The Influence of Production Networks' Complexity on the Performance of Autonomous Control Methods

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Abstract
Autonomous control means the decentralised coordination of intelligent logistic objects and the routing through a logistic system by the intelligent parts themselves. This paper analyses the influence of the structural complexity of a production network on the performance of two different autonomous control methods. A matrix model of a shop floor is introduced and used to model different levels of complexity and to simulate the performance of the two different control methods. The simulations results are analysed by comparing statistics on throughput time data resulting from the system's behaviour in dynamic order arrival situations.

Keywords:
Complexity, Autonomy, Shop Floor Control

1 INTRODUCTION

In recent manufacturing industry, production planning and control (PPC) systems have to cope with rising complexity and dynamics [1-3]. One approach to meet these demands is to develop decentralised systems with autonomous control methods to reduce the amount of complexity that has to be taken into account for decision making [4, 5]. Autonomous control means the decentralised coordination of intelligent logistic objects and the routing through a logistic system by the intelligent parts themselves. Therefore it is necessary to develop local decision rules that allow for local autonomous decisions making while the global objectives are reached through interaction and emergent behaviour [6, 7]. In earlier work the authors have developed two different local decision rules that allow for autonomous control [8, 9]. The application of these rules to a shop floor scenario and their ability to cope with rising complexity will be analysed in this paper.

2 COMPLEXITY IN PRODUCTION LOGISTICS

The term complexity is widely used. Generally it does not only mean that a system is complicated. Ulrich/Probst understand complexity as a system feature whose degree depends on the number of elements, their interlinkage and the number of different system states [10]. An observer judges a system to be complex when it can not be described in a simple manner. Here Scherer speaks of subjective complexity [11]. Furthermore he distinguishes between structural complexity which is caused by the number of elements and their interlinkage and dynamic complexity caused by feedback loops, highly dynamic and nonlinear behaviour. It is obvious that complexity can not be measured by a single variable. It is necessary to describe complexity by multiple factors which are interdependent but can not be reduced to independent parameters [12].

In this paper we focus on a system's structural complexity and choose the parameter "number of elements" to vary the degree of complexity within the simulation.

3 AUTONOMY IN PRODUCTION LOGISTICS

The concept of autonomous control requires on one hand logistic objects that are able to receive local information, process this information, and make a decision about their next action. On the other hand, the logistic structure has to provide distributed information about local states and different alternatives to enable decisions generally. These features will be made possible through the development of Ubiquitous Computing technologies [13].

The application of autonomous control in production and logistics can be realised by recent information and communication technologies such as radio frequency identification (RFID), wireless communication networks etc. These technologies facilitate intelligent and autonomous parts and products which are able to communicate with each other and with their resources such as machines and transport systems and to process the acquired information. This leads to a coalescence of material flow and information flow and enables every item or product to manage and control its manufacturing process autonomously [4]. The coordination of these intelligent objects requires advanced PPC concepts and strategies to realise autonomous control of logistic processes. To develop and analyse such autonomous control strategies dynamic models are required. In the following a shop floor scenario introduced by Scholz-Reiter et al. [14, 15] is modified and used to model autonomous processes in a flexible production scenario.

4 SHOP FLOOR SCENARIO

To analyse the ability of autonomous control to cope with rising complexity a simulation scenario is needed that allows to model different but comparable degrees of complexity and allows for the application of autonomous control 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 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.

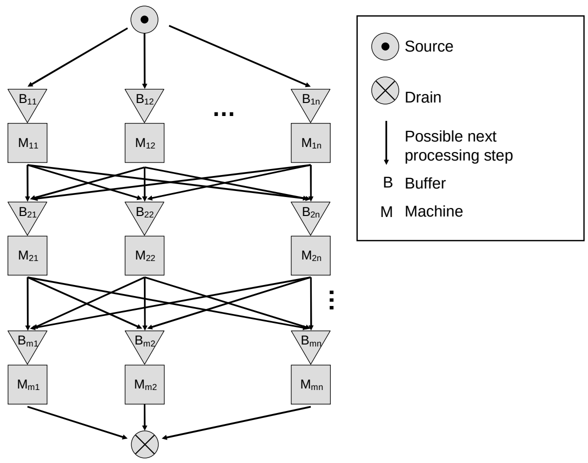

Figure 1: Matrix model of a shop floor.

5 AUTONOMOUS CONTROL METHODS

Two different control methods will be compared. The first method (Method 1) compares the actual buffer states at all the parallel machines that are able to perform its next production steps. Therefore the buffer content is not counted in number of parts but the parts are rated in estimated processing time and the current buffer levels are calculated as the sum of the estimated processing time on the respective machine. When a part has to render the decision about its next processing step it compares the current buffer levels i.e. the estimated waiting time until processing and chooses the buffer with the shortest waiting time.

The second method (Method 2) does not use information about estimated waiting time i.e. information about future events but uses data from past events. Every time a part leaves a machine i.e. a processing step is accomplished, the part leaves information about the duration of processing and waiting time at the respective machine. The following parts use these data about past events to render the decision about the next production step. The parts compare the mean throughput times from parts of the same type and choose the machine with the lowest mean duration of waiting and processing.

6 SIMULATION MODELL

The ability to cope with rising complexity of these two methods for autonomous control will be analysed by varying two parameters of structural complexity. On one hand, the size of the shop floor will be increased from 3x3 to 9x9 machines while the relative number of product classes will be kept constant i.e. the number of different products is equal to the number of parallel lines. On the other hand, the size of the shop floor will be held constant at 4x4 and the number of different product classes will be varied from 4 to 8 different products. The processing plan of the products will be created by random.

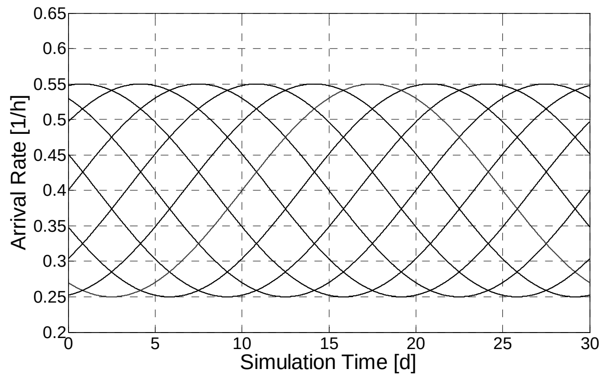

Figure 2: Arrival rate during one simulation period for eight different products.

To model a highly dynamic market situation the demand for the different products is set as an oscillating curve with situations of over and under load. The resulting arrival rates of parts that enter the shop floor is shown in figure 2.

As simulation period 30 days are chosen. After a phase of two month for avoiding transient effects the third month is used to measure the throughput times of every singe part that is finished.

For balancing conditions the minimal processing time per manufacturing step is equally 2 hours. This minimal processing time can only be reached if the parts follow exactly the pre-planned processing plan without taking into account the current situation on the shop floor. If the parts decide to use parallel machines instead the throughput time will rise because of transport processes and set up times and higher processing times on parallel machines. This additional time depends on the number of parallel machines that are available for a production step. The additional time t_b is calculated by the distribution of one hour over the number of parallel machines:

$$t_b = 1h / N \tag{1}$$

7 SIMULATION RESULTS

For simulation a discrete event simulator is used. Figure 3 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 the two different autonomous control methods. Additionally the minimal throughput time is shown 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 for method 1 as the curve is nearly parallel to the minimal throughput time. Method 2 on the other hand shows a more and more worse performance as the mean throughput time rises exponentially with increasing network size.

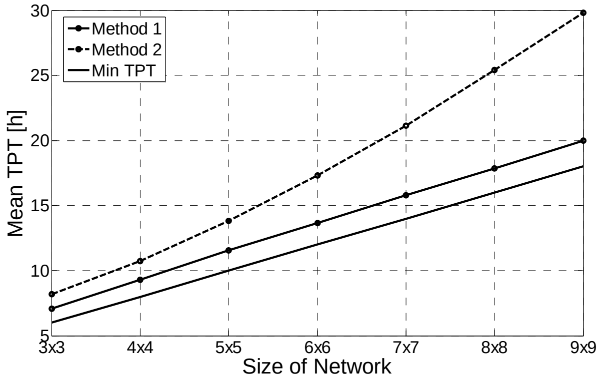

Figure 3: Mean throughput time for different network sizes.

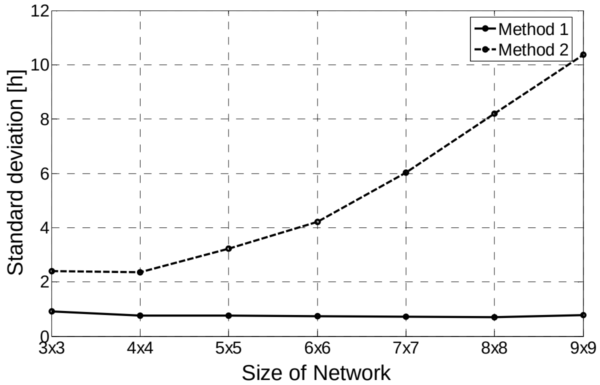

Figure 4: Standard deviation of the throughput time for different network sizes.

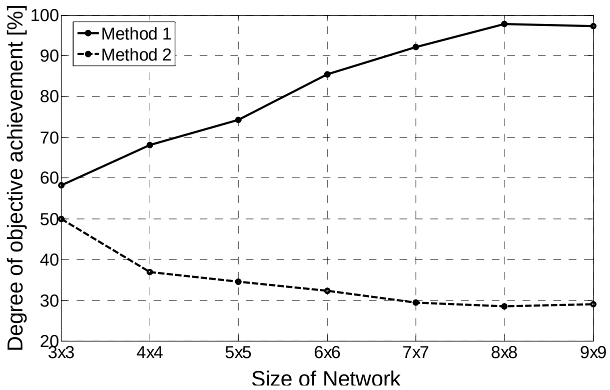

Figure 5: Fraction of parts that are finished within 120% of the minimal throughput time for rising network size.

One realizes the same effect in the standard deviation of the throughput times which is displayed in figure 4. With rising network size the standard deviation is even decreasing for method 1. For method 2 also the standard deviation of the through put time is rising with higher network size.

The mean and the standard deviation are important measurements for the predictability of the throughput time and therefore essential for the due date reliability. Figure 5 shows the fraction of parts that are finished within 120% of the minimal throughput time. For method 1 this fraction rises with larger network size while for method 2 this fraction decreases. This follows directly from the data for mean and variance. For method 1 mean and variance have a constant run. Therefore more and more parts are within the tolerance limit of 120% whose absolute value is rising analogue to the minimal throughput time. Accordingly the decreasing run of the

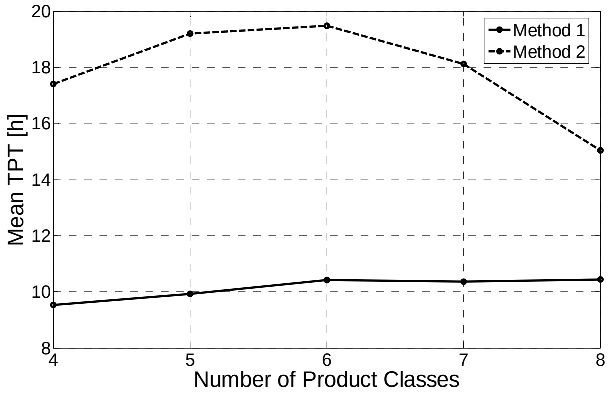

Figure 6: Mean throughput time for different number of product classes.

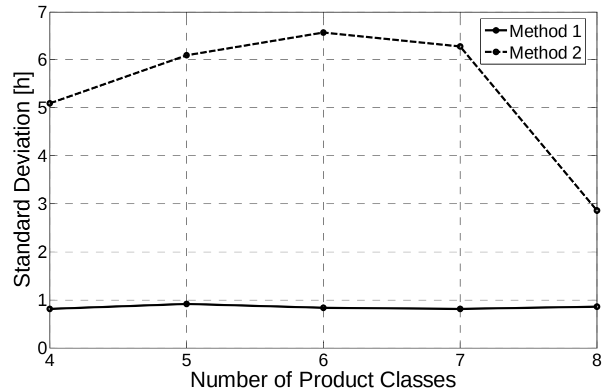

Figure 7: Standard deviation of the throughput time for different number of product classes.

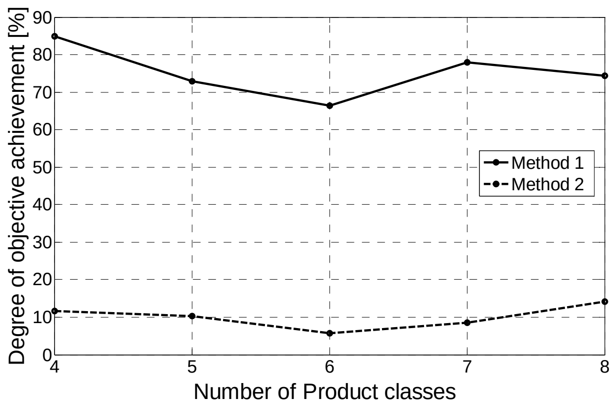

Figure 8: Fraction of parts that are finalised within 120% of the minimal throughput time for different number of product classes.

curve for method 2 follows from the data about mean and variance.

In a second step the number of different product classes is varied. Figure 6 shows the mean throughput time within a 4x4 shop floor for four to eight different products. Again method 1 shows a better performance than method 2 but a trend is observed that for a rising number of product classes the performance of method 2 is getting better. The same effect can be seen in figure 6 were the standard deviation of the throughput time is shown and for seven and eight product classes method 2 is showing a decreasing standard deviation. Figure 8 underlines this effect in showing the fraction of parts that are finished within 120% of the minimal throughput time and which is rising for method 2 from six to eight different products.

8 INTERPRETATION

The appliance of method 1 shows a constant performance in face of rising structural complexity i.e. a higher number of machines on the shop floor while method 2 is not able to maintain a sufficient performance. An exponential increase in mean and standard deviation of the throughput times is observed. This is also caused by the fact that with a rising number of machines the number of possible parallel machines is increased and therefore the switching onto other less utilised machines is facilitated. Because method 2 shows in general a more slow behaviour than method 1 the ability to switch more frequently is not exploited. In the second case of a higher number of different product classes than parallel machines also the order arrival is modified. Because the mean utilisation should be comparable the mean arrival rate has to be lowered every time a new product class is added to the model. Therefore the higher number of product classes causes also a more balanced utilisation of the system. This reduces the possibility and the necessity to change the processing plan and to move to a parallel machine. This improves the situation for the slower method 2 and allows for a trend to better results at a higher number of product classes. The major difference between the two methods is the character of the used information. Method 1 uses information about future events i.e. estimated processing times while method 2 uses information about past events. Because method 2 calculates a mean value of the past throughput times this method reacts more slowly on highly dynamic situations with fast changing system conditions. This causes fewer switches to parallel machines.

As a result one can state that in situations of a high number of machines that have to be equally utilised method 1 is more advisable because it shows a constant performance despite rising structural complexity. Method 2 shows here a decreasing performance. In case of a high number of different products method 2 could be an alternative. In particular when the trend is extrapolated method 2 could show a better performance than method 1.

6 Summary and Outlook

In this paper the ability to cope with rising complexity of two different autonomous control methods has been compared. Thereby different trends have been determined. Method 1 shows a constant performance at rising system complexity. It is obvious that systems of this size can also be controlled by traditional centralised PPC systems. But, if one extrapolates the trend there will be certainly a critical size were the constant performance of method 1 is superior to a centralized PPC method.

Method 2 shows a slowly reacting behaviour and could be an alternative if it is not favourable to have permanent processing plan changes. Furthermore the quality and dependability of data used by the two methods have not been taken into account. It seems to be realistic that information about past events is more reliable than information about future events. The smaller error in the information could further improve the performance of method 2 in comparison to method 1. This will be the topic of further research.

9 ACKNOWLEDGMENTS

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10 REFERENCES

[1] Tönshoff, H.K., Herzog, O., Timm, I.J., Woelk, P.-O, 2002, Integrated process planning and production control based on the application of intelligent agents. 3rd CIRP Int. Sem. on Intelligent Computation in Manufacturing Engineering – CIRP ICME ’02, Ischia(Naples), 3-5 July: 135-140

[2] Kim, J.-H., Duffie, N. A., 2004, Backlog Control for a Closed Loop PPC System. Annals of the CIRP, 53/1: 357-360.

[3] Scholz-Reiter, B., Windt, K., Freitag, M., 2004, Autonomous Logistic Processes: New Demands and First Approaches. 37^{th} CIRP Int. Sem. On Manufacturing Systems – CIRP ISMS ‘04, Budapest, 19-21 May: 357-362.

[4] Scholz-Reiter, B., Peters, K., de Beer, C., 2005, Autonomous Control of Shop Floor Logistics. Chryssolouris, G.; Mourtzis, D. (ed.): Manufacturing, Modelling, Management and Control 2004, IFAC Workshop Series, Elsevier Science, Amsterdam

[5] Scholz-Reiter, B.; Freitag, M.; de Beer, Ch.; Jagalski, Th., 2005, Modelling dynamics of autonomous logistic processes: Discrete-event versus continuous approaches. Annals of the CIRP 55/1: 413-417

[6] Ueda, K., Markus, A., Monostori, L., Kals, H.J.J., Arai, T., 2001, Emergent synthesis methodologies for manufacturing. Annals of the CIRP, 50/2: 535-551

[7] Parunak, H. van Dyke, 1997, Go to the Ant: Engineering Principles from Natural Multi Agent Systems. Annals of Operations Research, 75: 69-101

[8] Scholz-Reiter, B., Freitag, M., de Beer, Ch., Jagalski, Th., 2005, Modelling and analysis of autonomous shop floor control. 38th CIRP Int. Sem. on Manufacturing Systems – CIRP ISMS ’05, Florianopolis, 16-18 May, CD-ROM.

[9] Armbruster, D., de Beer, C., Freitag, M., Jagalski, T., Ringhofer, C., 2006, Autonomous control of production networks using a pheromone approach. Physica A 363: 104–114.

[10] Ulrich, H., Probst, G., 1988, Anleitung zum ganzheitlichen Denken und Handeln, Haupt, Bern/Stuttgart.

[11] Scherer, E., 1998, The Reality of Shop Floor Control – Approaches to Systems Innovation. Scherer, E. (ed.): Shop Floor Control – A Systems Perspective, Springer Verlag, Berlin.

[12] Schuh, G., 2005, Produktkomplexität managen. Carl Hanser Verlag, München.

[13] Fleisch, E., Kickuth, M., Dierks, M., 2003, Ubiquitous Computing: Auswirkungen auf die Industrie, Industrie Management 19/6: 29-31.

[14] Scholz-Reiter, B., Hamann, T., Höhns, H., Middelberg, G., 2004, Decentral closed loop control of production systems by means of artificial neural networks. 38th CIRP Int. Sem. on Manufacturing Systems – CIRP ISMS ’04, Budapest, 19-21 May: 199-203.

[15] Scholz-Reiter, B., Wirth, F., Freitag, M., Dashkovskiy, S., Jagalski, Th., de Beer, Ch., Rüffer, B., 2005, Some remarks on the stability of production networks. In: Proc. of Operations Research 2005.