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Complexity Assessment of Supply Chains Structure: A Comparative Study

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Abstract: In the study it is presented a comparative study for evaluating different supply chain structures in the context of complexity analysis. The process of choosing appropriate supply chain complexity measures is difficult due to the different criteria used to measure complexity of such structures. The study describes selected measures used for supply chain models and also offers results achieved from correlative analysis of selected indicators used for evaluation of eight different supply chain graphs. Finally, the pertinent findings are discussed.

Key words: Context, evaluation, graph, operational costs, delivery, decisive, Slovakia

INTRODUCTION

Since, the term Supply Chain Management (SCM) was introduced in the early 1980s (Oliver and Webber, 1982) it has received considerable and growing interest both in theoretical framework as well as in its practical applications.

Now-a-days is no doubt that SCM is considered as the most topical area of operation research. This is due to the fact that much competition occurs between supply chains, not just between individual firms. According to the SCM perspective, companies have to run these areas as efficiently and effectively as possible.

Therefore, managing the supply chain presents a complicated task since, supply chains are in generally increasingly complex. In this sense Gilmore (2008) states that complexity is like a cancer that destroys supply chain efficiency.

According to Lambert and Pohlen (2001), the lack of proper metrics for a supply chain will result in failure to meet consumer/end user expectations. They also add that the lack of a widely accepted definition of complexity associated with overlapping supply chains make the development of supply chain metrics difficult.

In generally, a complexity problem is topical in supply chain management since, high level of complexity generate many negative consequences on supply chains such as high operational costs, customer dissatisfaction, time delay in delivery, excess inventory or inventory shortage, lack of cooperation, collaboration and integration among supply chain participants etc., (Isik, 2011a, b). In this study, researchers focus on testing of two possible approaches to complexity metrics of supply chain structures. Specifically, researchers examine the complexity of supply chain structure based on topological analysis of selected supply chain models.

RELATED WORK

The modern science of complexity is close related to the field of study known as Chaos Theory. The focus of Chaos Theory is on the manner in which simple systems give rise to very complicated unpredictable behavior while complexity theory focuses on how systems consisting of many elements can lead to well-organized and predictable (Bloom, 2000). Complexity of systems has different aspects; it refers to the negative effects triggering an effort for avoiding or reducing complexity and on the other hand, it refers to the driving business advantage. According to Vichers and Kodarin (2006) companies with more mature SC practices manage their SCC better than less mature industry peers and they are able to reduce costs faster and achieve higher profit margins. In order to achieve a balance between the diverse complexity impacts (Kaluza *et al.*, 2006) presented so called complexity strategy msatrics that demonstrates the described dimensions to determine the optimal strategy for complexity management in SCs.

Naturally, new challenges related to the increasing complexities of global supply chains mean that new and different approaches have to be applied for managing the supply chain including measurement methods for the

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evaluation of supply chain complexity. Frizelle and Woodcock (1995) used entropy to quantify a supply chain's structural and operational complexity derived from the material and information flow uncertainty.

Based on Shannon information entropy (Shannon, 1948), complexity of supply chains is defined as the quantitative variations between actual and predicted flows caused by uncertainty and variety through material and information flows.

Research undertaken by Wilding (1998) that is exploring the Chaos Theory within supply chains also provides certain inspirations that topological entropy can be used as a tool to quantify a supply chain complexity. Different views on complexity in supply chains were presented for example, in research by Parker (1994), Stacey (1993) and McMaster (1996) who argued that the complexity experienced may force organizations to innovate and learn.

According to Dima *et al*. (2010) through simplification of material flows can be achieved better synchronization and action focused on simplification lead to rethinking and reconsideration of the strong tendency for super-specialization.

DESCRIPTION OF INDICATORS FOR SUPPLY CHAIN COMPLEXITY

Specifics of supply chain structure assessment: Presented approach for complexity metrics is based on investigation of the supply chain structures by means of a topology analysis in terms to which the basic elements of the process structure-vertices (or nodes) and edges (or links) are subjected. Topological analysis is the procedure concerned with the determination of all or selected relevant topological features of the structure. However, this approach does not include Geographic Dispersion (GD) of supply chain subjects. Geographic dispersion refers to the extent to which the subjects of a supply chain are located across a wide range of geographic regions. Subjects of the supply chain include suppliers, production facilities, distributors and customers (Stock *et al*., 2000).

The question is whether GD and SCC are causally related. According to Lorentz (2010) increased GD of supply chain subjects results in higher costs of warehousing inventory carrying and logistics administration in the decline of perfect orders and increase in order fulfillment cycle time.

However, potential impacts of GD on SC complexity can be explored through simulation approaches (Grabara and Kot, 2004). In contrast, geographically dispersed production network enables improved service performance as closer proximity to customers enables shorter order cycle times. Further they add that GD in all tiers of the supply chain affects negatively asset utilization since both the inventory days of supply and cash-to-cash cycle time increase. Hence, researchers could stand that GD has direct negative impact on supply chain efficiency.

On the other hand GD in the global economy is not only a negative quantitative parameter but also has a positive qualitative dimension involving the development of horizontal concentration (Ernst, 1996; Grabara *et al*., 2010). Because a horizontal concentration allows controlling a given industry by one producer or small number of leading producer, horizontal or market concentration received a great attention with increasing globalization.

Bearing in mind this fact, it is safe to say that the significance of geographical dispersion is minimal and it can be omitted when supply chain structure complexity is measured. In case we want to involve GD in supply chain structure assessment, then so called Network Links Coefficient can be applied. This coefficient is used to calculate flow complexity matrices.

INDICATORS FOR SUPPLY CHAIN COMPLEXITY

Indicator for SCC based on D4G Model: D4G Model is based on the following initial assumption to measure complexity in SC (Crippa *et al*., 2006). Complexity in any system is directly related to relationship between its subjects such as plants, supplier distributors, etc. Accordingly, they proposed a few indicators for complexity metrics. One of them is Flow Complexity metrics (FC).

The FC assumes a positive, linear relationship between tiers, nodes, links and complexity. In mathematical terms, FC can be expressed by Eq. 1 that counts all tiers (including tier 0), nodes and links and adds all these counts, weighted with arbitrary chosen coefficients:

$$FC = \alpha \times \sum_{i=1}^{n} T_i + \beta \times \sum_{s=1}^{m} N + \gamma \times \sum_{i=1}^{n} \sum_{j=1}^{k} LK_{ij} \qquad (1)$$

Where:

α = Multi-Tier Complexity coefficient ($\alpha \geq 0$)
β = Manufacturing Network Nodes coefficient ($\beta \geq 0$)
γ = Manufacturing Network Links coefficient ($\gamma \geq 0$)

Ti = ith tier level
Ns = sth Node
Lk_{ij} = jth Network Link in ith tier level

Restiveness estimator: Indicator RT was originally defined and presented by Thesen (1976) and applied to project networks measurements. Later, Latva-Koivisto (2001) and Modrak (2004) in their researches applied this indicator to measure network and/or process structure complexity.

Definition of restrictiveness by Thesen (1976) is based on the number of feasible sequences in a graph which is impossible to evaluate in practice for large graphs. Thesen proposed several estimators for his measure of restrictiveness and one of them was further studied by Schwindt (1995) and De Reyck (1995). Formally RT is expressed by the Eq. 2:

$$RT = \frac{2\sum r_{ij} - 6(N-1)}{(N-2).(N-3)} \tag{2}$$

where, r_{ij} an element of the reachability matrix, $R = [r_{ij}]$ such that $r_{ij} = 1$ if there is a path from the vertex v_i-v_j, otherwise $r_{ij} = 0$ and N is a number of vertices in a graph.

Aggregate indicator of process complexity: In order to measure structural properties of supply chains researchers suggest applying so called aggregate indicator of process complexity (AC). Its concept is based on the use of integration of three sub-indicators: binding of structure (B), Diameter of network (L) and Structure diversity (D). The following expression for an aggregate complexity indicator can be formulated (Modrak, 2004):

$$AC = \log\frac{(B+L+D)}{3} \tag{3}$$

Binding of structure: Binding of structure presents redundancy measure index of the structure linkage in graph theory. This term means the least possible number of linkage graphs, the reduction of which would lead to an incomplete graph containing isolated nodes. An incomplete graph is the opposite of a graph in which all vertices are adjacent to all others.

The minimum number of edges for graph binding is n-1. That is valid for both digraphs and non-directed graphs. Within digraphs, each link (i, j) has one element in the adjacent matrix $a_{ij} = 1$. Within the non-directed graph, each edge has two elements which is valid for $a_{ij} = a_{ji}$. To determine the measure of the binding structure, the following indicator expressing a relative measure of the size of the number of the m edges that occur within a given structure can be applied:

$$B = \frac{m}{n-1} - 1 \tag{4}$$

Diameter of network: The diameter of a network or a graph's diameter also appears to be a pertinent indicator for the comparison of the complexity of the business processes structures. This indicator is commonly defined in the graph theory as the longest shortest path in the network. That is if the length (in point-to point hops) of the shortest path between i and j is $L_{i,j}$, then the diameter of the network, directed or undirected graph, $L = \max_{i,j}(L_{i,j})$.

Structure diversity: The formalization of the process structure diversity is based on the supposition that the investigated network structure can be represented as a transformation process of input effects into output ones encompassing distribution activities.

When determining one of the possible indicators of the process structure complexity, it is supposed that the more heterogeneous transition paths from input nodes to output nodes imply a more complex process structure. Based on these suppositions, a measure of the degree of structure diversity can be assessed by the following indicator:

$$D = \frac{1}{n_1 n_2}\sum_{i=1}^{n_1}\sum_{j=1}^{n_2} c_{ij} - 1 \tag{5}$$

in which n_1, n_2 are numbers of initial and final nodes of the process structure and c_{ij} represents number of heterogeneous paths from the ith input node to the jth output node of the process (without any possibility to pass twice through the same node within one route). If the process structure does not contain alternative transition ways from input nodes to output nodes within the structure then the structure diversity indicator D = 0.

COMPARISON OF SCC INDICATORS

In order to assess the potential of the benchmarked SCC indicators they have been tested for a set of selected graphs. The group of graphs (Fig. 1) has been designed to reflect a variety of supply chain structures. Supply chain complexity problem requires a different approach for specifying assessment criteria depending on subject of interest.

From the manufacturer's perspective a supply chain can be represented as an uprooted tree where the roots

Table 1: Results of benchmarked indicators

		Flow complexity parameters			Complexity sub-indicators				Complexity indicators		
Types	Graph No.	$\Sigma\Sigma$ LK_{ij}	N	Σ TN_i	Σ T_i	B	D	L	FC	AC	RT
Inventory SC	1	18	16	16	5	0.20	4	0.56	39	0.23	0.22
	2	26	22	22	6	0.24	5	0.75	54	0.26	0.23
	3	38	32	32	8	0.23	7	4.20	78	0.35	0.35
	4	30	29	29	11	0.07	10	1.64	70	0.36	0.38
Entire SC	5	23	20	20	7	0.21	6	4.00	50	0.34	0.62
	6	33	26	26	9	0.32	8	8.00	68	0.40	0.67
	7	48	39	39	11	0.26	10	3.67	98	0.38	0.63
	8	32	32	32	12	0.03	11	1.50	76	0.37	0.68

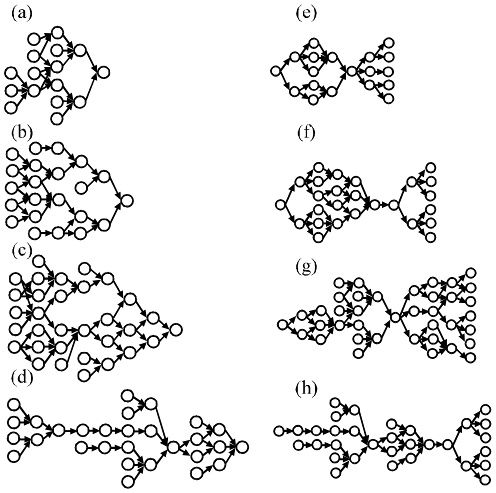

Fig. 1: Graphs representing a variety of SC structures

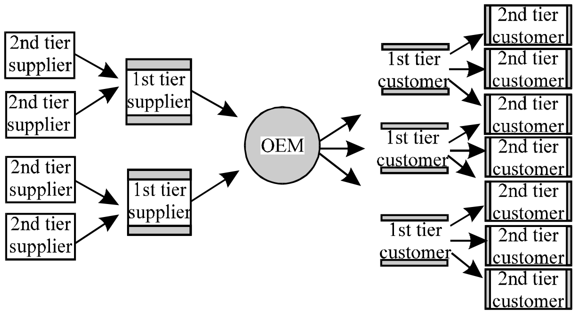

Fig. 2: Generic Model of SC (Modrak and Moskvich, 2011)

are the suppliers and the branches are the customers (Fig. 2). Table 1 shows the results of the implementation of complexity indicators that were described in the study with the aim to predict of future outcomes of benchmarked indicators the Coefficient of Determination R^2 is used. R^2 is applied for the all pairs of the indicators to measure the proportion of dependence between two groups of values.

In Fig. 3 scatter plot diagrams and calculated values of R^2 for three pairs of indicators. The purpose of this figure is to illustrate how individual indicators are mutually correlated.

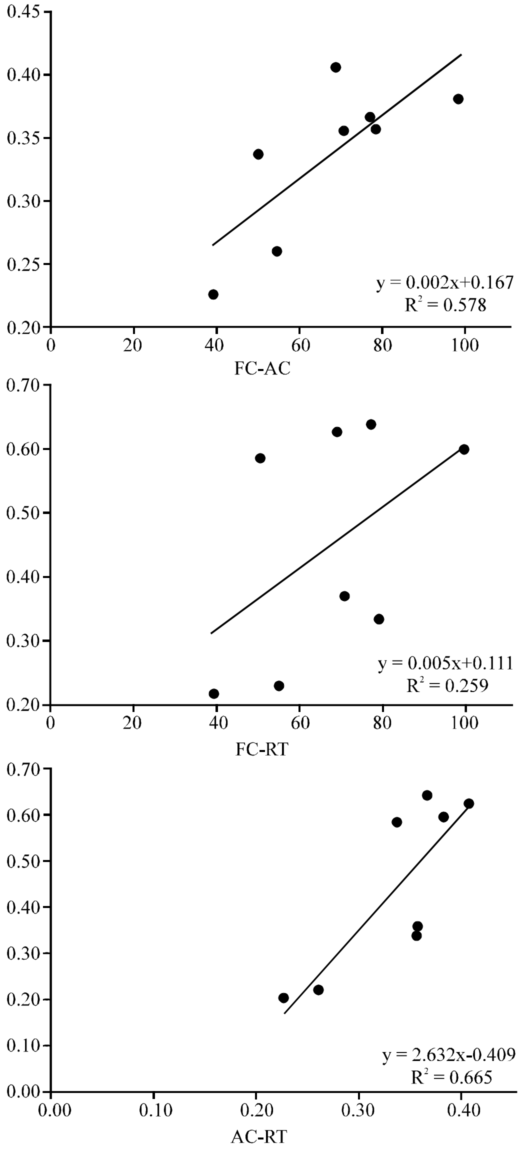

Fig. 3: Mutual comparisons of FC, AC and RT indicators

CONCLUSION

Based on the obtained results the following findings can be described:

- RT and AC indicators reflects flow complexity of the supply chain better than FC due to the fact that the flow complexity metric is based more or less on absolute parameters i.e., it introduces quantitative metric of the structure
- Based on the correlation analysis of FC and RT researchers can state that given indicators have different supply chain complexity estimation concepts
- On the other hand the FC indicator can be applied to evaluate structures using assessed edges. This potential of FC can be effectively utilized when geographic dispersion as one of complexity criterion has to be included
- The correlation analysis between FC and AC showed that these two indicators have similar supply chain complexity estimations

From this analysis, it is clear that the parallel use of alternative indicators may gradually lead to the development of objective evaluation of the structural complexity of supply chains. On the other hand, the results confirm the more or less known fact that a universal measure for the assessment of the complexity of supply chain is probably not attainable in the near future.

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