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Throughput Time Characteristics of Rush Orders and their Impact on Standard Orders

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Abstract

The focus of this paper is to present modeling approaches for the rush and standard orders' throughput times. An additional aim is the modeling of a critical rush order share. Starting with a literature review on rush orders, we present an overview of the existing literature which deals with the production planning and control (PPC) and the modeling of the logistic targets of rush orders. Then we present a modeling approach for rush and standard orders' production throughput times. The last section of this paper deals with the problem of the modeling of a critical rush order share.

Keywords: Rush orders; Throughput time; PPC

1. Introduction

The existing literature treats rush orders as a special case or even as a disturbance that influences the performance of a job shop. Nowadays, rush orders for prototypes, replacement orders or specific customer's demands have become a regular content of companies' daily business. For that reason it is advisable to decrease throughput times in general. Remaining requirements concerning very short throughput times can be fulfilled by rush orders with an increased margin.

With their specific characteristics rush orders have a significant influence on the logistical performance. This paper has three particular objectives. After a literature review that combines the existing work on rush orders in the research area of PPC, we will focus first on the modeling of throughput times for rush orders including a discussion about the influential parameters of rush orders. Secondly, we will investigate the impact of rush orders on standard orders' throughput times. As rush orders are prioritized at the work stations, they overtake standard orders, which suffer a delay by this kind of sequence deviation. The consequences are extended throughput times for standard orders. To predict the delay caused by rush orders and to decide whether the standard order can be completed within its schedule we want to model the effect of rush orders on standard orders throughput times.

Finally, we seek for a critical rush order share of the order volume, which determines the amount of rush orders a manufacturing area can handle without endangering its logistical targets, i.e. short throughput times or schedule reliability.

The paper concludes with a summary and an outlook on the usage of the results for the order acceptance and scheduling stage of manufacturing planning.

2. Literature review

Despite the fact that the basic relationship between an increasing share of rush orders and the delay of standard orders was stated quite early by Plossl's research in PPC, it had touched on rush orders only for particular questions [1]. The interest in obtaining a more extensive understanding of the processing of rush orders through PPC was stated, however, by several other researchers [2] [3].

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For the order accepting stage of PPC, the relevant issue in literature was whether an incoming rush order increases the revenue or not. Therefore, the additional benefits of rush orders and the evoked tardiness costs of standard orders were compared [4] [5]. In a recent paper Chen presents a heuristic model for justifying the acceptance of rush orders. For the evaluation of his model, he varies the rush order share and observes increasing costs due to increasing tardiness costs [5]. A modeling of the relation between an increasing rush order share and increasing delays of standard orders is missing, however, in Chen's analysis.

The crucial question of the critical rush order share that can be handled by a production and its influencing variables remains thus an unanswered research question. The result of a case study conducted by Hendry suggests a rush order share of 10 to 20% of the order volume, with reserved capacity [2]. Simulation experiments conducted by Thürer show that up to a rush order share of 30%, the rush orders' throughput time remains stable [3]. He points out though, the disadvantage of reserving a certain capacity for rush orders as this measure increases the planning periods for capacity control.

With regard to the order release stage, the existing literature identifies the need of considering the workload caused by rush orders in order to maintain an overall throughput time [3]. Due to prioritization, the throughput times of rush and standard orders vary [6].

The work of Kingsman *et al*. describes an approach which allows an incorporation of orders with a requested throughput time below the standard throughput time of a production area into a PPC concept [7]. A distinctive property of rush orders is to fall below the standard orders' throughput times. The approach proposed by Kingsman *et al*. accelerates rush orders by prioritization at the order release stage and at the work stations. These measures enable manufacturing throughput times to be close to the operation and set-up times. Yet again, a more exact quantification of the achievable throughput times and the influencing variables as well as the consequences for standard orders are missing.

Although certain aspects regarding rush orders have been investigated, there is no comprehensive concept of how to integrate rush orders into PPC based on their characteristics, influencing variables and effects.

3. Throughput time characteristics of rush orders

3.1. Assumptions and influencing variables

In the approach proposed in this paper the particular short throughput times of rush orders are obtained by prioritization at the shop floor. Figure 1 illustrates the processing of a rush order.

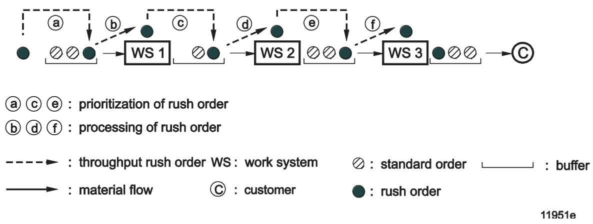

Fig. 1 Processing and prioritization of rush orders

The goal of the modeling of the rush orders' throughput times is to gain the ability to predict their mean values and the standard deviations. Thus, the different influencing variables have to be considered. Our aim is therefore to find an equation that can be used for the calculation of rush orders' throughput times.

When rush orders are planned, one of the crucial questions is: to what extent can they be accelerated? In other words, what is the minimal achievable throughput time?

In order to answer this question we want to model the attainable throughput time of a rush order under the following assumptions:

- There is only one rush order at once at a work system (There is no competition between rush orders for capacity at the queues).
- Pre-emption of a work system in order to accelerate a rush order is forbidden.
- Rush orders are transported batch wise (overlapping manufacturing is not allowed). During the sequencing rush orders are prioritized.

Under these conditions, we want to quantify the influence of the following influencing variables on the rush orders' throughput times:

- utilization of the work systems;
- number of parallel work stations;
- structure of the work contents of rush and standard orders

The utilization of a work system influences the inter-operation time of a rush order directly. The higher the utilization of a work system, the higher the probability that the work system is already processing an order when the rush order arrives. In practice, companies usually tend to operate close to a utilization of 100%. As a consequence, the acceleration of rush orders due to the decrease of utilization is only imaginable in situations where companies do not succeed in gaining enough orders to keep up utilization. An example can be a period of economic slowdown. The existence of parallel machines at a work station shortens the time a rush order has to wait for processing in the queue. The higher the number of parallel machines at a work system, the higher the probability that a machine finishes the currently processed order within the next period of time.

The influencing variables mentioned until now represent measures that can be classified as structural variables. In practice, the increase of machines with a positive effect on rush orders' throughput times is possible, but expensive. Keeping down the utilization level in order to ensure short throughput times for rush orders contradicts especially cost driven targets.

The structures of the work contents of both order types can be classified as operational variables. The standard orders' work contents are expected to have the most significant influence on the rush orders' throughput times. Increasing mean work contents and standard deviations of the work contents of the standard orders result in longer inter-operation times for rush orders. In contrast to the utilization and the number of work stations, the structure of the standard orders' work content can be modified easier, e.g. by harmonizing the batch sizes.

Further, the structure of the rush orders' work content has a direct impact on the resulting operation times. The rush orders' mean work content and its standard deviation influence the processing time of a rush order.

3.2. Modeling of the rush orders' throughput times

The modeling of the achievable throughput time for rush orders will be conducted in this paper by following the model of throughput time elements developed by Wiendahl [8]. In his work, Wiendahl builds up the throughput time of an order as the sum of the inter-operation time and the processing time. This throughput time starts with the order release or the completion of the previous operation and ends with the operation time of the order at the considered work system. The following equation describes the relationship:

$$TTP_i = TOP_i + TIO_i \qquad (1)$$

TTP_i	throughput time of order i [SCD]
TOP_i	processing time of order i [SCD]
TIO_i	interoperation time of order i [SCD]

Operation time [8]

$$TOP_i = \frac{WC_i}{CAP} \qquad (2)$$

TOP_i	processing time of order i [SCD]
WC_i	work content of order i [hrs]
CAP	capacity [hrs/SCD]

Inter-operation time

Due to the prioritization of rush orders during sequencing, the inter-operation times of rush orders decrease. This prioritization allows rush orders to overpass standard orders in the work systems' queues and reduces their waiting time.

It is also imaginable that rush orders are transported preferentially and thus accelerated further. Nevertheless, for the modeling of the inter-operation times we will neglect this particular effect and transportation times in general.

The prioritization of rush orders and the neglect of transportations times result in the following inter-operation time for rush orders, if they are not idle:

$$TIO_i = t_{e,\, ord\ i-1} - t \qquad (3)$$

TIO_i	inter-operation time of order i [SCD]
$t_{e,\, ord\ i-1}$	end of order processing for order i-1 [SCD]
t	current date [SCD]

In a later stage of the modeling of the rush orders' throughput times, we plan to apply weighted values. These values relate the throughput time and their elements to the work content. Using different relationships of the production logistics theory, statements concerning the processing behavior and the development of the WIP can be made.

In order to obtain the weighted inter-operation times for the rush orders, the individual work contents have to be considered. The crucial question for the modeling of the rush orders' inter-operation time is: how long do they have to wait for the completion of the previous order? This period of time is influenced by all the influencing variables mentioned in section 3.1.

4. Throughput time characteristics of standard orders

4.1. Assumptions and influencing variables

The prioritization of rush orders evokes a delay of standard orders. As shown in section 2 of this paper, this relation has been described early in literature. However, the quantification to what extent standard orders are delayed by rush orders is still not provided by the existing research.

Hence, our goal is to propose a solution that will fill in this knowledge gap. We will investigate the impact of defined influencing variables on the standard orders' throughput times. The aim is to provide a calculation equation that expresses the mean throughput time of a standard order as a function of their influencing variables. For reasoning and visualization we will use logistic operating curves [9]. Logistic operating curves show up the influence of the WIP level on different logistic target values such as throughput times, performance or utilization. With order and work system related values, i.e. operation times, throughput times and capacity, the curves can be calculated. Knowing the actual WIP level, a logistic positioning is possible which can be used to reveal potential for logistic improvement.

Until now, the following influencing variables on the standard orders' throughput times have been identified:

- mean WIP at the work station
- structure of the rush orders' work contents
- share of rush orders

Figure 2 presents the assumed course of the mean throughput time curves. At very low WIP levels (a) the utilization is low as well. This situation makes it possible to process both rush and standard orders without queuing times (see Figure 2). Under these circumstances the mean throughput times of rush orders are lower in figure 2 because of their lower assumed operation times. With increasing WIP (b), in the transitional operating zone of logistic operation curves, competition for the provided capacity begins. As rush orders are prioritized, standard orders have to wait for processing and are therefore delayed. Because of a utilization that tends towards 100%, waiting times for rush orders occur. Arriving rush orders have to wait more often for the completion of orders that are currently processed. This is a reason of an increase of the rush orders' mean throughput times in the transitional zone of the logistic operating curves. The beginning of the transitional operating zone is influenced by the structure of work contents and the number of machines at the workstations.
When the WIP is elevated (c) and the work station is running in the overload operating zone, the rush orders' mean throughput times stay low. Due to their prioritization, rush orders do not suffer from increasing inter-operation times. In contrast, the standard orders' mean throughput times increase rapidly in the overload operating zone as their inter-operation times are growing. This relation is also shown in Figure 2.

The depicted effect of the rush orders' throughput time structure on the delay of standard orders is intuitional. The higher the rush orders' work contents, the higher the standard orders' delays. Accordingly, smaller rush orders have a lower impact than bigger rush orders. Rush orders such as product samples or service orders are often smaller compared to standard orders, but generalization is not possible.

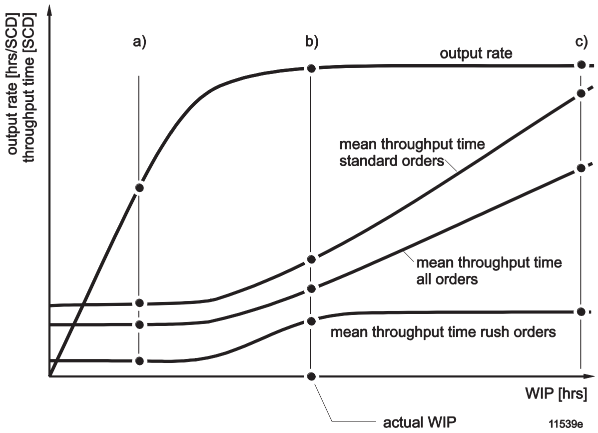

Fig. 2 WIP dependent throughput times for rush and standard orders

4.2. Modeling of the standard orders' throughput times

For the modeling of the standard orders' throughput times, we will follow the general model for throughput times developed also by Wiendahl. In line with the modeling of the rush orders' throughput times, we will use weighted values that can be transformed into unweighted values [8].
The general equation for the weighted throughput time is:

$$TTP_w = \frac{\sum_i (TTP_i \bullet WC_i)}{\sum_i WC_i} \tag{4}$$

TTP_w	weighted throughput time [SCD]
TTP_i	throughput time of order i [SCD]
WC_i	work content of order i [hrs]

This equation describes the weighted throughput time for the entire order volume, including rush and standard orders. The weighted throughput time can be calculated based on historical data.
For the identification of the standard orders' throughput time, equation 4 has to be modified as follows:

$$TTP_w = \frac{\sum_j (TTP_{rj} \bullet WC_{rj})}{\sum_i WC_i} + \frac{\sum_k (TTP_{stdk} \bullet WC_{stdk})}{\sum_i WC_i} \tag{5}$$

TTP_w	weighted throughput time [SCD]
TTP_{rj}	throughput time of rush order j [SCD]
TTP_{stdk}	throughput time of standard order k [SCD]
WC_i	work content of rush order i [hrs]
WC_{rj}	work content of rush order j [hrs]
WC_{stdk}	work content of standard order k [hrs]

The realized modification visualizes the contributions of rush and standard orders to the weighted overall throughput time. Equation 5 can be transformed further using the following relations:

$$\sigma = \frac{\sum_j WC_{rj}}{\sum_i WC_i} \tag{6}$$

$$1\text{-}\sigma = \frac{\sum_k WC_{stdk}}{\sum_i WC_i} \tag{7}$$

WC_{rj}	work content of rush order j [hrs]
WC_{stdk}	work content of standard order k [hrs]
WC_i	work content of order i [hrs]
σ	rush order share

Insertion of equations 6 and 7 into equation 5 and a further transformation leads to the expression of the weighted standard orders' throughput time:

$$TTP_{stdw} = \frac{TTP_w - TTP_{rw} \bullet \sigma}{(1- \sigma)} \tag{8}$$

TTP_{stdw}	weighted throughput time of std. orders [SCD]
TTP_{rw}	weighted throughput time of rush orders [SCD]
σ	rush order share

5. Determination of the critical rush order share

5.1. Assumptions and influencing variables

In order to assure short throughput times for rush orders, one question remains: To what extent a production can be loaded with rush orders? It is obvious that a rush order share of 100% undermines the idea of accelerating orders by prioritization. Beginning at a critical rush order share, rush orders start to compete for capacities at the work stations and are therefore retarded. Our analysis aims to provide a model for the identification of a critical rush order share under specific conditions.

The following influencing variables have been identified:

- structure of rush orders' work contents
- structure of standard orders' work contents
- variation of the rush order share
- number of parallel work stations

The expectation is that the structures of operation times for rush and standard orders have a very significant influence on the achievable rush order share. Work stations with elevated mean (weighted) operation times and considerable standard deviations are occupied for longer periods of time. This causes longer inter-operation times for rush orders as they have to wait for processing as long as a standard order is processed (no preemption) even if they are prioritized.

The variation of the rush order share also influences the critical rush order share. Important variations of the rush order share evoke increased complexity for the order planning. In order to have a current status of the production concerning rush orders and to achieve a high utilization of the work stations, the planning periods have to be reduced. From a strategic point of view, a crucial decision has to be made: For a given critical rush order share and fixed capacities, either rush orders that exceed this critical share have to be refused or increased lead times have to be accepted. A quasi-constant share of rush orders reduces the complexity of their planning. For longer periods of time, the critical rush order share has to be checked against the actual rush order share. The last influencing variable with an effect on the critical rush order share is the number of parallel machines. In addition to the accelerating effect of prioritization, rush orders benefit from shorter intervals of order completion at the work station in the multi-machine case. As a consequence, the inter-operation times shorten. The expectation is that a higher number of work stations with parallel machines will allow a greater share of rush orders.

5.2. Modeling of the critical rush order share

The second stage of the modeling comprehends the evaluation of the model for the critical rush order share. Due to stochastic effects, we expect that at times rush orders will compete for capacity before the critical rush order share is reached. Therefore, we will use simulation for the evaluation of the critical rush order share. The modeling of the operation times will follow a characteristic statistic distribution.

We expect two principle results which will have an impact on the handling of rush orders:

- For very low WIP levels and thus low utilization rates, there will be no competition for capacities. With increasing WIP levels the lead times begin to rise, especially when the transitional zone of the logistic operation curves is reached. The higher the rush order share, the lower the WIP level at which the rise begins. This effect is depicted in Figure 3 for different rush order shares.
- With further increasing WIP levels the effect of the critical rush order share becomes noticeable. When operating with a rush order share that is below the critical rush order share, the rush order's lead times stabilize and do not rise further. In the other case, the rush orders' lead times continue to grow, with high rush order shares accelerating this growth.

In practice, a company can counteract increasing throughput times caused by the exceeding of the critical rush order share by reducing the WIP level. This relationship underlines the importance of a logistic positioning and of WIP-regulating manufacturing control. In case of exceeding the critical rush order share, the following measure can be taken: the structure of operation times for standard orders should be modified. By reducing the mean operation time and especially the standard deviation, inter-operation times of rush orders can be shortened. As a consequence, less competition for capacity is expected and the critical rush order share can be met.

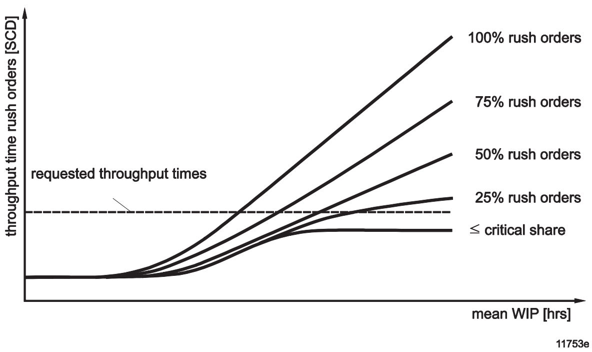

Fig. 3 Hypothetical rush orders' mean throughput time as a function of different rush order shares

6. Summary

In this paper we investigated the effects of rush orders. Starting with a literature review, we examined and brought together the already existing research in the field of rush orders. In the main part of this paper, three modeling questions concerning rush orders were analyzed: we first presented a modeling approach for the rush orders' throughput times based on the identified influencing variables. Then we investigated the effect of rush orders on the standard orders' throughput times including the influencing variables and a modeling approach. This paper concludes with the presentation of a modeling approach of the critical rush order share that can be handled by a production.
The results for the mean throughput times of rush and standard orders, as well as the critical rush order share will be used for the development of an order acceptance and scheduling method that decides on the acceptance of both order types and performs their scheduling.

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