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Conceptual Approach of Robustness in Logistical Control

Alexander Bader[1], Ann-Kathrin Onken[1], Kirsten Tracht[1,2]

[1]University of Bremen, Bremen Intitute of Mechanical Engenieering (bime), Badgasteiner Str. 1, 28359 Bremen, Germany
[2]MAPEX Center for Materials and Processes, University of Bremen, Bibliothekstr. 1, 28359 Bremen, Germany

Abstract

The logistical control and order release of structurally dynamic systems represent a great challenge. In contrast to classical shop floor production, these systems can involve transitions between the two different organizational forms job shop production and flow production. This results in a system that is susceptible to turbulence and malfunctions. This paper presents an approach that improves the robustness of these systems and achieves a stable system state even under external influences. Decentralized stock control loops control the WIP of the individual stations in a closed loop. When organizational transitions occur, interlinking losses arise, which reduce the productivity of the system. Similar effects can cause disturbances and blockages. The introduction of a robustness controller adapts the input parameters of the order release to the current system status, so that an adapted reaction takes place in the event of strong disturbances.

Keywords

Production Planning; Robustness; Logistics; Manufacturing system

1. Introduction

The fulfilment of customer requests is one of the most important objectives in production. Changed market conditions and target audiences during the distribution of high-quality products lead to flexible mass production. As a result, a challenge arises to develop an adjusted system of production, which deals with a high variety of products whenever the quantity of individual variants declines [1]. Flexible manufacturing systems are used for instance, to operate the production system with a high capacity. The increasing use of flexible and scalable assembly lines leads to further development from flexible manufacturing systems to reconfigurable production systems [2]. In order to fulfill the customer requests, the flexible mass production is developed into a personalized production [3]. One aspect of these systems is the different working stations, which can be freely interlinked and adjusted to the individual product or variant. A similar system design can be found while looking at the high-throughput system used for the development of new structural materials [4]. The free interlinkage of the working systems found in these high throughput systems requires a change of the organizational structure of the different sections of the system. These so-called temporarily paced sequences describe a shift from job shop production to flow production [5]. Thus, the productivity advantages of the flow production are linked with a flexible job shop production. This results in a complex material flow, which in turn increases the overall complexity of a system. Due to this, the sturdy design of these systems presents a particular challenge, as they need to be especially resistant to external influences, so that the systems are still able to achieve a high productivity, despite complex and volatile surrounding conditions. In this context, other challenges are the order authorization and the logistical control. These systems are among those for which it applies that a high flexibility of the system is achieved by short lead

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times with low circulating stocks. In this paper, an approach is presented, which is used to design an order release and a logistical control for dynamic production systems, which in turn will prevent capacity loss and performance loss in the case of malfunctions and ensure the robustness of the system. The presented multidimensional order release prevents an upward oscillation of the production system and can avoid capacity losses.

2. Robustness in Production Systems

2.1 Definition of Robustness

The term *robustness* can be found in various disciplines with different cases of application. No matter in what discipline it is used though, robustness is generally understood as something having resistance towards malfunctions or as a sensitivity of the quantity of results of input controls [6]. For instance, in biology, robustness encourages the development of organisms, as these can survive and evolve in unpredictable environments [7]. With regard to an assembly line, robustness can be understood as the ability to be able to reach the planned production output, despite possible malfunctions, changing working conditions, or faulty components [8]. Thus, the robustness of an entire supply chain stems from the robustness of individual assemblies, as well as from the communication and interaction between business partners. Each of these aspects has to be taken into account whenever a robust supply chain is established, as a single unreliable supply partner is able to reduce the robustness of every other following partner of the supply chain [9].

[9] describes robustness as the ability to deal with turbulence while maintaining system performance on a high leverage. This robustness is achieved by resistance to disturbances. If a major malfunction occurs, the system is adjusted, after which the system if returned to its original state. It is also possible for the system to learn from said malfunctions and to be permanently changed, so that similar malfunctions, that may occur later, are less serious [9]. Furthermore, it is possible to react to a change of circumstances adequately, in order to minimize the damage and to further handle customer requests satisfactorily. In literature, this is known as flexibility or variability, even though the differences are not always well defined. While flexibility is only concerned with the changes within a defined structure, variability refers to changes beyond that structure. An example for flexibility is the use of a replacement machine in the case of the malfunction of the machine that was originally intended to be used. This fixed structure is not present when looking at an agile system. This kind of system is able to adapt to unpredictable events without a prior defined procedure, by developing alternative actions whenever a malfunction occurs [10]. In contrast, according to [6], a stable system abides to the defined schedule, even in the event of a malfunction. This schedule does not only include the position of orders, but also other features, such as the regulation of delivery dates, times for the order authorization for suppliers, or the planning of equipment, as for example tools. Thus, the performance of a stable system depends on the quantity of planned orders [6].

Robustness is generally understood as a resistance against malfunctions. However, it is essential to define the term malfunction more concretely. In the VDMA 66412, interruptions that are caused by malfunctions are defined as periods, that occur during order processing and extend the occupancy time unintentionally [11]. Within a production process, this usually describes, among others, machine failures, changes of production structures, problems with quality, missing tools or parts, or the occurrence of urgent orders. In addition, during the execution of production plans, error occur, which tend to be caused by missing organizational discipline, and can lead to a lengthening of the occupancy time and a reduction of the performance of the production system [12,13,9].
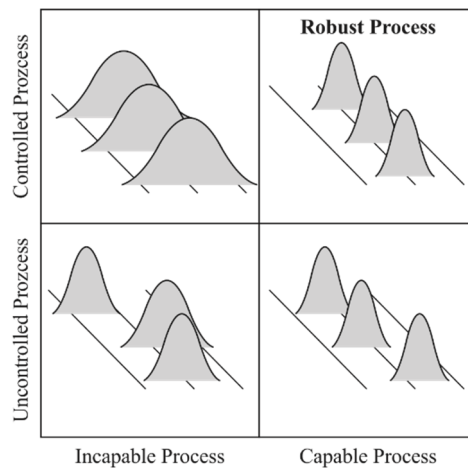
Figure 1: Process characteristics of a robust system [14]

Therefore, it is possible to describe robustness as a combination of controlled and capable system characteristics in a production engineering context [6]. In both cases, the spread of the output value and spread of the result quantity of one process differs from one another, as it can be seen in the figure. In this context, while controlled processes are characterized by a consistent mean, capable processes are defined by a minimal process scatter. Thus, the combination of both can be understood as a robust system.

2.2 Robust Optimization

For the calculation of robustness, [15] use the correlation between robustness and the performance of the network with varying malfunctions. For this, the production system is modeled and the addressed malfunctions are simulated with the help of a discrete event simulation. During such a simulation, all resources and entities are simulated, while the system status only changes during defined events and defined times. Thus, an interaction between multiple entities at arbitrary times is impossible, which is why a distinction can be made between discrete event simulations and agent-based modelling. A significant advantage of the discrete event simulation is the comparably short processing time [16]. Furthermore, the performance of the network is measured with the help of a priory defined key performance indicators (KPI) [15]. Examples of such a KPI are the capacity of the machines, an average processing time, and an average delay of orders [17]. All malfunctions have a cause, which can be further analyzed. Moreover, it is possible to interfere with the system, in order prevent malfunctions or to reduce the extend of said malfunction. Each of these interferences significantly changes the production model. In order to measure the impact each interference has on robustness, an interference is integrated in the simulation model, so that the KPI can once again be captured. Due to the summation of all relevant and independent KPI to a single figure known as aKPI, it is possible to compare the robustness of both systems and to measure the increase of robustness caused by an interference [15]. According to [17], it is possible to generate robustness through an excess of operational capacities of equipment or through the creation of redundancies of equipment. Both options generate costs, which is why it is necessary to find a balance between robustness and generated costs for each individual system. The higher the robustness is, the higher are the costs und the efficiency of the system [17].

3. Logistical Control of Dynamic Systems

In production control, important information for processing orders, such as type, quantity, sequence, quality, and the time distribution of products, is defined. Thus, production control is the link between long-term production program planning and short-term operative execution [18]. In addition to controlling planned orders, production control must also react to random disturbances without compromising the fulfillment of

logistical targets. This is only possible if production control has been set up according to certain principles. [19] divides production control into tasks, manipulated variables, controlled variables, and target variables. The tasks are divided into order generation, order release, sequence planning, and capacity control. When implementing production control in a production system, it is essential to select suitable control variables. This includes the entries and exits, as well as the sequence of the orders. The planned values are defined in production planning and compared with the actual values from production control. Furthermore, the backlog and the stock, which is also to be seen as the logistical target variable, are used as control variables [19]. This special role of work in progress in a production system and its good controllability gives it a special status in order release procedures.

Order release for logistic control can be divided into the two different approaches of push and pull principles. According to [20], due to several specific differences, pull systems are generally preferable to push systems due to the consideration of the throughput instead of the stock when releasing the order. The main reason for the higher performance of pull systems compared to push systems is the several beneficial effects resulting from the limited work in-progress. This reduces capital commitment costs, lead times and the schedule performance with decreasing stocks. At the same time the reaction time of the production decreases, since changed release decisions have a faster impact on the rest of the production due to the shorter throughput times. In addition to reducing break in material flow, this leads to a smoothing of peak loads and thus helps to avoid bottlenecks. According to the authors, this significantly simplifies the control of pull systems compared to push systems. In [21] they make clear that pull systems are much more robust against a false estimation of the existing capacity, since they restrict the existing stock explicitly. In push systems, on the other hand, such a false assessment leads to an unlimited build-up of stock in the affected work system. This has correspondingly negative consequences for the lead time and thus the future adherence to schedules.

4. Multi Dimensional Extremum-Seeking Logistical Control

In production planning and control, the order release is the central method of controlling the load in a production system. In the event of disturbances and external influences from the production environment, the performance of the production system changes, for example, due to delays in order processing or logistical blockages within the system. In this way, critical system states can arise in which a significant decline in performance and thus a reduction in capacity utilization and productivity occurs. A specific order release for corresponding system areas shortens the effects of the critical system states or reduces them. The result is a system that is robust against breakdowns and that, despite its high complexity, has a high level of productivity. The occurrence of organizational transitions, for example in the form of temporarily paced sequences, results in a complex planning and control system that leaves the operating point of the system, for example due to breakdowns or material bottlenecks. A robust, logistic control system can identify critical system states and a control system can stabilize the system by means of a targeted order release. This prevents a continuation of the disturbance effects along a process chain and ensures the achievement of objectives.

The consideration of order release as a control engineering system leads to a differentiated decision in order release with regard to the load of individual stations or system sections. Additional order control elements are used to adapt controller parameters to the current system status. For example, a pacing controller can delay the processing release until the paced sequence is reset. In order to achieve a stable system state, it is essential to avoid turbulences caused by organizational transitions and to reduce the effects of disturbances. Studies show that an adapted method for order control reduces interlinking losses due to temporary pacing in particular. Despite this specific release of paced sequences, the method does not completely prevent blockages and does not achieve a high utilization level at all stations [22]. From these studies, it can be deduced that in particular the highly complex material flow is not completely controlled by the applied control system. The undirected material flow leads to an uneven load in the system. Many process chains

begin with processing at a selection of a few stations, but then have different processes and focuses. The inventory control loops selected there are not sufficient to counteract this effect.
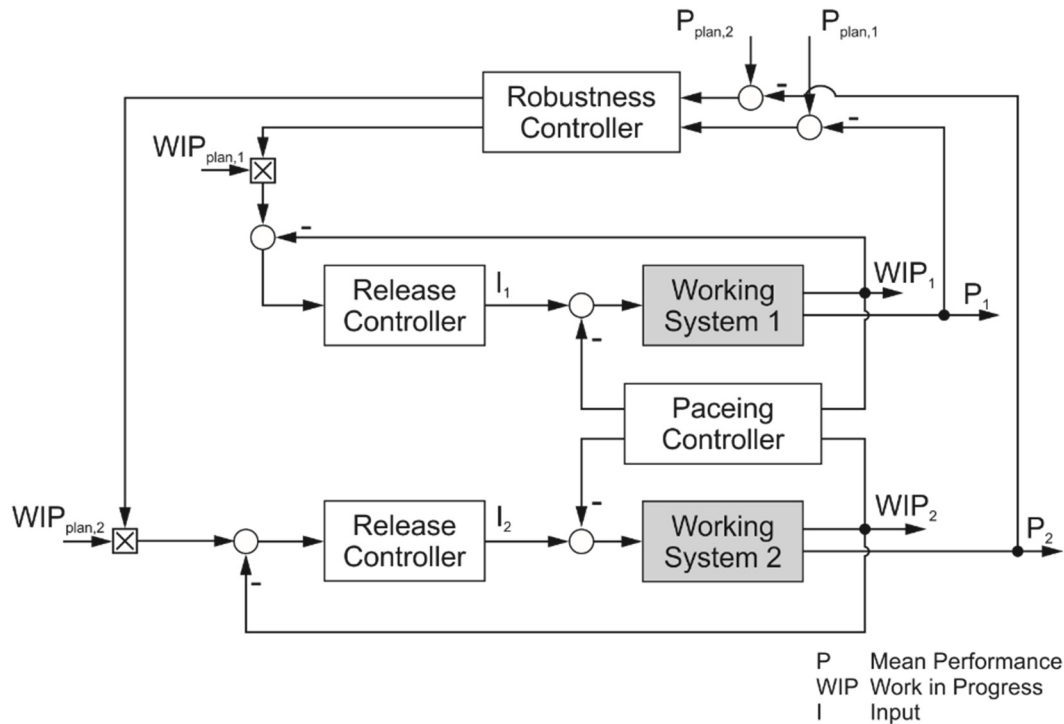

Figure 2: Closed loop control system for order release

The logistic control presented in this paper distinguishes three control loops for order release (see Figure 2). Decentralized allocation control loops keep the stock level of each workstation constant at the operating point. This ensures that capacity utilization and throughput times are achieved. The pacing control loop blocks the workstations when a paced sequence arrives. This enables continuous processing of the order over several stations without delay due to unplanned throughput times. The robustness control loop is the outermost control loop. Disturbances and blockages lead to oscillations in the system, which lead to an increase or decrease of the stock and thus also of the output. A low-pass filter identifies strong changes at the signal outputs for which readjustment is required.

5. Conclusion and Further Research

This paper presented a method for logistical control and order release that can increase the robustness of the system when used. The logistic control of production systems with a high number of variants for small quantities requires the use and development of reconfigurable production systems, which represent a highly dynamic system. The order-specific combination of manufacturing and assembly steps to a quasi-unique process chain results in a high material flow complexity with a high proportion of return flows. Organizational transitions can also occur, which further increase the overall complexity. This creates a high degree of sensitivity to internal and external influences. Particularly in the case of malfunctions, they can worsen the logistical target values, so that overall productivity drops sharply. The presented logistic control can stabilize the system with its small, decentralized loading control loops and the larger robustness control loops. The corresponding signal filters of the output signals of the individual working systems are used to address different areas of the control system, resulting in an integrated logistic control system. The presented procedure for order release and logistic control is suitable for the integration of a Manufacturing Execution System (MES) of a structurally dynamic system. After each processing step or sequence of a process chain, a repeated processing release or change of the order throughput takes place. Depending on the system-

specific control parameters, further releases can be withheld or accelerated in the event of faults in order to avoid critical system states. For example, if there is a risk of underutilization, additional orders can be released by adjusting the parameters accordingly.

The performance of the method should be investigated in future investigations. For controller selection and design, it makes sense to use an event-discrete simulation model. Different controller combinations and their characteristics can be implemented and tested in this model. It is also possible to adapt the model to different system characteristics.

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Biography

Alexander Bader, M.Sc is research assistant at the Bremen Institute for Mechanical Engineering (bime) at the University of Bremen since 2016. His flied of research is production planning and scheduling of dynamic networks.

Ann-Kathrin Onken, M.Sc is research assistant at the Bremen Institute for Mechanical Engineering (bime) at the University of Bremen since 2016. Her research focuses on Design of production chains for linked micro parts.

Prof. Dr.-Ing. Kirsten Tracht is head of the Bremen Institute for Mechanical Engineering (bime) at the University of Bremen since 2008. She received her PhD from the University of Hanover in 2001. Prof. Dr.-Ing. Tracht is member of the MAPEX Executive Board.