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Rule-based vs. optimisation-based order release in workload control: A simulation study of a MTO manufacturer

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ABSTRACT

The paper presents a simulation study that compares multi-period models for order release optimisation (Input/Output Control with fixed lead times and a clearing function model) with a traditional workload control-based order release mechanism (control of aggregate workload with periodic release). For the optimisation models the study assumes periodic re-planning and thus can also assess the effects of demand predictability. The simulation model is based on a practical case of a manufacturer of optical storage media. The results indicate that optimisation models for order release planning largely outperform traditional workload control-based order release mechanisms even in the case of poor demand forecasts.

1. Problem description

Short, predictable flow times are an important goal in manufacturing planning and control (MPC), especially in environments where high flexibility in meeting customer demand is required. To attain this goal, both the manufacturing system and the manufacturing planning and control system must be designed appropriately. This paper concentrates on the contribution of manufacturing planning and control systems to keeping flow times at a pre-determined (low) level while at the same time maintaining high output and due-date performance.

An MPC concept that is specifically designed for this task is workload control (WLC): Work orders are released to the production units such that the work-in-process (WIP) (i.e., queues at the work centres) is kept at a pre-determined level. This target WIP level should lead to a good compromise between the conflicting goals of low WIP level and short flow times on the one hand, and high output on the other hand, and releasing the right orders (within the "budget" allowed by the WIP norm) should lead to good due-date performance and appropriate load balancing among the work centres or production routings, respectively. Thus the WLC concept emphasises the importance of the order release function in MPC systems. Models and algorithms for determining the release times of the work orders have been studied extensively. Two streams of literature, which have been developed largely separately, can be distinguished:

- Traditional order release mechanisms that determine the release times of the work orders for a short time horizon (typically one planning period) without explicit reference to an objective function, following a set of rules (*rule-based approach*).
- Multi-period optimisation models where the order releases in the periods of the planning horizon are decision variables. The models aim at optimising the order releases for the entire planning horizon with respect to an appropriate objective function (*optimisation-based approach*).

Note that traditional order release mechanisms are "myopic": The ability to use demand forecasts or work orders that are available for the future to perform production smoothing is very limited since information on the demand pattern is only used to determine the parameter setting (see Missbauer, 2009). Multi-period optimisation models can optimise production smoothing and load balancing among work centres based on medium-term demand information. A company that intends to use a WLC-based order release system first has to decide whether the rule-based or the optimisation-based order release approach should be applied. This question is the topic of the paper.

The paper is organised as follows: Section 2 reviews the relevant literature and derives the hypotheses that are tested. Section 3 describes the order release methods that are compared. In Section 4 the simulation model is presented, structured into its relevant sub-models: factory model, demand generation model, and demand forecast model. In Section 5 the experimental setting is described. Section 6 presents the simulation results with respect to the hypotheses formulated in Section 2. Conclusions and topics for future research are given in Section 7.

2. Short-term order release mechanisms versus multi-period order release planning: literature review

The order release approaches that are compared in this paper developed from two research traditions that have been pursued

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rather independently since the 1970s and early 1980s, starting from the same underlying idea.

The WLC concept and the importance of the order release function for the control of WIP and flow times was described in conceptual publications mainly in the 1980s (Bertrand and Wortmann, 1981, Bertrand et al., 1990, Zäpfel and Missbauer, 1993a). WLC aims at maintaining a pre-specified level of WIP (e.g., hours of work waiting at the work centres) in the production units, which leads to predictable flow times and hence to reliable planned lead times. The pre-specified WIP level can be maintained by releasing the right number and the right product mix of orders (or amount of work) to the production unit. This is the common idea of the two research streams. See Tatsiopoulos and Kingsman (1983) for an early review of this concept and of methods to implement it.

One way to realize this – and the first research stream – is *traditional WLC-based order release mechanisms.* Assuming that a pool of unreleased orders is available and the load situation on the shop floor is known, these release mechanisms decide which orders are to be released for a short time horizon (usually one planning period) in order to maintain the workload norm. Early examples of this approach include the model by Irastorza and Deane (1974), load-oriented order release (Bechte, 1980; Wiendahl, 1995), and the LUMS approach (Hendry and Kingsman, 1989, 1991; note that LUMS also includes the customer enquiry and order acceptance stage). Meanwhile a fairly large number of short term order release mechanisms have been developed (reviews in Bergamaschi et al., 1997; Sabuncuoglu and Karapinar, 1999; Fredendall et al., 2010) that can mostly be considered as special cases of a "basic release procedure" (Land, 2004). The release mechanisms can be derived from the basic release procedure by specifying certain design parameters (Bergamaschi et al., 1997; Missbauer, 2009). The question of how the design parameters that specify the release mechanism should be set in a specific case has been treated extensively, mainly using simulation. Note that the order releases over time result from a sequence of myopic release decisions over time, not from a release schedule that is optimised for a longer planning horizon. The release mechanisms can be interpreted as a set of *rules* for releasing orders; therefore we refer to this as a *rule-based approach* to order release. The basic release procedure is our reference for the rule-based approach described in Section 1. Since there is no multi-period planning model, order release mechanisms of this type are largely independent of detailed demand forecasts and time-phased load projections (Bechte 1980, p.71; Tatsiopoulos and Kingsman 1983, p. 356).

An alternative approach to designing order release systems – and the second research tradition in our comparison, termed *optimisation-based approach* – is multi-period models for order release planning (for a description, see Missbauer and Uzsoy, 2011). These can be considered as an extension of the well-known production planning models that use linear programming (see, e.g., Johnson and Montgomery, 1974) by incorporating the relationship among WIP, flow times and output. Thus the queuing behaviour of capacity-constrained production resources is expressed in the model, which makes the approach a workload control technique. This approach originates from Input/Output Control published in the 1970s (Wight, 1970; Plossl and Wight, 1973; Belt, 1976). In its basic version, Input/Output Control calculates the time-dependent WIP level at a work centre for the periods of a specified planning horizon from the initial WIP level, the time-dependent work input (which results from the release schedule) and work output (which results from the work centre capacity). Input/Output Control can be extended to production units consisting of multiple work centres. This leads to a network flow model in discrete time where the work centres are represented explicitly, the (continuous) material flows between the work centres are represented by WIP inventory balance equations, and a fixed lead time for each work centre is specified. The model allows optimisation of the material flow with respect to an appropriate objective function usually by linear programming, which also yields the optimal time-dependent release quantities at the specified level of aggregation (usually products or product families which similar routings). Unlike the lag before or lag after models described in Hackman and Leachman (1989), the time-dependent output of the work centres are separate decisions, thus the buffering capability of WIP can be utilised (a similar model formulation is described in de Kok and Fransoo (2003)). If the work orders are given in a pool of unreleased orders (from the customer orders or from the MRP system) then the orders to release in the first period must be selected so as to match the optimised release quantities and to consider the required due dates of the orders. Note that the model requires demand forecasts at the specified level of aggregation, and the optimal solution includes time-phased load projections for the work centres.

Input/Output Control models assume fixed lead times, but queueing-theoretical results and practical experience indicate that lead times are load-dependent, which leads to the well-known trade-off between short lead times and high capacity utilisation. Thus the lead time norms usually must allow high utilisation at least of the bottleneck work centres, which means that the model cannot take advantage of the possibility to reduce lead times in periods of low capacity utilisation. Therefore relaxing the fixed lead time constraint should provide a potential for improvements. Load-dependent lead times require the representation of the relationship between output and WIP or lead time in the model. One important way to accomplish this are nonlinear, saturating clearing functions. A *clearing function* of a work centre is the functional relationship between some measure of WIP in a period t and the expected or maximum output of the work centre in period t. This allows adaptation of planned WIP and lead times to the load situation in the shop. But clearing function models still suffer from technical difficulties (see Missbauer and Uzsoy, 2011; Missbauer, 2011), which might at least partly diminish the potential advantage. A second approach to include load-dependent lead times in models for order release planning has been initiated by Zäpfel (1984) and Hung and Leachman (1996). It iterates between a fixed lead time order release planning model (usually linear programming) and a simulation model that updates the lead times. Iterative procedures of this type have also been developed in Riaño (2003) (queueing model instead of the simulation) and Kim and Kim (2001) (updating both the lead times and the capacities based on the simulation results). This approach is not considered further here (see Irdem et al., 2010 for a literature review and a numerical analysis).

A relatively small number of studies compare different order release planning models. Asmundsson et al. (2006, 2009) compare their clearing function model and a fixed lead time model by simulation. They conclude that the clearing function model performs better and estimates the WIP levels at the work centres more precisely. Kacar et al. (2009) examine the performance of clearing function models and iterative LP-simulation procedures. To our knowledge studies comparing clearing function and Input/Output Control models have not yet been performed.

The literature described above provides very little insight into the relative performance of the rule-based and the optimisation-based approach to order release planning. Zäpfel and Missbauer (1993b) and Missbauer (2002) provide simulation results that indicate that the optimisation-based approach can cope with different demand scenarios better than load-oriented order release (Wiendahl, 1995) with standard parameter settings. Orcun and Uzsoy (2011) conclude from preliminary experimental results of a simple supply chain system using system dynamics modelling that "the dynamics of supply chains operating under optimisation-based planning models are qualitatively different from those operating