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What is Really “On-Time”? A Comparison of Due Date Performance Indicators in Production

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Abstract

On-time delivery is essential in today’s dynamic conditions: if a company cannot produce and deliver on time, it has to make up for it by using high cost express delivery or faces customer dissatisfaction. One factor influencing the delivery reliability is the due date performance (DDP) within production. Although the significance of DDP has been established, the question of how to measure it remains. A review of existing literature shows the vast amount of different DDP measures (lateness, relative lateness, tardiness, schedule reliability, etc.). The purpose of this paper is to compare different DDP measures used in manufacturing in order to assess their interrelationship, so that companies are better able to understand the impact of their choice of measure. A review of DDP measures described in literature is performed, followed by statistical analysis of the relations between those measures computed on production feedback data from four real-world manufacturers. The results indicate that there exist differences across DDP measure groups. Further research is needed to assess the benefits of each measure in a given situation.

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1. Introduction

Economic complexity nowadays poses immense challenges to the majority of organizations in their pursuit of growth and profitability [1]. Therefore, outperforming competitors in the most significant competitive elements is crucial for any company. In a study by Deloitte & Touche that gathered input on how management officials rank competitive factors, delivery reliability, i.e. the percentage of orders delivered in a defined tolerance window, emerged as the most vital component [2]. But even though delivery reliability has such a strong impact on costs and expenses, many companies still struggle in reaching high delivery reliability levels, leaving substantial space for improvements [3].

One of the factors impacting delivery reliability is the measured due date performance (DDP), also described as schedule reliability. This indicator assesses whether orders and jobs within production processes have been executed on time. When DDP is low and products are made available for transport later than planned, meeting targeted delivery dates becomes more difficult and the respective delivery reliability is likely to decrease as well [4]. While the significance of DDP has been established, the question of how to measure it remains. There is a vast amount of different approaches available in the literature leading to the core motivation of this research. Various authors seem to rely on different DDP measures and it seems that no single approach is established [5]. Different studies use different calculation methods, leading to results that are difficult to compare. Hence, it is not always clear which measure is the optimal one. Accordingly, one could hypothesize that depending on the situation different measures bring specific advantages and disadvantages.

Hence, this paper aims at comparing existing DDP measures in order to assess their interrelationship. For this purpose, we use production feedback data from four real-world manufacturers in order to derive the various DDP measures. We then compare them by applying three statistical tests: Spearman’s correlation analysis, Friedman-Test and Wilcoxon signed rank test. The paper is structured as follows. Section two describes existing DDP measures. We present and interpret our results in section three. Finally, section four discusses the overall findings as well as provides a summary of the

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investigation, its limitations and outlook for further research.

2. Literature Review

Seven of the most commonly used indicators found in literature are introduced: (1) Output Lateness, (2) Absolute Lateness, (3) Squared Lateness, (4) Tardiness, (5) Relative Lateness, (6) Binary Lateness, and (7) Schedule Unreliability. Four time points are at the core of the computation for each measure. Those are the actual (t_{start}) and planned ($t_{startplan}$) starting point of operation (i) as well as its actual (t_{end}) and planned ($t_{endplan}$) point of completion. The difference between end and starting point (planned or actual, respectively) yields the operation's throughput time (TTP).

The most basic DDP measure is *output lateness*, also sometimes denoted as job lateness [4, 6]. It describes the time difference between the planned and actual end date of an operation (i). Output lateness $L_{i, out}$ is defined as follows:

$$L_{i,out} = t_{i,end} - t_{i,endplan} \quad (1)$$

An operation's lateness yields positive, while its earliness yields negative values. However, one of the main disadvantages of this DDP measure is the acceptance of early production finish dates as a positive case, whilst studies have suggested the negative impact of earliness such as higher inventory levels and associated costs [4]. *Absolute lateness* is an approach that addresses this issue. It considers absolute rather than positive and negative values [6, 7]:

$$AL_i = \left|t_{i,end} - t_{i,endplan}\right| \quad (2)$$

For both, early and late completion, positive values are retrieved. Absolute lateness is regarded an accuracy indicator between predicted and real values [7].

Moreover, derived from absolute lateness, *squared lateness* proposes another possibility of looking into due date performance and can be described as a precision indicator for the level of variability of lateness [7]:

$$SL_i = (t_{i,end} - t_{i,endplan})^2 \quad (3)$$

This indicator penalizes higher extents of lateness more, as lateness is plotted in a quadratic function [6, 7, 8].

Furthermore, literature on due date assignment rules has been considering the measure *tardiness* [9, 10]. As the term suggests, tardiness only considers lateness of an operation (i):

$$T_i = \begin{Bmatrix} 0, & \text{if } t_{i,end} \leq t_{i,endplan} \\ t_{i,end} - t_{i,endplan}, & \text{if } t_{i,end} \geq t_{i,endplan} \end{Bmatrix} \quad (4)$$

For all operations completed early or on time, the value zero is assigned. In all other cases, the actual delay is counted. Hence, the higher average tardiness, the more delay is present in the investigated system.

So far, all lateness measures presented take into account the time deviation an operation has from the production schedule. However, the total output lateness of an operation comprises of two key elements – input lateness and TTP deviations. Subsequent operations are likely to be delayed in respect to total output lateness if they start with an input lateness [11]. TTP deviations mark the differences between planned and actual throughput time of an operation [4]. In the DDP context, these deviations are referred to as *relative lateness* and can be described as the difference between output and input lateness ($L_{i, out}$ and $L_{i, in}$) [12]:

$$RL_i = TTP_{act} - TTP_{plan} = L_{i,out} - L_{i,in} = (t_{i,end} - t_{i,endplan}) - (t_{(i-1),end} - t_{(i-1),endplan}) \quad (5)$$

Equation 5 shows how to compute relative lateness, where positive values indicate lateness and negative values indicate earliness in operation completion time [11]. This measure represents the individual operation's contribution to the overall order lateness and can help identify bottlenecks [13].

Another DDP school of thought has been utilizing DDP measures which assign values not directly correlating to the extent of lateness, but rather use a binary system of evaluating lateness.

The first measure of this type is *Binary Lateness* [14]. In this case, values zero or one are assigned to all operations:

$$BL_i = \begin{Bmatrix} 0, \text{if } t_{i,end} \leq t_{i,endplan} \\ 1, \text{if } t_{i,end} \geq t_{i,endplan} \end{Bmatrix} \quad (6)$$

Zero marks all operations being completed early or on time, one indicates completion after the scheduled due date. Binary lateness is a concept with close connection to service levels and can be described as the percentage of tardy jobs and operations [5]. As operations get assigned the value 1 regardless of whether they are late by a few minutes, hours or days, the extent of lateness is not considered.

The second measure of the binary type is *schedule reliability*. Schedule reliability defines the percentage of orders that were finished within a specific window of due date tolerance [4]. This tolerance covers the time frame in which the company considers a production being on-time and covers both early and late completion [11]. For the purpose of this research, schedule reliability was changed into schedule unreliability, as all measures before indicate increasing delay with increasing computed values [15]:

$$SU_i = \begin{Bmatrix} 0, \text{if } \left|t_{i,end} - t_{i,endplan}\right| \leq a \\ 1, \text{if } \left|t_{i,end} - t_{i,endplan}\right| \geq a \end{Bmatrix} \quad (7)$$

Equation (7) shows the mathematical formula behind the concept of schedule unreliability. For all orders completed within the tolerance window of size (a), we assign value 0, for all others 1 is set as a value. The magnitude of the tolerance window depends on factors such as the delivery buffers present and cost of lateness [16].

Overall, one can observe that the presented DDP measure computations vary as they focus on different features. Three such features stand out: (1) extent of lateness, (2) assessment of early completion, and (3) consideration of input lateness. The two binary measures do not consider the *extent of lateness* of an operation and are therefore only insightful on a system