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# An Integrative Model of Productivity and Logistic Objectives

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**Abstract.** Labor productivity as well as its influencing factors are closely linked to the logistic objectives. This linkage has been so far only described on a qualitative basis. Consequently a coordinated configuration of production planning and control and productivity management is missing. This paper presents an approach to link labor productivity and production planning and control on a quantitative level..

**Keywords:** Labor productivity · Logistic objectives · Production planning · Control

## 1 Introduction

Manufacturing companies compete in the target dimensions time, quality and cost. On the one hand models for production planning and control (PPC), such as Lödding's manufacturing control model [1] or the underlying funnel model [2], aim to explain and influence the time related logistic objectives. They determine to what extend a company can achieve short lead times and high delivery reliability. On the other hand the productivity determines the manufacturing costs. Thus productivity management tries to organize the use of manufacturing resources in the most effective way. Although a fair amount of research has been conducted in both disciplines, it is often difficult to put methods and knowledge into practice. A reason for these difficulties lays in the interdependencies between productivity and logistic objectives [1].

This paper presents an approach to model these interdependencies.

## 2 Productivity and Logistic Objectives

### 2.1 Labor Productivity

Productivity is generally defined as the ratio of input and output [3,4].

$$PRO = \frac{Output}{Input} \quad (1)$$

There are several approaches to measure productivity. The output can be measured in pieces, target hours or monetary units. Depending on the specific

productivity different inputs are considered. Common productivity figures are machine productivity and labor productivity [5].

This paper focusses on labor productivity, since labor costs are especially important in high wage countries. The labor productivity of a manufacturing system may thus be defined as the ratio of number of products produced (output) and paid working time (input) [5].

$$PRO_L = \frac{Output}{Paid\ working\ time} \quad (2)$$

According to Saito [6] several factors influence labor productivity. These factors are method, performance and utilization.

$$PRO = Method \cdot Performance \cdot Utilization \quad (3)$$

The utilization describes how much of the payed working time is actually used to perform the intended work task. This considers losses such as the sickness rate and idle times that result from maintenance or a lack of orders. The method describes how the working time spent on the task performance is transferred into actual output. The factor can be calculated as the inverse of the ideal cycle time. It maps losses resulting from a poor task design or wrong tooling. The performance determines how fast a certain task is performed by the worker compared to a standard time, such as provided by MTM [7].

## 2.2 Logistic Objectives and the Manufacturing Control Model

The manufacturing control model shows the tasks of production planning and control and its effects on logistic objectives via several actuating and control variables. Fig. 1 shows the model. The presented logistic objectives are WIP,

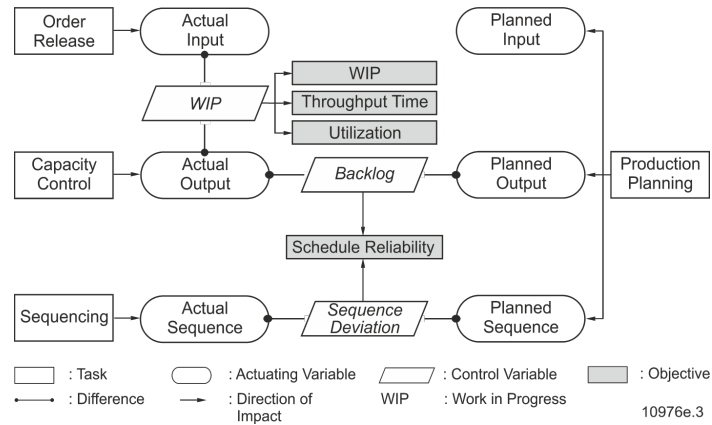


Fig. 1. Manufacturing control model [1]

throughput time, schedule reliability and utilization. The WIP describes the number of orders at a workstation either in queue or in the process of completion. The time period from the release of a job until its completion is the throughput time. Schedule reliability is defined as the percentage of jobs that are completed within a certain due date tolerance before and/or after the planned date of completion. Utilization describes the ratio of maximum possible output rate and actual output rate of a workstation or worker. Losses in utilization occur due to a lack of orders [2]. The manufacturing control model further presents the control variables WIP, backlog and sequence deviation. Backlog is defined as the difference of the cumulated planned output and the cumulated actual output of a work station. Yu [8] describes the mean output lateness as the ratio of the mean backlog and the mean out-put rate. Therefore backlog directly influences the schedule reliability. Sequence deviations occur when the actual sequence deviates from the planned sequence [1]. Sequence deviations lead to an increase in the variance of the lateness and therefore cause a decrease of the schedule reliability. Besides its appearance as a logistic objective WIP functions as a control variable as well. It influences the logistic objectives WIP, throughput time and utilization. A detailed analysis of the relationship between WIP and throughput time is given by the funnel formula [9] as well as by Little's Law [10].

### 3 Linking Capacity, Productivity and Output

The capacity of manufacturing systems can be defined as the capability of all resources in a system, such as workers or machines, in a certain reference period. Capacity is usually measured as a ratio of output and time and can thus be directly compared to an output rate, such as pieces per shop calendar day. On the contrary, capacity planning and control as capacity related tasks aim at influencing the amount of working time. In terms of labor this means the number of workers assigned to a work system, the number of shifts and the duration of the shifts including overtime and shortened work. Due to this, PPC related literature distinguishes several types of capacity. Nyhuis and Wiendahl [2] for example are using the terms theoretical capacity, available capacity and effective capacity. The working time as determined by capacity planning and control is considered as theoretical capacity. It can be calculated as shown in equation 4.

$$CAP_{theo} = NO_{work} \cdot NO_{shift} \cdot WT_p \quad (4)$$

$CAP_{theo}$ : Theoretical capacity [hrs/SCD]

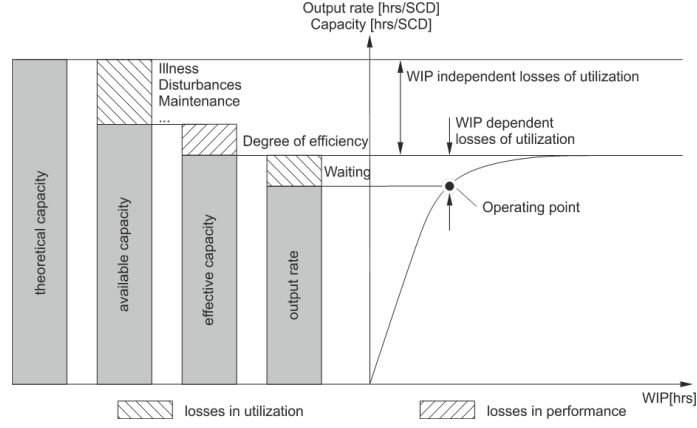
$NO_{work}$ : Number of workers [-]

$NO_{shift}$ : Number of shifts per SCD [-/SCD]

$WT_p$ : Paid working time per shift and worker [hrs]

Due to illnesses, maintenance and other disturbances the available capacity is regularly somewhat lower than the theoretical capacity. The effective capacity describes the maximum output rate of a work system. It results from the available

capacity and the degree of efficiency. The degree of efficiency is dependent on the work system's performance. The actual output rate of the work system again is determined by the effective capacity and the WIP-dependent utilization. Fig. 2 shows the transformation of theoretical capacity towards output rate.



**Fig. 2.** Differentiation of the capacity and output rate, according to [2]

By examining the considerations that lead from the theoretical capacity or the working time of a work system towards its output rate one can see that the influences equal the factors utilization and performance of Saito's productivity model. The method factor is not represented in the figure, because the capacity here is given in planned hours.

As explained before, labor productivity describes to what extend an input of paid working time can be transformed into actual output. The working time as part of the labor productivity is directly related to the theoretical capacity in terms of capacity planning and control. Consequently the transformation from a work system's theoretical capacity to its output rate can be described by its productivity.

To illustrate this, the relations between capacity, productivity, output rate and output are shown in Fig. 3. The complete working time in a reference period is shown in Fig. 3 Left. It is calculated as the product of theoretical capacity and the duration of the reference period.

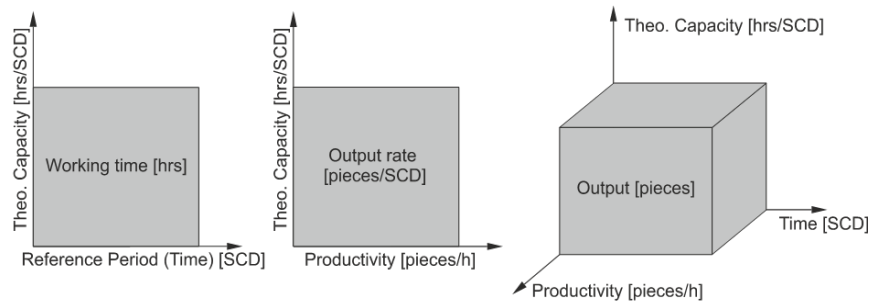
$$WT = CAP_{theo} \cdot PE \quad (5)$$

WT: Working time [hrs]

$CAP_{theo}$ : Theoretical capacity [hrs/SCD]

PE: reference Period (time) [SCD] Based on the observations above, a work system's output rate can be calculated as the product of the system's theoretical capacity and its productivity (eq. 6).

$$ROUT = CAP_{theo} \cdot PRO \quad (6)$$

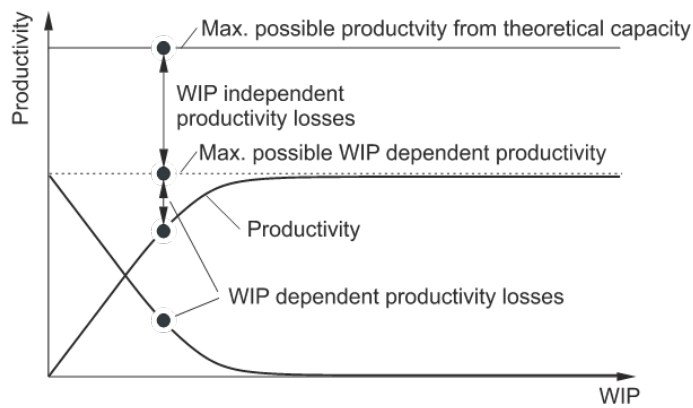


**Fig. 3.** Left: Working time; Center: Output rate; Right: work system’s output as product of theo. capacity, productivity and time

ROUT: Output rate [pieces/SCD]  
 $CAP_{theo}$ : Capacity [hrs/SCD]  
 PRO: Productivity [pieces/h] The output rate therefore can be plotted as shown in Fig. 3 Center. The cuboid shown in Fig. 3 Right represents the work system’s output depending on the amount of capacity in the work system, its productivity and the duration of the reference period.

$$OUT = CAP_{theo} \cdot PRO \cdot PE \tag{7}$$

OUT: Output of the work system [pieces]  
 $CAP_{theo}$ : Theoretical capacity [hrs/SCD]  
 PRO: Productivity [pieces/h]  
 PE: Reference period [SCD] To better understand the influence of productivity on the output rate, logistic operating curves were observed. It can be seen



**Fig. 4.** Interdependencies of WIP, productivity and output rate

from Fig. 4 that the influence of productivity on the output rate is only partly dependent on the WIP. Productivity losses such as a high sickness rate or a poorly designed work task reduce the maximum possible productivity to the maximum WIP dependent productivity. WIP dependent productivity losses result from too low WIP levels. The mechanics behind that are therefore the same as described by logistic operating curves. It must be noted that Fig. 4 shows an operating point in the underload operating zone to demonstrate the effect of WIP on productivity. Usually an operating point with higher WIP would be chosen and thus WIP dependent productivity losses would be much lower. Therefore a much lower effect of WIP on productivity has to be expected.

Productivity improvement actions usually aim at improving WIP independent productivity e.g. by improving ergonomic conditions, reducing non-value-adding processes, etc.

#### 4 Integrating Productivity into the Manufacturing Control Model

According to the findings of section 2.3, capacity control as well as capacity planning are not able to directly influence the actual or planned output of a manufacturing system. They rather determine the actual or planned working time. To this aim, the planned and actual working time is introduced. Fig. 5 shows the adapted manufacturing control model. To reduce complexity, the task

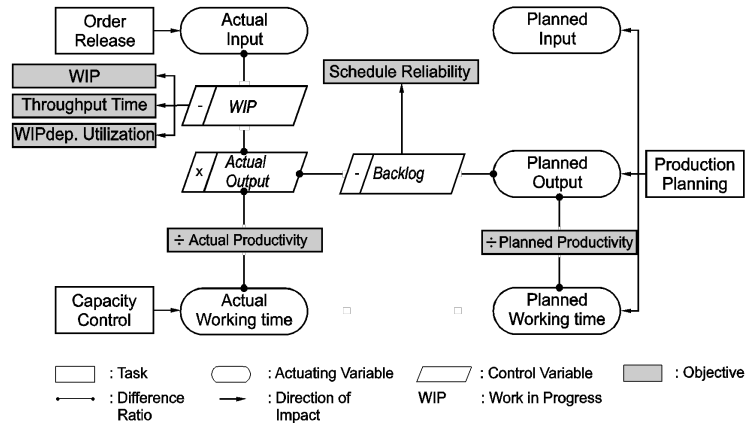


Fig. 5. Adapted manufacturing control model

of sequencing and the related actuating variables actual sequence and planned sequence as well as the control variable sequence deviation are omitted. The focus of the adapted model lies on the newly included objectives actual and planned productivity.

The planned productivity results from the ratio of planned output and planned working time. Production planning is a hierarchical process that, in the beginning, determines the planned output based on the expected customer demand. In further steps the planned working time is determined on the basis of the planned productivity. The planned productivity is thus an important objective. On the one hand it should be aligned with the productivity targets for the actual productivity. On the other hand it is used to calculate the required working time for a given planned out-put. From a planning perspective, planned productivity needs to reflect the possible productivity of a work system precisely, in order to enable realistic planning. From a productivity perspective, the planned productivity should be raised in a way that enables productivity improvement.

The actual productivity results from the ratio of actual output and actual working time. This ratio is influenced by the objective utilization. The actual working time is determined by the task of capacity control. Based on the actual productivity, a certain actual output results from the product of actual working time and actual productivity. For this reason the actual output is not considered as an independent actuating variable, but as a control variable.

## 5 Interaction of Productivity and Logistic Objectives

To illustrate the several effects caused by the interaction of productivity and logistic objectives a simple scenario is examined. The scenario is based on a simple assembly work system with two operators working an 8h shift. The planned output rate of the work system is 32 pieces/SCD with a planned productivity of 2 pieces/h.

As an example we assume a lower actual productivity (due to ambitious productivity targets) of 1.8 pieces/h leading to an actual output rate of 28.8 pieces/SCD (eq. 7).

$$ROUT = 16[hrs/SCD] \cdot 1,8[pieces/h] = 28.8[pieces/SCD] \quad (8)$$

This deviation would lead to a backlog increase of 3.2 pieces per SCD causing a backlog of 32 pieces after two weeks (10 SCD) representing an output lateness of roughly one SCD.

We further assume that overtime is used to reduce the resulting backlog. To compensate the backlog, 16 h overtime are planned based on the planned output rate. As a result of the lower actual productivity, these 16 h would raise the output by 28.8 pieces leaving a backlog of 3.2 pieces. Capacity adaptations are therefore depending on precise productivity data. In case the backlog is the result of a lower actual productivity, the capacity increase will not lead to a sufficient increase of output and some backlog will remain.

If order release is based on the planned output rate (actual input = planned out-put), a deviation of the actual from the planned productivity will as well cause a changing WIP increase. In the example stated above, the lower actual productivity would lead to a WIP of 16 pieces per week. If the work system is not already working at maximum utilization, this could lead to a (most likely



modest) increase in productivity. The growing WIP level would also lead to an increasing throughput time. Based on the actual productivity and output rate, throughput time will have increased by roughly one SCD after two weeks.

## 6 Summary

This paper presents an approach to model the interrelations between productivity and the logistic objectives as presented in Lödding's manufacturing control model. As an outcome, the enhanced manufacturing control model offers the following advantages:

- Better understanding of capacity control: Considering actual productivity allows a better adjustment of capacity control (especially when overtime is applied).
- Better understanding of production planning: The understanding of the effect of production planning on the planned productivity exposes the need for productivity considerations in production planning.

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