MEASUREMENT OF METALLURGICAL SUPPLY CHAIN RESILIENCE - CASE STUDY

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The paper presents an application of the methodology for resilience measuring of selected metallurgical supply chain. The methodology is based on the multi-criteria decision making method - Analytic Hierarchy Process (AHP). The basic steps of the methodology include: determination of analysed resilience skills, selection of measurable criteria, building a hierarchical system to determine the local and global weights, measurement and analysis of values of examined measurable criteria, the calculation of results based on the principles of AHP. The SuperDecisions software was used for the application. Strategic set of recommendations on the development of supply chain resilience for the investigated metallurgical supply chain is created based on acquired results.

Keywords: Metallurgical supply chain, supply chain resilience, Analytic Hierarchy Process.

1. INTRODUCTION

Today´s supply chains must face a wide spectrum of trends causing their disruption [1, 2, 3, 4, 5, 6]: globalization, outsourcing, centralization, IT-dependence, complex product and service, deficit of information, specialized factories, volatility of demand, technological innovations. The concept of supply chain resilience represents a way how to handle with these trends and disruptions. In the scholar literature, there is a relatively large number of authors dealing with the definitions and strategic concept of building resilience. The main authors in this area include Christopher and Peck [7], Fiksel [8] or Sheffi and Rice [9].

On the other hand, at introducing the concept of resilience to the real-operation conditions systematic shortcomings were found, which have made the task more difficult. One of the first problems is the lack of a methodology for measuring and assessing degree of resilience in the supply chain, which would be based on quantitative approaches and enable analysing the initial and the and required state of the supply chain resilience.

In spite of gradually emerging efforts aimed at quantitative analysis and measurement of resilience (e.g. Bukowski and Feliks use fuzzy sets [10] for measurements; Shuai applies the theory of elasticity of biological cells [11]), the majority of proposed systems are qualitative in nature. A comprehensive assessment tool for measuring resilience SCRAM™ (Supply Chain Resilience Assessment and Management) created by Pettit can serve as a typical example based on a qualitative approach [12]. The authors of the article have found this approach flawed. Major shortcomings include: high rigidity and subjectivity of the assessment. The elimination of these shortcomings has been the reason for creating a new, comprehensive methodology for assessing and measuring the resilience of the supply chain, a draft of which is the main focus of previously published articles [13, 14, 15, 16]. The aim of this article is the application and verification of parts of the methodologies dealing with measuring the resilience of the supply chain on a case study of the global metallurgical supply chain.

2. DEFINITION OF METALLURGICAL SUPPLY CHAIN

To obtain relevant results the case study has been working with a model of a global metallurgical supply chain, which only includes its key elements in terms of its overall resilience. The structure of the supply chain includes 5 mines (suppliers of raw materials), 15 production plants, 50 wholesalers selling steel and 500 direct consumers. The supply chain spans four continents and operates in a relatively wide range of fields of metallurgical production. A large part of the analysed supply chain has a holding structure. The holding owns a majority of the production plants and suppliers of raw materials (ore and coal mines). With this structure the supplier part of the chain features a large degree of mutual interdependence and financial interconnectedness.

3. MEASUREMENT OF SUPPLY CHAIN RESILIENCE

The methodology proposed by the authors respects the specifics of the analysed supply chain and provides accurate and realistic results that may well support management decisions. On the part of the supply chain this approach requires its creative application or modification. This requires participation of the management of involved companies and other experts. Main parts of the measurement methodology include:

- Analysis of resilience skills of the metallurgical supply chain.
- Draft hierarchical system of indicators of the metallurgical supply chain.
- Creating a hierarchical system of indicators.
- Evaluation of the resilience of the metallurgical supply chain.
- Obtaining and interpretation of final results.

3.1. Analysis of the resilience skills of the metallurgical supply chain

When selecting the major groups of resilience skills that will be included in the analysis two basic ideas have been respected:

- The starting point will be the skills identified on the basis of theoretical research.
- Experience and views of the management of the supply chain shall be respected.

On a basis of literature review the original theoretical list of the most important skills, including criteria has been adjusted: cooperation, flexibility, visibility, capacity and adaptability. The ability of financial strength has been added as the supply chain management has indicated it as one of the key skills for the development of a metallurgical supply chain. On the other hand, adaptability has been considered relatively insignificant and therefore has been removed.

Also other metallurgical supply chains as well as supply chains from related areas of the industry may theoretically adopt this list for the needs of measurement of resilience, but it is always recommended to examine a comprehensive list of skills and identify those that are most suitable for a particular supply chain. This procedure guarantees higher information value and usefulness of acquired results. In addition, it we do not recommend to select the full set of resilience skills since such a measurement would be very difficult, while its complexity would result in a loss of clarity and insights for the management. A similar approach has to be adopted in relation to the implementation of the next step, i.e. the determination of specific measurable indicators of individual skills that can be decomposed at various levels of detail. It turns out that for the high-quality information value it is not desirable to measure a large number of indicators or to break down the indicators too much in detail.

3.2. Draft hierarchical system of indicators of metallurgical supply chain

Again, partial indicators of individual skills are determined with regard to the implementation in the analysed metallurgical supply chain. Generally, it is desirable to create or modify the system according to the specifics of the supply chain, so as to reflect the specific needs that are placed on it. Additionally, the theoretical basis of indicators created by various authors is extremely heterogeneous and without further adjustments inapplicable, since at the creation of individual indicators for each skill authors did not create a system with respect to the other surveyed skills and the resilience as such, but they only focused on the analysis and measurement of individual partial skills instead. Due to this fact only inconsistent lists of partial skills and characteristics have been created so far, whereas each pursues a different objective. Some of the indicators may include the number of enterprises as a parameter that determines what part of the supply chain meets the measured or evaluated criterion. This issue itself has several solutions. The simplest approach consists in a simple consideration when every enterprises in the supply chain is considered equivalent. However, this consideration is insufficient for practical application, as individual enterprises have got varying importance for the functioning of the supply chain. For a better grasp of this phenomenon, for example weights can be assigned to individual enterprises of the chain – these weights would represent the size of the material or financial flow. A complete analysis of partial indicators, including a detailed description of the principle of their measurement can be found in the thesis of the lead author [17]. For the final list of indicators see the Table 1.

Table 1 List of indicators of resilience skills utilized at measurement

Resilience skill	Indicator – indication (unit)
Cooperation	Number of cooperating partners in the supply chain - U_{D11} (number of enterprises weighted by the size of material flow)
	Investment in cooperation development - U_{D12} (mil. €·year $^{-1}$)
Flexibility	Width of portfolio of supply chain - U_{D21} (the number of groups in the classification of economic activities NACE)
	Alternative options to ensure production in the supply chain - U_{D22} (% of own capacities)
Visibility	Weighted number of enterprises sharing basic information from the area of planning and supply chain management - U_{D31} (number of enterprises with the weighted size of material flows)
	Weighted number of enterprises using an integrated system for supply chain planning and management - U_{D32} (number of enterprises weighted by the size of material flow)
Capacity	Reserve capacity of the supply chain - U_{D41} (% of own capacities)
Financial strength	Creditworthiness index - such as Králíček´s Quick Test - U_{D51} (trademark)

3.3. Creating a hierarchical system of indicators

The hierarchical system of indicators for assessing the resilience of the analysed metallurgical supply chain has got 4 levels. The first level is represented by an objective. The second level contains the skills of resilience, the third level includes specific measurable indicators and the fourth level represents various examined options. The entire system is shown in the Figure 1.

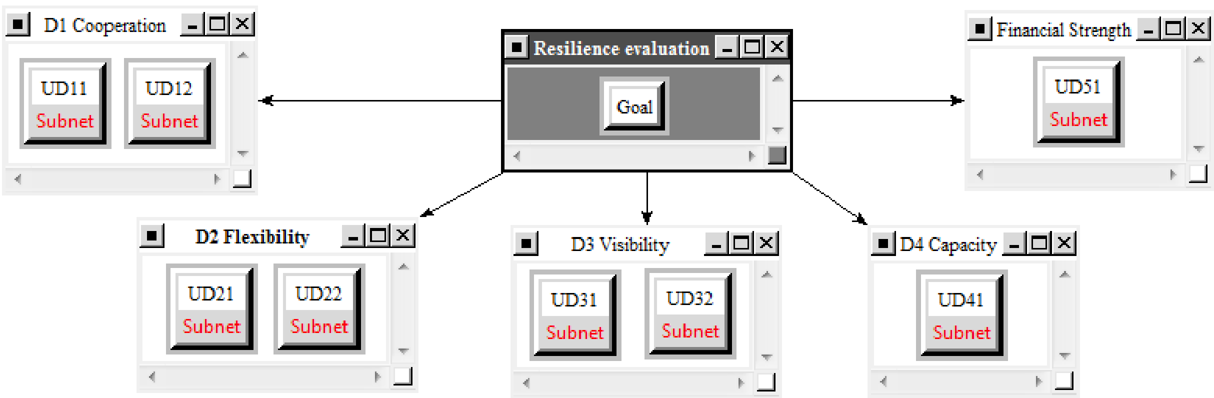

Fig. 1 The hierarchical system of indicators for assessing the resilience of the investigated metallurgical supply chain in the SuperDecisions software

The figure has been created by the SuperDecisions software, which is the leading software for solving problems using AHP method. The transfer of a task to the software environment involves editing individual clusters and nodes of the decision-making system. The variations are in a given case represented by sub-networks that allow entry of theoretical and real values of the respective measurable indicator. When applying the AHP method individual nodes or measurable indicators are independent of each other. This approach allows a simple understanding and application of the method.

3.4. Assessment of the resilience of the metallurgical supply chain

Assessment of the resilience consists of three basic steps:

Determining weights of indicators

The process is based on creation of the file of matrices according to the Saaty method of the pairwise comparison. The values needed to determine the weights of individual indicators were determined under the participation of the supply chain management. The calculation of weights was made in the SuperDecisions software. An important step is to check the consistency of the pairwise comparison matrices. With this check, it is possible to verify the correctness of the internal logic of entering values. For the analysed hierarchical structure it is necessary to create and complete 4 matrices and then to use the partial results to calculate the global weighs of each measurable indicator (see Table 2).

Table 2 Global weights of measurable indicators

Indicator	Weight of indicator (%)	Indicator	Weight of indicator (%)
U_{D11}	12.11	U_{D31}	2.38
U_{D12}	12.11	U_{D32}	7.15
U_{D21}	9.16	U_{D41}	13.84
U_{D22}	9.16	U_{D51}	34.09

Determining input values

The process allows determining the minimum, threshold, optimal, and real values of individual measurable indicators. The above values have the following characteristics:

- Minimum - the lowest possible value of the indicator.
- Threshold - the lowest acceptable value of the indicator based on the strategic plans of the supply chain.
- Optimal - the target value of the given indicator also determined based on the strategic objectives of the supply chain.
- Real - value of the indicator achieved during the evaluation of the resilience of the supply chain.

For the calculation of indicators related to numbers of enterprises in various parts of the chain, the following weighting system has been chosen. Enterprises of the same category are equivalent, and the weight of the company is related to the flow of materials in the amount of 15 million tonnes. The result of this simplified reasoning is as follows:

- Each mine has a weight of 3 (15 mil. tonnes / 5 mines).
- Each plant has a weight of 1 (15 mil. tonnes / 15 production plants).
- Each direct consumer has a weight of 0.015 (7.5 mil. tonnes / 500 direct consumers).
- Every wholesale selling steel has a weight of 0.15 (7.5 mil. tonnes / 50 steel wholesalers).

The total sum of the weighted number of enterprises in the supply chain is 45.

The complete analysis of determining input values of individual indicators, including a detailed description of the principles is a part of the thesis of the lead author [17]. The final output of this part can be found in Table 3.

Table 3 Input values of measurable indicators

Indicator	Minimum value	Threshold value	Optimum value	Real value
U_{D11}	0	30	45	30
U_{D12}	0	10	30	3.33
U_{D21}	1	3	9	5
U_{D22}	0	20	40	15
U_{D31}	0	30	45	20
U_{D32}	0	30	45	15
U_{D41}	0	10	15	20
U_{D51}	5	3	1	2.75

Obtaining and interpretation of final results

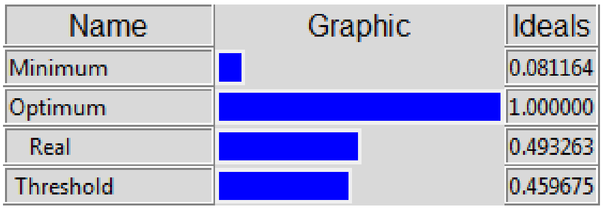

Fig. 2 Results of measurements of resilience of the investigated metallurgical supply chain

The results of resilience evaluation using the SuperDecisions software can be obtained using the "Synthesize Whole Model" (see Fig. 2). The calculation in the software is based on the principle of calculating the limit super-matrix. The interpretation of the obtained results is a part of the conclusion.

CONCLUSION

The result consists in obtaining the minimum, threshold, optimal and real value of the overall resilience of the examined supply chain. Generally, it can be stated that if the real value of resilience is in the interval between the minimum and the threshold level the supply chain has insufficient resilience and its increase should be prioritized in its future strategic decisions. Otherwise it can expect major performance problems at future occurrence of potential disruptions. The interval between the threshold and optimal value can be divided into three identical intervals that symbolize the low, medium and high resilience. Since the upper limit for assessing the resilience is the optimum value the supply chain management should strive to achieve this target. When exceeding the optimum value the chain is rated as highly resilient, but this fact might also have negative effects. Especially if this is associated with high investment and operating costs and the supply chain management becomes cost ineffective. The resilience value for the investigated metallurgical supply chain is at the lower limit of the low resilience and is thus at the insufficient level. Strategic decisions in supply chain management should therefore promote and further develop this skill so that it gradually increases.

Another result of the application of the methodology is the recommendation as to which skills of resilience should be prioritized. At first, it is necessary to analyse, which of these skills are important for the development of resilience, and which of them at the same time are current weak points for the supply chain. In case of the examined supply chain the most important skills include financial strength, capacity and cooperation. Real values of indicators for measuring the skills of cooperation and financial strength are far too remote from the optimum. Especially investments in the development of cooperation are smaller than the required threshold limit. For this reason, these two skills should be prioritized at resilience building. The real value of the capacity indicator is above its optimum level, and can therefore be concluded that the given skill is at a high level in the investigated supply chain. This fact raises the question of supply chain efficiency in the given field and in future strategic decisions it is also possible to concentrate on optimizing this indicator.

In future research, the authors want to focus on obtaining concrete results also using the method of ANP and then incorporate the Fuzzy logic in the proposed methodology.

ACKNOWLEDGEMENTS

The work was supported by the specific university research of Ministry of Education, Youth and Sports of the Czech Republic No. SP2015/112.

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