C) factors. Since 126 managers and experts of Alpha Cement Company expressed opinions about each index, their opinions about each index needed to be added up at first. In the next step, the grey numbers required to be whitened and finally normalized. Table 4 shows the aggregated grey interval numbers regarding the case Company's vulnerabilities, as well as, the rank of each factor measured through “mean whitening" and the " degree of grey possibility” approaches.

Table4. Aggregated Delphi scores for vulnerability factors

Factor	Grey interval numbers obtained from aggregated respondents views		Crisp values through whitening method	Normalized values by whitening method	Ranking by whitening method	Crisp values by degree of grey possibility method	Normalized values by degree of grey possibility method	Ranks by degree of grey possibility method
	minimum	maximum						
V 1-1	2.142	3.142	2.642	0.142	5	0.244	0.081	5
V 1-2	3.190	4.190	3.690	0.199	1	0.850	0.283	1
V 1-3	2.349	3.349	2.849	0.153	4	0.358	0.119	4
V 1-4	2.523	3.523	3.023	0.163	3	0.463	0.154	3
V 1-5	2.111	3.111	2.611	0.141	6	0.231	0.077	6
V 1-6	3.190	4.190	3.690	0.199	1	0.850	0.283	1
V 2-1	3.063	4.063	3.563	0.342	2	0.571	0.269	2
V 2-2	3.190	4.190	3.690	0.354	1	0.844	0.416	1
V 2-3	2.650	3.650	3.156	0.302	3	0.66	0.314	3
V 3-1	2	3	2.5	0.221	3	0.285	0.142	3
V 3-2	2.873	3.873	2.373	0.210	4	0.201	0.100	4
V 3-3	2.619	3.619	3.199	0.276	2	00.698	0.349	2
V 3-4	2.793	3.793	3.293	0.291	1	0.814	0.407	1
V 4-1	3.015	4.015	3.515	0.264	1	0.632	0.316	1
V 4-2	2.888	3.888	3.388	0.255	2	0.547	0.273	2
V 4-3	2.634	3.634	3.134	0.264	3	0.378	0.189	4
V 4-4	2.730	3.730	3.230	0.243	3	0.441	0.220	3
V 5-1	2.634	3.634	3.134	0.264	1	0.772	0.386	1
V 5-2	2.158	2.158	3.338	0.255	2	0.455	0.227	2
V 5-3	2.095	2.095	3.134	0.236	4	0.412	0.206	3
V 5-4	2.015	2.015	3.230	0.343	3	0.359	0.179	4

On this basis it is possible to determine the importance of each vulnerability index factor, for instance, regarding factor V1 (external factors and problems), fluctuations in currency rates and prices and international sanctions are the most important vulnerabilities threatening the alpha cement company. Table 5 displays the aggregated grey numbers of respondent opinions about capability factors and their relative ranks.

Table5. Aggregated Delphi scores for capability factors

Factor	Grey interval numbers obtained from aggregated respondents views		Crisp values through whitening method	Normalized values by whitening method	Ranking by whitening method	Crisp values by degree of grey possibility method	Normalized values by degree of grey possibility method	Ranks by degree of grey possibility method
	minimum	maximum						
C 1-1	1.190	2.190	1.690	0.168	4	0.511	0.170	4
C 1-2	1.238	2.238	1.738	0.173	2	0.539	0.179	2
C 1-3	1.238	2.238	1.738	0.173	2	0.539	0.179	2
C 1-4	0.936	1.936	1.436	0.143	6	0.358	0.119	6
C 1-5	1.126	2.126	1.626	0.162	5	0.473	0.157	5

C 1-6	1.301	2.301	1.801	0.179	1	0.577	0.192	1
C 2-1	1.158	2.158	1.658	0.134	6	0.258	0.086	4
C 2-2	1.777	2.777	2.227	0.184	2	0.630	0.210	2
C 2-3	1.539	2.539	2.039	0.164	3	0.487	0.162	3
C 2-4	1.492	2.492	1.992	0.161	4	0.458	0.152	4
C 2-5	1.492	2.492	1.992	0.161	4	0.458	0.152	4
C 2-6	1.904	2.904	2.404	0.194	1	0.706	0.235	1
C 3-1	2.111	3.111	2.611	0.270	1	0.914	0.365	1
C 3-2	1.588	2.588	2.087	0.216	2	0.597	0.237	2
C 3-3	1.317	2.317	1.817	0.187	3	0.428	0.171	3
C 3-4	1.26	2.26	1.563	0.166	5	0.275	0.110	5
C 3-5	1.079	2.079	1.579	0.163	4	0.283	0.113	4
C 4-1	1.276	2.276	2.261	0.232	1	0.696	0.287	1
C 4-2	1.428	2.428	1.928	0.198	3	0.488	0.195	3
C 4-3	1.252	2.252	1.753	0.180	4	0.378	0.151	4
C 4-4	1.682	3.682	2.182	0.224	2	0.646	0.258	2
C 4-5	1.111	2.111	1.611	0.165	5	0.289	0.115	5
C 4-6	1.301	2.301	1.081	0.179	1	0.577	0.192	1
C 5-1	1.396	2.396	1.896	0.304	1	0.727	0.363	1
C 5-2	0.952	1.952	1.452	0.233	2	0.431	0.251	2
C 5-3	0.920	1.920	1.420	0.287	4	0.410	0.205	4
C 5-4	0.952	1.952	1.452	0.233	2	0.431	0.215	2
C 6-1	21.634	2.634	2.134	0.417	1	0.827	0.369	1
C 6-2	1.095	2.095	1.595	0.311	2	0.686	0.331	2
C 6-3	0.888	1.888	1.388	0.271	3	0.563	0.272	3

Table 5 offers valuable information about the state of each capability factor index of Fars Cement Company. For instance, the degree of company's success and ability in each of the indices defined for C1 (Compatibility) can be determined. According to the results shown in Table 5, the most adaptability indices in the cement company are realized as: gathering information on various aspects of business, leaning from past events and attention to the early warning signs. In the next step the gray numbers related to capability and vulnerability indices needed to be combined in order to evaluate the main factors. For this purpose, and assuming each main factor includes m indices, the means of gray interval numbers were used. The results of this stage are shown in Tables 6 and 7.

Table6. Obtained ranks for vulnerabilities

Index	Grey interval numbers		Crisp values through whitening method	Normalized values by whitening method	Crisp Values by degree of grey possibility	Normalized values by degree of grey possibility	Ranking obtained from whitening method	Ranking obtained from degree of grey possibility
	minimum	maximum						
V1	2.584	2.584	3.084	0.203	0.530	0.212	3	3
V2	2.726	3.726	3.226	0.212	0.619	0.247	2	2
V3	2.321	3.321	2.821	0.185	0.366	0.146	4	4
V4	2.817	3.817	3.317	0.218	0.676	0.270	1	1
V5	2.226	3.226	2.726	0.179	0.306	0.122	5	5

According to Table 6, Distribution problems and supply limitations are identified as the most pressing vulnerabilities of the case company

Table7. Obtained ranks for capabilities

Index	Grey interval numbers		Crisp values through whitening method	Normalized values by whitening method	Crisp Values by degree of grey	Normalized values by degree of grey	Ranking obtained from whitening	Ranking obtained from degree of grey
	minimum	maximum						

					possibility	possibility	method	possibility
C1	1.171	2.171	1.671	0.095	0.344	0.092	4	5
C2	1.560	2.560	2.060	0.117	0.413	0.110	1	2
C3	1.431	2.431	1.931	0.109	0.391	0.105	3	3
C4	1.447	2.447	1.947	0.110	0.418	0.112	2	6
C5	1.055	2.055	1.555	0.088	0.319	0.086	6	1
C6	1.146	2.146	1.646	0.093	0.379	0.102	5	4

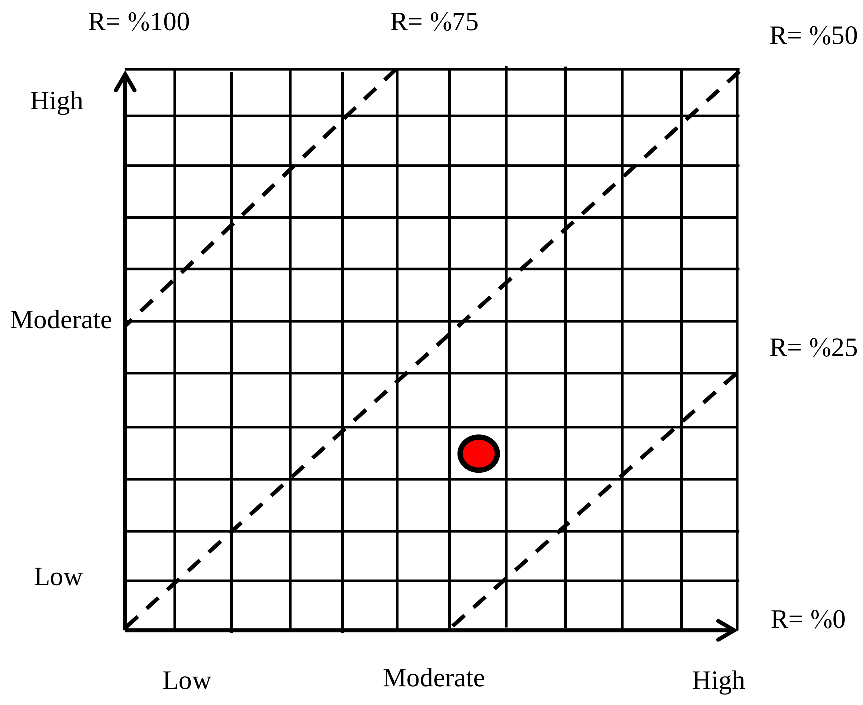
Thus company managers could identify their greatest capabilities. Table 7 indicates that the most important capabilities of the case company are effectiveness, flexibility in order fulfillment and resilience in supply, respectively. Using the whitening method for the company based on capabilities(C) and vulnerabilities (V) criteria, the final values will be as shown in table 8.

Table8. V and C values

Index	Grey interval numbers		Crisp Values by whitening method	Normalized values by whitening method
	maximum	minimum		
C	1.259	2.259	1.759	0.367
V	2.535	3.535	3.035	0.632

According to the calculated values of V (0.63) and C (0.37), the Alpha Cement Company SCR equals 37%. Figure 1 shows the state of its resilience.

Capabilities



Vulnerabilities

Figure 1 – Zone of balanced SCR

Alpha Cement Company's resilience falls within zone 2 which does not indicate a favorable situation. Therefore, the company needs to make a plan to improve its resilience by choosing an appropriate set of capabilities which are most compatible with its vulnerabilities.

5. Conclusion and future studies

The rapid change of market-related factors puts managers under pressure to coordinate organizational long range planning with the complexities of the competitive business environment. Moreover, lack of enough consideration to supply chain resilience could result in costly and sometimes irreversible effects on the organizations. In this situation managers face multiple challenges in removing the supply chain complexity. Identifying the reasons for these complexities and ways of dealing with them are among the primary concerns for organization managers and leaders in a supply chain. Several research studies have shown that through creating and developing elements of resilience, organizations will become more able to successfully deal with disruptions and overcome future uncertainties. The resilience concept makes it possible for organizations to possess higher viability and adaptability which are inherent system qualities necessary for overcoming the existing complexities in undesirable environmental circumstances and reaching the targets.

In this study, a method for measuring resilience of supply chain was introduced. The results obtained from this research could provide mangers with invaluable information regarding the present resilience of their organization so they would be able to make effective plans to improve organizational resilience by identifying the most important vulnerabilities and linking these to relevant capabilities applicable in the same area. As a case study, Alpha Cement Company's resilience was measured. To do this, at first the values of the company's capabilities (C) and vulnerabilities (V) were calculated by using a grey theory approach and the values C=0.63 and V=0.37 were obtained. Therefore Alpha Company's resilience was estimated to be at 37% which indicates the situation is not desirable for the company. Therefore we can conclude that there are vulnerabilities that, if left unaddressed, make the company susceptible to various eventualities. Distribution problems and supply limitations were determined as the most important vulnerabilities of the Alpha cement company. The findings of the study also suggested that Alpha Company possesses great capabilities are effectiveness, resilience in supply and flexibility in order fulfillment. For future studies, it is suggested that in addition to collecting data from the manufacturing company, other members of supply chain (producer and distributor) be included as well. It is also possible to apply the fuzzy logic and fuzzy numbers to assess SCR and compare the results with those of the grey theory.

References

Baskaran, V., Nachiappan, S., & Rahman, S. (2012). Indian textile suppliers' sustainability evaluation using the grey approach. *International Journal of Production Economics*, *135*(2), 647-658.

Carvalho, H., Barroso, A. P., Machado, V. H., Azevedo, S., & Cruz-Machado, V. (2012). Supply chain redesign for resilience using simulation.*Computers & Industrial Engineering*, *62*(1), 329-341.

Fiksel, J. (2006). Sustainability and resilience: toward a systems approach. *Sustainability: Science, Practice, & Policy*, *2*(2).

Falasca, M., Zobel, C. W., & Cook, D. (2008, May). A decision support framework to assess supply chain resilience. In *Proceedings of the 5th International ISCRAM Conference* (pp. 596-605).

Julong, D. (1989). Introduction to grey system theory. *The Journal of grey system*, *1*(1), 1-24.

Kaviani, M. A., & Abbasi, M. (2014). Analyzing the operations strategies of manufacturing firms using a hybrid Grey DEA approach–A case of Fars Cement Companies in Iran. International Journal of Supply and Operations Management, 1(3), 371-391.

Liu, S., & Forrest, J. Y. L. (2010). *Grey systems: theory and applications*. Springer.

Mitra, K., Gudi, R. D., Patwardhan, S. C., & Sardar, G. (2009). Towards resilient supply chains: Uncertainty analysis using fuzzy mathematical programming. *Chemical Engineering Research and Design*, *87*(7), 967-981.

Manzardo, A., Ren, J., Mazzi, A., & Scipioni, A. (2012). A grey-based group decision-making methodology for the selection of hydrogen technologies in life cycle sustainability perspective. *International journal of hydrogen energy*,*37*(23), 17663-17670.

Mobin, M., Roshani, A., Saeedpoor, M., & Mozaffari, M. (2015). Integrating FAHP with COPRAS-G method for supplier selection (case study: an Iranian manufacturing company). Proceedings of the International Annual Conference of the American Society for Engineering Management (ASEM), IN, USA.

Mobin, M., & Dehghanimohammadabadi, M. (2014). Food product target market prioritization using MCDM approaches. In Proceedings of the 2014 Industrial and Systems Engineering Research Conference.

Pettit, T. J., Fiksel, J., & Croxton, K. L. (2010). Ensuring supply chain resilience: development of a conceptual framework. *Journal of business logistics*, *31*(1), 1-21.

Pettit Timothy J., Joseph Fiksel, Keely L. Croxton (2013) "Ensuring supply chain resilience: Development and implementation of an assessment tool", *Journal of Business Logistics*, 34(1), pp. 46–76.

Pettit, T. J. (2008). *Supply chain resilience: development of a conceptual framework, an assessment tool and an implementation process* (Doctoral dissertation, The Ohio State University).

Priya Datta, P., Christopher, M., & Allen, P. (2007). Agent-based modelling of complex production/distribution systems to improve resilience. *International Journal of Logistics Research and Applications*, *10*(3), 187-203.

Saeedpoor, M., Vafadarnikjoo, A., Mobin, M., & Rastegari, A. (2015). a SERVQUAL model approach integrated with fuzzy AHP and fuzzy TOPSIS methodologies to rank life insurance firms, Proceedings of the International Annual Conference of the American Society for Engineering Management (ASEM), IN, USA.

Salmon, C., Mobin, M., & Roshani, A. (2015, January). TOPSIS as a Method to Populate Risk Matrix Axes. In IIE Annual Conference. Proceedings (p. 1504). Institute of Industrial Engineers-Publisher.

Schmitt, A. J., & Singh, M. (2012). A quantitative analysis of disruption risk in a multi-echelon supply chain. International Journal of Production Economics, 139(1), 22-32.

Skeete, A., Mobin, M., & Salmon, C. (2015). Aviation technical publication content management system selection using integrated fuzzy-grey MCDM method. Proceedings of the Industrial and System Engineering Research Conference (ISERC), TN, USA.

Sutcliffe, K. M., & Vogus, T. J. (2003). Organizing for resilience. *Positive organizational scholarship: Foundations of a new discipline*, *94*, 110.

Sheffi, Y. (2005). The resilient enterprise: overcoming vulnerability for competitive advantage. *MIT Press Books*, *1*.

Svensson, G. (2004). Vulnerability in business relationships: the gap between dependence and trust. *Journal of business & industrial marketing*, *19*(7), 469-483.

Smith, D., & Fischbacher, M. (2009). The changing nature of risk and risk management: The challenge of borders, uncertainty and resilience. Risk management, 11(1), 1-12.

Tavana, M., Kaviani, M. A., Di Caprio, D., & Rahpeyma, B. (2016). A two-stage data envelopment analysis model for measuring performance in three-level supply chains. *Measurement*, *78*, 322-333.

Vafadarnikjoo, A., Mobin, M., Salmon, C., & Javadian, N. (2015). An integrated gray-fuzzy cause and effect approach to determine the most significant categories of project risks. Proceedings of the Industrial and System Engineering Research Conference (ISERC), TN, USA.

Vafadarnikjoo, A., Mobin, M., Allahi, S., & Rastegari, A. (2015). A hybrid approach of intuitionistic fuzzy set theory and DEMATEL method to prioritize selection criteria of bank branches locations. In Proceedings of the International Annual Conference of the American Society for Engineering Management (ASEM), IN, USA.

Vafadarnikjoo A., Mobin M. (2015). Ranking the Project Risks based on the PMBOK Standard by Grey DEMATEL. Proceedings of the 2015 Industrial and Systems Engineering Research Conference (ISERC2015), Tennessee, USA.

Vugrin, E. D., Warren, D. E., & Ehlen, M. A. (2011). A resilience assessment framework for infrastructure and economic systems: Quantitative and qualitative resilience analysis of petrochemical supply chains to a hurricane.Process Safety Progress, 30(3), 280-290.

Wu, T., Blackhurst, J., & O'grady, P. (2007). Methodology for supply chain disruption analysis. International Journal of Production Research, 45(7), 1665-1682.

Yao, Y., & Meurier, B. (2012, August). Understanding the supply chain resilience: a Dynamic Capabilities approach. In *Proceedings of 9th International meetings of Research in Logistics 2012*.

Biography

Mohamad Amin Kaviani is a research fellow at Young Researchers and Elite Club, Islamic Azad University (IAU), Shiraz, Iran. He obtained his Bachelor degree in Industrial Engineering from IAU, Shiraz, Iran. After that he achieved his Master degree in Industrial Engineering as a top student from the same university. His main research interests are supply chain management, decision sciences, operations management and operations research. He is a member of Decision Science Institute (DSI) and Production and Operations Management Society (POMS). He is also the editorial board member of Management Decision and International Journal of Supply chain and Inventory Management. In addition, he is the regular reviewer of some prestigious international scholarly journals. He has published some papers in international refereed scholarly journals such as Applied Soft Computing, Management Decision, Measurement, International Journal of Advanced Manufacturing Technology, Decision Science Letters, International Journal of Strategic Decision Sciences and International Journal of Supply and Operations Management.

Mohammadsadegh Mobin is a doctoral student in Industrial Engineering and Engineering Management at Western New England University, MA, USA. He holds a Master degree in Operations Research (OR) (2011) and a bachelor degree in Industrial Engineering (IE) (2009). He served as a quality engineer (2006-2012) in different industries. His research interests lie in the areas of different applications of operations research tools.

Eleonora Bottani is Associate professor of Industrial logistics at the Department of Industrial Engineering of the University of Parma. She graduated (with distinction) in Industrial Engineering and Management in 2002, and got her Ph.D. in Industrial Engineering in 2006, both at the University of Parma. Her research activities concern logistics and supply chain management issues. She is author (or co-author) of more than 120 scientific papers, referee for more than 50 international scientific journals, editorial board member of five scientific journals, Associate Editor for one of those journals, and editor-in-chief of the International Journal of Supply Chain and Inventory Management.