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Manufacturing performance measurement and target setting: A data envelopment analysis approach ☆

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ABSTRACT

Manufacturing decision makers have to deal with a large number of reports and metrics for evaluating the performance of manufacturing systems. Since the metrics provide different and at times conflicting assessments, it is hard for the manufacturing decision makers to track and improve overall manufacturing system performance. This research presents a data envelopment analysis (DEA) based approach for performance measurement and target setting of manufacturing systems. The approach is applied to two different manufacturing environments. The performance peer groups identified using DEA are utilized to set performance targets and to guide performance improvement efforts. The DEA scores are checked against past process modifications that led to identified performance changes. Limitations of the DEA based approach are presented when considering measures that are influenced by factors outside of the control of the manufacturing decision makers. The potential of a DEA based generic performance measurement approach for manufacturing systems is provided.

1. Introduction and context

Most manufacturing executives face three major obstacles as they strive to keep a handle on their operations: information inundation, information isolation, and information indecision. In a nutshell, executives often receive too much information from isolated sources that is devoid of practical guidance for improvement. Further, in order for manufacturers to improve operational performance and in this context reduce manufacturing costs, they must have an effective method of measuring and evaluating the performance of their manufacturing processes. This issue of effective measurement is paramount in today's manufacturing companies.

There is little guidance on setting performance improvement targets in manufacturing systems. External benchmarks available through industry trade associations or through consulting organizations are occasionally used for setting performance targets. Targets based on these benchmarks need to be adjusted to the unique configuration and circumstances of the manufacturing system that is being evaluated and this is a non-trivial task. Furthermore, defining targets using a set of often conflicting performance indicators, such as combinations of due date performance, inventory levels, quality levels, throughput, cycle time and machine utilization typically cause confusion. For example, a conflict exists between the objectives of achieving low inventory levels and high machine utilizations if there are long changeovers between manufacturing different product types.

Simulation modeling also provides a potential approach to setting performance targets that take into account the manufacturing system's resource availabilities and stochastic demand generating large amounts of information. However, developing and maintaining current simulation models for a manufacturing system requires high expertise and effort. Therefore, both of these approaches, i.e., the use of external benchmarks and simulation, do not solve the information inundation or isolation problems.

Consequently, organizations have typically tried to focus on one or two measures. Such focus does help to improve performance on selected measures but at times to the detriment of overall performance. What is needed is an approach that allows the manufacturing enterprise to focus on a small number of measures; yet take into account multiple facets of performance. Further, a mechanism is required for setting realistic targets that take into account the capabilities and changing circumstances of the manufacturing

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system. Such a mechanism should ideally not require large effort and expertise for maintenance.

This research presents an approach based on data envelopment analysis (DEA) (Charnes et al. 1978) for manufacturing performance measurement and target setting. The potential of DEA for managerial diagnosis and control was noted years ago (Epstein and Henderson 1989). DEA can typically be used for relative performance measurement and evaluation, benchmarking, target setting, and is one of the techniques available for identifying best practices. This paper reports on efforts to apply the DEA based approach to two manufacturing organizations. The main conclusion drawn from our interaction with the two organizations that is consistent with many applications of DEA reported in the literature is that the fundamental value adding potential of the DEA approach for manufacturing decision-making lies in its ability on the one hand to simplify the way by which decision makers are alerted of underperforming manufacturing units and on the other hand its ability to point to peers and potential performance improvement targets.

The approach can be used on a continuous (rolling) basis as more data are collected whereby operational performance can be continuously monitored. It is not inconceivable to think of showing weekly/monthly/yearly performance reports in the manufacturing areas just as one can view statistical process control (SPC) charts (Hoopes and Triantis 2001). Even though, control charts are based on statistical theory whereas the DEA performance reports are based on linear programming, they both point to observations that are out of control in the case of control charts and underperforming units in the case of DEA. Performance improvement interventions are in both cases found by asking why an observation is in the out-of-control range or why a unit is underperforming. Unlike SPC, DEA provides guidance on why a unit is underperforming through performance improvement targets and comparison with peers. It can also provide a deeper understanding of the manufacturing process structure that has a large impact on the observed process performance over time. Typically, statistical techniques evaluate the stochastic behavior of the production process by studying process and/or product characteristics one at a time. On the other hand, efficiency measurement approaches include as part of their evaluation the entire set of critical product and/or process characteristics simultaneously. Previous research (Hoopes and Triantis, 2001) shows that these two approaches can be used in a complementary manner to identify unusual or extreme production instances, benchmark production occurrences, and evaluate the contribution of individual process and product characteristics to the overall performance of the production process. However, the potential linkage of DEA efficiency scores and performance targets that are derived from statistical process techniques such as control charts, six sigma, etc. is beyond the scope of this paper.

The focus of the work reported here is on supporting performance improvement efforts over time by the management for two very different real manufacturing scenarios and to evaluate the ability of DEA to effectively assist decision-makers in performance improvement. The DEA based performance measurement approach received positive feedback from decision makers in both of the manufacturing systems. A general approach for the implementation of a DEA based performance system is suggested based on this experience.

This paper adds to the manufacturing performance measurement and decision making body of knowledge by addressing DEA implementation issues. Appropriate input and output specifications are discussed that deal with manufacturing issues such as undesirable outputs, variables that could potentially be defined as both inputs and outputs, feedback mechanisms such as rework, and others. Such combinations of issues that occur in real manufacturing systems have not been extensively addressed in the literature. Additionally, the specific manufacturing technologies studied in this research have led to the definition of the variables used in the DEA models that can be used and modified by other researchers in the future. It would be appropriate to define reasonable input/output specifications associated with various manufacturing technologies (wafer manufacturing, assembly line manufacturing, etc.) as long as the mapping between the real world and the modeling world is reasonable and can be verified by those operating within these manufacturing environments. These specifications can be then catalogued for future research and implementation. The modeling differences associated with the two manufacturing scenarios are identified to highlight the value of selecting appropriate variables and models for the application of DEA, something that continues to be a research and application challenge. Approaches used for the validation and verification of the models built are described. The implications for decision making based on DEA results for the two scenarios are presented to demonstrate practical relevance. To the extent that all of the above can be generalized, a framework of performance measurement is proposed for manufacturing facilities in general. The framework provides a starting point by highlighting the possibility of end users' driving the process of DEA implementation in manufacturing environments.

This section introduced the need for manufacturing performance measurement and target setting and DEA as an approach to meet this need. The next section reviews the relevant literature. The third section presents the two manufacturing scenarios and describes the process of selecting the appropriate conceptual DEA models. Section 4 presents the data and the results from the DEA models including the performance scores, the grouping of decision making units into peer groups and their utilization for target setting. The fifth section discusses the impact on decision making based on the results and provides a framework for the application of the DEA approach to manufacturing organizations. The last section presents conclusions and future directions for research.

2. DEA based performance measurement systems for manufacturing

Since DEA was first proposed by Charnes et al. (1978), it has been applied in many sectors, including manufacturing and the associated sector of logistics and distribution. The applications in manufacturing have been studied across a wide range of issues for example evaluating alternatives, for alignment with business goals, etc. We include relevant recent efforts here. A modified DEA model was developed by Cook and Green (2004) to identify the core business performance in multi-plant firms. Ertay et al. (2006) used DEA to evaluate layout configurations in manufacturing systems. Liu and Liu (2008) used DEA to compare relative efficiencies of nine production lines in an electronics assembly environment.

Recent efforts have focused on enhancing DEA formulations to address manufacturing realities. Triantis et al. (2003) used possibility theory as an approach to evaluate the performance of the newspaper preprint insertion manufacturing process. Zeydan and Çolpan (2009) combined TOPSIS (technique for order preference by similarity to find an ideal solution) for measuring qualitative performance and DEA for measuring quantitative performance to assess 28 job shops engaged in manufacturing and maintenance for the Turkish air force. Wang and Chin (2009) used DEA, enhanced with double frontiers, to evaluate and select advanced manufacturing technology. Chen (2009) visualized a production network that is comprised of multiple interdependent sub-decision making units (SDMUs) and used a network-DEA approach to propose measures that consider the dynamic effects of SDMUs. Our