HAL open science

Order Acceptance and Scheduling with a Throughput Diagram

Christopher Mundt, Hermann Lödding

To cite this version:

Christopher Mundt, Hermann Lödding. Order Acceptance and Scheduling with a Throughput Diagram. IFIP International Conference on Advances in Production Management Systems (APMS), Aug 2020, Novi Sad, Serbia. pp.351-359, 10.1007/978-3-030-57993-7_40 . hal-03630858

HAL Id: hal-03630858

https://inria.hal.science/hal-03630858v1

Submitted on 5 Apr 2022

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Distributed under a Creative Commons Attribution 4.0 International License

Order acceptance and scheduling with a throughput diagram

Christopher Mundt and Hermann Lödding

Hamburg University of Technology, Hamburg, Germany
{christopher.mundt, loedding}@tuhh.de

Abstract. Determining realistic delivery times is difficult for make-to-order manufacturers, especially due to uncertainties such as future production capacity utilization. Nevertheless, delivery times have to be stated in new offers. In this paper, we show a simple procedure for determining delivery times using the throughput diagram and determining a likely future situation by including early available information such as the acceptance of offers in the planning process. In a first simulative evaluation, the procedure is examined for its basic effect on the order lateness.

Keywords: Production planning, Order scheduling, Throughput diagram

1 Introduction

Order acceptance and scheduling has the task to determine a realistic delivery time when customers request an offer. The delivery time, a company offers is an important decision criterion for the customer, along with the price and the quality of a product. Therefore, order acceptance and scheduling is a particularly important task for make-to-order companies, which has an impact on sales, profits and capacity utilization in production. Also, good order scheduling protects production from overload by scheduling orders for a later date or even rejecting them, if necessary.

The challenge is to acquire as many orders as possible without overloading production, building up backlogs and causing late delivery. Measured by the importance of the task, the implementation in many companies is inadequate: It is common for companies to use standard delivery times or to systematically accept more orders than the production capacity can handle, especially when the economy is prospering [1].

Due to a high number of variants and varying delivery time demands from customers, it is difficult for make-to-order manufacturers to perform reliable production planning. Another difficulty is that at the time of order acceptance and scheduling, realistic work plans with detailed target times are usually not available. In addition, other open offers are usually not sufficiently taken into account when scheduling offers. It is therefore not surprising that customers of make-to-order manufacturers complain about a low delivery reliability [2] and that the make-to-order manufacturers themselves rate high delivery reliability as the most important logistical goal [3].

This article shows a simple procedure for scheduling and capacity planning using throughput diagrams.

2 Fundamentals and current state of research

Already with the offer, contractors usually must state not only technical specifications but also a binding delivery date. In many cases, the offer is only valid for a limited period of time, during which the customer can accept it. At the time of the offer preparation, usually neither work plans nor order times are available as input to calculate the delivery time. Moreover, it is also unclear whether the customers will accept the open offers or not. The reliability of the load of open offers therefore is very low, which makes scheduling and capacity planning more difficult [4].

Based on their experience, some companies can estimate the probability that offers for their most important products or from long-term customers will be accepted. This acceptance rate can help to better estimate the future load on production. For a systematic assessment of this acceptance rate, it is necessary to keep statistics on accepted and rejected offers. However, the planning software often does not support this, so that many companies fail to keep track of these statistics [5].

Often companies therefore neglect requests, offers and even orders prior to product design and work planning. In many cases, the sales department promises delivery times without first carrying out a sufficient capacity check of production. The customers are instead given standard delivery times, which cannot be guaranteed to be met. Because Sales and Distribution is rewarded for winning orders, this can lead to a systematic overload of production capacity, especially under good economic conditions. Various authors suggest procedures for integrating offers in the scheduling and capacity planning process.

Already in the 1960s, Brankamp suggested to take offers into account in capacity planning. His proposal is based on multiplying unplanned capacities by a factor for the probability of acceptance. This acceptance rate is the reciprocal of the probability that customers will accept an offer [6].

Kingsman and Hendry propose to multiply the work content of the offers by their probability of acceptance. They then calculate a range of coverage that includes not only the orders in production, but also orders waiting to be released and the open offers. This range of coverage can be used for scheduling, but also for rejecting customer inquiries or adjusting capacity [7, 8].

Wiedemann proposes to determine the possible delivery date by simulating future capacity requirements [9].

However, these procedures have not been established as common practice in industry so far, possibly because the procedures take a very detailed look at the loads of individual workstations, thus becoming complex and also requiring the knowledge of the work content for the required processes. Our approach aims to cover less detailed information to make the procedure easier to apply in an earlier stage of the order process. The question is if that is sufficient to meet the requirements for the accuracy of scheduling.

There are some basic requirements for an effective scheduling procedure. Such a procedure should be simple to use, which may be even more important than the accuracy of the procedure. Nevertheless, it has to deliver good and robust results. Furthermore, the procedure should be comprehensible in order to increase the insight into

the cause-effect relationships of production. In addition, the procedure should take into account the various order states (request, offer and order in design and work preparation) before a production order is generated.

Throughput diagrams show the cumulative actual and planned output of a work system or the entire production over time. The work can be measured in number of orders, in hours or similar capacity equivalents. The throughput diagram is often used in the analysis or controlling of work processes. It is used to visualize the existing situation of the logistic target values or to compare it with a target state [10]. Another application is the visualization during production planning [11].

3 Scheduling offers and orders in a throughput diagram

3.1 General considerations

The proposed order acceptance and scheduling procedure does not take into consideration individual operations and workstations an order will pass through, but is restricted on the entire manufacturing department and the entire order. This makes it easy to apply, but also reduces the transparency over relevant information on workstation level. Therefore, in contrast to other procedures, it requires less information, especially workstation related information is not necessary.

The workload can be considered in different ways to align the planned output with the capacity of the production. The unit of output should be chosen in a way that it reflects the capacity requirements of the orders as accurately as possible. Standard hours are often well-suited to reflect the capacity requirements of an order in a work system. However, the effort required to estimate the standard hours at the time of offer processing is usually considerable. If a company produces a large number of orders, large and small orders balance each other out. In this case, it is often sufficient to measure the output in number of orders. This simplifies the calculation of the planned output, especially for open offers. Alternatively, the average work content can be used as a basis.

In all cases, open offers should be discounted with the likely acceptance rate to calculate the planned output from offers following the suggestion of Kingsman and Hendry [8]. In this way the planned output represents its likely future value at the current day.

Some values have a crucial impact on the planned due date and therefore on the scheduling procedure itself. The throughput time by its definition forms a lower boundary for the delivery time and needs to be considered respectively. The customer usually needs time for his decision on a placed offer. The customer response time can be considered in different ways. The validity of the offer is an upper limit. For the sake of simplicity, we assume that there is no difference in the customer response time between accepted and unaccepted offers. In order to prevent minor disturbances in production from directly leading to a delayed delivery, it is also useful to use a delivery time buffer.

3.2 Construction of a throughput diagram with planned data

Figure 1 shows a throughput diagram with planned data. The following quantities are shown cumulatively over time:

- Actual output
- Planned output
  - from requests and offers
  - from confirmed orders in different states
- Possible output with planned capacity

The planned output might be detailed further, e.g. according to the order status, for example orders after release, orders after work preparation but before release, orders after design but before work preparation. For reasons of clarity, however, this paper does not present these different planned outputs individually.

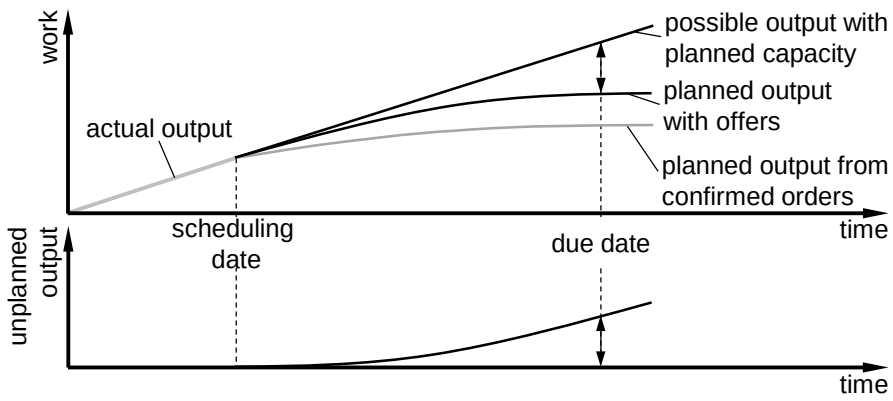


Fig. 1. Throughput diagram for scheduling purposes

3.3 A generic and simple to use scheduling procedure

The scheduling of incoming requests and the determination of the delivery time is generally made by checking three conditions. Firstly, the planned delivery time has to be at least the throughput time, because this is the shortest time the product can be produced under standard conditions (1). Secondly, the promised delivery time does not need to be shorter than the customer requests (2). Lastly, the unplanned output at the possible due date has to be larger than the work content of the offer (3).

$$TT_{poss} \geq TT_m \tag{1}$$

$$TT_{poss} \geq TD_{req} - T_{Buffer} \tag{2}$$

$$OUT_{up}\,(D_{scheduling} + TT_{poss}) > WC_i \tag{3}$$

With: TT_{poss} *possible throughput time* TT_m *mean throughput time*
TD_{req} *requested delivery time* T_{Buffer} *delivery time buffer*
OUT_{up} *unplanned output* $D_{scheduling}$ *scheduling date*
WC_i *work content of offer i*

The possible throughput time is now calculated by determining its maximum value in the above stated conditions. To compensate minor disturbances, the delivery time buffer is added to get the delivery time that can be communicated to the customer (4).

$$TD = TT_{poss} + T_{Buffer} \tag{4}$$

With:	*TD*	*delivery time*	TT_{poss}	*possible throughput time*
	T_{Buffer}	*delivery time buffer*		

3.4 Consideration of offers and orders in the planned output

Basically, the planned output from confirmed orders is considered at the time of their planned completion and the planned output from offers is considered at their likely completion date. Comparing the planned output with the capacity in a throughput diagram (Figure 2) illustrates the above stated scheduling and works as follows.

Order requests from customers and open offers are added to the planned output from confirmed orders with an expected value. The expected share of offers that are converted into an order is calculated by multiplying the offers by an acceptance rate. In the simplest case, the acceptance rate can be calculated based on historical data from the ratio of the number of accepted offers to the total number of submitted offers (5).

$$AR = \sum O_{acc.} / \sum O_{sub.} \tag{5}$$

With:	*AR*	*acceptance rate*	$O_{acc.}$	*accepted offers*
	$O_{sub.}$	*submitted offers*		

In practice, the acceptance rate can be estimated individually for each offer. Possible differences result from the consideration of different customers, products, projects or similar criteria. The workload of an offer is then multiplied by the acceptance rate. For the planned output in number of orders the considered workload equals the acceptance rate (6). If the order times are also to be taken into account, equation (7) is obtained.

$$OUTO_{plan,off,j.} = AR_i \tag{6}$$

$$OUT_{plan,off,j.} = AR_i \cdot WC_m \tag{7}$$

With:	$OUTO_{plan,off,j}$	*planned output of offer j [number of orders]*	AR_i	*acceptance rate of offer i*
	$OUT_{plan,off,j}$	*planned output of offer j [h]*	WC_m	*mean work content*

To determine the likely due date of an offer, three factors are taken into account: the current scheduling date, the customer response time for accepted offers and the previously calculated possible delivery time. The customer response time is considered with its mean value (8). If the customer response behaviour differs for various customers individual values might be considered here.

$$EDD = D_{scheduling} + TCR_m + TT_{poss} \tag{8}$$

With:	*EDD*	*expected due date*	$D_{scheduling}$	*scheduling date*
	TCR_m	*mean customer response time*	TT_{poss}	*possible throughput time*

The discounted workload from the offer calculated with (6) or (7) is added to the output at the due date calculated with equation (8).

To determine the possible output with the planned capacity the procedure is as follows. The curve starts at the end of the actual output on the scheduling date. If the capacity remains unchanged, the average output rate of the previous planning period can be used to estimate the possible output. Accordingly, the curve of the possible output proceeds linearly with the output rate as gradient.

The unplanned output is the difference between the two curves, if the planned output is below the possible output or displays the overload when it is the other way around.

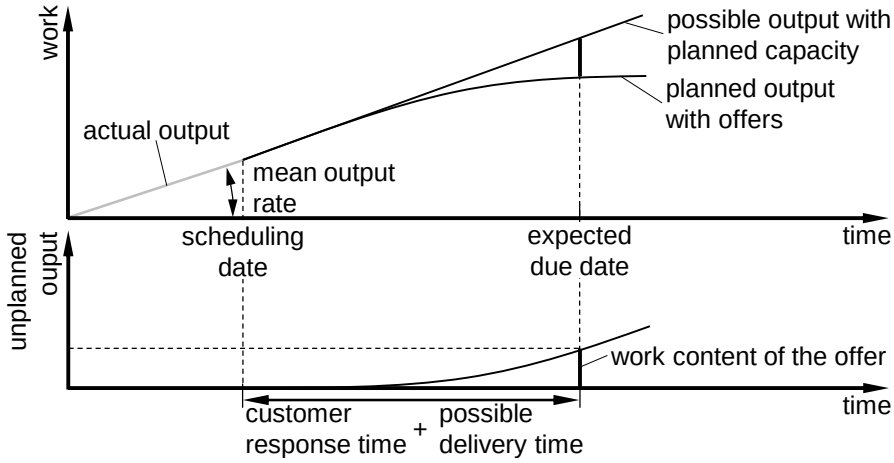


Fig. 2. Adding offers to the planned output

After the customers decision there might be an accepted or rejected offer. If the offer is accepted, it will be scheduled with their whole workload and the promised delivery time. The earlier scheduled status as offer will be removed from the planned output. If the offer is not accepted, then its scheduled output will just be removed.

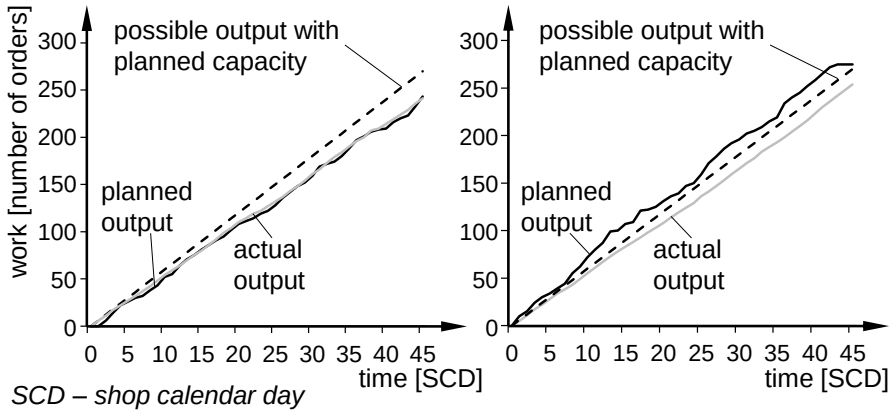
The throughput diagram also allows the initial backlog of production to be included. In this case the actual output and the planned output deviate at the scheduling date.

4 Evaluation by simulation

Production disturbances and uncertainties can lead to production performance deviating from capacity. Usual disturbances are for example machine failures, sick employees, sequence deviations of orders or other issues. Uncertainties with regard to the procedure which might vary over time are the acceptance rate, the customer response time or the workload. Varying these variables in the throughput diagram visualizes this overload to support decisions about increasing the capacity.

The presented scheduling procedure was compared to scheduling with standard delivery times in a simulation to evaluate the basic effect. Therefore, a simplified simu-

lation model was built with a linear material flow of five workstations and a situation with fifty percent overload. Also, short-term fluctuations in offer request rate, acceptance rate and customer response time have been implemented. A delivery time buffer of one day was used. The simulation was conducted for both procedures with 1000 offer requests each. The resulting throughput diagrams for the backwards scheduling procedure and the throughput diagram scheduling procedure are shown in Figure 3.



a) presented procedure b) backwards scheduling

Fig. 3. Resulting throughput diagrams of the evaluated procedures

The planned output for the backwards scheduling procedure (5b) is mostly above the capacity limit. The difference between the planned and actual output, which represents the backlog, is large and increases over time. This results in a mean lateness of four shop calendar days with a standard deviation of more than two days. The schedule reliability with limits of plus minus one day is only 18 percent.

The planned output for the presented procedure (5a) is below the capacity limit and close to the actual output all the time. On average the orders are finished slightly early with a mean lateness of minus one-third shop calendar days and a standard deviation of one shop calendar day. The schedule reliability is 87 percent, in the limits of plus minus one day for this procedure.

However, the presented procedure comes along with the cost of a slightly lower output rate of five percent compared to the backwards scheduling. A WIP regulating order release such as CONWIP could compensate for this effect, by utilizing unused capacity.

5 Summary and Outlook

The presented paper shows how companies can visualize the future load situation in production using a throughput diagram, determine their unplanned output and schedule orders. The throughput diagram enables companies to schedule offers taking into account backlogs, previous orders and the expected load of open offers. Compared to

other procedures it works without information on workstation level, therefore needs less information and is easier to apply. This makes the procedure particularly suitable for practical application.

In a first simple evaluation we were able to show its general effectiveness. Under the considered conditions this comes with a slightly lower output rate. These downsides of the procedure appear to be uncritical under the considered conditions. Our procedure generally aims to be sufficient for a wide variation of make-to-order situations, as long as the required acceptance statistics are available. Nevertheless, the greater the offer backlog, the greater is the procedure's impact. To prove this, further simulations with different situations will be performed and an implementation in practice is planned. Furthermore, we will extend the procedure to include special order types, such as rush orders.

Acknowledgement. The Authors would like to thank Deutsche Forschungsgesellschaft (DFG) for funding the project "Model-based order acceptance and scheduling" (Project No. 405645389).

References

[1] Bretzke, W.-R. (2020). *Logistische Netzwerke*, Springer, Berlin, Heidelberg, doi: 10.1007/978-3-662-59757-6.

[2] Schuh, G. (2007). *Produktionsplanung und -steuerung: Grundlagen, Gestaltung Und Konzepte*, Springer, Dordrecht.

[3] Nyhuis, P. (ed.) (2016). *Aktuellen Herausforderungen der Produktionsplanung und -steuerung mittels Industrie 4.0 begegnen: Studienergebnisse*, PZH Verlag, Garbsen.

[4] Schuh, G., Schmidt, C. (2014). *Produktionsmanagement: Handbuch Produktion und Management 5*, Springer Vieweg, Berlin, doi: 10.1007/978-3-642-54288-6.

[5] Hentschel, D. (2008). Kunde "droht" mit Auftrag: Risiko Auftragswahrscheinlichkeit, *PPS-Management*, Vol. 13, No. 1, 55–58.

[6] Brankamp, K. (1967). *Ein Terminplanungssystem für Unternehmen der Einzel- und Serienfertigung*, Aachen.

[7] Kingsman, B.G., Tatsiopoulos, I.P., Hendry, L.C. (1989). A structural methodology for managing manufacturing lead times in make-to-order companies, *European Journal of Operational Research*, Vol. 40, No. 2, 196–209, doi: 10.1016/0377-2217(89)90330-5.

[8] Hendry, L.C., Kingsman, B.G. (1993). Customer Enquiry Management: Part of a Hierarchical System to Control Lead Times in Make-to-Order Companies, *Journal of the Operational Research Society*, Vol. 44, No. 1, 61–70, doi: 10.1057/jors.1993.7.

[9] Wiedemann, M. (2016). *Methodik zur auslastungsorientierten Angebotsterminierung für hochvariante Produkte mit kundenindividuellen Leistungsanteilen*, München.

[10] Nyhuis, P., Wiendahl, H.-P. (2012). *Logistische Kennlinien*, Springer Berlin Heidelberg, Berlin, Heidelberg, doi: 10.1007/978-3-540-92839-3.

[11] Lödding, H. (2016). *Verfahren der Fertigungssteuerung*, Springer, Berlin, Heidelberg, doi: 10.1007/978-3-662-48459-3.