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Autonomous Shop Floor Control Considering Set-up Times

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Abstract

In this paper, a new autonomous control strategy, which incorporates both (1) expected waiting times based on local information about buffer levels at hand and (2) the experience of predecessor parts' decisions, i.e. a pheromone-based decision making process will be presented. This new autonomous control strategy will be applied to a general production logistic scenario with set-up times. Furthermore, its effects on the performance of the system will be analysed.

1 INTRODUCTION

In order to cope with increasing dynamics and complexity, production planning and control systems have seen the introduction of autonomous control strategies. In accordance to the definition of autonomous control [1], the term can be understood as decentralised coordination of intelligent logistic objects and the routing through a logistic system by the intelligent objects themselves. For scenarios with varying processing times and without set-up times, different autonomous control strategies have been developed, i.e. the queue length estimator [2, 3], which is based on local information about buffer levels and thus expected waiting time and a pheromone-based approach [4, 5]. It was shown that these approaches can lead to shop floors, which can adapt themselves to changing work loads and unexpected disturbances [2, 3, 5]. In the following, the focus is on autonomous control of a shop floor scenario with set-up times. In a pheromone-based concept, set-up times are somewhat hard to handle because predecessors' decisions have influence on successors, which is ordinary not communicated by the pheromone. Hence, a correction term is introduced. With this correction term it is possible to implement a new autonomous control strategy, which includes a weighted combination of the queue length estimator and the pheromone strategy. This new autonomous control strategy is promising as it offers the possibility to describe and adjust the trade-off between performance and structural complexity the two can not solve separately [6]. The scenario is simulated with the continuous System Dynamics methodology as it is able not only to store the moving average of the throughput times for each part on each buffer-machine system [4], but also to implement a feedback loop for the pheromone concentration according to current data during the simulation.

2 THE SCENARIO

The considered shop floor is a matrix-like flow-line manufacturing system producing k different products at the same time. Each of the products has to undergo m production stages. For each of these production stages there are n parallel production lines available. Therefore, the shop floor consists of mxn machines. The raw materials for each product enter the system via sources and the final products leave the system via drains. The production lines are coupled at every stage and every line is able to process every type of product within a certain stage. At each production stage a part has to make an autonomous decision to which of the lines to go to in the next stage. Each machine has an input buffer in front, containing items of the k product types (for the topology cf. [2, 3]). It is assumed that each machine at each stage has the same processing time for each product and different set-up times for the cases it has to switch product types. Thus, the machines' service rule for the different product types is important; for the time being, it is assumed to be first in - first out (FIFO).

2.1 Pheromone-based control in a scenario with set-up times

The parts' decisions are based on backward propagated information about the throughput times of finished parts for different routes. Routes with shorter throughput times attract parts to use these routes again. This process can be compared to ants leaving pheromones on their way to communicate with following ants. As in other pheromone concepts [7, 8], the communication takes place indirectly by changing the environment. In this model the parts have to be able to access updated information about throughput time only. Thus, the pheromone-based strategy differs from approaches from ant colony optimization (ACO, e.g. [7]) since there is no self-reinforcing guided search process for optimal solutions. The pheromone concentration depends on the evaporation of the pheromone and on the time previous parts had to spend waiting in the buffer in addition to the processing time on the respective machine as well as the throughput time. Clearly the fine-tuning of the evaporation constant for the pheromone is crucial. Here it was chosen in order to minimize buffer levels. In a pheromone-based concept, set-up times are somewhat hard to handle because predecessors' decisions have influence on successors, which is ordinary not communicated by the pheromone. This is because the pheromone concentration does not include information about the set-up status of the respective machine. The following simulations will point this out.

3 SIMULATION RESULTS

In order to handle the complexity, the simulation model is reduced to 3x3 machines producing 3 different products. The set-up times are shown in Table 3.1. The arrival functions for the three product types are defined as sine functions. They are identical except for a phase shift of 1/3 period and modelled in a way that every 2:24 h a new part of every type arrives. The processing times for each product are the same: 120 minutes.

Table 3.1. Set-up times on the differrent machines.

Set-up times [min]		Machine	
	M_{m1}	M_{m2}	M_{m3}
A -> B	30	10	60
A -> C	60	30	10
B -> A	10	60	30
B -> C	60	30	10
C -> A	10	60	30
C -> B	30	10	60

3.1 A simple pheromone strategy

For simplicity the aggregated buffer levels of the first production step are considered only because the following stages act qualitatively in the same way. With a simple pheromone-based strategy the model does not perform in a satisfactory manner (cf. Figure 3.1). The maximum buffer is at 13.86 pieces and the mean buffer level is 8.65 pieces with a standard deviation of 6.11 pieces.

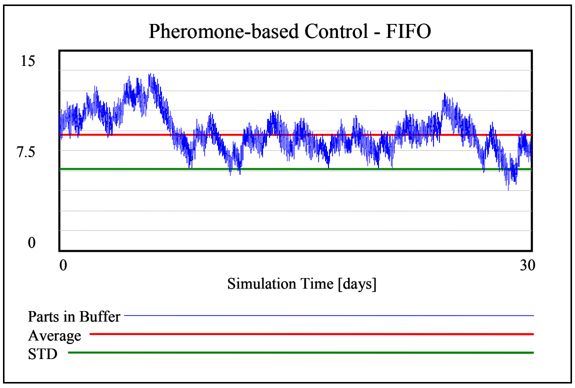

Figure 3.1. Simple pheromone strategy and FIFO service rule.

For two reasons this performance seems to be improvable: The pheromone concentration does not include information about the set-up status of the machine and, because of the FIFO-rule, a part's decision can be both, good or bad, depending on how many set-ups the machine has to perform before the part can be processed. The second reason is not included in the pheromone concentration either. Thus, in a first step, the FIFO-rule is replaced.

3.2 Pheromone strategy with adjusted service rule

Figure 3.2 shows the buffer levels for the pheromone strategy and a service rule, which enables the machines to select autonomously, which part to process next. The performance is very well: The maximum buffer level is reduced to 8.83 pieces. The mean buffer level is 5.77 pieces with a standard deviation of 3.88 pieces. The implementation of an automomous decision strategy for the machines instead of the FIFO-rule (cf. 3.1) leads to improved performance. The next problem to solve is that the pheromone does not include information about the set-up status so far.

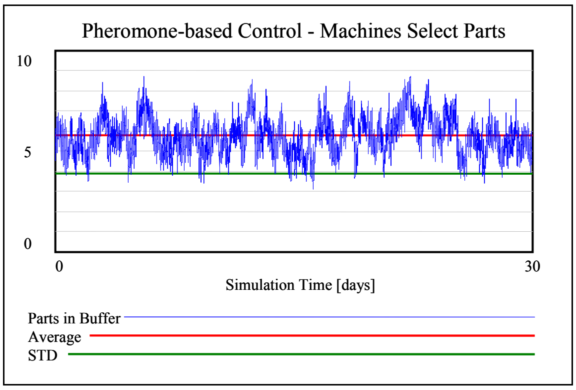

Figure 3.2. Simple pheromone strategy and adjusted service rule.

2.3 Pheromone strategy with correction term

The pheromone based strategy is improved by a correction term that includes information about the product type a machine is set-up to after a part has been processed. This can not be done by simply leaving a higher amount of the pheromone because this additional information should effect a direct successor's decision only. A higher pheromone quantity would evaporate over time according to the evaporation constant leading to bad information for the next but ones' decisions. Thus, the correction term consists of an increasing of the pheromone concentration but with a higher evaporation constant. Adjusting this higher evaporation constant to the execution time (processing time plus set-up time) of the next part on a particular machine, the pheromone-based control strategy performs better (cf. Figure 3.3). Compared to the pheromone strategy without correction term (cf. 3.2) the maximum buffer level is reduced to 8.55 pieces and the mean buffer level to 5.51 pieces with a standard deviation of only 3.67 pieces. This pheromone strategy with correction term together with the improved service rule offers the basis to develop a new and sophisticated autonomous control strategy.

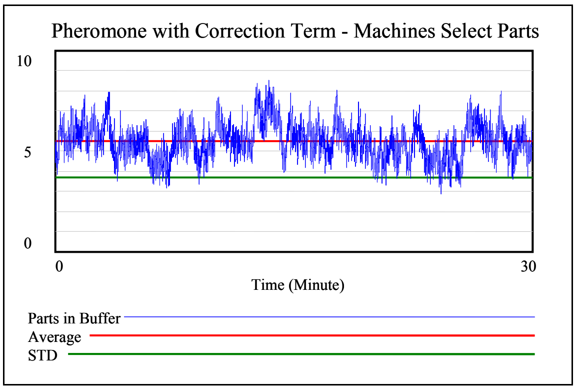

Figure 3.3. Pheromone-based autonomous control strategy with correction term.

3.4 New autonomous control strategy

A new autonomous control strategy is proposed: a part's decision is based on a weighed combination of the queue length estimator method and the pheromone-based method. Both methods have shown their performance capabilities in different scenarios [2-5]. On the other hand, their degree of logistic goals achieved differs in scenarios with rising structural complexity. The pheromone strategy shows a diminishing degree of logistic goals achieved when the structural complexity rises. The queue length estimator method's degree of logistic goals achieved is hardly affected by rising structural complexity [6]. Thus, the combination of the two strategies is promising. Figure 3.4 shows the aggregated buffer levels of the first production stage for this new autonomous control strategy. The performance of this new autonomous control strategy is excellent. The maximum buffer level is reduced to 8.21 pieces and the mean buffer level to 5.44 pieces with a standard deviation of only 3.55 pieces.

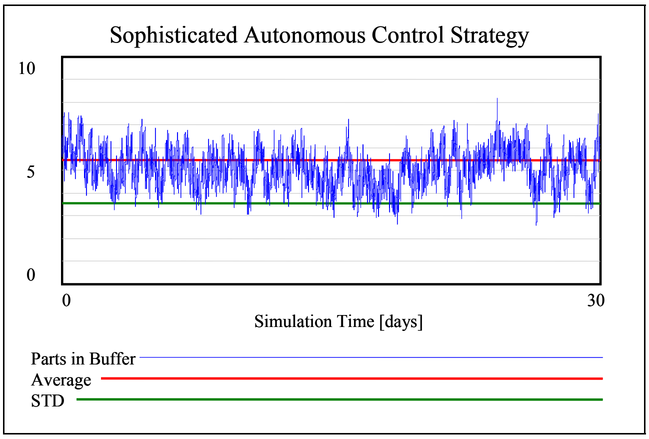

Figure 3.4. New and sophisticated autonomous control strategy.

4 CONCLUSIONS

It was shown that pheromone-based autonomous control strategies can be applied to shop floor scenarios with set-up times. The obvious obstacles, the inadequate FIFO-rule as well as the problem, that the pheromone concentration has to include information about the set-up status of the machine, were overcome by an adjusted service rule as well as by the introduction of a correction term for the pheromone concentration. With that, a new autonomous control strategy that incorporates a weighted combination of the pheromone concentration with correction term and the previously introduced queue length estimator method could be introduced. This new autonomous control strategy outperformed the other strategies. Further research comprises the capability of this new autonomous control strategy to analyse the trade-off between performance and behaviour in scenarios with different structural complexity.

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