

Chapter 1

# **Autonomous Cooperation as a Method to cope with Complexity and Dynamics? – A Simulation based Analyses and Measurement Concept Approach**

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## **1.1. Introduction**

Over the past years an increase of complexity of production systems has been observed, caused by diverse changes, for example, short product life cycles as well as a decreasing number of lots with a simultaneously rising number of product variants and higher product complexity. To achieve the ability to adapt on these new requirements autonomous cooperating logistic processes seem to be an appropriate method.

In general, it is postulated that autonomous cooperation (AC) is one possible approach to cope with rising dynamics and complexity while by now this assumption has not been sufficiently validated. In this paper the main objective is to contribute to the investigation of the relationship between the performance of AC methods and rising dynamics and complexity.

To fulfil this purpose first AC has to be defined to isolate the object of interest. Secondly by simulation studies within production environments the influence of complexity and dynamics on AC will be validated. Due to the fact that in (real) business systems different degrees of AC exist one further purpose is the development of a measurement concept. Therefore, a first basic concept of measurement of AC will be introduced. With such a tool for measuring AC it is possible to implement AC in the design of business processes to increase the adaptivity for a better dealing with complexity (e.g. mass customization) and dynamic (e.g. real economy). Therefore, AC in business process engineering has at least strategic relevance for the management of business systems [Hülsmann & Wycisk 2005a; Hülsmann & Wycisk 2005b].

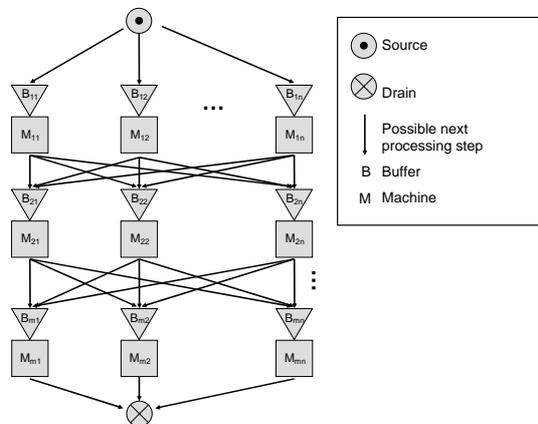
## **1.2. Definition of Autonomous Cooperation**

The idea of autonomous cooperation is based on the idea of self-organization, which origins from different disciplines (e.g. cybernetics [von Foerster 1960], chemistry [Prigogine & Glansdorff 1971], physics [Haken 1973], biology [Maturana & Varela

1980], and mathematics [Peitgen & Richter 1986]. The focus of the study of AC is the autonomous evolution of ordered structures in complex systems. To specify the term ‘autonomous cooperation’ for the following analysis, a working definition is presented. In this paper, AC describes processes of decentralized decision-making in heterarchical structures of logistic processes. It requires that interacting elements in non-predictable systems possess the capability and the possibility of making decisions independently. The implementation of AC aims at an increased robustness and positive emergence of the complete system through distributed and flexible coping with dynamics as well as complexity [Hülsmann & Windt 2006].

### 1.3. Analysis of complexity and dynamics

To analyse the ability of AC to cope with rising complexity and dynamics a simulation scenario is needed that allows to model different but comparable degrees of complexity and dynamics and allows for the application of AC methods. Furthermore it should be general enough to be valid for different classes of shop floor types. For these reasons a shop floor model in matrix format, introduced by Scholz-Reiter et. al. [Scholz-Reiter 2005a], has been chosen, see figure 1. Subsequent productions steps are modelled horizontally while parallel stations are able to perform resembling processing steps. At the source the raw materials for each product enter the system. Each product class has a different processing plan i.e. a list of processing steps that have to be fulfilled on the related machine. In case of overload the part can decide autonomously to change the plan and to use a parallel machine instead. The final products leave the system via a drain.

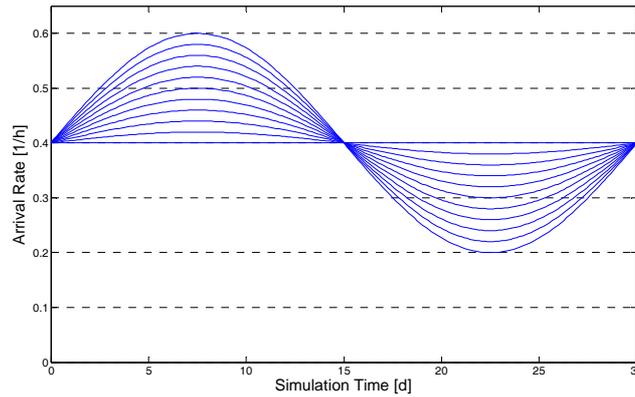


**Figure 1:** Matrix model of a shop floor.

To understand the impact of rising dynamics on the behaviour of the autonomously controlled system different seasonal demand fluctuations are modelled. The amplitude  $\nabla$  of the sinusoidal arrival rate is varied like shown in figure 2. The amplitude rises here from  $\nabla = 0.0$  1/h to  $\nabla = 0.2$  1/h.

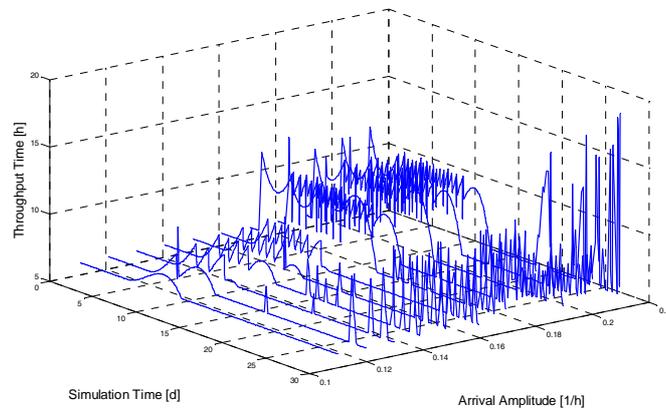
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The resulting throughput times are shown in figure 3. For amplitudes lower than 0.1 1/h, the throughput time remains constantly the minimal throughput time which is in this case equal to the total processing time.



**Figure 2:** Varying amplitudes of the arrival function.

For amplitudes higher than 0.1 1/h, the temporary overload results in an increased throughput time caused by an additional waiting time in the first buffer.



**Figure 3:** Throughput time of product type A for rising amplitudes in the sinusoidal arrival rate

The AC effects start at amplitude of 0.1 1/h. The time series show a more complex dynamics in throughput time when the amplitude of the arrival rate is increased.

In the upper right corner, a beginning destabilisation is observed [Scholz-Reiter 2005b]. For higher amplitudes, the throughput time rises to infinity because of the system's overload.

In a second step the system's ability to cope with rising complexity is analysed. Figure 4 shows the influence of the rising network size on the mean throughput time. The throughput time is measured as the time difference between job release i.e. the

appearance of a part at the source and job completion i.e. leaving the shop floor at the drain. The figure shows the mean throughput time for all parts and all different product classes for AC in comparison to the minimal throughput time which is a linear rising function of the network size because more production steps have to be undertaken as the shop floor size is increased. It appears that the rising system size has no effect on the mean throughput time as the curve is nearly parallel to the minimal throughput time.

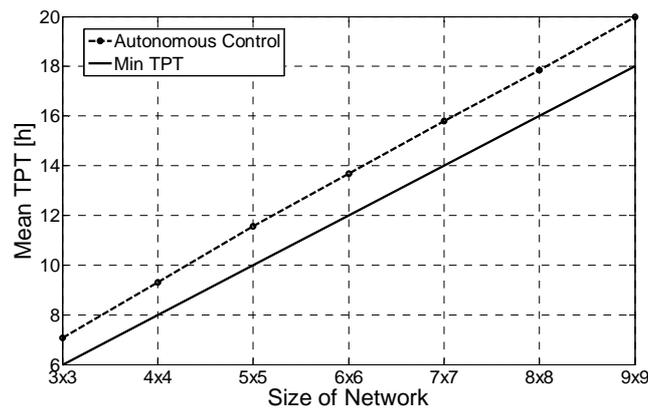


Figure 4: Mean Throughput time for rising system's complexity.

## 1.4. Measurement Concept of Autonomous Cooperation

Due to the verified influences of dynamics and complexity on a logistic system a changing optimum of the degree of AC in logistic processes is assumed. To manage the design of business processes under the usage of AC in its dynamic and complex context of a logistic system, a continuous monitoring is needed to measure the degree of AC on all logistic levels, e.g. for the decision system (management), information system (information and communication), execution system (material and goods flow) [Scholz-Reiter et al. 2004]. The developed measuring and evaluation concept of AC consists of three sub-components that are a scoring model to measure AC, a polarization graph to visualize, a relativization concept to interpret the measured degree of AC [Hülsmann & Grapp 2006].

### 1.4.1. Scoring Model to Measure the Degree of Autonomous Cooperation

In a first step the degree of AC will be measured by a scoring model. In this scoring model the constitutive characteristics of the definition of AC (decentralized-decision-making, autonomy, non-determinism, interaction, heterarchy) [Hülsmann & Windt 2006] are transferred and specified in each case into indicators and key operators for each level of a production logistic system [Hülsmann & Grapp 2006]. A morphological box contains the description alternatively operationalization for the different characteristics [Windt et al. 2005]. Figure 5 illustrates the process of measurement by the characteristic of "decentralized decision-making" at the executive level of a logistic system, which could be specified as local disposition.

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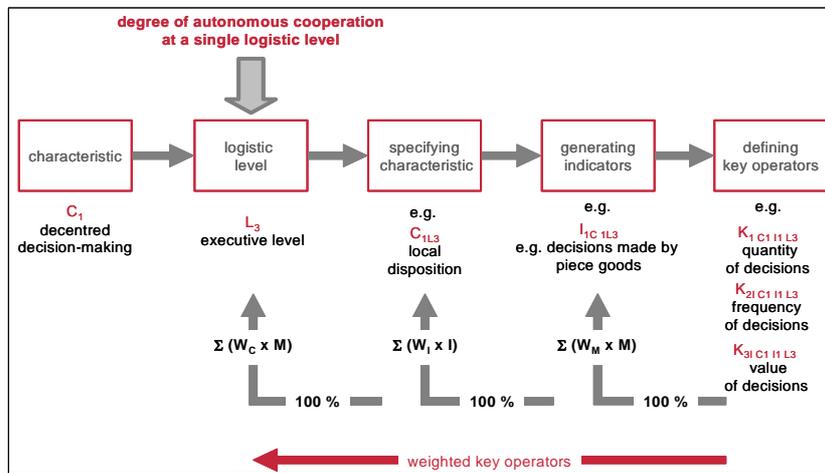


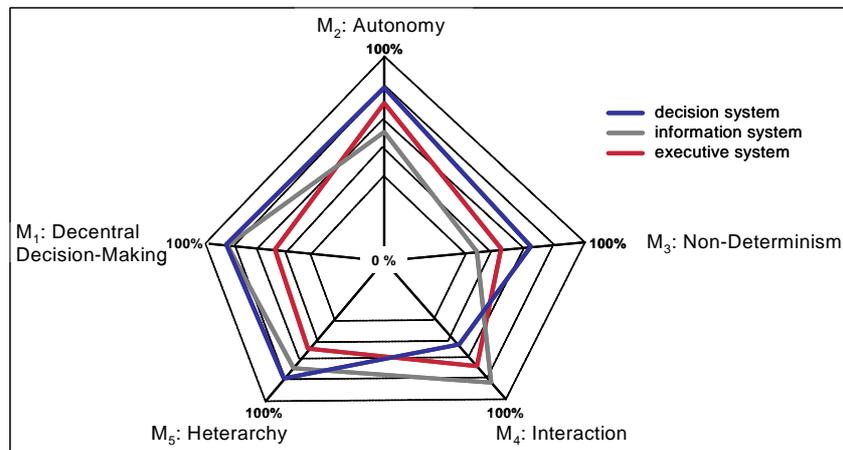
Figure. 5. Scoring Model [Hülsmann & Grapp 2006].

The specified characteristic local disposition will be transferred into indicators e.g. "decisions made by piece goods". Key operators enable to measure each indicator [Orth 1974] such as in the example: quantity, frequency or value of decisions. The sum of all weighted key figures assigns the value of the particular indicator. Finally, the sum of all weighted indicators composes the weighted score of the specific characteristic for the particular level of the production logistic system. To apply the scoring model in practice one possible tool could be a software-based question sheet [Hülsmann & Grapp 2006].

#### 1.4.2. Polarization Graph to Visualize the Degree of Autonomous Cooperation

One way to visualize the measured degree of AC is by using a polarization graph [Hülsmann & Grapp 2006]. The polarization graph represents the measured degree of AC based on its constitutive characteristics: M1: Decentralized-Decision-Making, M2: Autonomy, M3: Non-Determinism, M4: Interaction and M5: Heterarchy (see figure 6). The measured results of each characteristic of AC could be pictured on a scale form from 0 to 100%. A higher percentage indicates relatively more AC and a lower percentage indication stands for relatively more centralized coordination in logistic processes.

Additionally a comparison of different logistic levels of a production logistic system is assumed to be possible regarding their individual degrees of AC [Hülsmann & Grapp 2006]. Figure 6 exemplifies this through differentiating the logistics levels decision system (e.g. management), information system (e.g. information- and communication technologies) and executive system (e.g. the physical flow of products and goods within the logistic process).



**Figure 6.** Polarization Graph [Hülsmann & Grapp 2006].

#### 1.4.3. Relativization of the Degree of Autonomous Cooperation

After measuring the degree of AC a context based interpretation of the gained results are necessary to qualify the validity of the degree of AC in the individual specific complex logistic system. Therefore, a temporal and spatial analysis of AC is planned as a third step of the measurement concept [Hülsmann & Grapp 2006]. The degree of AC can be equal for certain characteristics in different logistic systems. However, the relevance of the respective value differs with an increasing spatial and temporal validity. The score of the measured degree of AC of the scoring model cannot be used to gain perceptions about the quantity of autonomous cooperating elements. It just represents a tendency of more or less AC within a logistic system. Furthermore, due to the logistics systems immanent dynamics it is assumed that the calculated values of the scoring model cannot be considered as absolute. Consequently, the degree of AC should be measured or monitored at different phases in a logistic process [Hülsmann & Grapp 2006].

#### 1.5. Conclusions

The simulation studies show that AC could be an appropriate method to cope with complexity and dynamism. Therefore, AC might be considered in designing business processes which are embedded in complex and dynamic worlds like business processes of logistic service providers. First ideas of a measurement concept of AC are introduced. It might help the business process management to use a certain degree of AC and its specific effects to overcome complexity and dynamics. A further research task is to relate the achieved results of the simulation results to different degrees of AC to achieve specific findings about AC in different contexts and degrees. Therefore, one purpose is transferring the simulation of autonomous controlled processes in logistics to realistic production scenarios and the validation of the results by industrial and business key figures. To manage AC in praxis, a concretion of the represented measuring and

evaluating concept of AC is necessary regarding its key operators and evaluation basis. Concerning the evaluation of AC the real-options-theory could be one possible method to evaluate AC from a financial perspective, which has not been proofed before in this context yet.

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