Performance Measurement System for Efficiency of Intralogistics-Systems – a Practical Proposal

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Abstract
In the industry (e.g. automotive engineering, machine and plant construction), efficiency savings can be discussed at various system levels. A considerable application potential is at the level of the production system, within which the field of intralogistics-systems is considered to be an innovative starting point. Especially large-scaled (mostly oversized) or (highly) automated conveying systems are characterized by a “high” energy consumption. The oversizing and the use of wear-susceptible components within obsolete or substandard intralogistics-systems (ILS) offer great room for improvement within the field of resource and energy efficiency. In the course of a resource- and energy-saving dimensioning of intralogistics-systems, it is first of all worthwhile to holistically analyze and evaluate the resource and energy efficiency of intralogistics-systems and their components through a performance measurement system.

Keywords
Efficiency, Logistics System, Performance Measurement System

1 INTRODUCTION
In the light of the worldwide dwindling resources and increasing resource demand, the efficient utilization of resources becomes an important competitive factor. Intralogistics-systems¹, as one the most important subsystem of modern manufacturing systems, are still insufficiently adapted to this turbulent environment and are therefore operating extremely inefficiently. A fundamental reason is the robust construction and oversized dimensioning of intralogistics-systems. [1]
Oversizing does not only entail high cost, but also conceals several problems in the planning, construction and operation of intralogistics-systems (cf. Figure 1).

As a logical consequence, transparency throughout the whole life cycle of intralogistics-systems (conception, production, operation and disposal) is needed to identify the aforementioned inefficiency.

2 IMPROVEMENT POTENTIAL IN INTRALOGISTICS-SYSTEM
With the globalization of the market and the rising competitive constraints, existing production systems and processes have to be redesigned to avoid unneeded wastage of resources and capital. Modern low-stock delivery strategies within lean production system require a highly available and reliable intralogistics-system. Therefore, robust construction, oversizing and the use of redundancies pose a simple and established practice to meet the demand. [1]

This practice is justifiable in order to provide the demanded availability and reliability, but against the backdrop of the rising importance of resource and energy efficiency as well as ecological sustainability, this practice is outdated. [1, 3, 4]

It is also remarkable that current intralogistics-systems are maintained breakdown- or time-based. These maintenance strategies cannot fulfill the aforementioned demands of availability and reliability. [5, 6]

Breakdown maintenance is a maintenance strategy where the equipment and system will be utilized until a failure occurs. The use of this strategy can be ascribed to the fact that the maximum utilization of the equipment can be achieved. But a complete breakdown of equipment or subsystem can affect the availability of the total system, and furthermore entails high follow-up costs of unscheduled

¹ According to the common definition, intralogistics include the organization, control, execution and optimization of the in-house material flow as well as stock turnover in industry, trade and public institutions. [2]

Figure 1 - Oversized dimensioning conceals problems [2]
downtime, which can be up to four times higher than maintenance costs [7]. On the other hand time-based maintenance prevents breakdowns by performing periodic maintenance. Nevertheless it is not possible to completely prevent unplanned breakdowns or the early replacement of components before they reach a critical condition, which obviously constitutes a waste of resources.

The “right” replacing time of intralogistics-components is usually not analyzed. Therefore, adjusting the intervals for time-based maintenance according to the wear-out of components is not possible. [8]

An intelligent maintenance concept is the utilization-based maintenance, which forecasts the necessity of a maintenance activity based on the utilization as well as the wear-out of the equipment and system. [9]

A further field of improvement has been identified in the operation of intralogistics-systems. For example, most electric drives are oversized, resulting in huge inefficiencies such as higher energy consumption as well as higher material demand for the manufacturing of those oversized electric drives. The reasons behind the oversizing of electric drives lie in the planning-uncertainties and thus the demand for flexibility. Uncertainties are inter alia exaggerated safety factors or expected system loads². For these reasons, intralogistics-systems are normally designed from the outset to cope with the anticipated system load in 10 years. [1, 10]

This practice, as analogical to maintenance, does not suit today’s demand for efficiency and ecological sustainability.

In addition, to face the challenges in a turbulent environment, flexibility is not sufficient anymore. Changeability and reactivity are key characteristics to meet the challenges. [12]

Identifying these improvement potentials in intralogistics-system is the major task of a research project at the Chair for Factory Organization (LFO). An adequate tool to identify these potentials and initiate improvement activities is a performance measurement system.

3 PERFORMANCE MEASUREMENT SYSTEM

3.1 Key figures for a performance measurement systems

There are different key figure systems for more or less every special field in a company. Examples are:

- Controlling: DuPont key figure system [13, 14, 15]
- Logistics: key figures referring to VDI-Guideline 4400 [16], VDI-Guideline 4490 [17]
- Maintenance: key figures referring to VDI-Guideline 2983 [18], DIN EN 15341 [19]
- Energy: Cumulative energy demand (KEA) [20]; key figure system for energy efficiency [21].

An analysis or an evaluation for resource efficiency (incl. energy efficiency) of production or intralogistics-systems is not possible at the moment, because of the missing key figure system [22]. At the moment different research institutes have created some approaches, but they do not focus on intralogistics-systems [cf. 23].

A “new” key figure for an innovative performance measurement system is the efficiency of intralogistics-systems. The efficiency of an intralogistics-system in general is a relation between the reached input (fulfillment of the demanded system load) and the utilization-based output (driving power, degree of wear out, operating time, etc.) of intralogistics-components – and resultant – of the whole system. [24]

The aims of an efficiency performance measurement system are to increase the utilization through higher effectiveness and better quality as well as to decrease the effort through a lower utilization of resources (e.g. energy, compressed air) (cf. Figure 2).

Efficiency for intralogistics-systems is based on the Overall Equipment Effectiveness (OEE). The OEE can be calculated as the mathematical product of quality (Q), availability (A) and performance (P). The formula for the OEE is the following [cf. 25]:

\[ OEE = Q \times A \times P \]  

(1)

In the given formula a consideration of resource utilization is missing. Due to this missing consideration of resources utilization, it has to be included a new element – a resource rate (R) (cf. Figure 3).

² The system load is the amount of objects which enter a socio-technical system in a given period. The several objects enter in a defined time or interval (“interarrival time”), in a defined quantity on a particular point of time. The objects contain attributes for the socio-technical system for information and transformation purposes and can be altered. [11]
The energy utilization is depending whether there is a measuring tool for energy consumption. If there is no tool for measuring, it is necessary to calculate the energy utilization, by the formula:

\[ \text{Energy Utilization} = \frac{\text{pt} \cdot (e) - \text{it} \cdot (e) - \text{ud} \cdot (e)}{\text{pt} \cdot (e)} \]  

Where:
- \( \text{pt} \cdot (e) \) = process time (by energy consumption)
- \( \text{it} \cdot (e) \) = idle time (by energy consumption)
- \( \text{ud} \cdot (e) \) = unscheduled downtime (by energy consumption)

Due to the formula, the energy consumption of the intralogistics-component is considered. A high rate for energy utilization means low idle time and low unscheduled downtime under the condition of energy consumption. An example is an electric drive of a roller conveyor. If the roller conveyor does not handle a material flow object, it does not need any energy.

With this new element it is possible to determine the efficiency – especially the resource efficiency – of an intralogistics-component (e.g. roller conveyor) as well as a whole intralogistics-system (e.g. distribution center). The “new” key figure system for efficiency is supporting a better transparency in using intralogistics-systems.

To establish an evaluation tool with this performance measurement system a consistent database is necessary.

### 3.2 Database and data acquisition for performance systems

A consistent database is very important for a valid performance measurement system, but a lot of data accumulates on different control levels within an intralogistics-system. The challenge for every consistent database lies in the acquisition of the right data from the electronic data processing system on different control levels.

Several methods for data acquisition currently exist. These methods could be ranged from automatic operation data logging to hand-written log sheets. [27]

Current material flow controls of intralogistics-systems are designed centrally, hierarchically and pyramidal (cf. Figure 5). [28]

![Figure 3 - Key figure system for resource efficiency](image-url)

The new formula for the efficiency for an intralogistics-system is:

\[ \text{Efficiency} = Q \cdot A \cdot P \cdot R \]  

The resource rate will be explained through an example - energy utilization (it does not mean though that the key figure system is only for energy utilization).

The resource rate can consist of different elements (cf. Figure 4). These elements are [cf. 26]:
- Stock,
- Area,
- Personnel,
- Tools,
- Work appliance; and
- Resources (energy, compressed air, oil).

![Figure 4 - Resource rate](image-url)

[27] Current material flow controls of intralogistics-systems are designed centrally, hierarchically and pyramidal (cf. Figure 5). [28]

![Figure 5 - Configuration of Material Flow Control](image-url)
Data for an evaluation of efficiency of intralogistics-systems can be found on different system control levels. These data and information are e.g.:

- Time data: operating time, planned production time, unplanned down time, planned down time
- Quality data: good and bad pieces
- Performance data: ideal cycle time, number of transport objects
- Resource data: energy consumption, compressed air consumption

The lowest control level is the drive and sensor level (Level 1). As the name implies, on this level the actuating elements and sensor systems of the intralogistics-components reside. These are condition monitoring sensors, e.g. flow control for energy and compressed air, which are installed on this level of control. [30]

The following three higher-level systems (Unit, Zone and Subsystem Control) represent the equipment control. Programmable logic controllers (PLC) is one of the most often used control technology. On the one hand PLCs receive all sensor information from the lowest control level and send them in aggregated form to the higher level control system, e.g. to a warehouse management system. On the other hand the PLCs receive control commands from higher level control system and convert them to control commands for the lowest control level [31]. Data about down times and from condition monitoring sensors can be extracted for the performance measurement system by using data loggers. With data and information about control commands for the lowest control level, it is possible to gain information about the operating time of a drive within a whole intralogistics-system.

The system control level (Level 5) is the central material flow control for all operations. On this level information and data relating to topology, backlog of transport orders and status information are stored [30]. The display and communication level (Level 6) is the highest material flow control level. This level connects the warehouse management system and production planning and control with the subordinate control level and transmits the transport orders to it [30]. Typical hardware on these two control levels are warehouse management and material flow computers, where time, quality and performance data can be extracted and transferred to the evaluation tool.

The host and the warehouse management control do not belong to the material flow control. Typical deployed systems are e.g. an enterprise resource planning system, a production planning and control system as well as a warehouse management system [cf. 28, Figure 5]. This system level contains order disposition and warehouse management data [30]. Depending on the functional scope and connection to subordinate systems, all needed data for the evaluation can be queried from these superordinate systems. Thus this system level poses an appropriate database for the acquisition of all data needed for the performance measurement system.

Data / information sources for an evaluation tool are (cf. Figure 6):

- Logistic Control Station
- Enterprise Resource Planning System
- Condition Monitoring Sensors (connected to superordinate system via data logger)
- Computerized Maintenance Management System
- Manufacturing Execution System
- Anticipatory Change Planning

![Data interface for a performance measurement system](image)

4 EVALUATION TOOL

The developed performance measurement system has been realized in the form of a database. This tool allows the user to evaluate the efficiency of intralogistics-systems on the component level, e.g. rack feeder or roller conveyor. This level has several advantages for the evaluation. Through the aggregation of the component efficiency key figures,
the efficiency of a section or even a whole department can be evaluated. Furthermore, the evaluation on the component level permits the identification of inefficient components. The tool consists of an input screen and an analysis unit. In the first version of the tool, the data for the calculation of availability, performance, quality and energy efficiency has to be inserted manually by using an input screen. Later versions will contain an automated retrieval of the needed data from higher-level and sub electronically data processing systems. The analysis unit processes the data and calculates the efficiency, which will be saved in the form of a table.

To increase the system transparency a filter and a "traffic light system" have been implemented. The filter enables selection of the evaluated components by component type and department, whereas the traffic light systems indicate efficient and inefficient components. According to the predefined requirements and boundaries, a green colored key figure means that the intralogistics-component runs in a favored condition. An amber light indicates that the components operate in the tolerable range while a red light reveals a critical condition. A complete overview of the efficiency of all components and departments can be conducted with the report function, where the traffic light system is also implemented.

6 ACKNOWLEDGMENTS
The findings illustrated in this paper are results of the research projects "Paketantrag 672 Leistungsverfügbarkeit – Logistics on Demand" funded by the German Research Foundation ("Deutsche Forschungsgemeinschaft (DFG)"). More information about the projects can be found on the webpage or by contacting the authors of this publication.

7 REFERENCES

5 SUMMARY
It was shown in this paper that efficiency for intralogistics-systems have a huge potential. There are a lot of potentials for example in the dimensioning of intralogistics-components and systems. A first step to identify (resource) efficiency potentials are described with the performance measurement system for efficiency of intralogistics-systems and an associated evaluation tool. In a newly established research project the performance measurement system and an extended tool (realized with service-oriented architecture) will be verified and validated.
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