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FUZZY APPROACH TO SUPPLY CHAIN MANAGEMENT

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Abstract

During recent years, the supply chain performance management has become a key strategic consideration. Many manufacturers seek to collaborate with their suppliers and customers in order to upgrade their competitiveness and management performance. Because of complexity, uncertainty and vagueness inherent in supply chains, performance measurement using fuzzy approach was also identified as a new research direction. The main aim of the paper is focused on evaluation of logistic dimensions (sets of logistic indicators) in supply chain, where the uncertainty arises from the inability to perform adequate measurement, and deals with application of fuzzy approach, that provides a formal method for modeling imprecise, vagueness or incomplete relationships inherent in supply chains. Gathered data from questionnaires are analyzed by cluster analysis. Afterwards fuzzy methods are used evaluations of basic five dimensions, which contain several numbers of logistic indicators. The new methodology adopted from Soyer, Kabak, Asan (2007) research based on the intersection of fuzzy sets and fuzzy entropy method has been applied to evaluations in a case study. Results are afterwards modified by a applying of different membership functions, and changes of dimensions measures are analyzed. Finally supply chain modifying by adding new companies with capability of bind to supply chain are examined. New results of evaluation are compared according to new companies' membership to different clusters.

Keywords: Supply Chain, Fuzzy Sets, Fuzzy Measures, Fuzzy Entropy.

JEL Classification: C21, L14, L60

1 Introduction

As globalization took hold and supply chains became longer and more complex, a number of firms realized the potentials of supply chain in day-to-day operations management. However, many relationships of the underlying system and the complexity of interactions within prevent from gather comprehensive and complete information's. Competition and cooperation in an industry is rooted in its underlying economic structure and goes well beyond the behavior of current firm's attention. Companies often lack the insight for the development of effective performance measures needed to achieve a fully integrated supply chain management due to lack of a strategic approach and decisions that are usually complex and unstructured. During recent years, while there are still supply chains in which the parties collaborate, there are also many other supply chains in which this is not the case (Gattorna, 2009). Building on the closeness and long-term relationships between buyers and suppliers is going to critical success factor to establish the supply chain system.

Many attempts have been made on supply chain performance measurement using conventional approaches. Most of these approaches have, to a great extent contributed in performance measurement of a supply chain, but there are still rooms for improvement as highlighted in the ensuing lines (Olugu, Wong, 2009). Because of a large amount of data and inability to handle stochasticity, ambiguity and inconciseness inherent in supply chain performance measurement (with conventional approaches and methods), the application of a more robust and computational capable approach in the form of fuzzy operations in the measurement have led. The supply chain performance measurement using fuzzy approach was also identified as a new research direction in measuring the uncertainty, ambiguity and vagueness surrounding supply chain performance measurement. Fuzzy set theory provides a formal method for modeling complex systems, because of ability to represent imprecise, incomplete or approximate relationships and models. In this paper we are proposed methodology how to evaluate supply chain with fuzzy method based on the intersection of fuzzy sets and fuzzy entropy.

The paper is divided into following chapters: Chapter 1 (Introduction) that is contained short introduction to research topic. In Chapter 2 (Literary Overview), the literary overview for fuzzy approach in supply chain is introduced and described of fuzzy logic theory, supply chain management, entropy concept used in the paper are given. The methodology and main aim of cluster analysis, fuzzy entropy method is defined in Chapter 3 (Methodology). To address practical issues, an application of the used theoretical knowledge and methodology is elucidate and demonstrate in Chapter 4 (Results). Finally, Chapter 5 (Conclusions) summarizes the contributions of the paper.

2 Literary overview

Literary overview is divided into three parts: fuzzy logic and fuzzy sets, supply chain management and the concept of entropy. Special emphasis is placed on the application of fuzzy logic in supply chain performance measurement. This is because fuzzy logic operation has a lot of benefits which are reflected in the fuzzy aspect of this paper.

2.1 Fuzzy logic and fuzzy sets

Fuzzy logic, a discipline of mathematics, became highly popular at the late 1980s and early 1990s thanks to the rather fascinating applications it found in Japan and later on in also other countries (Novák, 2000). Fuzzy theory is becoming more and more a core paradigm of research. A number of basic concepts and methods already introduced in the early stages of the theory have become standard in the application of fuzzy-theoretic tools (Sadegh-Zadeh, 1999). Success of the discipline can be primarily attributed to its capability of allowing for inaccuracies and using a relatively simple method to process the meanings of words found in natural language, one of the most important factors of human life. That is why the fuzzy logic has spread into a host of human activities and new possibilities of application have been constantly emerging (Novák, 2000).

A feature typical of the natural language, to be in no way circumvented, is the vagueness of its semantics. That is why a description delivered in the natural language cannot be translated directly into mathematical formulas. According to Zadeh (1999) there are widely accepted assumption – much of the information on which human decisions are based is possibilistic rather than probabilistic in nature. In particular, the intrinsic fuzziness of natural languages-which is a logical consequence of the necessity to express information in a summarized form-is, in the main, possibilistic in origin (Zadeh, 1999). To be able to apply the classical mathematics, we have to have the task described in precise figures. This method, however, can return unsatisfactory results, as precise figures often do not properly reflect the reality. Fuzzy logic offers a solution to the problem, since it allows us to model the meanings of words used in the natural language (Novák, 2000).

Fuzzy logic is, however, not fuzzy. Basically, fuzzy logic is a precise logic of imprecision and approximate reasoning (Zadeh, 1975). More specifically, fuzzy logic may be viewed as an attempt at formalization/mechanization of two remarkable human capabilities. First, the capability to converse, reason and make rational decisions in an environment of imprecision, uncertainty, incompleteness of information, conflicting information, partiality of truth and partiality of possibility; in short, in an environment of imperfect information. And second, the capability to perform a wide variety of physical and mental tasks without any measurements and any computations (Zadeh, 2008).

The fuzzy logic is workable just because it employs somewhat vaguely characterized expert knowledge, i.e. the very opposite to what has always been required - higher accuracy. Here we encounter an actual contradiction, whose solution does not exist, namely the relation between the relevance of a piece of information and its accuracy. The principle, called by Zadeh the principle of incompatibility, can be characterized as follows (Novák, 2000): whoever wants to describe reality will have to decide between more relevant but less accurate information and more accurate but less relevant information. Increasing the accuracy, we will reach a point where the accuracy and the relevance become mutually exclusive features.

Reality has almost always an aspect of randomness and an aspect of vagueness. The mathematical apparatus of the theory of fuzzy sets provides a natural basis for the theory of possibility, playing a role which is similar to that of measure theory in relation to the theory of probability (Zadeh, 1999). Vagueness can be modeled using the theory of fuzzy sets, while the randomness is modeled with reliance on the probability theory and possibly other theories like the theory of possibility, different rates of veracity, etc. (Novák, 2000). Viewed in this perspective, a fuzzy restriction may be interpreted as a possibility distribution, with its membership function playing the role of a possibility distribution function, and a fuzzy variable is associated with a possibility distribution in much the same manner as a random variable is associated with a probability distribution (Zadeh, 1999).

Key concept is a fuzzy set of objects and a degree to which an object belongs to the set, i.e. the degree of membership (truth). Fuzzy sets are to avoiding the sharp separation of conventional sets into two values - complete membership or complete nonmembership. Instead, fuzzy sets can handle partial membership. So in fuzzy sets we have to determine to what degree or extend an element is a member of this fuzzy set (Michels, Klawonn, Kruse, Nürnberger, 2006): A fuzzy subset or simply a fuzzy set μ of a set X (the universe of discourse) is a mapping $\mu: X \to [0, 1]$, which assigns to each element $x \in X$ a degree of membership $\mu(x)$ to the fuzzy set μ. The set of all fuzzy sets of X is denoted by $\mathcal{F}(X)$. A conventional set $M \subseteq X$ can be viewed as a special fuzzy set by identifying it with its characteristic function or indicator function:

$$I_M : X \to \{0,1\}, \qquad x \mapsto \begin{cases} 1, & \text{if } x \in M \\ 0, & \text{else} \end{cases} \tag{1}$$

Seen in this way, fuzzy sets can be considered as generalized a characteristic functions (Michels, Klawonn, Kruse, Nürnberger, 2006) that is sometimes called as “membership function”. For simplicity, the membership function is denoted by $A(x)$ rather than μ_A(x). The main operations of fuzzy sets: given two fuzzy sets $A(x)$, $B(x)$, the union, intersection and complement of $A(x)$ and $B(x)$ are (Medasani, Kim, Krishnapuram, 1998):

$$\begin{gathered}(A \cup B)(x) = \max\left[A(x), B(x)\right], \\ (A \cap B)(x) = \min\left[A(x), B(x)\right], \\ \overline{A} = \left[1 - A(x)\right]\end{gathered} \tag{2}$$

It can be seen that a membership function of fuzzy sets can be interpreted in two ways: one probabilistic, the other structural, for more see (Medasani, Kim, Krishnapuram, 1998). Fuzzy set (concept), it may probably be described by different types of membership functions (triangular, trapezoidal, Gaussian, etc.), as long as their structures are the same, they will represent the fuzzy sets with the same property. They seem to be relevant in three types of information-driven tasks where graded membership plays a role: classification and data analysis, decision-making problems, and approximate reasoning. The three basic tasks that have been investigated by many researchers actually correspond and/or exploit three semantics of the membership grades, respectively, in terms of similarity, preference and uncertainty (Dubois, Prade, 1997).

Workable applications of fuzzy logic built in industrial products appeared late in the 1980s, particularly in a range of home appliances. Engineering applications of fuzzy logic utilize this continuous transition in subset membership to transform a problem from crisp numeric to fuzzy linguistic domains. Instead of operating with numeric values of variables and using mathematical functions to describe relationships, fuzzy logic uses common everyday language to describe variables and uses fuzzy linguistic rules to define relationships. This is particularly advantageous in grinding where some variables, such as grit size, wheel grade, and the effect of coolant, have no precise numeric values (Ali, Zhang, 1999).

To give an example, the automatic washer is fitted with a sensor capable of distinguishing the sort of clothes and how they are soiled, and choose accordingly one of about 600 programs available. A "fuzzy" vacuum cleaner can likewise respond to the type of flooring and how much it is dusted and set the suction intensity. Moreover, fuzzy logic is used for automated control of subway in the Japanese city of Sendai; to control a group of fast lifts in a skyscraper; to operate a variety of soil-moving machines (excavators, forest machinery) and in a host of other applications (Novák, 2000).

2.2 Supply chain management

Supply chain is a network of firms involved in different processes and complex activities such as planning, design, distribution, selling, support, usage and recycling of the product through upstream and downstream linkages, to produce value in the form of products and services delivered to ultimate customers (Kanda, Deshmukh, Arshinder, 2007).

Over the past years, most of existing supply chain management models are solely optimized by only one objective for a single firm, and lack the consideration of strategic partnership (Min, Zhou, 2002). Chen, Larbani, Liu (2010) and others describes in context of this case basic supply chain problem: if an enterprise is requested to provide adequate commodities to its customers on time, it should be able to design its own appropriate purchase/production/ transportation network at the lowest-cost level in time.

Evaluating strategic behavior of supply chain partners as a new way of doing business with a growing number of firms connected to network is going important. It is necessary to avoid focused attention on separating business functions to form a supply chain and aim one´s effort to the cooperation of controlling, planning and other business functions. Strategic partnership lie in common supply chain strategy design, information sharing and balanced objectives and business functions set.

Supply chain management according to Harvani, Helms, Sarki (2005) also includes the coordination and management of complex network of activities involved in the development of finished product to the end consumer. The supply chain members can coordinate strategy and business functions by sharing information regarding demand, orders, inventory, storage, etc. The value of information sharing increases as the service level at the supplier, supplier-holding costs, demand variability and offset time increase, and as the length or the order cycle decreases (Karaesmen, Buzacott, Dallery, 2002). It´s not surprising that advanced commitments from downstream customers or timely demand information can be a substitute for lead time and inventory. Decisions and guarantee of optimal providing these advantages are made under uncertainty and uncompleted information’s.

Wilding (1998) provides a useful framework named “Supply chain complexity triangle” for understanding the generation of uncertainty within supply chains. It describes the interaction of deterministic chaos, parallel interactions and demand amplification. The three interacting phenomena result in complex demand patterns with limited forecast horizons. The uncertainty results in additional costs being experienced by those in the supply chain. There is also uncertainty inherent in supply chain decision making processes, control systems, dynamic demand amplification, long term planning, etc.

Different view described supply chains as networks, constructions made of boxes and arrows; the former identify the components and the latter describe flows of various nature. Flows can be divided in four classes: a) inputs from outside the system; b) flows between components; c) exports to other systems; and d) dissipation and losses (Zhang, Xu, 2009).

Euler, a Swiss born mathematician who spent his career in Berlin and St. Petersburg, had an extraordinary influence on all areas of mathematics, physics, and engineering (Barabasi, 2002). Many consider his proof to be the first theorem in the now highly developed field of discrete mathematics known as graph theory. He set simple and elegant insight that many problems should be viewed as a graph, a collection of nodes connected by links. According to Barabasi (2002), in many ways Euler´s result symbolizes an important message: “The construction and structure o graphs or networks is the key to understanding the complex world around us. Small changes in the topology, affecting only a few of the nodes or links, can open up hidden doors, allowing new possibilities to emerge.” Yet a proper understanding of most networks requires that we characterize the assembly process that generated them (Barabasi, 2005).

Supply chains performance depends on connections of all nodes (companies) and overall network (supply chain) topology. There are two types of interactions in supply chains: a) interactions that occur between each echelon in the supply chain i.e. a single customer and a supplier; b) interactions that occur between different channels of the same tier in a supply network. Relationships as a links in supply chains have different weights that reflect power of certain company (Wilding, 1998). Logistics networks and supply chains (comprising multiple organizations in 3-D arrays) are largely driven by people power, either in customer or employee capacities. Systems are critical area because these deliver information to people for decision-making, such a s “make or buy or act” in some way in the enterprise (Gattorna, 2006).

Building more responsive supply chains means building more responsive enterprises overall, because service means different things to different people, and customers do not split hairs between functions inside the enterprise (Gattorna, 2006). There is according to Gattorna (2009) only one fail-safe frame of reference when designing and operating contemporary supply chains –the customer and the customer situation. To fully understand the behavioural structure of marketplace it is possible to “reverse engineer” the configuration of supply chains back through the organization to actual operations on the ground and the strategy too.

Logistics (supply chain) strategy is the set of guiding principles, driving forces and ingrained attitudes that help to coordinate goals, plans and policies, and which are reinforced through conscious and subconscious behaviour within and between partners across a network. It has according to Cohen and Roussel (2004) five fundamental building blocks: operations strategy, channel strategy, outsourcing strategy, customer service strategy, and asset network. Management strategies for the supply chain require a more holistic look at the links, and an understanding that organizational boundaries easily create barriers to flow (Harrison, van Hoek, 2008).

The essence of formulating competitive strategy generally is relating a company to its environment. Although the relevant environment according to Porter (1980) is very broad, encompassing social as well as economic forces, the key aspect of the firm’s environment is the industry or industries in which it competes. The rules of competition are embodied in competitive forces, which strongly influence the firm position in industry. Two of five of these forces are focused on buyers and suppliers as a part of supplier-customers relationships.

While the supply chains are interconnected networks of companies, they are clustered by common relationships, strategies or objectives. As networks are clustered, nodes that are linked only to nodes in their cluster could have a central role in that subculture or genre. Without links connecting them to the outside world, they can be quite far from nodes in other clusters. The truly central position in networks is reserved for those nodes that are simultaneously part of many large clusters (Barabasi, 2002). The real supply chain centers are denoted by graphs theory as hubs. Hubs are also special. They dominate the structure of all network in which they are present, making them look like small world. Indeed, with links to an unusually large number of nodes, hubs create short paths between any two nodes in the system (Barabasi, 2002). Power of buyers and suppliers should be viewed as weights (power) of connection (links) and they are determined importance of companies (nodes) in certain supply chain network.

With idea of bargaining power of suppliers and buyers concern Porter (1980) in “forces governing competition model in an industry” that contain five basic competitive forces shown in Fig. 1. The five competitive forces – threat (barriers) of entry, threat of substitution, bargaining power of buyers, bargaining power of suppliers, and rivalry among current competitors – reflect the fact that competition in an industry goes well beyond the established players. A number of important economic and technical characteristics of an industry are however critical to the strength of each competitive force (Porter, 1980).

Fig. 1 Forces governing competition in an industry

Source: Porter (1979)

The power of each important supplier or buyer group depends on a number of characteristics of its market situation and on the relative importance of its sales or purchases to the industry compared with its overall business (Porter, 1979). The power could be exert by powerful firms on participants in an industry by raising prices or reducing the quality of purchased goods and services. Table 1 depicts determinants of supplier and buyer power.

Table 1 Determinants of supplier and buyer power

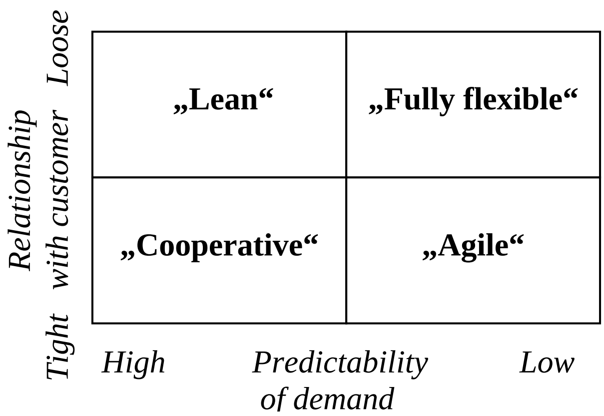
Determinants of Supplier Power
Differentiation of inputs
Switching costs of suppliers and firms in the industry
Presence of substitute inputs
Supplier concentration
Threat of integration by firms in the industry
Cost relative to total purchases in the industry
Impact of inputs on cost or differentia-tion
Importance of volume to supplier

Determinants of Buyer Power	
Bargaining Leverage	*Price sensitivity*
Buyer concentration vs. firm concentration	Price / total purchases
Pull-through	Product differences
Buyer volume	Brand identity
Buyer switching costs relative to firm or costs	Impact on quality / performance
Buyer information	Buyer profits
Ability to backward integrate	Decision makers´ incentives
Substitute products	

Source: Porter (1985)

Determinants of supplier power represent more and less classic economic characteristic such a differentiation and substitution of inputs, cost switching (or barrier entry), and concentration or integration of firms (opposite to number of independent firms in the industry). Most of sources of buyer power can be attributed to consumers as a group as well as to industrial and commercial buyers; only a modification of the frame of reference is necessary (Porter, 1979). Consumers tend to be more price sensitive, to the contrary industrial buyers power is rather characterized by bargaining leverage. The buying power of retailers is determined by the same rules, with one important addition. Retailers can gain significant bargaining power over manufacturers when they can influence consumers´ purchasing decisions (Porter, 1979).

Fig. 2 Four generic types of supply chains



Source: adopted from (Fiala, 2009), (Husdal, 2009)

Because there is always more than one type of dominant buying behaviour evident in any product/service-market situation, it follows that there is likely to be more than one type of supply chain, which can coexist in parallel to provide different supply experiences for customers in the same market. Indeed, there are consistently found empirical evidence to suggest three to four generic types of supply chains (Fig. 2), and/or variations of these, in different mixes, depending on the product, service or country.

Briefly, these are described as follows (Gattorna, 2009):

a) Continuous replenishment supply chains to service the “collaborative” segment where relationships matter most. The focus is clearly on service reliability and retention of the relationship over the long term. Here we are measuring such factors as: length of customer relationships; the degree of information being shared both ways; and the percentage that we, as a supplier, represent of a particular customer´s spend in a particular product category.
b) Lean supply chains to service the “efficiency” segment where the focus is on efficiency and lowest Cost-to-Serve. In this type of supply chain we are bent on delivering a low-cost predictable service to customers who otherwise don´t care for extras. In terms of measures, those that come to the fore are forecast accuracy, Delivery-In-Full-On-Time (DIFOT); cost per unit; and selected productivity ratios.
c) Agile supply chains to service the “demanding” segment where quick response is paramount. The emphasis in this type of supply chain moves from reliability to time sensitivity. This is the world or unpredictability, and surviving and thriving requires wholly different capabilities. It is more a case of optimizing resources than maximizing utilization, because, by definition, servicing customers in this mode means that we need to design in redundancy, and that costs money, which customers must be prepared to pay for at some point. We measure time to respond and we measure the capacity of the supply chain at vital points along the pathway to our customers.
d) Fully flexible supply chains to service the “innovative solutions seeking” segment where accommodate customers needs is crucial. This is a “catch-all” supply chain configuration that uses a high degree of human intervention, and potentially any and all systems as required, to produce an innovative solution in quick time for the customer, who at this stage doesn´t care about the price. It means that uses whatever it takes to get a satisfactory result for the customer, opportunistically respond, and the technology can be sophisticated or basic. Measures are focus on fast, creative solutions.

There are many recent studies and application of fuzzy logic in supply chain management. Determination the order quantities for inventory in the supply chain with all facilities in a serial connection described Petrovic's fuzzy model (Petrovic, Roy, Petrovic, 1999), that give an acceptable service level of the supply chain at reasonable total cost. In paper has been various simulation tests carried out to assess particularly the effects of uncertain external supply on the supply chain service level.

Carrera, Mayorga (2008) provide an application of fuzzy set theory in supplier selection for new product development. Fuzzy Inference System is proposed there as an alternative approach to handle effectively the impreciseness and uncertainty. Selected variables in study are Technological Level, Economical Situation, Production Capacity, Market Share, Quality Level, Delivery Rate, Cost Reduction, Part Quotation, Investment Cost, and Project Time. Some of similar indicators are selected in our study.

Study of fuzzy multiple attribute decision making (FMADM) method based on the fuzzy linguistic quantifier proposes Chang (2006). An attempt is made to ensure that the evaluation results satisfy the current product competition strategies, and also improve the effectiveness and efficiency of the entire supply chain. Green supply chain (GSC) strategy ranking model is used by Chen, Ma (2009) to integrate the fuzzy attribute values by the HWA operator that is applied to transform the fuzzy decision matrices regarding attribute values into a complex decision matrix. After that MDEA method allows a ranking of the efficient units while evaluating the relative efficiency of decision making units. Final model propose ranking of GSC strategies and selecting the optimal strategy under the attribute weight information

Special fuzzy decision methodology develops Wang, Shu (2005), who provides an alternative framework to handle supply chain uncertainties and to determine supply chain inventory strategies. A fuzzy model based on possibility theory allows decision makers to express their risk attitudes and to analyze the trade-off between customer service level and inventory investment in the supply chain. Many others studies of fuzzy logic in supply chains are published in last few years.

Fuzzy method for solving the problem of risk factor identification in supply chain based on experts judgment is proposed by Lie, Xie (2009). Linguistic interval judgment information is used for describing the degree of direct influence between risk factors occurred in supply chains and their ranking and classing.

2.3 The concept of entropy

The term entropy introduce Rudolf Clasius, a German physicist, who formulated the second law of thermodynamics in 1865 by conjecturing that matter must have a previously unrecognized property which he called entropy and observation led him to formulate the second law as: the entropy of the universe tends to a maximum (Shuiabi, Thomson, Bhuiyan, 2005).

The Shannon entropy is a measure of uncertainty in information formulated in terms of probability theory. Shannon in Wang, Lee (2009) developed three properties for a measure of information in a communication stream. Shannon, Weaver (1947) proposed definition of information entropy of C_j based e.g. on Roberts, Lattin (1991), Wang, Lee (2009) research as shown in equation:

$$E(C_j) = -k \sum_{i=1}^{n} p_{ji} \ln(p_{ij}) \tag{3}$$

where $k = 1 / \ln(n)$ is a positive value which guarantees that $0 \le E\ (p_1, \ldots, p_n) \le 1$. Greater $E(C_j)$ value implies less information contained in Cj, or smaller variations among p_{ij}s. As all normalised performance ratings p_{ij} are the same, i.e. C_j has zero variations, $E(C_j)$ achieves its maximum of 1 (Tsuen-Ho, Ling-Zhong, 2006).

De Luca and Termini (1972) introduced the axiom construction of fuzzy set entropy and referred to Shannon's probability entropy as a special case in special circumstances. The upshot is that entropy equals fuzziness, and entropy equals information (Kosko, 1986). Measures of fuzzy entropy in contrast to fuzzy measures indicate the degree of fuzziness of a fuzzy set. The entropy of a fuzzy set is a measure of the fuzziness of a fuzzy set (Hung, Yang, 2006). De Luca, Termini are used Shannon´s function, and they defined a measure that became largest at the grade of membership of 0,5 (Suzuki, Kodama, Furuhashi, Tsutsui, 2001). Therefore, entropy is zero at the two Boolean states 0 and 1, and is unity at the intermediate, completely fuzzy state, 0,5. Clearly, the more deterministic information sharing system, the more valid they are.

Because the measure of entropy is a result of geometric interpretation of fuzzy sets, there are many methods how to obtain it. Yager (1979) give method to view the degree of fuzziness (fuzzy entropy) in terms of a lack of distinction between the fuzzy set and its complement. Another way investigated Kosko (1986) in relation to a measure of subsethood (submessagehood) or Ju (2009), who posses fuzzy entropy in case of an interval-valued fuzzy set. Hung, Yang (2006) extended the De Luca, Termini (1972) axiom definition to fuzzy entropy and proposed two families of entropy measures on intuitionistic fuzzy sets. They make comparisons of entropy measures for search of more reliable presenting the degree of fuzziness of fuzzy sets. Some new methods of entropy are quoted in Fan, Ma (2002), Liang, Chin, Dang, et al. (2002)

Many researches and application of entropy in supply chain management are published in last few years. The most important recent studies for the paper are cited below:

Under the situation of separated and integrated information source, it has analyzed Huang, Yan (2008) the complexity of manufacturer inventory management by information entropy. Based on the analysis of correlation factors affecting the complexity, they have proposed several strategies to the complexity problem. Isiks' paper (Isik, 2010) describes an approach to the measurement of complexity in supply chains based on Shannon's information entropy with main aim of complexity measure associated with information and material flows in the chain. On the application of the operational complexity index reports Wu, Frizelle, Efstathiou (2007). They are addressed what is the relationship between costs and the complexity index. The investigation carried out measurements on two types of supplier-customer systems in the UK.

Raj, Lakshminarayanan (2010) are evaluated benefits of four complexity management strategies under diverse business scenarios using Shannon's entropy-based measures by tweaking supply-chain decision parameters (replenishment parameters). Results demonstrate that the strategy which aims to minimize an additive measure of information and material flow complexity outperforms other complexity management strategies under all business scenarios. Tsuen-Ho, Ling-Zhong (2006) apply entropy method of information theory to the customers' assessments of the performance of related competitors to obtain another set of ratings, called competitive priority ratings. Utilizing a fuzzy quality function deployment and entropy method helps to structure the amount of information about a customer's cognition.

Bai, Wang, Qu, et al. (2009) presented entropy mechanism of fractal supply chain network system mutation, which is deduced from entropy model of order degree of fractal supply chain network system established based on organizational structure entropy and information entropy. Similarly Sun, Ye, Iee Computer (2008) are analyzed relation between generalized fractal dimension and generalized entropy to obtain entropy through fractal dimension, and expand and improve the system structure entropy model, furthermore, establish entropy model of order degree of fractal supply chain network system based on organizational structure entropy and information entropy.

Zou, Gao (2008) shows that flow structure as a whole work system could be studying by the orderly model of various subsystems; eventually establish supply chain management efficiency model based on entropy theory. It can be used to evaluate the effectiveness of supply chain management. Similarly Xu, Zeng, Society (2006) evaluate the performance of five listed electronic enterprises according to the entropy appraisal model, which is able to evaluate objectively and scientifically enterprises performance.

The results of research Lv, Zhou, Huang, et al. (2008) illustrates time-effect and quality entropy of the supply chain structure in the single central and multiple coal preparation plants. Study offers particularly qualitative and analytical methods of supply chain structure optimization for large scale coal enterprise. In Shuiabi, Thomson, Bhuiyan (2005) is entropy used to monitor process flexibility for manufacturing operations. Results showed that entropy succeeded in measuring flexibility when the relative demand for the fabrication of products changed.

Martinez-Olvera (2008) outlined an entropy-based formulation as the basis of a methodology for comparing different information sharing approaches in a supply chain environment. Xue, Shen, Li, et al. (2009) presents a relative entropy method for improving agent-based negotiation efficiency (REANE) in a construction supply chain. REANE provides a path forward to help negotiators reach an acceptable solution when other methods fail; the key insight is the use of relative entropy to measure the relative degree of consensus among parties and hence minimize necessary compromises.

3 Matherial and methods

The methodology explains various research method including data analysis, clustering, fuzzy evaluation and fuzzy entropy concept to generate supply chain evaluation in following phases (Figure 3):

a) Data describing and analysis. In this phase are five dimensions which contains several numbers of logistic indicators described. Then are main results of research of the most frequented logistic indicators in supply chains (by average values) presented. Since the average values of indicators dimensions are measured on different scales, they are standardized be range; see (Řezanková, Húsek, Snášel, 2007) for mathematical equation. Because of asked questions used for different indicators answering provides valid results with some degree of vagueness and ambiguity, which arises from the inability to perform adequate measurements, fuzzy approach is selected for process of supply chain dimensions evaluation.

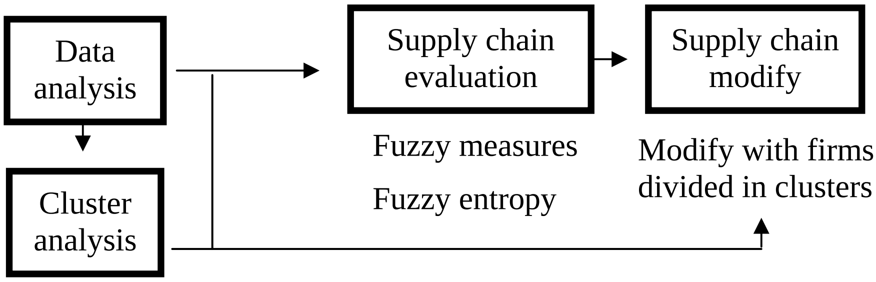
b) Cluster analysis. The purpose of this phase is to cluster gathered data having same features. Cluster analysis divides data into groups or clusters that are meaningful (it means that conceptually substantial groups of objects share common characteristics important for more understanding problems occurred in complex world) and useful (it provides and abstraction from individual data objects to the clusters in which those data objects reside). Cluster analysis in the paper has two basic steps: agglomerative hierarchical clustering (AHC) and k-means clustering. In hierarchical clustering clusters permit to have subclusters, which are a set of nested cluster that are organized as a tree (figured in Dendrogram). Hierarchical clustering is employed for number of clusters determination. K-means clustering in second step is used for grouping of companies according to the indicators dimensions. The algorithm that used information about the desired number of cluster (obtained by AHC) iteratively estimates the cluster means and assigns each case to the cluster for which its distance to the cluster mean is the smallest.

c) Supply chain fuzzy evaluation (a case study). The purpose of this phase is application of fuzzy approach in case study for evaluation of supply chain. The construction of the fuzzy set membership of indicators is undertaken (linear membership functions are used) in this phase. Afterwards fuzzy measures of indicators dimensions are aggregated according to three different decision levels (medium, high, very high). The results of calculated fuzzy entropy measures are reflected uncertainty inherent in supply chain used for case study.

d) Supply chain fuzzy evaluation modifying by applying of different membership functions. In this phase is influence of different membership functions of indicators and indicators dimensions measures examined. In addition to linear membership functions are S-shaped and Z-shaped memberships functions used and new evaluation measures are analyzed in order to different functions progress.

e) Supply chain modifying by adding new companies into chain (a case study). The main purpose of this phase is to analyzing measures changes, which are obtained by adding new set of companies into supply chain. Joined companies (with capability of linkage to supply chain are preferred; in fact they are potentially able to connect to hubs) are common to cluster (based on cluster analysis) with the same features and characteristics. Evaluations are compared according to cluster membership (variants with companies from different clusters are compared).

Fig. 3 Methodology foundation



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3.1 Main aim

The main aim of the paper is focused on evaluation of logistic dimensions (groups of logistic indicators, only dimensions next) in supply chain, where the uncertainty arises from the inability to perform adequate measurement, and deals with application of fuzzy approach, that provides a formal method for modeling imprecise, vagueness or incomplete relationships inherent in supply chains.

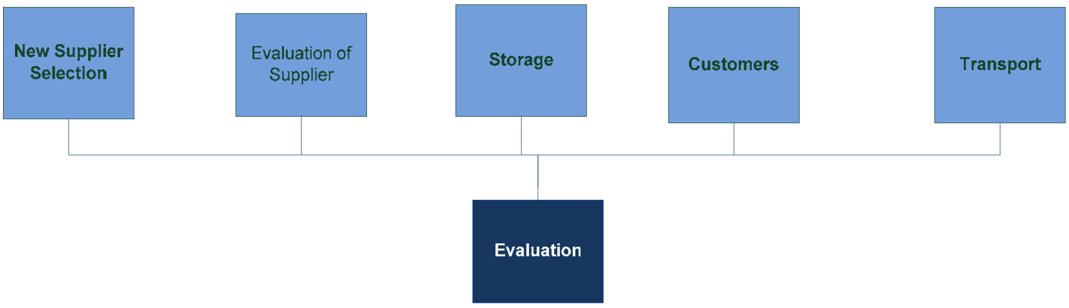
3.2 Questionnaire research

The data for case study are part of those used in previous studies (Pech, Smolová, 2010), (Smolová, 2009a), (Smolová, 2009b). They come from questionnaire research performed in 2008 and 2009. The main aim of the research was finding the most frequented logistic indicators which are used in asked Czech companies (Pech, Smolová, 2010).

Companies are focused on five different production groups. Four dominated groups from total number of 188 companies were food industry, building, machine industry, consumer goods industry. Only micro companies (companies with less than 5 employees) were not participated in this research.

Suppose the data set under investigation consists of the five dimensions where in every dimension several indicators marked by respondents according to frequency of use are given. Used questionnaire was divided into following dimensions (Fig. 1): New supplier selection (N), Evaluation of suppliers (E), Storage (S), Customers (C) and Transport (T). The questionnaire does not deal with indicators, which are used for performance of production. All of used indicators are specified in Appendix A3 (Table 13 - Questionnaire research indicators).

Fig. 4 Research dimensions of supply chain



Source: authors

In every dimension were given several indicators, which were marked by respondents according to frequency of use. **The respondents are specially asked to indicate their opinions about indicators importance. Each respondent has also his/her own opinion about the meaning of the same subjective concept.** Asked questions used for different answering scales which tend to provide valid results with some degree of uncertainty, vagueness and ambiguity. Fuzzy approach is also selected for process of supply chain dimensions evaluation (Pech, Smolová, 2010).

In this research were two dimensions focused on suppliers. First of them was New supplier selection (N), respondents had fourteen indicators for classification. Scale used for this dimension had fifteen degrees from 0, which remarks "no importance", to 14 "the most important". Second dimension is Evaluation of suppliers (E), this dimension had thirteen basic indicators and respondents were able to bring another one or more used indicators. Scale for this dimension was from 0, that means "we do not use this at all", 1 – "we use it sometimes", 3 – "we use it regularly". It is possible to divide this dimension into two smaller groups of indicators: perfect delivery and supplier profile. First group "perfect delivery" describes indicators used for evaluation of promised and real terms of deliveries.

Next part of every supply chain is customers. This dimension used the same scale and system for evaluation as the dimension before (Evaluation of supplier). Respondents were asked for nine indicators evaluation. These nine indicators were mainly concentrated on “perfect order” and “warranty and returns”.

Many of production companies monitored storage costs, in this research ware used sixteen basic indicators. Respondents can evaluated indicators from 0 to 6, with respect to frequency of indicators using. The last but not least were transport indicators. This dimension consists of twelve indicators that are able to divide into two groups according to orientation on one vehicle or all vehicles. Scale for this dimension was the same as in Customers dimension.

3.3 Fuzzy evaluation and entropy

Fuzzy evaluation in case study is based on soft measures to quantify imprecision, vagueness and incompleteness of information. Various methods are available, and the concept of fuzzy measures and entropy adopted in the paper comes out from the research of Soyer, Kabak, Asan (2007). They developed simply tool for measuring the presence of culture type in an organization, which is measured by the presence (degree of membership) of the relevant values gained from the questionnaire (Pech, Smolová, 2010). Instead of culture values are used logistic indicators divided into 5 supply chain dimensions. The uncertainties of the dimension sets are quantified by the common measure of fuzziness, fuzzy entropy. Our software FAHP is selected for all calculations of fuzzy measures and fuzzy entropy. Method of Soyer, Kabak, Asan (2007) in case study is defined and modified as follows:

3.3.1 Creating of membership functions

To represent the uncertainty and ambiguity arising in the assessment of respondents’ opinions about indicators relevance, the results of the questionnaire are fuzzified by means of a fuzzy membership function which allows varying degrees of memberships in a set. This method is similar to Soyer, Kabak, Asan (2007). Fuzzification process is originated from scales used in questionnaire and maintains the scale’s basic characteristics.

Fuzzy sets, by means of fuzzy membership functions, are used to represent successfully the vagueness inherent in the assessments. The parameters associated with the membership function are provided by expert judgments. Considering the nature of the problem (companies preferences of indicators), the use of a predefined classic linear function used in our study (Pech, Smolová, 2010) and original Soyer, Kabak, Asan (2007) shifted linear function is replaced by linear function with following features:

a) the function is continuous;

b) it maps an interval [*a*, *e*] to [0, 1];

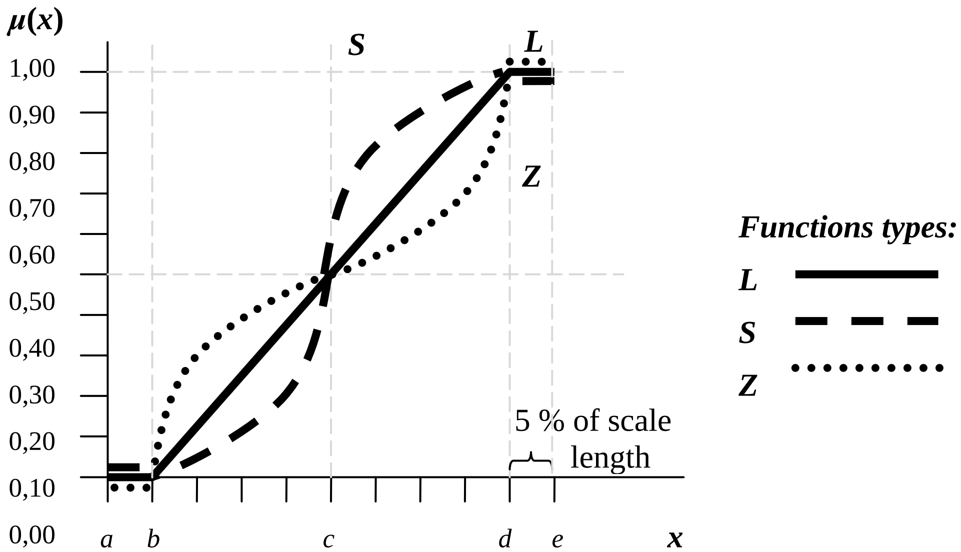
c) it is monotonically increasing;

d) it isn't restricted;

e) is defined by the value *x* as average of all respondent judgments for a given indicator and parameters *a*, *b*, *c*, *d*, *e*.

In addition to linear membership function are used parameterised S-shaped and Z-shaped functions (see Fig. 4) too. All used membership functions (L-linear, S-shaped, Z-shaped) are defined in appendix (A1) by parameters *a*, *b*, *c*, *d*, *e*. Where parameter *a* is represent as minimum, *e* as maximum of relevant scale and *b*, *c*, *d* as facultative parameters. In case study is selected parameter *b* defined as *a* + 5% of scale length and *d* as *e* – 5 % of scale length and *c* = (*a* + *e*) / 2 (for more understanding of function parameters see Fig. 4).

Fig. 5 Different membership functions



Source: authors

Degrees of membership are also generated as a value of membership function. For instance when membership function is defined as linear (see appendix A1) on scale 1-3, then parameters *a* = 1; *b* = 1,1 (i.e. *a* + 5% of scale length); *c* = 2; d = 2,9 and *e* = 3. If *x* (average of all respondent judgments for a given indicator) is smaller than *b*, then the membership value of linear function should be 0. Similarly, if *x* is greater than *d*, then the membership value is 1. Additionally, the membership value for $b < x < c$ can be easily assigned according to function rules defined in appendix A1. The membership degrees show to what extent the supply chain presents a value represented by a particular fuzzy set. Values for S-shaped and Z-shaped membership function are given in a similar way (appendix A1).

3.3.2 Fuzzy evaluation of dimensions

Evaluation of dimensions is based on the presence (measured by gradual membership to relevant dimension) of indicators in companies of researched supply chain. Each dimension is consisted of number indicators according to Table 12 (Appendix A2). While the presence of indicators is expressed by using of membership function, the fuzzy approach enables according to Soyer, Kabak, Asan (2007) to interpret the results in compliance with different decision levels indicating gradual membership to dimensions.

Similarly to methodology (2007) we use different decision levels (average, high, very high) indicating gradual membership to dimensions are used. Three decision levels are shown as the mode for identify the evaluation of dimensions in supply chain network. To satisfying these different levels of each dimension, the minimum numbers of indicators is determined. Original list of corresponding numbers of indicators for each level and dimension is enlarged (our complete list has also 1 to 20 indicators for each dimension, see Table 12 in Appendix). Results of each dimension are given in order to transform the membership degrees of the indicators to dimension membership degrees. Following concept derived from the intersection of fuzzy sets has been used:

$$\mu_{C-L}(x) = \sup_{r_1,\ldots,r_n \in CS} \left\{ \bigwedge_{k=1}^{n} \mu_v(x_{rk}) \right\} \tag{4}$$

where C-L denotes the dimension decision level and CS the dimension set; n represents the number of indicators that should exist for a given dimension and dimension decision level, and x is a vector of all average values of indicators. Results are given for all of 5 supply chain dimensions of companies connected in supply chain network.

3.3.3 Non-probabilistic entropy

Proposed methodology is based on definition (see chapter literary review) of non-probabilistic entropy that (similarly to Shannon's entropy) expresses uncertainty. This type of uncertainty differs from probabilistic uncertainty (randomness) and nonspecificity in that it deals with situations where the boundaries of the sets under consideration are not sharply defined (Soyer, Kabak, Asan, 2007). It permeates discourse and systems. It connects deeply with information and conditioning (learning). And, in principle, it has nothing to do with probability theory (Kosko, 1986).

Fuzzy entropy in case study is viewed as a degree of uncertainty (fuzziness) inherent in each dimension set that we are exposed to in any judgment about these dimension set.

A value close to one indicates high uncertainty. Measure of non-probabilistic entropy is based on the membership functions of the intersection and union of the set and its complement set. Shang, Jiang (1997) defined it follows:

$$E(A)=\frac{1}{n}\sum_{i=1}^{n}\frac{\mu_{A\cap\bar{A}}(x_i)}{\mu_{A\cup\bar{A}}(x_i)} \tag{5}$$

where n denotes the number of indicators in a related dimension; x_i is the average of all respondents' judgments for a given indicator i and $\mu_A(x_i)$ denotes the degree of belongingness of indicator i to the dimension set A. $\bar{A}$ is the complement set of A (Soyer, Kabak, Asan, 2007). In chapter 2.3 are quoted other measures of non-probabilistic entropy.

According to Wu, Frizelle, Efstathiou (2007), (Martinez-Olvera, 2008) high level of entropy (or complexity) in the supply chain has the effect of impeding flow by building obstacles, the bigger this obstacle is, the longer lead times and less predictable operations, making more uncertain the state of the system, and as a consequence, a bigger amount of information is required to monitor and manage that system. The non-probabilistic entropy of a fuzzy set A shows the degree of fuzziness of A. It means that by estimating the entropy is estimated the degree of fuzziness of the results which is a good measure of their reliability (Spartalis, Iliadis, Maris, 2007).

4 Results

The chapter results is divided into five parts: data description and analysis (basic descriptive statistics and data characteristics), cluster analysis (where the groups with the same features are acquired), fuzzy evaluation (focused on fuzzy measures and fuzzy entropy), membership function modifying (where the possibilities of other membership functions are examined) and in the end modifying of supply chain (by adding new companies to chain).

4.1 Data description and analysis

One of the main questionnaire results was arrangement of the most frequented indicators list, which were used by companies from branches mentioned above. List of the most frequented indicators consists of 27 indicators which are grouped by dimensions. This number represents 42 % of all surveyed indicators. List of the most frequented indicators has from three to eight indicators in every dimension (Table 2).

Table 2 The most frequently used indicators

New supplier evaluation (N)	Storage and stock level evaluation (S)
Price	Stock level in money
Quality	Stock level in unit in kind
Responsibility	Stock turnover cycle time
Delivery terms	Number of employees
Supplier change reaction time	Transport (T)
Suppliers experience	Total km per one vehicle
Suppliers evaluation (E)	Fuel used up one vehicle
Price adherence	Total incomes per one vehicle
Bulk discount adherence	Customers (C)
Delivery terms adherence	Total number of orders
Speed of deliveries change reaction	Orders per customer
Quality of deliveries adherence	Order on time
Amount of deliveries in pieces adherence	Delayed orders
Speed of reclamation service	Number of warranty and returns
Document completeness	Total incomes per one customer

Source: author research (2009)

For entering to this list, indicator must reach three requirements:

- Indicator must be used by one third of all 188 companies at least.
- Indicator must reach higher than average results in given dimension.
- Indicator must reach higher than average results in all dimensions.

4.2 Cluster analysis

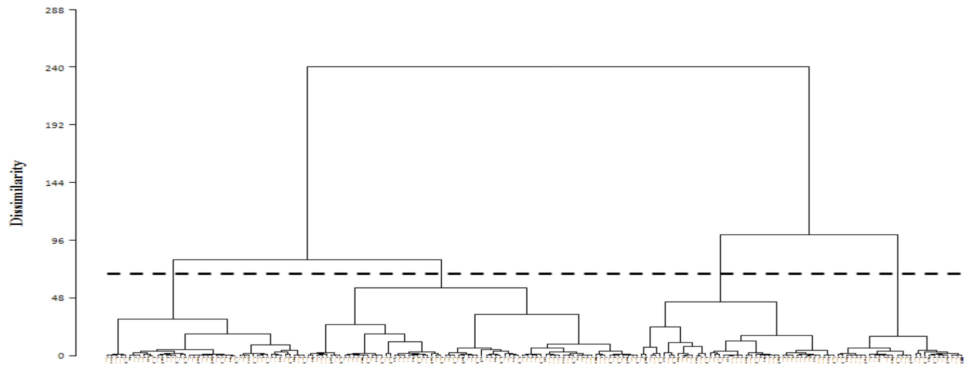
The purpose of cluster analysis is to discover a system of organizing and placing companies into groups based on the correlation found among their indicators dimensions evaluations. Companies with high positive correlations are grouped together and segregated from those with negative correlation. For clustering (agglomerative hierarchical, k-means) are used all 188 companies examined in questionnaire research.

4.2.1 Agglomerative hierarchical clustering (AHC)

In Agglomerative hierarchical clustering are clusters arrived from joining together similar observations. We are employed AHC for determination number of desired clusters (which are used for k-means clustering in next phase). In the paper are clustered companies (rows) according to the dimensions (average values of dimensions). There are a number of clustering algorithms available, all having as their primary purpose the measurement of mathematical distance between individual observations, and groups of observations (Finch, 2005). For instance following parameters are examined in XLStat software: dissimilarity criterion Euclidean distance, Aggregation criterion Ward's method, uniform weighting of columns (by default) and data have been standardized by columns. For this purpose, the proposed method employs classified into four clusters. The chart below (Fig. 6) shows the dendrogram. It represents how the algorithm works to group the companies, then the sub groups of companies. As you can see, the algorithm has successfully grouped all the companies. The dotted line represents the automatic truncation, leading to four groups.

The automatic truncation in XLStat is (according to manual) based on the entropy and tries to create homogeneous groups. However it should not prevent from using a different number of groups either because of operational constraints, or because of other prior knowledge.

Fig. 6 Agglomerative Hierarchical Clustering (Dendrogram)



Source: XLSTAT

We tested five aggregation criterions in conjunction with several dissimilarity methods, but presented here only results (shortly only number of truncated groups) that were obtained by using Euclidean, Bhattacharya, Chebychev, Mahalanobis, Manhattan distance and single, strong linkage and Ward´s algorithm as aggregation method. Results of combinations of these are depicted in Table 3.

Table 3 Results of AHC depending on entered parameters

	Number of clusters according to aggregation criterion		
Dissimilarity criterion	**Single linkage**	**Strong linkage**	**Ward's method**
Euclidean distance	5	4	4
Bhattacharya distance	5	4	4
Chebychev distance	4	5	-
Mahalanobis distance	4	4	5
Manhattan distance	4	4	-

Source: XLSTAT

There might be no definite or unique answer as to how many groups choice is the best, but it's obvious that most of calculations leads to four clusters. Four clusters are also used for next phase of k-means clustering.

4.2.2 K-means clustering

The k-means method is carried out to divide the observations into homogeneous clusters, based on their description by a set of quantitative variables (in this paper dimensions). This type of clustering is iterative. It means, wherever it starts from, converges on a solution. The solution obtained is not necessarily the same for all starting points. The calculations are also generally repeated several times in order to choose the optimal solution for the selected criterion. An important question that needs to be answered before applying the algorithms is how many clusters there are in the data. Desired number of clusters is obtained by AHC.

In this paper has k-means clustering method following parameters entered in XLStat: number of clusters = 4; repetitions = 10; iterations = 50; convergence = 0,0001; number of partitions used in order to identify the stable groups = 10 and data have been standardized by columns. After basic descriptive statistics of the selected variables, the first result displayed in MS Excel and XLStat is the optimization summary and the initial and final within-class variances. Afterwards initial centroids are redefined from the objects assigned to the various classes. The distance between the objects and the k centers is calculated and the objects are assigned to the centers they are nearest to. Table 4 shows results of clustering and basic statistical characteristics of gained clusters.

Table 4 Clusters characteristics

Characteristics	Cluster 1	Cluster 2	Cluster 3	Cluster 4
Within-groups inertia	8,247	7,014	7,662	6,193
Minimum distance from centroids	0,205	0,123	0,180	0,184
Average distance from centroids	0,351	0,354	0,374	0,462
Maximum distance from centroids	0,761	0,685	0,928	0,747
Size (Number of companies)	**62**	**51**	**49**	**26**

Source: XLSTAT

For more illustrative description of clusters characteristics could be final cluster centroids examined. Table 5 contains in columns four clusters which have different features expressed by dimensions. Strong linkages of dimensions to clusters are depicted in bold (there are values higher than or close to 0,5). We have indentified one cluster with very strong linkages to all dimensions evaluations (cluster 3), cluster with weak linkages (cluster 4) and two clusters that have partial strong dependence on dimensions evaluations. According to those characteristics are clusters named.

Table 5 K-means clustering (cluster centroids)

Dimension	Cluster 1	Cluster 2	Cluster 3	Cluster 4
Evaluation of supplier (E)	**0,692**	**0,637**	**0,750**	0,143
New supplier selection (N)	**0,613**	**0,726**	**0,758**	0,238
Customers (C)	**0,685**	0,138	**0,771**	0,220
Storage (S)	0,220	0,192	**0,427**	0,103
Transport (T)	0,239	0,198	**0,624**	0,228

Source: XLSTAT

There are following four clusters determined:

Cluster 1 - "Companies focused on relationship (up and down stream cooperation)"

This cluster contains of 62 companies, 36 % of all these companies are focused on engineering (almost 50 % of all asked engineering companies). Total number of engineering companies grouped in this cluster is 22, 7 of them fulfill EU terms for big companies and the rest are small and middle sized companies. The second biggest group of production companies is represented by consumers goods producers (18 companies, more than one third of asked consumer goods producers). Remaining 22 companies are equipollently from other asked group of production companies. In this cluster are grouped more than 40 % of all asked big companies through the asked branches.

With respect to finding results, it is possible to say, that almost big companies are focused on up and down stream cooperation regardless of branches. Storage and transport are not usually so important with respect to using of outsourcing or subcontracts. Other reasons for less importance of storage and transport indicators for this group of companies are: very specific and narrow production program or job-order manufacturing. On the other hand, there is a big group of SME's too. This group of companies is very often close to customers and their production consists mainly of job-order manufacturing.

Cluster 2 - "Companies focused on downstream cooperation"

Consumer goods producers (36% of all 51 companies) have dominant position in this cluster, building companies (24% of cluster 2 companies) and engineering industry (22 % of cluster 2 companies). Only 5 of these 51 companies fulfill EU terms for big companies. Suppliers are very important especially for SME's, these companies have only week bargain power to their suppliers, and on the other hand these companies are very sensitive on delivery price. They are oriented on quality of deliveries (for example buying materials and semi finished products), customers and good downstream cooperation.

Cluster 3 - "Companies focused on reporting by indicators, which tend to be perfect"

Totally account of this group companies is 49. More than half of these companies are represented by food producers, second important group are engineering companies (18 % of cluster 3). In this cluster there are 41% of asked big companies, they are mainly from food industry and build industry.

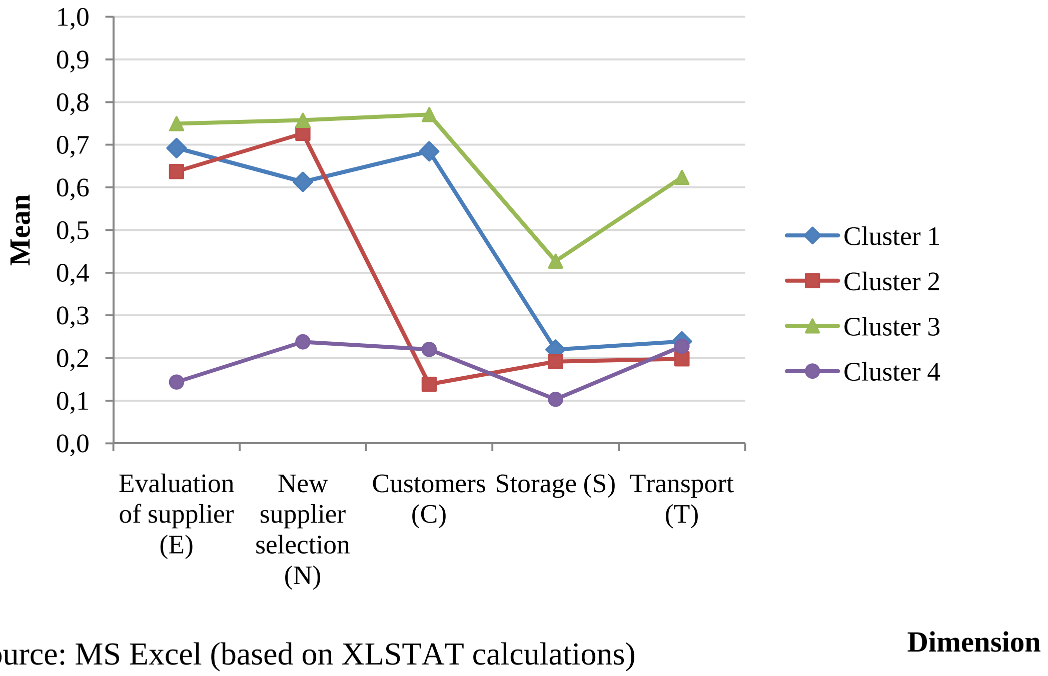
These companies are focused on reporting by indicators in each of five dimensions. There are two main groups of companies: First of them concentrated big companies with conducted evaluation system of process and performance indicators. They have operated many years on the market or they are subsidiaries of traditional companies. These companies are mainly from food and engineering industry. Second group of companies are new firms, which try to create new information system for performance or process evaluation. This first step of information system creating brings time period, when companies monitored big amount of information and will precise their information system in future. This cluster has big potential to sharing information in supply chain on condition that methodic of this indicators calculation is identical.

Cluster 4 - "Companies - indicators are not so important"

Come up to expectation, this cluster is created by small companies across the branches (only 2% difference among different branches). Companies monitored only a few indicators, which are connected with accounting. Reasons for not using many indicators of these five dimensions are: very specific and narrow production portfolio (only 2 of 3 different products), short-run production system, and orientation on providing services (especially transport companies).

As shows Fig. 7 all clusters could be draw by plot of means. Differences between clusters are depicted by plot for clearness.

Fig. 7 K-mean clustering (plot of means for each cluster)



Source: MS Excel (based on XLSTAT calculations)

Finally we are presented centers of clusters (Table 6) which are represented by typical companies' evaluations for each cluster. Average values showed in Table 6 are conducted on original scales (before standardizing), where different minimal and maximal values of scales are set. Very high values are depicted in bold.

Table 6 K-means clustering (centers of clusters)

Dimension / cluster	**1** (Obs59)	**2** (Obs14)	**3** (Obs107)	**4** (Obs58)
Evaluation of supplier (E)	**2,15**	**2,08**	**2,31**	1,62
New supplier selection (N)	**6,79**	**10,71**	**9,64**	3,64
Customers (C)	**2,33**	1,22	**2,56**	1,33
Storage (S)	0,83	0,87	**2,23**	0,63
Transport (T)	1,63	1,33	**2,00**	1,33

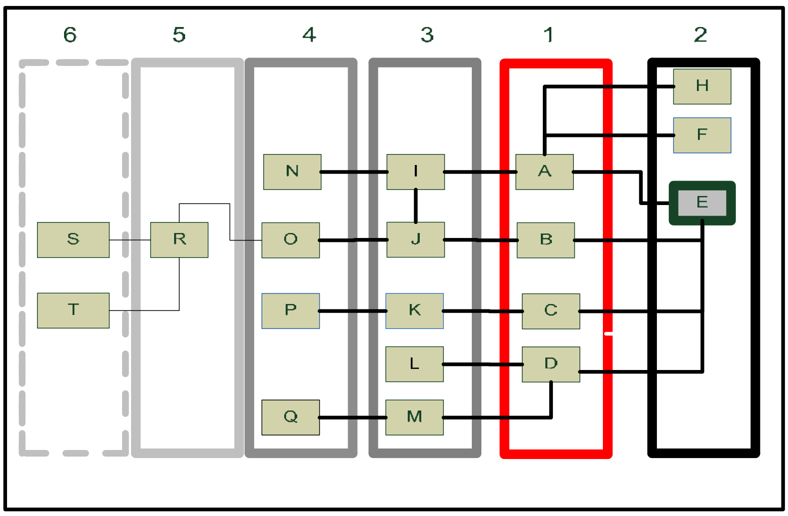
Source: XLSTAT

Results in Table 6 demonstrate differences among these 4 clusters. Centroid for cluster 1 is concentrated on suppliers and customers especially on new supplier selection. Companies 14 – centroid of cluster 2 – is oriented on monitoring of 2 suppliers dimensions (Evaluation of supplier, New supplier selection). Cluster 3 centroid use many indicators across dimensions, and the centroid for cluster 4 is not concentrated to indicators monitoring.

4.3 Supply chain fuzzy evaluation

Presented case study describes supply chain depicted as network (Fig. 8). Supply chain is concerned on producing components for automobile industry. This network consists of six rectangles; each of them represents one part of this network. Part 1 in diagram represents hubs of this network, part 2 describes customers, parts 3 - 6 depict four levels of suppliers. Base for verification of linkages was information on web sites of these companies and structured interviews.

Fig. 8 Supply chain



Source: authors

Nodal part is composed of automotive components producers and there are 9 companies. Four of these companies are depicted in area 1 and 5 are in grey area 3, these companies are key suppliers and companies from area 1 are very close to them. This part of network is strictly oriented on B2B customer needs. Nodal part of network is partly linked with end customers and suppliers too. Companies H and F are service departments, their customers buy spare parts. And that's why these two companies have feedback from them (Pech, Smolová, 2010). Company E represents last part of supply chain, it is key customer. This company is depicted at the picture for completeness; it is not used for next calculation, because they did not give sufficient information about using of indicators. Most of suppliers represent producers of small automotive components; three companies (S, T, R) are potential suppliers of energy. In Fig. 8, there are only capital letters instead of the name of companies.

Results of dimensions evaluation are adopted from (Pech, Smolová, 2010) and enlarged by modifying parameters of linear membership function (in this paper are membership function refined at both-sides of function progress by 5 %). By this way are new results obtained. Proportion of results and dimension comparison ranking are also maintained.

Membership degrees of a predefined linear membership function are obtained by average responses of collected data from questionnaire. Degrees of membership shows to what extent the supply chain evaluates an indicator represented by a particular fuzzy set. From indicators measures are gained corresponding aggregated dimensions fuzzy evaluations. Three different decision levels ("average", "high", "very high") for each dimension evaluation are calculated by equation 4. They represent different gradual membership to dimensions and strictness of decisions to evaluation results. Results of degree of belongingness indicators to dimensions are enclosed in appendix (see Appendix A4, Table 14). According to results dimensions and results of indicators, depicted supply chain indicates attributes of cooperative supply chain type (Gattorna, 2009).

Table 7 presents results of membership degrees of dimension at relevant decision levels. Highest (bold) values at level "average" (E = 0,81 – Evaluation of supplier; C = 0,62 Customers; N = 0,52 – New supplier selection) indices that companies connected in supply chain have high potential of information sharing in supplier-customers relationships. The similar results are obtained at levels "high" and "very high" except for dimension New supplier selection (N = 0,42) and Customers (C = 0,41) where dimension changes order at level "high". Even, if the decision level is increased to "very high" or "high" with stricter decision level (and lower membership degrees), dimension Storage (S) replaces dimension

Transport (T) too. All fuzzy measures of dimensions according to different decision levels (for more illustrative view) are showed in Fig. 9.

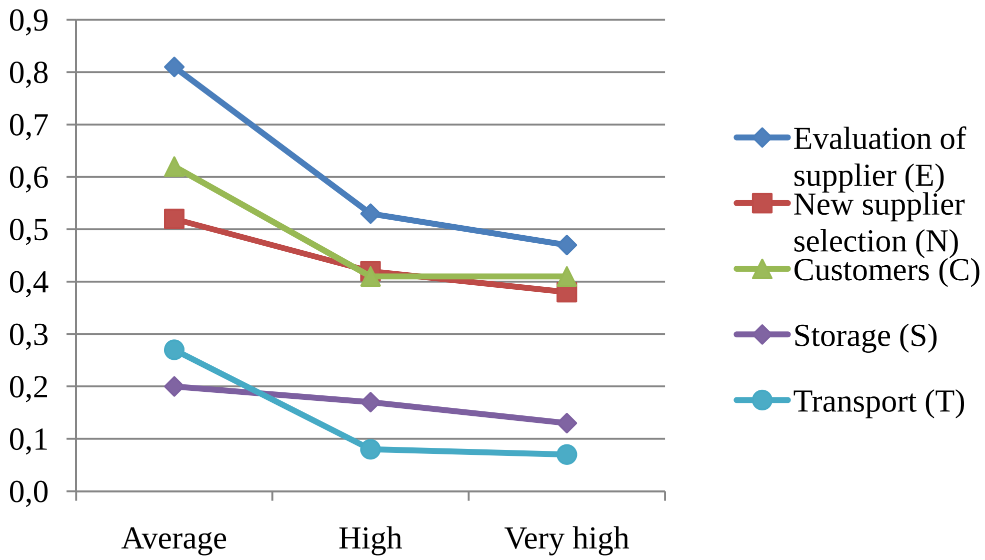
Table 7 Supply chain evaluation

	Entropy		Decision levels			Mean
	E_s	E_f	Average	High	Very high	
Evaluation of supplier (E)	0,98	**0,43**	**0,81**	**0,53**	**0,47**	**0,60**
New supplier selection (N)	0,98	0,56	**0,52**	**0,42**	0,38	**0,44**
Customers (C)	0,98	0,53	**0,62**	**0,41**	**0,41**	**0,48**
Storage (S)	0,93	**0,35**	0,20	0,17	0,13	0,17
Transport (T)	0,91	**0,33**	0,27	0,08	0,07	0,14

Source: FAHP application

To consolidate fragmented decision levels could be used mean of all decision levels that provides rank of measures supply chain dimension. In case study are supply chain indicators dimensions ranked as follows: E > C > N > S > T.

Fig. 9 Supply chain evaluation under different decision levels



Source: authors

Afterwards the fuzzy entropy (E_f) is calculated by using equation 5. The most uncertain value with fuzziness of 56 % has dimension customers (C). With the intention of simplifying the analysis, and based on the experience and common sense, we assume that higher value concludes high uncertainty and thus poor judgment about dimension evaluation. Contrariwise dimension set with a fuzziness of 33 % indices poor level of uncertainty, which is attended by high level of information. Because of the fuzzy entropy of all dimensions isn't greater than 0,60, calculated evaluations have relatively high capability of information notice. Fuzzy entropy (E_f) is then compared with classic probabilistic (Shannon) entropy (E_s) calculated by Equation 3 as shown table 7.

4.4 Modifying of membership functions

In this subchapter influence of different membership functions are examined and analyzed. The parameters associated with the membership functions are provided by expert judgments where quadratic progress of function is selected for skewing of original predefined linear function. By using the membership functions values of indicators are newly fuzzified.

Firstly the S-shaped membership functions are applied to supply chain in the case study. The main characteristic of this type of function is that high values of the average of all respondents' judgments are assigned to higher membership degrees (than in case of linear function; see Fig. 4, Chapter 3.2.1) and low values are assigned to lower membership degrees (than in case of linear function). It means that marginal (lower and higher) average values and membership degrees are preferred. Such a function and preference of marginal values take certain advantage particularly in psychology where the values far away to the center of scales are more worthful.

As shows Table 8 proportion of new results and dimension comparison ranking are maintained, but some values of membership degrees are increased and some decreased. Differences between original and new results lie in preferences to higher values (at level average E = 0,93; N = 0,55; C = 0,71) and lower values (at level average S = 0,08; T = 0,14). This type of membership function is also useful for emphasize that low values of respondents' judgments lead to very low performance and to the contrary high values leads to very high performance. The dividing line between low and high is defined according to S-shape function rules (see Appendix A1) as parameter c, which is defined in this paper as: $c = (a + e) / 2$.

Table 8 Supply chain evaluation (S-shaped)

	Fuzzy entropy E_f	Decision levels			Mean
		Average	High	Very high	
Evaluation of supplier (E)	**0,33**	**0,93**	**0,56**	0,44	**0,64**
New supplier selection (N)	**0,39**	**0,55**	0,35	0,29	0,40
Customers (C)	**0,34**	**0,71**	0,33	0,33	**0,46**
Storage (S)	**0,21**	0,08	0,06	0,04	0,06
Transport (T)	**0,19**	0,14	0,01	0,01	0,05

Source: FAHP application

Results of fuzzy entropy (E_f) are changed after applying S-shaped membership functions too, but as depict Table 8 it is obvious that order of dimensions according to entropy results are maintained. In case study dimensions with low fuzzy measures have after modification higher level of fuzzy entropy that implies less contained information and smaller variations among indicators dimensions. To the contrary high fuzzy measures of dimensions goes to lower level of fuzzy entropy that means more contained information.

Afterwards an influence of Z-shaped membership functions is examined. The main characteristic of Z-shaped membership function is that preferred are average values close to center of Z-curve (for more explanation see Figure 4, Chapter 3.2.1), which are assigned to higher membership degrees (than in case of linear function). It means that average of all respondents' judgments and membership degrees close to center are preferred.

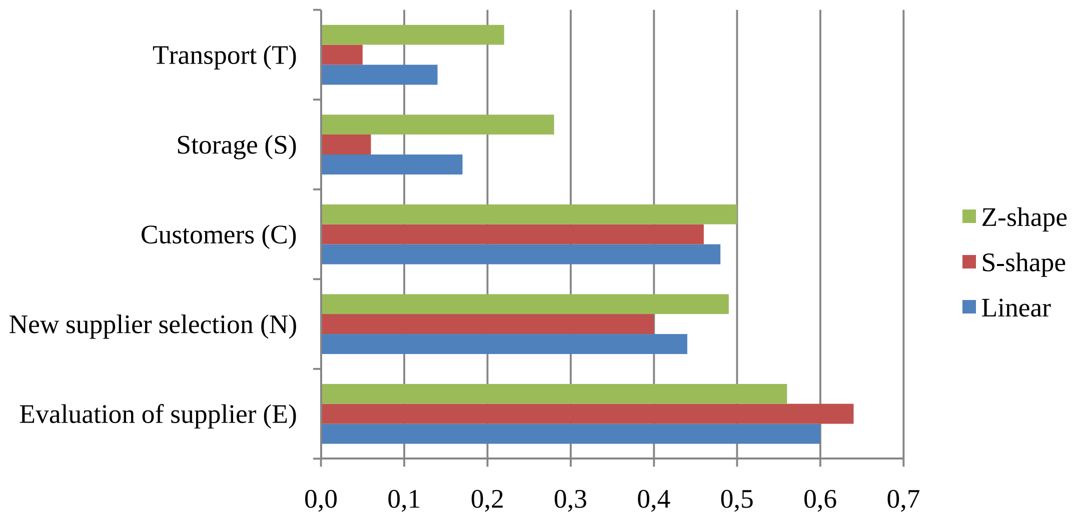
Table 9 Supply chain evaluation (low values and high entropy preferred, Z-shaped)

	Fuzzy entropy E_f	Decision levels			Mean
		Average	High	Very high	
Evaluation of supplier (E)	**0,55**	**0,69**	**0,50**	**0,50**	**0,56**
New supplier selection (N)	0,77	**0,50**	**0,49**	**0,47**	**0,49**
Customers (C)	0,79	**0,53**	**0,48**	**0,48**	**0,50**
Storage (S)	**0,53**	0,32	0,28	0,23	0,28
Transport (T)	**0,53**	0,39	0,15	0,12	0,22

Source: FAHP application

Table 9 includes results of fuzzy measures and fuzzy entropy after applying of Z-shaped membership functions. Dimension comparison ranking are (similarly to modification by S-shaped membership function) maintained. As depict Table 9 most of all fuzzy measures of dimensions are concentrated around the division line (value 0,5). Fuzzy entropy (E_f) of dimensions with low fuzzy measures is after modification increased; contrariwise fuzzy entropy of dimensions with high fuzzy measures is decreased.

Fig. 10 Comparing of supply chain evaluations with different membership functions



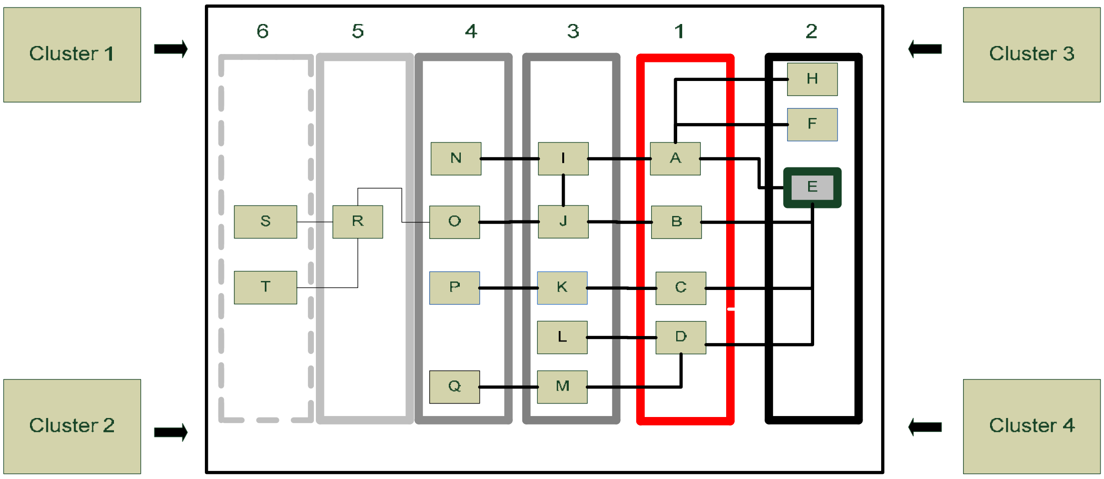
Source: authors

Results of analysis of membership functions modifying are presented in Fig. 10, where three columns for each type of membership functions according to relevant dimension and membership degrees are delimited. As we state above proportion of results and dimension comparison ranking are maintained without regard to modifying of membership functions. Modifying of membership functions could be also used for more specific adjudication and consideration the nature of the problem in dependency on researched domain.

4.5 Modifying of supply chain

Modifying of supply chain is made by adding new companies into original network. Enlargement of this network is only hypothetical, but new joined companies have capability of linkage to supply chain and they are potentially able to connect to hubs. Diagram consists of three main parts: hubs part (areas 1 and 3 in Fig. 11), customers (area 2), suppliers (parts 4 - 6 in Fig. 11) and new linkages grouped by clusters. New linkages aren’t verified by the same way as in nodal supply chain.

Fig. 11 Supply chain modifying by adding new companies into chain



Source: authors

The main purpose of supply chain modifying phase is to analyzing measures changes, which are obtained by adding new set of companies into supply chain. We present in this paper four modifications that are differed from each other by adding new companies, which are grouped in certain cluster. Results of cluster analysis are also used for modifications of supply chain. From each of four clusters with different features and characteristics are selected 2-5 companies, which are nearest to clusters centers (centroids) and have potential to become supply chain member. We make an effort to select companies, which represent related clusters, but their characteristics and features that influences connection to network are important too. Different number of companies, which are fulfilled these conditions are also obtained. Comparing phase is oriented to examination of differences between original supply chain and modification that is made by adding new companies.

Based on conditions for selecting companies from each cluster, original supply chain dimensions measures should be changed according to orientation and characteristics of different clusters. As depict Table 10 (we are used only means measures, for more detailed information see Appendix A5, Tables 15-18), some results of dimensions measures aren´t influenced by clusters characteristics. For example companies in Cluster 1 are mostly focused on Evaluation of Supplier (E), New supplier selection (N) and Customers (C), but some measures of these dimensions are decreased. However, orientation of Cluster 2 to Evaluation of Supplier (E) and New supplier selection (N), leads to dimensions measures increase. With connection to this case it´s important to note that some features and characteristics of clusters shouldn't selected companies from each clusters represented (because of having different distance from each clusters centers).

Table 10 Supply chain evaluation (means) after adding new companies from clusters

	Original	Cluster 1	Cluster 2	Cluster 3	Cluster 4
Evaluation of supplier (E)	0,60	0,57	0,62	**0,64**	0,60
New supplier selection (N)	0,44	0,42	**0,49**	0,48	0,46
Customers (C)	0,48	**0,55**	0,41	0,37	0,52
Storage (S)	0,17	0,16	0,15	0,15	**0,17**
Transport (T)	0,14	0,14	0,13	0,10	**0,19**

Source: FAHP application

The highest measures for each dimension are depicted in Table 10 in bold. Evaluation of supplier (E = 0,64) is the highest after adding companies from Cluster 3, New supplier selection (N = 0,49) after adding companies from Cluster 2, Customers (C = 0,55) measures after adding companies from Cluster 1 and measures of Storage (S = 0,17) and Transport (T = 0,19) after adding companies from Cluster 4. So, managing of supply chain could be focused on emphasize some of dimensions, which are increased by adding companies from relevant cluster. By way of illustration of Table 10 show results Fig. 12.

Results of modifying supply chain by adding new companies from different cluster are well arranged in Table 11, where only evaluation measures and fuzzy entropy changes are included. In bold are depicted changes values higher than 0,05, which are indicated very high influences of new added companies to current supply chain.

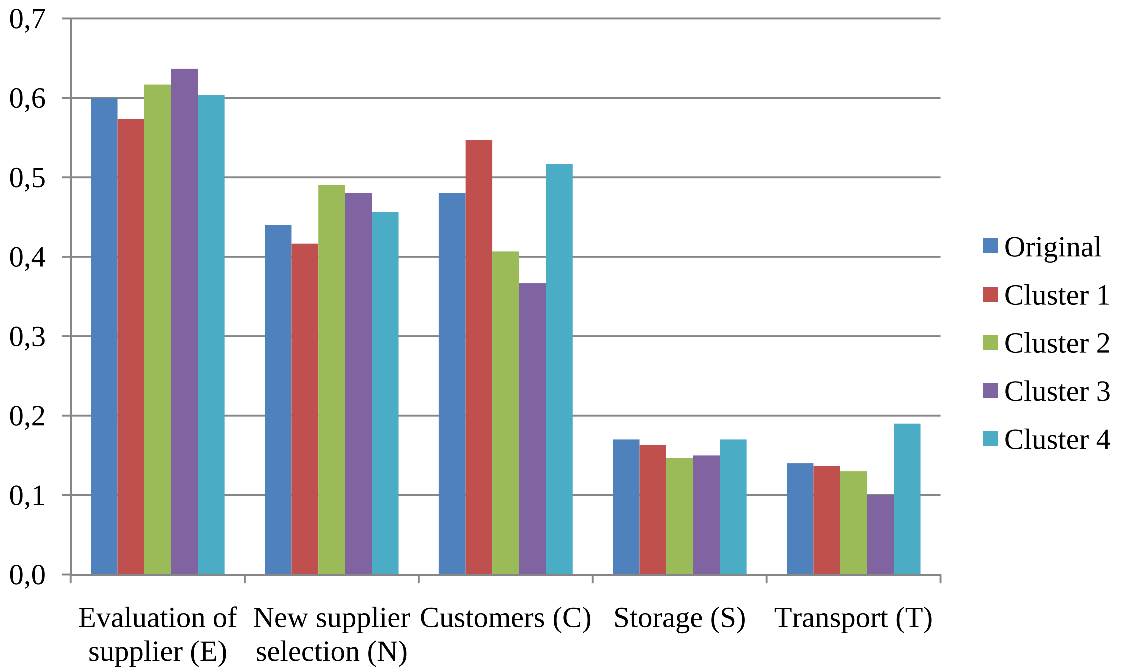
Table 11 Supply chain evaluation and entropy changes

	Cluster 1		Cluster 2		Cluster 3		Cluster 4	
	E_f	Mean	E_f	Mean	E_f	Mean	E_f	Mean
Evaluation of supplier (E)	-0,03	-0,03	**-0,05**	+0,02	-0,04	+0,04	-0,04	±0,00
New supplier selection (N)	**-0,06**	-0,02	+0,01	**+0,05**	+0,02	+0,04	+0,01	+0,02
Customers (C)	+0,02	**+0,07**	**+0,16**	**-0,07**	**+0,17**	**-0,11**	-0,02	+0,04
Storage (S)	-0,03	-0,01	-0,04	-0,02	-0,03	-0,02	+0,02	±0,00
Transport (T)	-0,01	±0,00	-0,03	-0,01	**-0,07**	-0,04	**+0,07**	**+0,05**

Source: FAHP application

There are determined following three types of changes: a) selected companies from cluster 1 have high positive impact on dimension Customers (C = + 0,07) and some negative impact on other dimensions; b) selected companies from cluster 2 and cluster 3 have positive impact on supplier evaluation dimensions - Evaluation of supplier (E = +0,02 and E = +0,04) and New supplier selection (N = +0,05 and N = +0,04), the rest of dimensions evaluations are decreased, particularly dimension Customers (C = -0,07 and C = -0,11); c) selected companies from cluster 4 have surprisingly positive impact on all dimensions evaluations (two of these have neutral impact to measures), particularly to Transport (T = +0,05).

Fig. 12 Supply chain evaluation after modification



Source: authors

All changes in dimensions evaluations are interconnect with fuzzy entropy, where greater values of entropy reveals the higher degree of uncertainty inherent in each dimension set that we are exposed to in any judgment about these dimension set. For example increasing values of fuzzy entropy after adding companies from cluster 2 and cluster 3 are determined evaluations of dimension Customers (C = +0,16 and C = +0,17). These results also have thanks to high degree of fuzzy entropy small reliability as state Spartalis, Iliadis, Maris (2007).

5 Conclusions

The performance of a supply chain depends on the ability of its components to act altogether and the co-operation of independent business units and strategy. Some parameters and relationships related to either supply chain network are inherently intangible while others are characterized by vagueness in measure. The use of fuzzy logic have it's uses in measuring the performance of non-linear systems which would be difficult or impossible to model mathematically (Olugu, Wong, 2009). The paper focused on evaluation of logistic dimensions in supply chain, where the uncertainty surrounding supply chain performance measurement arises from the vagueness or ambiguity, and deals with application of fuzzy approach, that provides a formal method for modeling imprecise or incomplete relationships inherent in supply chains.

The research presented here deals with the supply chain dimensions and various ways in which to gain performance measures and uncertainty, as a means to attain a high level of performance or effective modifying of the chain as a whole. The first step consists of data description phase and analysis of questionnaire results. One of the main results was arrangement of the most frequented indicators list, which were used by companies from different branches. List of the most frequented indicators consists of 27 indicators which are grouped by dimensions. This number represents 42 % of all surveyed indicators.

In cluster analysis phase there are five aggregation criterions tested in conjunction with several dissimilarity methods of agglomerative hierarchical clustering. Results of combinations of these have successfully grouped all the companies. The automatic truncation algorithm determined four clusters, which are also used for next phase of k-means clustering. We have indentified cluster with very strong linkages to all dimensions evaluations (named companies focused on reporting by indicators, which tend to be perfect), cluster with weak linkages (companies where indicators are not so important) and two clusters that have partial strong dependence on dimensions evaluations (cluster with companies focused on relationship up and down stream cooperation; and cluster with companies focused on downstream cooperation). These clusters have different characteristics and features based on supply chains dimensions.

In case study the supply chain that is concerned on producing components for automobile industry is examined. Results of fuzzy evaluations shows strong linkage with suppliers and this implies orientation on indicators of quality of buying materials and semi finished products. Companies aim their effort to new supplier selection, evaluation of their suppliers and orientation on customers. These results of dimensions are elicited on different decision levels (average, high and very high), which are then aggregated by mean values and ranked as follows: E > C > N > S > T. According to results dimensions and results of indicators, depicted supply chain indicates attributes of cooperative supply chain type (Gattorna, 2009). In addition to these results are also fuzzy entropy for each dimensions obtained. Because the fuzzy entropy of all dimensions isn't greater than 0,60, calculated evaluations have relatively high capability of information notice and reliability in sense of Spartalis, Iliadis, Maris (2007). Proportion of results and dimension comparison ranking are maintained without regard to modifying of membership functions.

Modifying of supply chain by adding new companies into original network is performed in case study. Enlargement of this network is only hypothetical, but new joined companies have capability of linkage to supply chain and they are potentially able to connect to hubs. Our findings show three types of changes influenced by selected companies from: a) cluster 1 with high positive impact to dimension Customers (C) and some negative impact on other dimensions; b) cluster 2 and cluster 3 with positive impact on supplier evaluation dimensions (E, N), the rest of dimensions evaluations are decreased, particularly dimension Customers (C); c) cluster 4 with surprisingly positive impact on all dimensions evaluations, particularly to Transport (T). All changes in dimensions evaluations are interconnect with fuzzy entropy, where greater values of entropy reveals the higher degree of uncertainty inherent in each dimension set that we are exposed to in any judgment about these dimension set.

Proposed methodology allows the assessment of the degree of uncertainty inherent in supply chains by using fuzzy entropy. New approach has potential for comparing information sharing in different supply chains or networks. Used fuzzy model is universally understandable in the data research phase. So, the model can be transformed in an expert system which permits evaluation of performance and process indicators based on a considerable amount of information coming from different sources and to merge heterogeneous measures. Future research lies in deeply examination and modification of supply chain model to dynamic perspective by applying of simulation method.

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Appendix

A1 - Definition of membership functions

Linear membership function used in methodology is defined as:

$$L(x,a,b,c,d,e) = \begin{cases} 0, & \mathrm{a} \le x \le b \\ \frac{1}{2} \cdot \left(\frac{x-b}{c-b} \right), & b < x < c \\ 0{,}5, & x = c \\ 1 - \frac{1}{2} \cdot \left(\frac{d-x}{d-c} \right), & c < x < d \\ 1, & \mathrm{d} \ge x \ge e \end{cases} \tag{6}$$

S-shaped membership function (without shifting) used in methodology is defined as:

$$S(x,a,b,c,d,e) = \begin{cases} 0, & \mathrm{a} \le x \le b \\ \frac{1}{2} \cdot \left(\frac{x-b}{c-b} \right)^2, & b < x < c \\ 0{,}5, & x = c \\ 1 - \frac{1}{2} \cdot \left(\frac{d-x}{d-c} \right)^2, & c < x < d \\ 1, & \mathrm{d} \ge x \ge e \end{cases} \tag{7}$$

Z-shaped membership function (without shifting) used in methodology is defined as:

$$Z(x,a,b,c,d,e) = \begin{cases} 0, & \mathrm{a} \le x \le b \\ \frac{1}{2} - \frac{1}{2} \cdot \left(\frac{c-x}{c-b} \right)^2, & b < x < c \\ 0{,}5, & x = c \\ \frac{1}{2} + \frac{1}{2} \cdot \left(\frac{x-c}{d-c} \right)^2, & c < x < d \\ 1, & \mathrm{d} \ge x \ge e \end{cases} \tag{8}$$

A2 - Enlarged list of corresponding numbers of indicators for each level and dimension

Table 12 Numbers of indicators significant for each dimension

Indicators in dimension	**Number of indicators needed**			**Percentage covered (%)**		
	Average	**High**	**Very high**	**Average**	**High**	**Very high**
2	1	2	2	50,00	100,00	100,00
3	2	3	3	66,67	100,00	100,00
4	2	3	4	50,00	75,00	100,00
5	3	4	5	60,00	80,00	100,00
6	3	4	5	50,00	66,67	83,33
7	4	5	6	57,14	71,43	85,71
8	4	6	7	50,00	75,00	87,50
9	5	7	8	55,56	77,78	88,89
10	5	7	9	50,00	70,00	90,00
11	6	8	10	54,55	72,73	90,91
12	6	9	10	50,00	75,00	83,33
13	7	9	11	53,85	69,23	84,62
14	7	10	12	50,00	71,43	85,71
15	8	11	13	53,33	73,33	86,67
16	8	11	14	50,00	68,75	87,50
17	9	12	15	52,94	70,59	88,24
18	9	13	15	50,00	72,22	83,33
19	10	13	16	52,63	68,42	84,21
20	10	14	17	50,00	70,00	85,00
Mean of percentage covered (%)				**52,98**	**75,14**	**89,21**
Interval covered (%)				**50-67,5**	**67,5-87,5**	**87,5-100**

Source: authors, modified and enlarged (Soyer, Kabak, Asan, 2007)

A3 – Questionnaire research indicators according to dimensions

Table 13 Questionnaire research indicators

Customers (C)	**New supplier selection (N)**
Number of complaints	Price
Order fulfillment cycle time	Declared amount
Orders not delivered in full	Declared maturity
Delayed orders	Supplier experience
Order on time	Reliability
Total number of orders	Warranty and return material
Orders per customer	Innovation
Warranty and return orders in CZK/EUR	Packaging
Income per customer	Quality
Storage (S)	Goodwill
Immediate or momentary stock level in money	Compatibility of information system
Immediate or momentary stock level in unit in kind	Declared speed of change reaction
Average level of stock	Delivery term
Total receipts	Information handing
Average daily stock receipt	**Evaluation of supplier (E)**
Stock turnover cycle time	Price adherence
Number of storage employees	Bulk discount adherence
Signal stock level	Delivery terms adherence
No signal level for ordering good	Speed of deliveries change reaction
Costs on m^2 or m^3 of stock	Quality of deliveries adherence
Transport (T)	Amount of deliveries in pieces adherence
Total km on group or all vehicles	Minimum order amount adherence
Total delivered t of goods or material	Advise of dispatches
Total tkm on group	Package terms adherence
Total fuel used up	Speed of reclamation service
Total transport costs	Document completeness
Total revenues	Application of innovation approaches
Total km on one vehicle	Supplier groups
Delivered t of goods or material per one vehicle	
Total tkm per one vehicle	
Fuel used up one vehicle	
Total costs per one vehicle	
Total incomes per one vehicle	

Source: authors

A4 – Results of supply chain fuzzy evaluations

Table 14 Indicators scores (case of different membership functions)

	Dimension indicators	Average values	Degree of Membership (L-linear)	(S-linear)	(Z-linear)
Evaluation of supplier (E)	Price adherence	2,56	0,81	0,93	0,69
	Bulk discount adherence	2,00	0,50	0,50	0,50
	Delivery terms adherence	2,94	1,00	1,00	1,00
	Speed of deliveries change reaction	2,56	0,81	0,93	0,69
	Quality of deliveries adherence	2,94	1,00	1,00	1,00
	Amount of deliveries in pieces adherence	2,83	0,96	1,00	0,93
	Minimum order amount adherence	1,94	0,47	0,44	0,50
	Advise of dispatches	2,06	0,53	0,56	0,50
	Package terms adherence	2,33	0,68	0,80	0,57
	Speed of reclamation service	2,72	0,90	0,98	0,82
	Document completeness	2,72	0,90	0,98	0,82
	Application of innovation approaches	1,83	0,41	0,33	0,48
	Supplier groups	1,94	0,47	0,44	0,50
New supplier selection (N)	Price	11,22	0,82	0,93	0,70
	Declared amount	6,11	0,38	0,29	0,47
	Declared maturity	6,67	0,43	0,37	0,49
	Supplier experience	7,39	0,49	0,48	0,50
	Reliability	11,22	0,82	0,93	0,70
	Warranty and return material	6,56	0,42	0,35	0,49
	Innovation	5,83	0,36	0,26	0,46
	Packaging	7,78	0,52	0,55	0,50
	Quality	12,11	0,89	0,98	0,81
	Goodwill	6,06	0,38	0,28	0,47
	Compatibility of information system	6,22	0,39	0,31	0,48
	Declared speed of change reaction	10,00	0,71	0,84	0,59
	Delivery term	10,39	0,75	0,87	0,62
	Information handing	8,50	0,59	0,66	0,51
Customers (C)	Number of complaints	2,56	0,81	0,93	0,69
	Order fulfillment cycle time	1,50	0,22	0,10	0,35
	Orders not delivered in full	2,11	0,56	0,61	0,51
	Delayed orders	2,28	0,66	0,76	0,55
	Order on time	2,33	0,68	0,80	0,57
	Total number of orders	1,83	0,41	0,33	0,48
	Orders per customer	1,83	0,41	0,33	0,48
	Warranty and return orders in CZK/EUR	2,22	0,62	0,71	0,53

	Income per customer	2,28	0,66	0,76	0,55
Storage (S)	Immediate or momentary stock level in money	2,67	0,44	0,39	0,49
	Immediate or momentary stock level in unit in kind	2,76	0,46	0,42	0,50
	Average level of stock	1,43	0,21	0,09	0,33
	Total receipts	1,02	0,13	0,04	0,23
	Average daily stock receipt	0,52	0,04	0,00	0,08
	Stock turnover cycle time	2,28	0,37	0,27	0,46
	Number of storage employees	1,24	0,17	0,06	0,29
	Signal stock level	1,39	0,20	0,08	0,32
	No signal level for ordering good	1,20	0,17	0,06	0,28
	Costs on m^2 or m^3 of stock	1,09	0,15	0,04	0,25
Transport (T)	Total km on group or all vehicles	1,56	0,26	0,13	0,38
	Total delivered t of goods or material	1,14	0,02	0,00	0,04
	Total tkm on group	1,25	0,08	0,01	0,15
	Total fuel used up	1,58	0,27	0,14	0,39
	Total transport costs	2,08	0,55	0,59	0,50
	Total revenues	1,61	0,28	0,16	0,41
	Total km on one vehicle	1,61	0,28	0,16	0,41
	Delivered t of goods or material per one vehicle	1,19	0,05	0,01	0,10
	Total tkm per one vehicle	1,47	0,21	0,09	0,33
	Fuel used up one vehicle	1,72	0,34	0,24	0,45
	Total costs per one vehicle	1,78	0,38	0,29	0,47
	Total incomes per one vehicle	1,22	0,07	0,01	0,12

Source: FAHP application

A5 – Results of supply chain fuzzy evaluations with companies adding modification

Table 15 Supply chain evaluation (after adding companies from cluster 1)

	Entropy		Decision levels			Mean
	E_s	E_f	Average	High	Very high	
Evaluation of supplier (E)	0,98	0,40	0,77	0,52	0,43	**0,57**
New supplier selection (N)	0,97	0,50	0,52	0,38	0,35	**0,42**
Customers (C)	0,99	0,55	0,64	0,52	0,48	**0,55**
Storage (S)	0,93	0,32	0,24	0,13	0,12	**0,16**
Transport (T)	0,92	0,32	0,26	0,08	0,07	**0,14**

Source: FAHP application

Table 16 Supply chain evaluation (after adding companies from cluster 2)

	Entropy		Decision levels			Mean
	E_s	E_f	Average	High	Very high	
Evaluation of supplier (E)	0,98	0,38	0,82	0,62	0,41	**0,62**
New supplier selection (N)	0,98	0,57	0,57	0,47	0,43	**0,49**
Customers (C)	0,98	0,69	0,48	0,41	0,33	**0,41**
Storage (S)	0,92	0,31	0,21	0,13	0,10	**0,15**
Transport (T)	0,91	0,30	0,20	0,11	0,08	**0,13**

Source: FAHP application

Table 17 Supply chain evaluation (after adding companies from cluster 3)

	Entropy		Decision levels			Mean
	E_s	E_f	Average	High	Very high	
Evaluation of supplier (E)	0,98	0,39	0,82	0,59	0,50	**0,64**
New supplier selection (N)	0,98	0,58	0,56	0,46	0,42	**0,48**
Customers (C)	0,98	0,70	0,48	0,31	0,31	**0,37**
Storage (S)	0,93	0,32	0,18	0,15	0,12	**0,15**
Transport (T)	0,89	0,26	0,20	0,06	0,04	**0,10**

Source: FAHP application

Table 18 Supply chain evaluation (after adding companies from cluster 4)

	Entropy		Decision levels			Mean
	E_s	E_f	Average	High	Very high	
Evaluation of supplier (E)	0,98	0,39	0,81	0,56	0,44	**0,60**
New supplier selection (N)	0,98	0,57	0,53	0,43	0,41	**0,46**
Customers (C)	0,98	0,51	0,67	0,44	0,44	**0,52**
Storage (S)	0,94	0,37	0,21	0,16	0,14	**0,17**
Transport (T)	0,92	0,40	0,33	0,17	0,07	**0,19**

Source: FAHP application

Contents of article