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Topological Complexity Measures of Supply Chain Networks

Vladimir Modrak[a,]*, Slavomir Bednar[a]

[a]Technical University of Kosice, Faculty of Manufacturing Technologies, Bayerova 1, 080 01 Presov, Slovakia

* Corresponding author. Tel.: +421-55-602-6449; fax: +421-51-773-3453. *E-mail address:* vladimir.modrak@tuke.sk

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Abstract

In this article, we firstly present an architectural framework for supply chain networks. Then, convergent supply chain models that are typical for assembly processes are divided into classes on the basis of the numbers of initial components. Subsequently, selected indicators for measuring topological complexity of assembly process are employed. The indicators used are benchmarked based on computational experiments. Finally, pertinent findings from this exploration are commented and some related future research directions are outlined.

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*Keywords:*Assembly system; Structural complexity; Vertex degree

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1. Introduction

Global supply chain networks are continually developing and expanding nationally. At the same time, supply chain networks are becoming more complex as manufacturing companies expand their economic cooperation. Evenly, assembly supply chains (ASCs) are becoming increasingly complex not only due to technological advancements but also as a result of the changes made to attract more customer interest. Therefore, assembly processes of OEMs must be optimized accordingly in order to increase the performance of the manufacturing system while respecting sustainable manufacturing (SM) principles. SM brings benefits and cost but can make companies more competitive, and in turn bring more resources into the business.

In this paper we consider the problem of topological complexity measurement of convergent assembly processes to find the least complex and sustainable designs in manufacturing area. As first step, we have described a methodological framework for the design of the assembly models based on generation of rooted trees. These supply chain models are divided into classes on the basis of the numbers of initial components. Subsequently, selected two indicators for measuring topological complexity of assembly process are proposed and analyzed. The indicators used are compared and analyzed based on computational experiments.

Finally, relevant findings from this exploration are formulated.

2. Related work

Assembly supply chains can be defined as interconnections of workstations that relate to each other through upstream and downstream linkages, in the different processes and activities that produce value in the form of products in the hands of the ultimate consumer [1]. Competition at company level has been replaced with competition of concurrent supply chains [2]. Performance models and their improvement have to take all chain aspects and processes into account. Moreover, it can be stated that the level of the network consists of facilities and different types of flows (material, information flows, etc.) and contribute to the overall complexity of the chain. The system complexity can be viewed from many aspects, some of which are directly or indirectly linked. In terms of sustainable manufacture it is important to follow and develop designs with minimal negative environmental and economic impact. Therefore, challenges in finding the best sustainable supply chain design is currently subject or researches. The first effective complexity measures have been developed some

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time ago. For example, algorithmic information complexity derived by Kolmogorov [3] and Chaitin [4] is linked with Shannon information entropy [5]. Both theories use the same unit (bit) as a measure of information to describe any system. The more facilities and their uncertain behaviour there are in the system, the more information is needed to describe the structure/system and the bigger is the entropy. Another category is the stochastic complexity applying the concept of minimum description length principle, e.g. [6]. These theories define system complexity as the minimum information description size in bits.

According to Strogatz [7], structural properties of the complex networks are the most basic issues since they always affect the function. Moreover, he added that there are missing unified approaches to underlay and uncover the topology of such networks related to complexity.

Assembly supply chain design and management can be very difficult since different sources of uncertainty are combined with combinatorial and topological aspects of ASCs. Such uncertainty may arise as a result of customer specification and its variability resulting in unreliability at external suppliers, which is normal at customized productions. In this context, various deterministic and stochastic topological models have been developed so far by different authors [8-9] but with no relevant implication on SC control and management while taking the system complexity into account. Possible way to cope with challenges and specific customer needs is through development of effective supply chain performance models and measures to provide them with product in shortest period of time. In order to have that, a mutual comparison of selected structural and axiomatic design-based (AD) measures was provided and graphical and numerical correlations have been obtained in order to decide about the most suitable topological complexity measure of ASCs.

3. Generating all possible assembly structures

Global supply chain networks are continually developing and expanding nationally. Under convergent assembly structure we understand that one in which each node in the chain has at most one successor, but may have any number of predecessors. Such assembly structures can be divided into two types, modular and non-modular. In the modular structure, the intermediate sub-assemblers are understood as assembly modules, while the non-modular structure consists only from suppliers (initial nodes) and a final assembler (end node). The framework for generating topological classes of assembly structures follows the work of Hu et al. [10], who outlined the way forward to model possible supply chain structures with four original suppliers in terms of production variety and in relation to product. Generation of all possible combinations of arbitrary class or rooted trees brings enormous combinatorial difficulties.

Thus, it is also assumed that each such assembly graph satisfies the following conditions. Let t be a node of rooted tree T and there is only one path from t to root r_t. The root has degree ≥ 2. Further we assume that vertex t of T with degree 1 is initial node of a path, and we denote number of initial nodes by i, where $i \geq 3$. Trees with the same number of initial nodes will be grouped in a corresponding class C_i. Finally, it is supposed that each ancestor node of T has degree ≥ 3.

Classes of the rooted trees begin with a class C_3, because the class C_2 is represented by only single graph. The class C_3 represents rooted trees that have initial nodes $i = 3$. In this simple case it is clear that the number of the trees equals two graphs since the number of partitions $p(3) = 3$ and its composition $p_3(3)$ does not meet specified conditions, because the root in given tree has degree 1. Then the number of the trees for the given class follows the expression $p(3) - p_3(3) = 3-1 = 2$. Based on this we can generate of all possible rooted trees (see example in Fig. 1).

Analogically, we can use pertinent partitions of $p(4) - p_4(4) = 5-1 = 4$ to determine an initial set of rooted trees for subsequent class C_4 (see Fig. 2, in the frame).

This class of trees consists also from composition (3, 1) represented by graph No.4. Its part $\lambda=3$ can be partitioned into two partitions (3) and (2, 1) and expressed by formula $p(3) - p_3(3)$. The partition $p_3(3)$ is already represented by graph No. 4 in Fig. 2 and the partition $p_2(3)$ has to be represented by additional graph No.5 in Fig. 2, which is missing to complete all possible graphs in the class C_4. Then a sum of all possible graphs in this class is 5.

Based on above description we can generate so called initial partitions and related graphs for arbitrary class C_i through partitions expressed by formula $p(n)-p_n(n)$. Subsequently, in order to obtain all possible rooted trees for arbitrary class it is necessary to multiple each partition in which at least one part $\lambda \geq 3$ by specific multiplication number as it was shown in case of class C_4.

Then, all possible assembly structures for given number of initial nodes can be created. An example of all possible rooted trees for the classes from C_2 to C_5 is shown in Fig. 3. The rooted tree partition presented in this section is further developed and applied on so called Vertex degree partition developed by authors in Section 4.

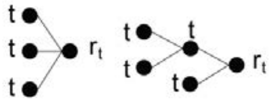

Fig. 1. All possible rooted trees for the class C_3.

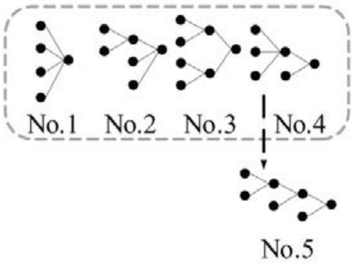

Fig. 2. Initial set and additional graph of rooted trees for the class C_4.