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ISSN 0543-5846
METABK 55(4) 783-786 (2016)
UDC – UDK 669.011:001.8:516.5/.9=111

MEASURING THE METALLURGICAL SUPPLY CHAIN RESILIENCE USING FUZZY ANALYTIC NETWORK PROCESS

Received – Prispjelo: 2015-11-06
Accepted – Prihvaćeno: 2016-04-25
Preliminary Note – Prethodno priopćenje

The article presents a methodology for measuring the metallurgical supply chain resilience, which enables the ascertainment of key resilience capabilities and measurable criteria, and determining a level of the resilience. The methodology is based on Analytic Network Process (ANP), which is used to solve the complex decision-making problems, whose structures can be mapped as non-linear networks. Since ambiguous pairwise comparisons expressed by fuzzy sets are considered, the Fuzzy Analytic Network Process (FANP) is applied. The methodology is verified on the generalised model of a metallurgical supply chain. The SuperDecisions software was used for the application. The experiments performed demonstrate the high level of suitability of the FANP approach for measuring metallurgical supply chain resilience.

Key words: metallurgy, methodology, supply chain resilience, Analytic Network Process, fuzzy sets

INTRODUCTION

Today's metallurgical supply chains face a turbulent environment, in which a wide spectrum of factors can result in supply chain disruption. For this reason, the authors of the article have developed a new methodology for assessing and measuring the metallurgical supply chain (MSC) resilience [1]. The methodology is based on the Analytic Hierarchy Process (AHP). The basic stages of the methodology include: I) Analysis of resilience skills; II) Draft of resilience indicators; III) Creation of a hierarchical system of resilience indicators; IV) Evaluation of the MSC resilience, and V) Interpretation of obtained results. However, the AHP method has two serious weaknesses: a) it does not take complex interdependencies between used criteria into consideration and b) it does not reflect the uncertainty of the managerial decision making process. The aim of the article is to apply and prove the feasibility of the Fuzzy Analytic Network Process (FANP) in the designed methodology.

ANALYTIC NETWORK PROCESS

The Analytic Network Process (ANP), developed by Saaty, is a multistage decomposition method used to solve decision-making problems involving more than one criterion of optimality [2]. The main principle behind ANP is to view decisions as based on a framework of interconnected factors and evaluate the given factors in relationship to each other. These evaluations are represented by weights, which are determined on the basis of pair comparisons.

ANP is performed on the basis of three basic steps (modified according to [2-4]):

1) Model construction. A decision-making problem is analysed by researchers and transformed into a network structure. This network contains elements, clusters and connections. The elements symbolise fundamental building blocks of the network. They represent both criteria and alternatives. Clusters are groupings of elements, which are logically related factors of the decision. Connections determine interdependence among elements.

2) Pairwise comparison matrices and local priority vectors. The determination of weights is based on node pairwise comparisons when one element depends on two or more different elements from one cluster and on cluster pairwise comparisons when elements (one or more) from one cluster depend on two or more elements from other clusters. The relative importance values are determined using Saaty's 1 - 9 scale. Pairwise comparisons are performed in the framework of node and cluster matrices, and local priority vectors are derived as estimates of the relative importance associated with the elements or clusters being compared.

3) Supermatrix construction. In the first step, the unweighted supermatrix is created directly from all local priority vectors. In the second step, the weighted supermatrix is calculated by multiplying the values of the unweighted supermatrix with their affiliated cluster weights. By normalizing the weighted supermatrix, it is made column-stochastic. In the third and final step, the limit supermatrix is processed by raising the entire supermatrix to powers until it converges in terms of lines.

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Limit priority values within this supermatrix indicate the flow of influence of an individual element towards the overall goal. Since the decision alternatives are elements of an original cluster of the network, their limit priorities are synonymous with their contributions to the goal and are used for the ranking of alternatives, being normalized within the cluster [5].

FUZZY ANP

Due to the ambiguity latent in pairwise comparisons, the fuzzy extension of the ANP is considered (FANP). Two possible approaches to deal with fuzziness exist – either fuzzy extensions of valued relations (see e.g. [6-8]) or defuzzification of the fuzzy quantities by some appropriate metric (e.g. a possibilistic mean, see [9]) could be used. In the authors' humble opinion, the first possibility is more suitable. It reflects the uncertainty in a better way because it does not use one real number to represent the whole fuzzy quantity.

Deviation of the FANP from the ANP is in Step 2) of the method. That is why only fuzzy pairwise comparison will be described more deeply in this section. Let us express the preference relationships given by triangular fuzzy numbers (TFNs) and linguistic description as follows (based on Saaty [10]): (1,1,1) – identity, (1,1,2) – weak importance, (1,2,3) – moderate importance, (2,3,4) – moderate plus, (3,4,5) – strong importance, (4,5,6) – strong plus, (5,6,7) – very strong, (7,8,9) – almost absolute importance, (8,8,9) – absolute importance, where $a_{ij} = (a_{ij}^l, a_{ij}^m, a_{ij}^u)$ is a triangular fuzzy number with the core a_{ij}^m and the support $\left[a_{ij}^l, a_{ij}^u\right]$ (see Figure 1).

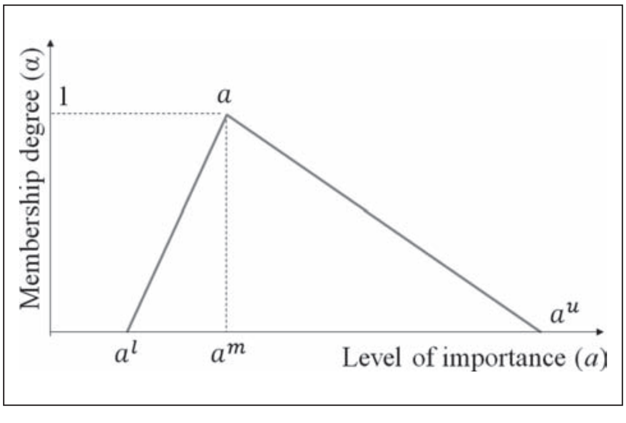

Figure 1 General triangular fuzzy number denoting a preference level

Inverse elements a_{ji} expressing the non-preference are expressed also by a TFN: $(1/a_{ij}^u, 1/a_{ij}^m, 1/a_{ij}^l)$. Deriving the weights of criteria from the fuzzy Saaty's matrix can be divided into the following steps [8]:

1) Fuzzy synthetic extension calculation. Fuzzy elements of Saaty's matrix have to be converted into TFNs called fuzzy synthetic extensions $S_i(s_i^l, s_i^m, s_i^u)$ using (1)-(4) [6].

$$S_i = \sum_{j=1}^n a_{ij} \otimes (\sum_{i=1}^n \sum_{j=1}^n a_{ij})^{-1} \quad (1)$$

$$\sum_{j=1}^n a_{ij} = (\sum_{j=1}^l a_{ij}^l, \sum_{j=1}^n a_{ij}^m, \sum_{j=1}^n a_{ij}^u) \quad (2)$$

$$a \otimes b = (a^l \cdot b^l, a^m \cdot b^m, a^u \cdot b^u) \quad (3)$$

$$a_{ij}^{-1} = 1/a_{ij}^u, 1/a_{ij}^m, 1/a_{ij}^l \quad (4)$$

for $i = 1, 2, \ldots, n$; where a and b are TFN's (a_l, a_m, a_u) and (b_l, b_m, b_u), respectively.

2) Use of fuzzy valued relations to calculate weights of criteria. In this step, fuzzy synthetic extensions are defuzzified by using the min fuzzy extension of the valued relation "≤" given by (5) and weights W_i are calculated, for more details (see e.g. Fiedler et al. [11]).

$$W_i = \min_j \left\{ \frac{s_j^i - s_i^u}{(s_i^m - s_i^u) - (s_j^m - s_j^l)} \right\} \quad (5)$$

for $i, j = 1, 2, \ldots, n$

3) Standardization of the weights. In order to obtain the sum of weights within one matrix equal to 1, final weights w_i are calculated using (6).

$$w_i = W_i / \sum_{i=1}^n W_i \quad (6)$$

for $i, j = 1, 2, \ldots, n$.

4) A check of a Saaty's matrix consistency. In the line with [6], a consistency of the matrix is sufficient if inequality (7) holds.

$$CR = \frac{CI}{RI} = \frac{\bar{\lambda} - n}{(n-1) \cdot RI} \le 0.1 \quad (7)$$

where $\bar{\lambda}$ stands for the arithmetic mean of the maximum real eigenvalues of the matrices $(a_{ij}^{\xi})_{1 \le i,j \le n}, \xi \in \{l, m, u\}$ for $i, j = 1, 2, \ldots, n$ is the size of the Saaty's matrix) and RI denotes a random index whose value depends on n [6].

EXPERIMENTS AND RESULTS

A generalised model of a global MSC was used to apply and confirm the developed methodology (see Introduction) using FANP. The model includes 5 mines (ore and coal suppliers), 15 metallurgical plants, 50 steel wholesalers, and 500 direct consumers. The MSC operates on four continents with a relatively wide metallurgical assortment. A large part of the MSC has a holding structure. The holding company controls metallurgical plants and their suppliers. With this structure the supplier part of the chain features a large degree of mutual interdependence and financial interconnectedness.

The first two stages of the designed methodology are described in [1] in details. As key resilience skills were determined (stage I): S1 Cooperation, S2 Flexibility, S3 Visibility, S4 Capacity, and S5 Financial Strength (see Figure 2 and Table 1). For each skill appropriate measurable indicators (stage II) SI11 - SI51 were selected (for details see Table 2). It was appropriate to modify and merge the third stage (creating a hierarchical system of resilience indicators) and fourth stage (evaluation of the MSC resilience) into one new stage:

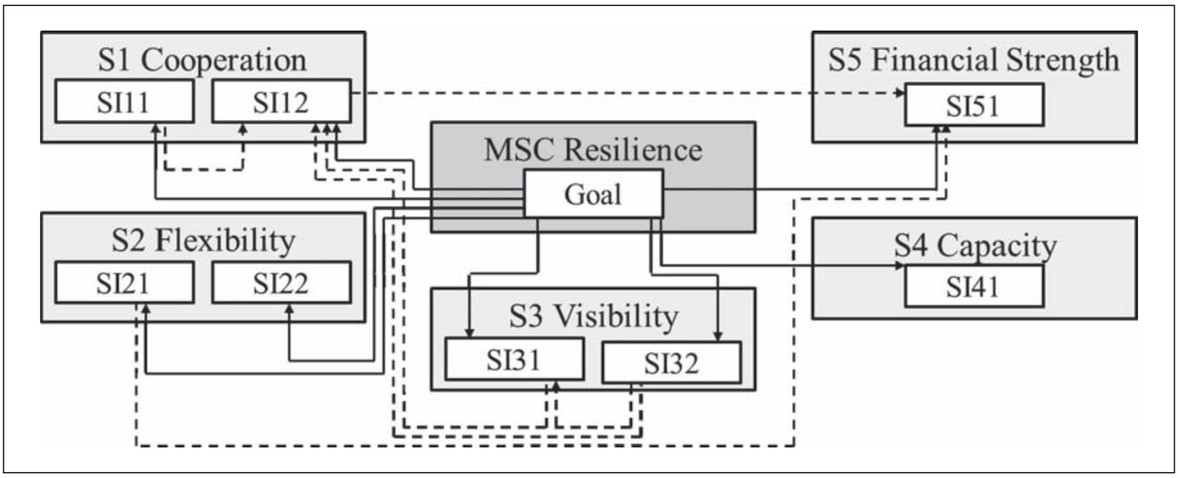

Figure 2 Model of the MSC resilience network

creating and evaluating a fuzzy network system of resilience indicators, which respects the ANP and FANP principles. This stage has three steps according to ANP methodology:

1) Model construction. When using the ANP method, it is possible to express not only hierarchical dependencies among indicators (see solid arrows in Figure 2) but non-hierarchical ones too (see dashed arrows in Figure 2).

2) Pairwise comparison matrices and local priority vectors. First, it is necessary to create and complete six matrices for the analysed network structure using the FANP approach described above. The local priority vectors of the resilience skills and indicators are obtained in this way. This part is computationally extensive, thus only results are shown in Table 1. Second, four alternatives are specified: Minimum, Threshold, Optimum, and Real. Values of these alternatives for each indicator are determined in Table 2 (for more details see [1]).

These alternatives are incorporated into the created network structure as a subnetwork of each indicator. Local priority vectors of the alternatives are calculated on the basis of pairwise comparison matrices using the deterministic values of the alternatives.

3) Supermatrix construction. This step was carried out using the SuperDecisions software. Global priority vectors of the resilience indicators and alternatives, shown in Tables 3 and 4, represent the final results.

The final stage of the developed methodology Interpretation of obtained results remained the same. The Threshold Alternative represents the lowest acceptable value and the Optimum represents a target resilience level based on the strategic plans of the MSC. From that point of view, it can be stated that the actual resilience of the investigated MSC (Real Alternative) is very close to the Threshold Alternative and thus very insufficient (see the column FANP in Table 4).

Table 1 **Local weights of skills and indicators**

Concerning MSC Resilience			Concerning S1 and S2	
S1	0,2528		SI11/SI21	0,5
S2	0,2578		SI12/SI22	0,5
S3	0,0725		With respect to S3	
S4	0,1520		SI31	0,2927
S5	0,3169		SI32	0,7073
With respect to S1			With respect to S3	
S1	0,5		S1	0,5663
S5	0,5		S3	0,4337

Table 2 **Description and values of measurable criteria**

Indicator	Name	Unit	Minimum	Threshold	Optimum	Real
SI11	Number of cooperating partners in the MSC	Number of enterprises weighted by the size of material flow	0	30	45	30
SI12	Investment in cooperation development in the MSC	Mil. € per year	0	10	30	3,33
SI21	Width of portfolio of the MSC	The number of groups in the classification of NACE	1	3	9	5
SI22	Alternative options to ensure production in the MSC	Percentage of own capacities	0	20	40	15
SI31	Number of enterprises sharing basic information in the MSC	Number of enterprises weighted by the size of material flow	0	30	45	20
SI32	Number of enterprises using an integrated ERP system in the MSC	Number of enterprises weighted by the size of material flow	0	30	45	15
SI41	Reserve capacity of the MSC	Percentage of own capacities	0	10	15	20
SI51	Creditworthiness index of the MSC	Kralicek´s Quick Test scale	5	3	1	2,75

Table 3 **Global weights of resilience indicators**

Indicator	AHP / %	FANP / %
SI11	12,11	7,25
SI12	12,11	20,22
SI21	9,16	5,48
SI22	9,16	5,48
SI31	2,38	2,86
SI32	7,15	4,29
SI41	13,84	8,29
SI51	34,09	46,13

Table 4 **Global weights of alternatives**

Alternative	AHP / %	FANP / %
Minimum	8,12	10,04
Threshold	45,97	40,59
Optimum	100	100
Real	49,33	41,6

To increase the MSC resilience it is necessary to focus on indicators and skills with the highest weight. From the column FANP in Table 3 it is obvious that the most important is to increase the Financial strength skill measured by the SI51 indicator. Its Real Value is lower than its Threshold one (see Table 2).

CONCLUSION

The presented experimental work has demonstrated that using the FANP approach is crucial for the developed methodology. If the AHP were to be used, the results would be significantly different. From the comparison of results in Table 4, it is obvious that the AHP gives a more optimistic evaluation of the MSC resilience than the FANP. It is caused by different weights acquired from using both approaches (see Table 3). The main reason is that the AHP is unable to take non-hierarchical dependencies among the resilience indicators into consideration (see Figure 2).

Acknowledgement

The work was supported by the specific university research of the Ministry of Education, Youth and Sports of the Czech Republic in VSB – Technical University of Ostrava No. SP2016/107 and by the grant No. GA 16-01298S of the Czech Science Foundation.

REFERENCES

[1] P. Wicher, R. Lenort, M. Čech, Measurement of Metallurgical Supply Chain Resilience - Case Study, Proceeding, METAL 2015: 24th International Conference on Metallurgy and Materials, Ostrava, 2015, TANGER, pp. 2125-2130.

[2] T. L. Saaty, L. G. Vargas, Decision Making with the Analytic Network Process: Economic, Political, Social and Technological Applications with Benefits, Opportunities, Costs and Risks, Springer, New York, 2013.

[3] T. L. Saaty, Fundamentals of the analytic network process—multiple networks with benefits, costs, opportunities and risks, Journal of Systems Science and Systems Engineering 13 (2004) 3, 348-379.

[4] T. L. Saaty, Fundamentals of the analytic network process—Dependence and feedback in decision-making with a single network, Journal of Systems Science and Systems Engineering 13 (2004) 2, 129-157.

[5] B. Wolfslehner, H. Vacik, M. J. Lexer, Application of the analytic network process in multi-criteria analysis of sustainable forest management, Forest Ecology and Management 207 (2005) 1, 157-170.

[6] Y. C. Tang, T. W. Lin, Application of the fuzzy analytic hierarchy process to the lead-free equipment selection decision, International Journal of Business and Systems Research 5 (2011) 1, 35-56.

[7] P. Srichetta, W. Thirachon, Applying Fuzzy Analytic Hierarchy Process to Evaluate and Select Product of Notebook Computers, International Journal of Modeling and Optimization 2 (2012) 2, 168-173.

[8] K. J. Zhu, Y. Jing, D. Y. Chang, A discussion on extent analysis method and applications of fuzzy AHP, European Journal of Operational Research 116 (1999) 2, 450-456.

[9] M. B. Ayhan, A Fuzzy AHP Approach for Supplier Selection Problem: A Case study in a Gearmotor Company, International Journal of Managing Value and Supply Chains 4 (2013) 3, 11-23.

[10] T. L. Saaty, Decision making with the analytic hierarchy process, International Journal of Services Sciences 1 (2008) 1, 83-98.

[11] M. Fiedler, J. Nedoma, J. Ramik, J. Rohn, K. Zimmermann, Linear Optimization Problems with Inexact Data, Springer, London, 2006.

Note: The responsible translator for English language is Ryan Scott (Mladá Boleslav, Czech Republic)