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Characterization of Cluster Structures in Material Flow Networks: A Network Approach

Darja Wagner[a,b,]*, Till Becker[a,b]

[a]*Facility of Production Engineering, University of Bremen, Badgasteiner Straße 1, 28359 Bremen, Germany*
[b]*BIBA-Bremer Institut für Produktion und Logistik GmbH at the University of Bremen, Hochschulring 20, 28359 Bremen, Germany*

Abstract

Current manufacturing systems are subjected to a high level of dynamics due to shorter product lifecycles, increasing customer requirements, and high fluctuations in demand. Therefore, present production planning and control is required to react quickly and flexibly to this increasing dynamics. Modern ICT merges with logistics systems and thus drives the transition from centralized to decentralized production control. Within this context, logistic objects receive the ability to communicate with each other and to make autonomous control decisions. Assuming bilateral communication between all entities, a linear increase in the number of entities results in an exponential growth in the coordination effort. To keep this effort as low as possible and simultaneously ensure the achievement of logistical objectives, it is promising to pool several workstations to clusters, so that decision making takes place inside the clusters. Clusters can be formed based on the underlying material flow system, modeled as a complex network. In this context, recent studies have shown that networks of the same class, such as social networks, biological networks, or communication networks have similar characteristics in terms of their cluster structure. We hypothesize that this fact is also applicable to material flow networks. Following, the aim of this paper is the structural characterization of clusters of material flow networks to support the introduction of decentralized control.

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Keywords: Material flow networks; Decentralized control; Cluster structure; Complex networks.

* Corresponding author. Tel.: +49-421-218-50039; fax: +49-421-218-9850030.
E-mail address: wan@biba.uni-bremen.de

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1. Introduction

Increasing complexity and dynamics in current production systems have a direct influence on the logistic targets high schedule reliability, high capacity utilization, short processing time, and low inventory level. The control of these effects with the aim to achieve the logistic targets is the main task of production planning and control (PPC) [1]. In conventional PPC systems all operations are planned in advance. However, the effects of a dynamic production environment can often not be answered satisfactorily. As a result, the logistic performance of the entire system can deteriorate [2]. The deterioration can be counteracted by rescheduling the original production plan. But, the rescheduling requires time to adapt. Meanwhile, the production environment can change again. Therefore, in a dynamic production environment, a control system is required, which is able to respond flexibly to changes [1]. Thus, there is a trend towards the development of autonomously controlled production systems. These enable logistic objects (for example work stations, orders, or parts) to make decisions independently. When implementing autonomous control systems the following three parameters are relevant: control algorithm, technology, and network topology. While many researches have addressed the other two factors, the impact of the topology of the underlying production system has not been adequately studied [3].

For the first time, the interrelation between network topology and autonomous control has been investigated by Vrabič et al. (2012), using methods from the theory of complex networks. Complex networks are commonly used for the analysis of the relationships between various elements of complex systems. To this end, they consist of two elements: nodes and edges. In connection with production systems, the nodes represent the work stations and the edges the material flow between two work stations. In addition, it is possible to assign various properties to the edges. In the context of production systems, the edge weight reflects the amount of material flow between two work stations. The result is a weighted and directed material flow network.

As highlighted by previous studies, there is a positive correlation between network topology and logistical performance. Becker et al. (2012) find a connection between logistical performance and the degree of connectivity in a material flow network, indicating that there is an optimal degree of connectivity. Furthermore, Liu et al. (2013) investigated supply networks with different connectivity structures. The results show that the performance measures order lead-time and efficiency at delivery achieve better outcomes when the supply network have cluster structure. Vrabič et al. (2012) also propose that autonomous units should be formed to clusters. Following, a cluster in this context is a merger of several work stations. As shown in Fig.1, the work stations (nodes) within a cluster are highly interconnected (large number of edges), they have few connections to work stations outside the cluster. So far, there is no information about size and composition of these clusters. However, Lancichinetti et al. (2010) studied statistical properties of different real networks. The results show that networks of the same category are identical with respect to their mesoscopic structure. Material flow networks have not yet been subjected to such an investigation. It stands to reason that these networks have also similar cluster structure. The aim of this paper is the comprehensive characterization of cluster structure in material flow networks. The findings will help in the

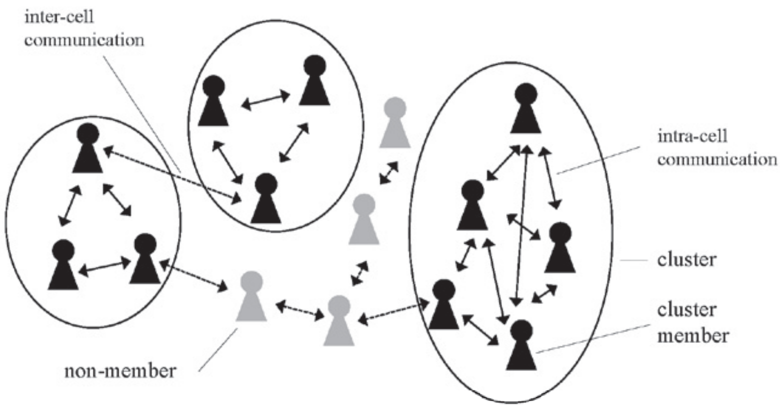

Fig. 1. Communication between work station agents (nodes) in a material flow network containing several clusters [3].