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RESILIENCE IN SUPPLY CHAINS

Abstract: *The term resilience can be used in different fields of life and business. At the beginning of the twenty-first century, it was obvious to modern business conditions impose new demands on organizations. At the same time, unpredictable factors that were not previously in the public focus emerged different types of research in order to improve and protect business. Therefore, the concept of resilience becomes paradigm of modern business and is studied more and more. This paper set out a point view how it should look like from the supply chains perspective. A model for assessing the supply chain resilience is presented as well as analysis of indicators that are of vital importance for supply chains.*
Keywords: *organizational resilience, supply chain, vulnerabilities*

1. INTRODUCTION

When supply chains (SC) are discussed, it should keep on mind that there are numerous definitions which can be treated as acceptable [1, 2, 3]. In the concept of SC, the common fact is that every organization is relied on its customers and suppliers in order to have successful business processes. If the facts are deeply analyzed, it can be concluded that every organization in SC has its own resilience which is more or less dependable on overall SC resilience. Resilience is very popular research subject area in the last few years with the same trend in future. The reasons for such situation are different and can be presented in wide range – the attack on World Trade Center, September 11 2001 [4], phenomenon of world economic crisis at the beginning of the twenty-first century [5], nuclear disaster in Japan 2011 [6]. In a situation where the risk management shows its shortcomings, the concept of resilience becomes more important.

J. B. Ayers [3], defines supply chain as the life cycle processes supporting physical, information, financial flows, and flows of knowledge that allow the movement of products and services from suppliers to consumers (figure 1).

Considering its complexity and uncertain business conditions, supply chains represent potential sources of risk. In many relevant reports, managers of different organizations identify risks in supply chains as a threat to the survival of their organizations [8]. The traditional approach of risk management shows the disadvantages when it is required to perform analysis of complex supply chain requirements and to assess the interconnectedness of risk as well as to predict future behavior of supply chain [9]. Having on mid these facts, a large number of managers and researchers realized the importance of organizational resilience concept. Definitions of this concept exist in the different scientific disciplines.

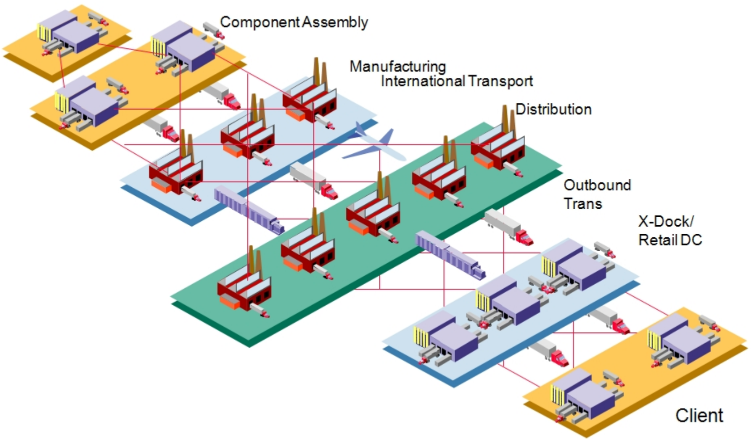

Figure 1 – Supply chain scheme [7]

If the business organizations are the subject of research, resilience represents function of system awareness, identification and management of keystone vulnerabilities and adaptive capacity in complex, dynamic environment which is under influence of its own elements and environment [10]. This definition is updated recently to incorporate the functions of resilience ethos into the overall resilience [11].

2. LITERATURE REVIEW

The industrial revolution in the twentieth century led to the development of transport and intensifying business relations which introduced the modern look of supply chains. Along with the increasing complexity of relations and the emergence of new factors in the market, the theory of uncertainty about the delivery time and demand was developed [12]. At the end of last century, the focus of the business philosophy was client. To maintain a good balance between the risks of supply and distribution, different concepts have been developed in the manufacturing philosophy – Just In Time (JIT), Vendor Managed Inventory (VMI), etc.

Considering the fact that the supply chain is viewed as a network of organizations focused on two-way flows of goods, services, financial resources and information, starting from the initial suppliers to final consumers [1], it is necessary to achieve a high level of cooperation of its parts in order to ensure an acceptable level of resilience of the entire chain.

As awareness of the importance of organizational resilience increased, a number of researchers had been worked on clarifying this concept in a variety of engineering and management disciplines. In the field of engineering science it is usual to deploy a research considering the resilience from the aspect of mechanical materials. In the material science, resilience stands for the ability of material to bounce back into the state before the impact of force which causes elastic deformations [13]. If this definition is compared with the reality of the supply chain, the conclusion is that it is more important for SC not to return to the initial position before the disturbance but to use the experience created for this event and to adapt to new circumstances. In ecology, it is widely accepted definition of ecosystems resilience is ability to recover from disturbances while retaining its diversity, integrity and environmental processes [14]. In this case, adaptability is crucial to the "living" systems and SC can be treated that way. In organizational theory, it is appointed that organizations have the best chance to succeed in the market if they are run by leaders who possess personality characteristics that match the high level of personal resilience on the leadership level and organizations which are run by those leaders will always be in front of their competition.

With the presence of factors that exist in the last two decades, the concept of resilience is relied on the highest organizational level on the proper application of information and communication technology (ICT). In order to effectively manage ICT in supply chain management, the organization must first make a distinction between form and function of transaction information technology and analytical information technologies [15]:

1. Transactional ICT: they refer to the acceptance, processing and merging raw data on the company's past and current operations of SC (eg. POS systems, quarterly reports resellers, ERP systems and e-commerce),
2. Analytical ICT: they refer to the development and implementation of a system for evaluation and dissemination of decisions based on models that are built from a database of decisions related to SC (eg. systems for forecasting, network optimization systems for SC, production scheduling).

In the analytical field of ICT, it is reasonable to assume that the introduction of new technologies can raise the organizational performances, and this can indirectly increase the values of organizational resilience indicators [16].

3. RESILIENCE IN SUPPLY CHAINS

Resilience in SC is the most relied on the concept of managing vulnerabilities which can be quantified by using risk management. Risk can be interpreted as a combination of probability of an event and its consequence effect [17]. The concept of vulnerability in SC has entered in the research focus after the crisis caused protests in the UK because of fuel prices in 2000. Analysis of this disruption in SC showed that:

- Vulnerabilities in SC are serious source of problems,
- Research in this area were insufficient,
- System awareness of SC entities is on the very low level,
- Methodology for management of the vulnerabilities in SC is needed.

After this, the serious research has been conducted in this area. Based on this empirical research [18] developed an initial framework for a resilient supply chain. They asserted that supply chain resilience can be created through four key principles: 1) resilience can be built into a system in advance of a disruption (i.e. re-engineering), 2) a high level of collaboration is required to identify and manage risks, 3) agility is essential to react quickly to unforeseen events and 4) the culture of risk management is a necessity. Characteristics such as agility, availability, efficiency, flexibility, redundancy, velocity and visibility were treated as secondary factors.

3.1 A new model of SC resilience

Supply chains are different scale organizations – from the regional to the global scale. Their every day operations are directed by a lot of information. This can be supported by the fact that information has a multiplier role, activating all economic sectors and it assists organizational optimization, raising productivity, while lowering costs.

Stephenson et al [11] presented a model of organizational resilience which is partially used and combined with the model of [19] in order to fulfill the requirements of the supply chain resilience. The central model of supply chain resilience is proposed in figure 2.

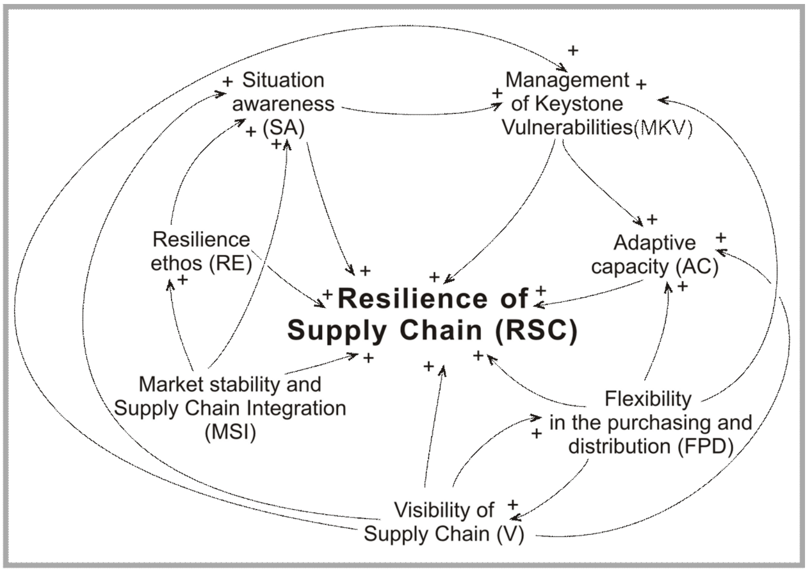

Figure 2 – The central model of supply chain resilience

Table 1- Organizational resilience components in SC

Dimension of SC Resilience	Indicators	
Management of the Keystone Vulnerabilities	Planning Strategies	KV1
	Participation in Exercises	KV2
	Capability and Capacity of Internal Resources	KV3
	Capability and Capacity of External Resources	KV4
	Organization Connectivity	KV5
	Robust Processes for Identifying & Analyzing Vulnerabilities	KV6
	Staff Engagement & Involvement	KV7
	Deliberate threats	KV8
	External pressures	KV9
	Resource limits	KV10
	Organizational sensitivity	KV11
	Supplier – Customer disruptions	KV12
Situation Awareness	Roles and responsibilities	SA1
	Understanding of hazards and consequences	SA2
	Connectivity awareness	SA3
	Insurance Recovery	SA4
	Recovery priorities	SA5
	Internal & External Situation Monitoring & Reporting	SA6
	Informed Decision Making	SA7
	Market position	SA8
	Collaboration with other entities	SA9
	Situation anticipation	SA10
	Organizational efficiency	SA11
	Decentralization	SA12
Adaptive capacity	Management of Silo Mentality	AC1
	Communications and Relationships	AC 2
	Strategic Vision and Outcome Expectancy	AC 3
	Information and Knowledge	AC 4
	Leadership, Management and Government Structure	AC 5
	Innovation & Creativity	AC 6
	Devolved & Responsive Decision Making	AC 7
	Organizational security	AC8
	Financial strength	AC9
	Adaptability	AC10
Resilience ethos	Commitment to Resilience	RE1
	Network Perspective	RE2

The four dimensions of organizational resilience – Situation awareness, Management of the keystone

vulnerabilities, Adaptive capacity and Resilience ethos are presented on the figure 2. These dimensions are made up organizational resilience components and supported by the most influental factors in the supply chain resilience – Market stability and supply chain integration, Visibility of SC and Flexibility in in the purchasing and distribution.
In the table 1 are presented the organizational resilience components.

The most influental factors in the supply chain resilience – Market stability and supply chain integration, Visibility of SC and Flexibility in in the purchasing and distribution has direct impact on these resilience dimensions and their indicators, so they need to be studied separately with great attention.

3.2 Quantification model

Nowadays, there are no defined methods for calculating of resilience in any organization's type either in the literature or in practice. The proposed fuzzy model is realized in two steps. In the first step, the rating of every resilience indicator is calculated and it takes into consideration both parameters' values of indicators $\tilde{v}_{ji}$ and their corresponding relative importance $\tilde{w}_{ji}$. In the second step, fuzzy resilience assessment is obtained with respect to evaluations of all factors as well as their weights. In order to better understanding of proposed method, firstly, the assumptions benefited for handling the problem and the notation are given.

Notation

The notation used this paper can be expressed as below:
i- factor index, i=1,..,I
I- number of factors
j- indicator index
J_i - number of indicator I, i=1,..,I
e - decision maker of management team index
E - number of decision makers of management team
$\tilde{w}^e_{ji}$ - a triangular fuzzy number $\left(x;l^e_{ji}, m^e_{ji}, u^e_{ji}\right)$ describing the relative importance of indicator j of factor i, j=1,.., J_i; i=1,..,I according to estimation of decision maker e, e=1,…,E.
$\tilde{w}_{ji}$ - a triangular fuzzy number $\left(x;l_{ji}, m_{ji}, u_{ji}\right)$ describing the aggregated relative importance of indicator j of factor i, j=1,.., J_i; i=1,..,I
w_{ji} -crisp the relative importance of indicator j of factor i, j=1,.., J_i; i=1,..,I
$\tilde{w}^e_{i}$ - a triangular fuzzy number $\left(x;l^e_{ji}, m^e_{ji}, u^e_{ji}\right)$ describing the relative importance of factor i, i=1,..,I according to estimation of decision maker e, e=1,…,E
$\tilde{w}_{i}$ - a triangular fuzzy number $\left(x;l_{ji}, m_{ji}, u_{ji}\right)$ describing the aggregated relative importance of factor i, i=1,..,I
w_i - crisp the relative importance of factor ii=1,..,I
$\tilde{v}_{ji}$ - a triangular fuzzy number $\left(y;l_{jk}, m_{jk}, u_{jk}\right)$describing the value of indicator j of factor i, j=1,.., J_i; i=1,..,I
$\tilde{r}_{ji}$ - a normalized value of $\tilde{v}_{ji}$, i, j=1,.., J_i; i=1,..,I

$\tilde{d}_{ji}$ - the weighted normalized value of the value of indicator j of factor i, j=1,.., J_i ; i=1,..,I

$\tilde{D}_i$ - the weighted value of factor i, i=1,..,I

$\tilde{R}$ - a triangular fuzzy number describing the value of resilience of considered SC.

R – scalar value of $\tilde{R}$

Modeling of Criteria Weights

All the indicators for evaluating factor are usually not of the same relative importance. Also, they can be considered as unchangeable during the considered period of time. They involve a high degree of subjective judgment and individual preferences of decision makers. We think that the judgment of each pair of treated criteria best suits human-decision nature (by analogy with AHP method). In conventional AHP, the pairwise comparison is established using a standard integer scale [1-9]. Value 1 denotes that criterion k is as important as criterion k', and value 9 denotes that criterion k is much more important than criterion k', $k,k' = 1,..,K; k \neq k'$. Decision makers express their judgments far better by using linguistic expressions than by representing them in terms of precise numbers. It feels more confident to give interval judgments than fixed value judgments.

In this paper, the fuzzy rating of each decision maker is described by linguistic expressions which can be represented as triangular fuzzy number $\tilde{w}^e_{jj'} = \left(x; l^e_{jj'}, m^e_{jj'}, u^e_{jj'} \right)$ with the lower and upper bounds $l^e_{jj'}, u^e_{jj'}$ and modal value $m^e_{jj'}$, respectively. The greater $u^e_{jj'} - l^e_{jj'}$, the fuzzier the degree. Values in the domain of these triangular fuzzy numbers belong to a real set within the interval [1-9]. Value in domain of each of these five fuzzy numbers has the same meaning as value of standard scale which is given in conventional AHP.

If strong relative importance of indicator j' over indicator j holds, then pairwise comparison scale can be represented by the fuzzy number

$$\tilde{w}_{jj'} = \left(\tilde{w}_{j'j} \right)^{-1} = \left(\frac{1}{u_{j'j}}, \frac{1}{m_{j'j}}, \frac{1}{l_{j'j}} \right)$$

.

If $j = j'$ ($j, j' = 1,..,J_i; i = 1,....,I$) then relative importance indicator j over indicator j' is represented by single point 1 which is a triangular fuzzy number (1, 1, 1).

The aggregated fuzzy rating of relative importance of each pair of the considered indicator, or all factors must include the fuzzy rating of all decision makers. The aggregation fuzzy rating is performed according to [20].

The relative importance of each pair of the considered indicators is described by triangular fuzzy number $\tilde{w}_{jj'} = \left(l_{jj'}, m_{jj'}, u_{jj'} \right)$ with the lower and upper bounds $l_{jj'}, u_{jj'}$ and modal value $m_{jj'}$, respectively.

Weights vector of the considered indicators and factors is calculated by applying the concept of extent analysis [**21**].

3.3 Modeling of Uncertain Values

Values of all defined indicators and factors cannot be stated quantitatively, as decision makers most often base their estimates on evidence data. In such cases, their values are adequately described by linguistic expressions.

The number and types of linguistic expressions are defined by decision makers depending on their estimation.

For instance, fuzzy rating of each indicator value is described by linguistic expressions which can be represented as triangular fuzzy number. Values in the domain of these discrete fuzzy numbers belong to a real set within the interval [1-5]. Rating 1 means that the value of indicator is the least and rating 5 means that the value of indicator is the greatest.

In this paper, fuzzy rating of management team can be described by using one of five linguistic expressions: *low value, fairly moderate value, moderate value, highly moderate value,* and *high value*. These linguistic expressions are modeled by triangular fuzzy numbers which are given in the following way.

The algorithm for resilience assessment is formally given as follows.

Step 1. Calculation of weights vector of each indicator and each factor is done by applying procedure [21].

Step 2. Calculation the normalization values of indicators which are benefit type:

$$\tilde{r}_{ij} = \left(\frac{l_{ij}}{u^{max}}, \frac{m_{ij}}{u^{max}}, \frac{u_{ij}}{u^{max}} \right),$$

$j=1,...,J_i; i=1,..,I$

$$u^{max} = \max_{j=1,..,J_i; i=1,..,I} u_{ij}$$

Step 3. Calculation the weighted normalized value of indicator j, $j=1,...,J_i; i=1,..,I$

$$\tilde{d}_{ji} = w_{ji} \cdot \tilde{r}_{ji}$$

Step 4. Calculate weighted value of factor i, $i=1,..,I$:

$$\tilde{D}_i = \frac{1}{J_i} \cdot \sum_{j=1}^{J_i} \tilde{d}_{ji}$$

Step 5. Calculate degree of belief that any $\tilde{D}_i'$, i=1,…,I, $i \neq i^*$, is higher than $\tilde{D}_{i^*}$ [22, 23].

Step 6. Calculate value of SC resilience:

$$\tilde{R} = \frac{1}{I} \cdot \sum_{i=1}^{I} \tilde{D}_i \cdot w_i$$

Step 7. Defuzzification of $\tilde{R}$.

4. CONCLUSION

Risks and vulnerabilities have become on of key concern of organizations, which is even further emphasized by the current economic crisis and market uncertainties of today. It is known that resilience is an evolving concept and differs from traditional risk management. The present paper analyzed the concept of resilience in SC which covers risks and vulnerabilites as well as situation awareness and adaptive capacity of SC. A new moodel for resilience assessment is presented and it is based on the fuzzy logic. Further reserearch is going to be directed in model testing and improvement.

REFERENCES:

[1] Christopher, M., Logistics and Supply Chain Management, Pitman, London, 1992.

[2] Harland, C., M., Supply Chain Management, Relationships, Chains and Networks, British Journal of Management, Vol. 7, Special Issue, 1996.

[3] Ayers J. B., Making Supply Chain Management Work, Design, Implementation, Partnerships, Technology, and Profits, Auerbach Publications CRC Press LLC, 2002.
[4] http://www.september11news.com/ (april 2011).
[5] http://en.wikipedia.org/wiki/Late-2000s_recession (april 2011).
[6] http://www.newser.com/tag/57377/1/fukushima-dai-ichi.html (april 2011).
[7] http://www.iso.org.tr/kongre/Kongre_2008/Sunumlar/2B-3-Enrico-Camerinelli.ppt
[8] Blome, C., Schoenherr, T., Supply chain risk management in financial crises – A multiple case-study approach, Int. J.ProductionEconomics, 2011, doi:10.1016/j.ijpe.2011.01.002.
[9] Starr, Randy, Jim Newfrock and Michael Delurey, Enterprise resilience: Managing risk in the networked economy, Strategy + Business, Issue 30, pp. 1-10, 2003.
[10] McManus, S., Organizational resilience in New Zealand, PhD thesis in Civil Engineering at the University of Canterbury,University of Canterbury, 2008.
[11] Stephenson, A., Vargo, J., Seville, E., Measuring and comparing organisational resilience in Auckland, The Australian Journal of Emergency Management, Vol. 25, No. 2, pp. 27-32, 2010.
[12] Whitin, T. M., Inventory control research: A survey, Management Science, Vol. 1, No. 1, pp. 32-40, 1954.
[13] Merriam-Webster, Merriam – Webster Dictionary, Springfield, MA: Merriam-Webster, Inc. 2007.
[14] Folke, C., Carpenter, S., Walker, B., Scheffer, M., Elmquist, T., Gunderson, L, Holling, C.S., Regime shifts, resilience and biodiversity in ecosystem management, Annual Review of Ecology, Evolution and Systematics, Vol. 35, No. 1, pp. 557-581, 2004.
[15] Shapiro J. F., Modeling the Supply Chain, Wardsworth Group, Duxbury, 2001.
[16] Aleksic, A., Arsovski, S., Arsovski, Z., Stefanovic, M., Improving organizational resilience by applying informa-tion and communication technology: A case study, Preceedings of the International Conference on Mechanical, Industrial, and Manufacturing Engineering (MIME 2011), 2011.
[17] Sheffi, Y., The resilient enterprise, Overcoming vulnerability for competitive advantage, Cambridge, MA: MIT Press, 2005.
[18] Christopher, Martin and Helen Peck, The five principles of supply chainresilience, Logistics Europe, Vol. 12, No. 1, pp. 16-21, 2004.
[19] Pettit, T., Supply chain resilience: development of a conceptual framework, an assessment tool and an implementation process, the PhD thesis, The Ohio State University, 2008.
[20] Tadić, D., Milanović, D., Misita, M., Tadić, B., New integrated approach to the problem of ranking and supplier selection under uncertainties, Proceedings of the Institution of Mechanical Engineers. Part B: Journal of Engineering manufacture, doi:10.1243/09544054JEM2105.
Chang, D.Y., Applications of the extent analysis method on fuzzy AHP, European Journal of Operational Research, 95, 649-655, 1996.
Dubois, D., Prade, H., Decision-making under fuzziness, in: Advances in Fuzzy Set Theory and Applications, M.M. Gupta, R.K. Ragade, R.R. Yager, eds., Elviser, North-Holland, 279-302, 1979.
Bass, M.S., Kwakernaak,H., Rating and Ranking of Multiple-aspect Alternatives using Fuzzy sets, Automatica 3 , 47-58, 1977.

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