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The Role Played by the Advance Maintenance Practice in manufacturing performances

Eng. Mohamed M. Elmesmary & Eng. Hassan Ali Al-Zenki
Public Authority of Applied Education &Training Kuwait

Abstract
It is not obvious how firms should measure their manufacturing performances. Various approaches, most of them with a large number of measures on different hierarchical levels, exist. Many of the measures used are considered obsolete and inconsistent for various reasons. The usefulness of most cost accounting systems, individual measures as well as more comprehensive activity-based costing systems, are frequently questioned since they do not cover manufacturing performances relative to the competitive capabilities (e.g. Dixon et al., 1990, White, 1996). Another serious problem with most performance measurement systems used in firms is that they often include too many different measures, which makes it difficult to understand the "big picture" (Keegan et al., 1989).

I. Introduction

Integration between measures is often problematic, and many papers have emphasised that firms have no effective system that covers all necessary performance dimensions (e.g. Caplice and Sheffi, 1995; Ghalayini and Noble, 1996; Maskell, 1991; Schmenner and Vollmann, 1994; Srikanth and Robertson, 1995). Schmenner and Vollmann (1994) showed in an empirical study that most studied companies needed seriously to consider changing their performance measurements. They argued that most firms were both using wrong measures and failing to use the right measures in correct ways. This is serious and it therefore seems important to identify the critical dimensions in a performance measurement system (what to measure) and the optimum characteristics of the measures (how to measure). Measurement systems could then be evaluated and improved with the dimensions and characteristics as comparative datums. Evaluation of the existing system against the identified set of dimensions and characteristics is the first step toward a more comprehensive and effective approach for measuring overall manufacturing performance (OMP). The second step is to suggest improvements of the existing performance measurement systems.

It has been identified that a large proportion of the total costs of production can be attributed to production losses and other indirect and "hidden" costs (Ericsson, 1997). The overall equipment effectiveness (OEE) measure attempts to reveal these hidden costs (Nakajima, 1988) and when the measure is applied by autonomous small groups on the shop-floor together with quality control tools it is an important complement to the traditional top-down oriented performance measurement systems. However, OEE is not a complete OMP measurement system.

It is important to evaluate individual measures as well as complete measurement systems. This paper focuses on the OMP measurement system level and not on individual measures. The OEE measure is studied, but it is evaluated from the overall systems level. The first objective is to develop a framework for evaluating overall manufacturing performance measurement systems. The second objective is to describe the OEE measure and explain how it fits into the overall performance measurement system. Three case studies are presented, which illustrate how OEE is being used in industry. These are used as a basis for showing how OEE is deficient as an OMP system but a useful part of an overall system of measurement.

II. Dimensions and characteristics of OMP measurement

The performance measurement system may be used for top management control or continuous shop-floor improvement. It may be compared against internal targets or external benchmarks. No matter what the objective of the system or use of the performance information, a complete OMP measurement system needs to be comprehensive and cover the most critical performance dimensions of the organisation.

We first review previous efforts to define the requirements of a good OMP system. Ghalayini and Noble (1996) asserted that to overcome the previous limitations of performance measurement systems new systems should be dynamic, stress the importance of time as a strategic performance measure and link the areas of performance and performance measurement to the factory shop-floor. Maskell (1991) stated that a good measurement system should be related to manufacturing strategy, include non-financial measures, vary between location, change over time, be simple and easy, give fast feedback, and aim to teach rather than to monitor. Caplice and Sheffi (1995) argued that a "good system" should be comprehensive, causally oriented, vertically integrated, horizontally integrated, internally comparable and useful. Lynch and Cross (1991) noted that good systems include the need to: link operations to strategic goals, integrate financial and nonfinancial information, measure what is important to customers, motivate operations to exceed customer expectations, identify and eliminate waste, shift the focus of organisations from rigid vertical bureaucracies to more responsive, horizontal business systems, accelerate organizational learning and build a consensus for change when customer expectations shift or strategies call for the organisation to behave differently, and translate "flexibility" into specific measurement.

When designing performance measurement systems it is necessary to decide first, what to measure, and second, how to measure. The dimensions "strategy", "flow orientation", "internal efficiency" and "external effectiveness" of the present framework mostly describe the "what to" question. It is not enough to identify what dimensions to measure; the measures also need to be designed so that the performance information can be successfully used. The way may differ between systems with different objectives. However, the characteristics "improvement drivers" and "simple and dynamic" describe the "how to" question. We now consider each of these dimensions and characteristics separately.

III. Strategy

The competitive priorities of the business or product have to be emphasised in corporate, business and manufacturing strategies, as well as in measures on various hierarchical levels. This dimension deals with two important aspects of performance measurement systems. First, the system should measure the long-term success factors (qualifying and order-winning criteria) of organisations, not just short-term departmental specific performances. Maskell (1991), for example, identified six elements of a manufacturing strategy that should be measured: quality, cost, delivery, lead time, flexibility and employee relationships. Allen (1993) further developed this list to 19 critical success factors. Second, it should emphasise that the long-term success factors have to be derived from management level to direct production personnel, and measured on all hierarchical levels of the organisation. The decisions made at different levels of the organisation vary in nature, but they should all strive towards the same overall strategy. Increased focus on quality, dependability and flexibility, and the fact that strategic priorities might vary between products, and between stages of a product's often short life-cycle, sometimes make it hard to link measures to strategies. Performance measures may even hurt a company's corporate strategy due to mismatch between goals on different levels (Caplice and Sheffi, 1995). This is serious. Lynch and Cross (1991) considered that qualitative and non-financial manufacturing performance measures can help organisations to link operations to strategic goals on all hierarchical levels, since they are easier to derive from the qualifying and order-winning criteria and easier to put into effect, but it is still necessary to link corporate, business and manufacturing strategies. To be a relevant tool for achieving the intended manufacturing strategy the performance information must be directly linked back to the personnel within the organisation.

IV. Flow orientation

Effective manufacturing contributes to efficient flow of materials, with high quality and short throughput times. We should therefore measure horizontal business processes, that cut through the firm, instead of functional processes, i.e. by products rather than shops. It is becoming more important to view manufacturing and business from supply chain perspectives, consisting of vertically integrated processes and firms, and chains of suppliers and customers. This makes performance measurement even more difficult to carry out, and leads again to flow-oriented measures. One way of switching to flow orientation is to measure times and throughput volume (e.g. Azzone et al., 1991). A time-based approach does not necessarily lead to a "flow measure", though.

First, it has to be vertically integrated and not just "inward looking", and then it has to be comparable to other measures. For example, inventory levels, turnovers, throughput times and service levels are more important from a supply chain perspective than from a functional production perspective. The measures are comparable if they cover the same functions and processes along the ever-more-integrated supply chains. Caplice and Sheffi (1995) argue that a flow-oriented system actively encourages inter-organisational co-operation and innovative approaches to the organisation. They mean that focus switches from orders already placed to trying to modify the order patterns by working with customers and suppliers as partners.

V. Internal efficiency

The objective of the internal efficiency dimension is to identify performances of a function. Use of financial metrics for internal efficiency can simplify trend identification and comparison of the overall internal efficiency between departments. Trade-off analyses between various performances can easily be carried out if they are all measured in financial terms as "costs" or "profits". However, several measures of internal efficiency, such as lead time, are difficult to operationalise with financial measures. Non-financial and qualitative measures are important complements to traditional financial measures, especially when it comes to day-to-day control of the manufacturing, as they are often more flexible and give fast feedback to the organisation (Maskell, 1991).

It is often advantageous to use operational and qualitative measures as improvement drivers in quality circles and project teams, while aggregated financial measures are more important for management, although mixing the two types of measures is necessary to cover all internal efficiency dimensions. However, mixing financial and non-financial measures can be considered complex from an overall management, as well from a shop-floor, perspective. To decrease the complexity of the overall measurement system, it is therefore important to focus on a small carefully-selected set of financial and non-financial measures of internal efficiency.

VI. External effectiveness

This dimension deals with measurement of customer satisfaction and fulfilment of the competitive priorities. Service level and quality measures, on both strategic and operational levels, are often used for measuring external effectiveness in firms, but they are not enough for measuring total customer satisfaction, or to cover competitive priorities. The definitions of quality often deal with product quality and internal efficiency, rather than customer satisfaction based on external data. Customer satisfaction research is neither quick nor easy. A significant commitment of company personnel is necessary, even if an outside research company manages the main part of the interviewing and analysis phase of the customer satisfaction measurement.

Dutka (1994) argues that six months elapsed time from developing a request for a customer satisfaction proposal to receiving the first customer satisfaction ratings is not uncommon. To be able to fulfil customer requirements direct production personnel have to be given more authority and more direct contact with external customers. This leads to identification of customer-oriented measures to be carried out on shop-floor level (Maskell, 1991). A practical problem in several firms is that measurement systems are often split between internal efficiency and external effectiveness. This might create a "measurement gap", that sometimes is considered to be a big obstacle. An important objective of the measurement system should be to bridge this gap (Andersson et al., 1989), and establish the relationship between the internal measures (causes) and the external measures (effects).

VII. Improvement drivers

According to Ishikawa (1982), the reason for collecting data should not be to present neat figures, but to create a base for action and development of processes. This is very much linked to what data are collected, how the analysis is carried out and how the performance information is used. The data source may be internal or external, the data type subjective or objective, the focus may be on the process input or outcome, the reference external benchmark or internal target (White, 1996). There are three aspects of future performance improvements. First, the set of measures should cover those aspects that indicate potential future improvements. Worker empowerment, job fulfilment and managerial commitment are not directly linked to process outcome, but are often considered vital conditions for improvement in performance (Deming, 1986). These more or less subjective aspects could therefore be used as indicators for potential future improvements, even if it is difficult to directly link them to the final result. Second, the measure should in itself identify and generate continuous improvements, instead of working as passive control. This is especially true for operational measures focusing on non-value added activities, such as OEE. Third, when measuring long-term rather than short-term performance on a continuous rather than a periodic basis the performance measurement system can work as an important component of a continuous improvement program.

VIII. Simple and dynamic

The measure should be simple and easy to understand, calculate and use, and not necessarily have fixed format. This is true for the individual measure, as well as for a system of several measures. Keegan et al. (1989) considered that the problem with most OMP systems is that there are too many obsolete and inconsistent performance measures. Schmenner and Vollmann (1994) showed in a survey that most manufacturing companies need seriously to consider changing their performance measurements. Most firms both used wrong measures and failed to use the right measures. Too many or too complex measures might lead to a reactive system, focusing on checking and controlling the past, or end up being ignored or discarded after a relatively short period of time. There probably exists no panacea that works well in all organisations, but the key is to evolve one's own - dynamically and iteratively. Table I provides a summary of OMP dimensions and characteristics

No single measure can possibly cover all these aspects on the management as well as the shop-floor level, but a structured set of measures and a balanced management interpretation is probably more suitable. Sets of integrated performance measurements, such as the SMART system (Lynch and Cross, 1991), balanced scorecard (Kaplan and Norton, 1992) and other synchronised measures (e.g. Ghalayini and Noble, 1996; Maskell, 1991; Srikanth and Robertson, 1995) have been proposed in order to link internally and externally focused measures and to give an overall view of companies' performances. Ghalayini and Noble (1996) emphasise the following limitations of existing integrated performance measurement systems (i.e. SMART and balanced scorecard) they are mainly constructed as monitoring and controlling tools rather than improvement tools; they do not provide any mechanism for specifying which objective should be met in a specific time horizon; they are not dynamic systems; they do not look ahead to predicting, achieving and improving future performances; they do not provide any mechanism to achieve global optimisation especially at the operational level; they do not stress the importance of time as a strategic performance measure; and none of the models provides a specific tool that could be used to model, control, monitor and improve the activities at the factory shopfloor.

The availability measures the total time that the system is not operating because of breakdown, set-up and adjustment, and other stoppages. It indicates the ratio of actual operating time to the planned time available. Planned production time (or loading time) is separated from theoretical production time and measures unplanned downtime in the equipment, i.e. by this definition unavailability would not include time for preventive maintenance. This definition gives rise to planning of preventive activities, such as preventive maintenance, but it might lead to too much maintenance of the equipment and too long set-up times. If planned downtime is included in the production time, the availability would be significantly lower, but the true availability would be shown. That would create motives for decreasing the planned downtime, e.g. through more efficient tools for set-up and more efficient planned maintenance.

The performance rate measures the ratio of actual operating speed of the equipment (i.e. the ideal speed minus speed losses, minor stoppages and idling) and the ideal speed (based on the equipment capacity as initially designed). Nakajima (1988) measures a fixed amount of output, and in his definition (P) indicates the actual deviation in time from ideal cycle time. De Groote (1995), on the other hand, focuses on a fixed time and calculates the deviation in production from planned. Both definitions measure the actual amount of production, but in somewhat different ways.

The quality rate only takes into consideration the quality losses (number of items rejected due to quality defects) that happen close to the equipment, not the quality losses that appear downstream. This is a very introspective approach. A wider definition of (Q) would be interesting, but would complicate the calculations and interpretations. It should be according to which process is to blame, and this is not always easy to identify.

Owing to different definitions of OEE and other varying circumstances between companies, it is difficult to identify optimum OEE figures and to compare OEE between firms or shops. Some authors have tried to do it though; e.g. Nakajima (Raouf, 1994) asserted that under ideal conditions firms should have $A > 0.90$, $P > 0.95$ and $Q > 0.99$. These figures would result in an $OEE > 0.84$ for world-class firms and Nakajima considers this figure to be a good benchmark for a typical manufacturing capability. Kotze (1993), on the other hand, argues that an OEE less than 0.50 is more realistic. This figure corresponds to the summary of different OEE measurements presented by Ericsson (1997), where OEE varies between 0.30 and 0.80. These disparate figures indicate the difficulties of comparing OEE between processes.

The framework of dimensions and characteristics is meant to be used when evaluating and improving a specific OMP measurement system. Here, the systems of three firms were studied. The first firm was the smallest and youngest. It relied on a flat and decentralised organisation structure. Its measurement system followed the process and structure of the Malcolm Baldrige Quality Award. The second plant belonged to a large corporation. Its measurement system was quite hierarchical and top-down controlled. The measurement system of the third plant differed between workshops in the organisation. One shop was organised according to a bottom-up approach with autonomous teams. The other shops were more top-down controlled.

A common weakness of all three measurement systems was that they did not measure flow orientation or external effectiveness to any great extent. They focused on functional measures and failed to integrate processes along the supply chain in the measurement system. Most of them used quite passive measures for controlling the external effectiveness and customer satisfaction, but all had several, more or less relevant, measures for internal efficiency.

There were several differences between the systems, as well. The holistic perspective and the measurement of the competitive capabilities of all hierarchical levels of the organisation were the primary strengths of the third system, but these aspects were weaker in the other two systems. The overall complexity was considered a problem in the system of the third plant, since it neither relied on tight control nor had decentralised authority. The only system that was considered to fully drive improvements was that of the first plant, which relied on several qualitative measures that were further analysed in autonomous teams.

All three manufacturing performance measurement systems were quite general in nature, and they could probably benchmark improvements from one another. Still, it is important to understand that each system is custom-made for its specific conditions and most likely to work best in the environment where it was developed. This is true for the studied measurement systems, as well, and it supports the statement that there does not exist any panacea of measurement systems that is applicable to most organisations. However, the presented dimensions and characteristics can be used to evaluate and initiate improvements of most specific systems.

IX. Conclusions

Four dimensions that indicate what should be measured and two characteristics that indicate how to measure in a comprehensive overall manufacturing performance (OMP) measurement system were identified. The strategy dimension indicates that the measurement system should translate the corporate and business strategies to all levels of the organisation. The flow orientation dimension means that the measurement system integrates all functions, activities and processes along the supply chain. The internal efficiency dimension emphasises the need for the measurement system to work as productivity control and comparison between internal functions. The interaction with customers and measurement of customer satisfaction is emphasised in the external effectiveness dimension. The improvement drivers, and simple and dynamic characteristics indicate the importance of using the system for continuous improvement instead of passive control, and the adjustment to the fast changing environment.

The OEE measure

The contribution of overall equipment effectiveness (OEE) for fulfilment of the identified dimensions and characteristics of the three manufacturing performance measurement systems was the second part of the study and analysis.

The definition of OEE sometimes varies. Planned downtime was included in production time in both "experiments". In the first, the losses that affected availability were divided into stops due to and not due to machine failure. This made the status of the losses more clear and simplified the analysis. Speed losses are sometimes difficult to define, but they often make up a large proportion of the total downtime. Some authors and firms have defined performance as actual production in relation to planned production. This definition is often too simple and since planned production sometimes is only updated annually the measured figures will over-estimate efficiency. In both cases the quality measure was considered general and brief. It is difficult to get a comprehensive view of the quality of the equipment when only using OEE. A wider definition of the quality parameter would, however, decrease the simplicity.

OEE is a measure of internal efficiency. OEE figures of cases I and II could not be compared, since manufacturing conditions and data collection techniques differed. Internal comparisons between the three robots in case II were still possible. OEE does not measure the strategy, flow orientation and external effectiveness dimensions to any great extent. Most studied systems did not have proper measures for flow orientation or external effectiveness, but consequently OEE did not improve the fulfilment of these dimensions.

The greatest contribution of OEE, if used in correct way, is its focus on the characteristics improvement drivers and simple/dynamic. Two different ways of collecting data were used in the two field experiments in cases I and II. In the first the frequency of bad activities was measured, and in the second data for downtime and speed losses were collected by measuring the times that these losses lasted. The main reason for using different methods for collecting data was the difference in complexity of the measured processes. The most important objective of OEE is not to get an optimum measure, but to get a simple measure that tells the production personnel where to spend their improvement resources, i.e. it contributes to both OMP characteristics. This was possible in both field experiments, no matter which data collection technique was used. However, proper analysis of the OEE figures requires a decentralised organisation with autonomous teams. OEE does not contribute very much to the measurement system if it is used only for top-down control of the internal efficiency.

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