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PERFORMANCE EVALUATION OF SHOP FLOOR OPERATIONS: AN EMPIRICAL APPROACH

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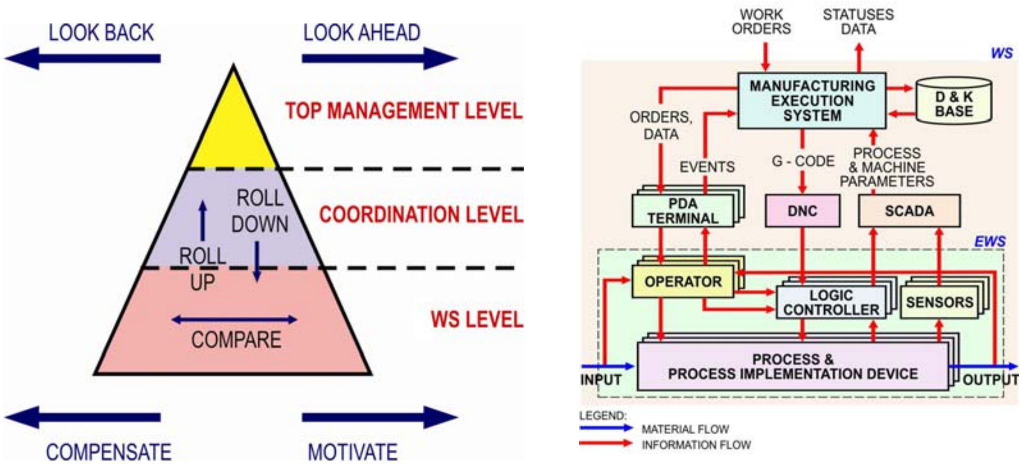
ABSTRACT
Manufacturing systems are becoming more and more complex, globalized and also overwhelmed with data in various forms generated by and located at different sources. Performance evaluation on the shop floor level must be observed and analyzed because of the direct correlation between shop floor operations and prosperity of the whole manufacturing company. Modern technologies, automated or semi-automated computerized manufacturing systems enable us to collect large volumes of production data. In order to have benefits from these datasets and to gain indispensable advantages over a competition - adequate evaluation should be performed. The article represents the interpretative and empirical building attempt to set relationships among the collected data and to assess performance of a manufacturing system.
Keywords: manufacturing, performance, decision-making, work system, LIMES.

1. BACKGROUND AND MOTIVATION
Over recent years many manufacturing organizations have faced increased competition from foreign and domestic firms. Many manufacturers, especially those with a clear vision to become more competitive in the today's global environment, are adopting performance alignment technologies to help them to link a corporate strategy to operational processes and activities. Manufacturing is considered to be an important element in a firm’s endeavor to improve its performance [1,2]. Many sources claim that conventional aggregate financial indicators are inappropriate in modern manufacturing settings [3,4]. More precise, manufacturing performance measures are required to ensure that strategies can be affected in ways which provide a balance between enhanced product characteristics and cost effectiveness [5,6,7,8]. Thus, performance measures (PM) are indispensable to manufacturing firms. The observation of the input and the output is a manufacturing system are of crucial task for the system optimization. PM have several generic functions: (1) reflection of the current state, (2) monitoring and control of operational efficiency, (3) driving of an improvement plan, (4) to observe the effectiveness of decisions [9]. As mentioned, PMs are indispensable and should not be threaten self-purposely or as a burden to the manufacturing company.
By definition, performance is result of operations, events, statuses, etc. which happened. Based on the PM, correctly measured and prepared, the proper decision-making choices and forecasting of the company strategy can be made.
The use of PM systems has received considerable interest and attention in the recent years. Since manufacturing firm’s prosperity rely on good performance of the shop floor, PM of the shop floor operations gain important role. In the field of manufacturing, shop floor scheduling, machining process monitoring and remote control are some examples of crucial processes. The shop-floor operations play an important role in a manufacturing company. The basic value-adding manufacturing processes, such as machining, welding, assembly, surface treatment, etc., are executed here. The shop-floor performance in terms of quality, availability, timing, throughput, productivity, costs, etc., is

reflected in the overall performance of a company. Therefore, its PM management, control and monitoring is of decisive importance.

2. PERFORMANCE MEASURES

In Figure 1a, the main purposes of performance measures are described. Meyer proposed that performance measures could have seven different purposes [7,8]. Looking from the time perspective, a performance measure could either look back or look forward. By looking back, PMs can forecast some future events and helps react more correctly. From the organizational perspective, a measure could be aggregated from the bottom to the top of the company to allow a clear visible linkage between the unit performance and the organizational performance. Similarly, it could cascade down from management via coordination level to the individual work system (WS) units. Furthermore, PM could also be used for performance comparisons among horizontal WS units across the workshops to facilitate performance comparison. This perspective also includes human perspective: a measure could be used for motivational and compensation needs.



a) Purposes of PM [9]. *b) WS control information system [11].*

Figure 1. Decision-making based on performance measures.

Figure 1b shows the structure of the control information system for acquisition of data and preparation of data for evaluation of PM. The role of the manufacturing execution system (MES) is to collect and interpret production data for the WS management in order to enable tactical and operational decisions on actual data. The decisions are delivered to the WS operator via the production data acquisition (PDA) terminal. The PDA terminal also transmits product related data (e.g. drawings, process plans) and production related data (e.g. schedules, set-up data, tooling lists, etc.) to the operator. NC-programs in the form of G-code are downloaded on the CNC machine-tool controller via the DNC service. Three kinds of data are collected in real-time to support MES: (1) production events which are entered by the operator via the PDA terminal, (2) machine tool states and (3) process parameters. The later two are collected over the supervisory control and data acquisition (SCADA) system partially from the CNC controller and partially from sensors. The collected data are stored in the D&K database and serve as the feedback for the real-time control and for performance evaluation in terms of performance indicators, which represent aggregate information and knowledge for closing the performance-based control loop. The third important aspect of the data is their visibility within the network in order to close the outside, i.e. network control loop.

In order to employ PMs on the shop-floor level, some basic PM's characteristics must be defined and described.

The characteristics of PM can be defined by a what-who-how-when method, as shown on Figure 2. Type of PM defines the nature of a PM. The aggregate means that PM is bound on many measures in order to gain some weighted information. Name, code, class, etc. attributes define other characteristics for data manipulation, PM definition and human (description) or machine understanding (code).

Basically, class defines the kind of the observed PM. The class can be of the following category: T-time, C-Cost, Q-quality, F-flexibility or P-productivity. The "Who" attribute defines to whom the observed PM is intended. This basically means how the measure is "rolled down" or "rolled up" (See Figure 1a). "How" and "when" define how PM is collected and presented.

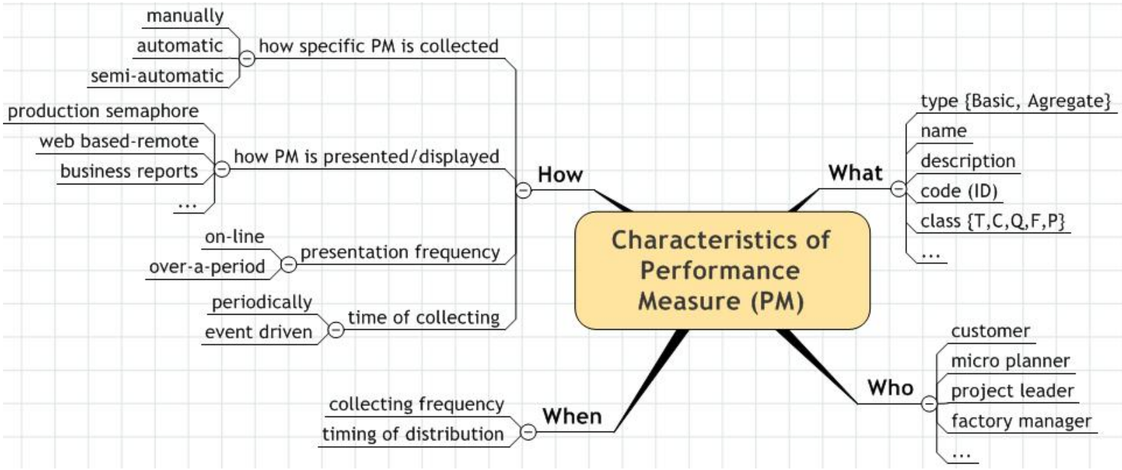


Figure 2. Performance measure characterisation

In order to evaluate a PM, data must be collected. In general, data can be gained by simple surveys, questioners, etc. In technical systems, such as workshop, data can be collected systematically as shown on Figure 1b. Table 1 shows some workshop measurements with basic attributes.

Table 1. Measurements collected during production.

Name	Code	Collecting	Trigger	Output	Examples
Machine status	MS	A	PE	on/off	{0,1,0,1,1,0,1}
WS events	WE	A / M	ED	event list	{Tool setup, Oil filter problems, ...}
Process param.	PP	A	PE	value	P_{max} {18.8bar, 20.2 bar, …}
Workpiece -conformance	WP	A / M	ED	yes/no	{OK, NOK}
Work order status	WO	A / M	ED	status list	{waiting, in progress, …}
…	..	…	…	…	…

Legend: Collecting: A-automatic, M-manual; Trigger: PE-periodically, ED-event driven.

As mentioned, PM can be formed by collecting data. Table 2 presents examples of PM based on measurements in Table 1.

Table 2. Examples of workshop performance measures.

Name	Reporting	Type	Class	Intended to	Display/Visualization
Machine utilization	OL	A	T	micro-planner	3D sequential graph
Workshop utilization	OL, OD	A	T	workshop manager	infinite color bar graph
No. of malfunctions per time unit	OD	B	Q	maintenance	histogram
Cost of WO	OD	A	C	cost manager	table
…	…	…	…	…	…

Legend: Reporting: OL-on line, OD-on demand; Class: T-time, Q-quality, C-cost; Type: A-aggregate, B-basic.

3. CASE STUDY-PMs IN AN ENGINEER-TO-ORDER COMPANY

The described approach is implemented in a workshop in an engineer-to-order firm. The company produce complex one-of-a-kind products, e.g. water turbines, hydro mechanical equipment, pumps, cranes and industrial equipment and forming equipment. In order to observe and to evaluate PMs of a workshop, the LIMES information system was developed [12,13]. Figure 3 shows an example of a "roll-down" function. This function enables decision-making personnel to gain information-performance measures- about state of manufacturing in the firm.

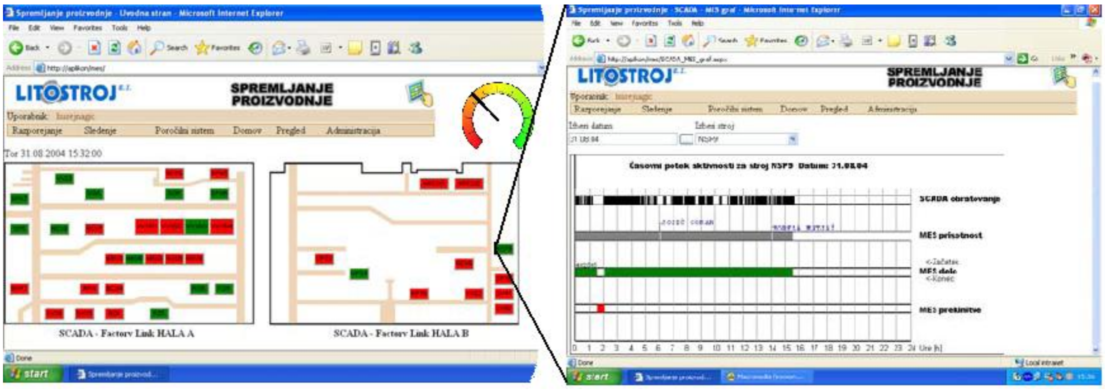


Figure 3.Example of workshop PM visualization.

With LIMES, the workshop PMs can be observed on-line, remote (web based) in a user-friendly visual manner. Multi-layer logical structure enables "roll down" and "roll up" functions for all three levels in the firm: WS level, coordination level and top management level.

4. CONCLUSION

In the paper, the performance measures for performance evaluation and decision making in production are presented. The focus is put on performance measures characteristics and related measurements. The typical examples are given.

Fine tuning of manufacturing processes based on knowledge from production data might bring competitive advantage. PMs, based on actual and reliable data represent compact aggregate information which is very suitable for operational and strategic decision making.

After one year of experiments, the following observations and effects are noticed: increase of transparency of workshop operations, reduction of lead-times and response times for standstills, more efficient transportation logistics, increased quality of work orders, higher work system availability, larger throughput, etc.

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