LEAN MANUFACTURING PERFORMANCE - METRICS AND EVALUATION

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Summary: The paper contains analysis of the performance measurement metrics related to the transformation process to lean manufacturing. It includes description of integral and specific performance indicators, provides formulas for the calculation of integral indicators, monitoring periods and target values.

Key words: lean manufacturing, performance measurement, lean metrics, First-Time-Through (FTT) capability, Overall Equipment Efficiency (OEE), Dock-to-Dock Time (DTD, Build to Schedule (BTS)

1. Introduction

Lean manufacturing represents an integrated approach to manufacturing of products/services with the purpose of achieving superior quality, timely delivery and competitive cost for customer satisfaction. The goal of lean manufacturing is to reduce the waste in human effort, inventory, time to market and manufacturing space to become highly responsive to customer demand while producing world-class quality products in the most efficient and economical manner [1]. Lean manufacturing combines in itself the best features of mass production and craft production – i.e. the ability to reduce per unit costs and to improve significantly quality providing simultaneously a wider range of products and more challenging work.

Lean metrics guides the organizations in their transformation into lean enterprises. It involves visible performance measures, targeted improvement, team reward and recognition [2]. Most of the existing metrics have poor links to production issues and better links to financial and accounting ones. The selection of effective performance measurement metrics is the key to achieving the declared goals. Intensive global competition forces companies to improve and optimize their productivity in order to stay on the market.

2. Essence of performance measurement

Performance measurement is a quantifying process for the efficiency and effectiveness of action [3]. On a more essential level efficiency and effectiveness focus on the central business related issues - cost, quality, delivery, people, suppliers, markets and new product introduction [4]. An effectiveness assessment quantifies the extent to which a process generates intended results. For the measurement process, the effectiveness assessment quantifies how well the measurement process provides timely, accurate, and useful information to
the decision makers. Fig. 1 gives a picture of the relationships between the factory efficiency efforts and other production practices.

Fig. 1 Relations between factory efficiency efforts and other production practices

A value stream analysis is critical to starting manufacturing operations with a minimum of waste. In the ideal case the analysis should be performed prior to the production floor layout accomplishment and manufacturing plan development. Practically it may be performed at any point. The baseline metrics are determined based on the input of the “as-is” value stream map. If the enterprise managers have decided to accomplish a transformation process implementing the principles of lean manufacturing it has to ensure the results of the transformation. For this purpose, at each stage of the transformation process the decision makers should use appropriate indicators for assessing the current status of the enterprise, as well as for the establishment of goals and managerial decision making. Experts have recommended the establishment of seven to ten simple indicators that could help the understanding of the performance effectiveness and their systematic implementation starting from the places (sections) where transformation has begun. The new indicators replace the old ones, which have been in use prior to the undertaking of the transformation. These indicators can be conditionally divided into two big categories [5]:

- Integral (complex) indicators, which allow the assessment of the overall status of the production system of the enterprise and the impact of the conducted transformations on the enterprise/company operation as a whole;

- Specific indicators for the assessment of the impact from concrete improvement initiatives on specific production processes.
3. Integral and specific indicators
   A) Integral (complex) indicators

   The following indicators may be called integral: production efficiency, inventory turnover, work-in-process (cash value), labor productivity, production rate, etc. Besides these well known indicators there are others, which are also important.

   First-Time-Through (FTT) capability

   Measures the percentage of units that go through production process without being scrapped, rerun, rested, returned by the downstream operation, or diverted into an off-line repair area. FTT is a leading indicator of quality and defects are calculated for each process and yield is calculated at the end production run and is a lagging indicator.

   \[
   FTT = \left( \frac{N_{in} - (N_s + N_{rer} + N_{rt} + N_{rep})}{N_{in}} \right) \times 100
   \]

   where:
   \( N_{in} \) – number of input units
   \( N_s \) – number of scrapped units
   \( N_{rer} \) – number of reworked (rerun) units
   \( N_{rt} \) – number of retested units
   \( N_{rep} \) – number of repaired units

   Usually the monitoring period is selected to be one working shift or one working day. The target value of FTT is 100%.

   Overall Equipment Efficiency (OEE)

   This indicator has been widely used by the manufacturers to determine the productivity at the equipment level. It is usually formulated as a function of a number of mutually exclusive components, such as availability, efficiency, performance efficiency, and quality efficiency in order to quantify various types of productivity losses, such as breakdown, set-up and adjustment, idling and minor storage, reduced speed, and quality defect and rework. It shows to what extent specific equipment (or equipment group) is used for the production of a concrete product type (product group).

   \[
   OEE = \frac{T_{pt} / T_{st}}{T_{pt} * (N_{fu} - N_d) / N_{fu}} \times 100
   \]

   where:
   \( T_{pt} \) – actual processing time of the equipment (total processing time of the equipment per shift)
   \( T_{st} \) – shift time (scheduled processing time)
   \( T_c \) - cycle time of the equipment (time per unit)
   \( N_{fu} \) – number of finished (processed) units
   \( N_d \) - number of defective (rejected) units

   Usually the monitoring period is selected to be one working shift. The target value of OEE is 100%.

   Dock-to-Dock Time (DTD)

   It is an indicator that measures how long it takes for raw materials or sub-components coming into plant to be turned into finished products.
Improving DTD time improves the company’s ability to make on-time deliveries, lowers material handling, obsolescence and inventory carrying costs which in turn leads to lower total cost. This indicator can be applied to the assessment of the whole enterprise, or to the assessment of single production lines or separate product groups. It is used to assess the flexibility and efficiency of the production systems.

$$DTD = T_{mi} + T_{mct} + T_{fi}$$

where:

- $T_{mi} =$ Volume of stored raw materials and subcomponents (days)
  - Average daily demand
  - (using numbers or cash values for the assessment of the inventory and the average daily production rate of the production line or the enterprise)

- $T_{mct} =$ Manufacturing cycle time (MCT) - the amount of time required to turn raw materials into finished units

- $T_{fi} =$ Volume of stored finished units (days)
  - Average daily demand
  - (using numbers or cash values for the assessment of the inventory and the average daily production rate of the production line or the enterprise)

The specific DTD values depend on the production type and on the utilization of the production processes. Lean manufacturing goal is to achieve significant reduction of DTD.

**Build-to-Schedule (BTS)**

It is an indicator that measures how well a plant executes plans to produce precisely what the customers want in the proper volume, mix and sequence.

$$BTS = K_v * K_{mix} * K_{seq} * 100$$

where:

- $K_v =$ Actual production volume
  - Scheduled production volume

- $K_{mix} =$ Actual of the scheduled mix
  - Scheduled mix

- $K_{seq} =$ Actual sequenced as scheduled
  - Number of sequences

The period of monitoring depends on the duration of the production cycle, but usually it is a shift, working day, or working week. The target value of BTS is 100%.

**B) Specific indicators**

To evaluate the efficiency of the transformation processes many well known indicators can be used – i.e. total idle time, production rate, scrap rate related losses, percentage of returned production by the consumers, etc. The following less known indicators though are also very useful:

**Floor space required**

This is the area occupied by the production line/cell. It is calculated as a sum of the areas, occupied by production equipment, storage and maintenance
zones. Monitoring is performed before and after an improvement initiative. The objective is to reduce the occupied production area while maintaining or raising production level.

*Product transportation length*
This is the total length (in meters/kilometres) travelled by the products from the beginning until the end of the production process. Monitoring is performed before and after an improvement initiative. The objective is to reduce product transportation.

*Idle time due to setups*
This is the amount of time a machine or process is down during changeover from the last good piece to the first good piece of the next product (in minutes or hours). Monitoring is performed at every next setup. The target is to reduce idle time, reducing setup waiting time, actual setup time, and setup-related material wastes.

*Work-in-process (WIP) turnover (in days)*
This is the quantity of materials and subcomponents, which are continuously in the production process divided by the average daily production demand for materials and subcomponents. The advantage of such WIP turnover indicator is its independence from the product price variations and the materials used for their production. Monitoring is performed before and after an improvement initiative. The objective is to reduce the WIP turnover period.

*Manufacturing Cycle Time (MCT)*
This is the total time from the beginning of the first operation until the end of the last operation from the production process for product manufacturing. It includes the time for operations, transportations, setups, etc. Monitoring is performed before and after an improvement initiative. The objective is to reduce MCT and as a result to reduce DTD value.

4. Conclusions
- Lean manufacturing principles and methods can and may play decisive role for the raising of the production competitiveness
- The transformation to lean manufacturing often does not require huge investments (purchasing of new expensive equipment, new materials and technology implementation, automation and complex computer system implementation can be avoided)
- There is a need for a change in the production culture, the relations between the different levels and divisions of the enterprises, the value system of the enterprise managers and staff which is not easier than the purchasing of new and expensive equipment.
- Lean metrics can be embedded into simulation models and simulation runs can be generated to investigate the significance of various improvement opportunities.
5. References

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