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Evaluation of the Applicability of Random Walks for Generation of Material Flow Network Models

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Abstract

Modeling material flow systems as networks in terms of graphs is a straightforward approach to investigate these systems. In this context, the nodes represent the workstations and the edges indicate a material flow between two nodes. Furthermore, the individual edges are weighted by the amount of material flow that actually takes place between two workstations. The network model is simple but powerful, because it is easy to build and understand, but it also contains the main information required for the analysis of flow in manufacturing systems. Due to the lack of availability of material flow data from industry, it is sometimes necessary to replicate given real networks in order to perform network based research in manufacturing. The majority of available approaches in the literature generate a network by iteratively adding nodes until the desired network size is reached. In most cases the edge weight is not considered, thus there is no information about the intensity of material flow. However, in the context of manufacturing systems there is a movement of individual parts through the system. These parts have a specific order in which they have to be processed. It is therefore essential to simulate the movement of the parts as a whole. For this purpose, we use the concept of random walks. Random walks describe the movement from a random start node to a random end node, whereby the choice of the subsequent steps is also random. We modify the procedure of random walks so that the properties of these walks are based on the characteristics of real material flow networks, such as number of parts (number of random walks), average number of operations (number of nodes visited by a random walk), etc. In this paper, we show how random walks can be used to generate weighted networks, which exhibit similar properties like real material flow networks. Finally, we evaluate our approach by comparing the properties of real material flow networks and the networks generated using random walks.

Keywords: Material flow networks; random walks; modeling

1. Introduction

In recent years, the use of complex networks has proven to be a very simple and effective way to describe the relation of individual elements of complex systems. Typical application fields include social networks (e.g., scientific collaborations), biology (e.g., metabolic networks), and computer science (e.g., Internet topology) [1, 2]. Furthermore, complex networks have also been used in manufacturing for some time, for example, to represent and study material or information flow between individual working stations (i.e. assembly stations, machines, buffers, etc.) [3, 4]. This is known as material flow networks in which the nodes are workstations and the edges denote the flow of materials between nodes. The direction of the material flow is represented by directed edges. As the intensity of the material flow between the individual workstations can vary over time, each edge is commonly assigned a value corresponding to the strength of the connection. This is also referred to as edge weight. Since complex networks are formally described by graphs, a directed, weighted graph results in this way [1].

Currently, the amount of available data for generating such networks is still low, despite the considerable technological advances in production and logistics [5]. In addition, as result

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of confidentiality agreements on the protection of sensitive data, these data can only be accessed by a small group of authorized users [6]. However, such data are required to carry out simulation studies with the aim of planning and optimizing manufacturing systems. In order to overcome this problem of data availability there are two approaches: either one specify assumptions concerning the manufacturing process, or one use data of material flow networks from literature. The second approach has the advantage that material flow networks depict real manufacturing systems. But the majority of these data sets only describe statistical properties of the material flow networks, such as number of nodes and edges or average number of edges of nodes [3, 4]. Additionally, in many cases there is no information about the movement of individual parts through the system (this means that there is no information which machines are needed to do the actual processing of a certain part), but this information are essential for simulation studies. We assume that through the replication of statistical properties of material flow networks, it is possible to draw conclusions on the logistical patterns behind those networks. Therefore, the main objective of this paper is to introduce a new method to generate networks, which are as similar as possible regarding the structure and properties of the original material flow networks known from literature, but not identical in terms of the individual nodes and edges.

In the context of material flow networks, it is noteworthy that these are created through a continuous order routing process. Such dynamic processes on an underlying network can be described by the concept of random walks [7, 8]. Generally, a random walk describes a sequence of visited nodes and is therefore ideally suited to describe the routing of a single order through the system. By the combination of several random walks, we are able to generate material flow networks which are similar to the original networks.

2. Related Work

There is a relatively small body of literature that is concerned with generation of networks using random walks. In general, the generation processes are based on the following two main aspects (e.g. [9-11]): i) the network grows over time through the addition of new nodes ii) the generation of new edges depends on the addition of new nodes and on the properties of random walks, such as the path length of random walks or the selection of the next step. However, this method is only suitable for the generation of unweighted networks and thus is not appropriate for material flow networks.

More often random walks are used for characterization of networks [12], community detection [13] or prediction of missing edges [14]. According to these and similar studies the following parameters may affect the results depending on the application field:

- topological structure of the underlying network,
- random walk path length,
- total number of random walks,
- selection of next step and
- starting point and endpoint of walker.

Since these parameters have not yet been sufficiently analyzed in connection with the generation of networks, its influence on the generation of material flow networks will be investigated in this paper.

3. Using Random Walks for Generating Material Flow Networks

3.1. Data Basis

In order to examine the efficacy and functionality of random walks for generation of material flow networks, we have used two different data sets from complex manufacturing systems, which are based on the job-shop-principle. We decided to use a job shop manufacturing scenario for our investigation because of the way orders are processed in such a manufacturing system. Here, almost each order has both an individual sequence of operations and number of operations. In this way, we were able to freely choose the path length of individual random walks.

Table 1 shows the central characteristics of the two data sets. A more detailed description of the data sets can be found in [4]. We deliberately decided for a small and a large material flow network (identifiable from the number of nodes) to verify whether the approach based on random walks has differing suitability for different sizes of networks.

Table 1. Data set statistics

Data set	Number of nodes	Average weighted in/out-degree	Max. weighted in/out-degree	Min. weighted in/out-degree
A	220	347/347	8570/5473	0/0
B	50	561/561	2831/1950	0/1

According to [15], the network measures listed in Table 1 served simultaneously as a guideline for the evaluation. Thus, the average degree (average number of edges per node) is responsible for the density of a network. The structure of a network is influenced by minimum and the maximum degrees of the overall network. Since the material flow networks are directed and weighted, we used weighted and directed variants of measures discussed above. However, in this paper, we used the ratios instead of the absolute numbers, because we aim to achieve the correct proportions of the topological structure. Since the ratio of min. weighted in- to out-degree for data set A and B is close to zero, it is no longer considered for further analysis.

3.2. Experimental Setup

The aim of this paper is to examine the effectiveness of random walks for generation of material flow networks. The approach consists of two main steps: Firstly, an undirected, unweighted network with same connectivity as the original network is generated. Similar to [16], the connectivity is evaluated by average degree. Secondly, the main parameters for the random walks, which moves on the network from step one, are defined.