An objective-oriented and product-line-based manufacturing performance measurement

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Abstract

Performance-measurement systems (PMSs) that are based on traditional cost-accounting systems do not capture the relevant performance issues for today’s manufacturing environment. A variety of integrated systems have been proposed to overcome the limitations of the traditional PMSs, but these systems have been inadequate. This paper presents an integrated dynamic performance measurement system (IDPMS) that integrates three main areas: company management, process improvement, and the factory shop floor. To achieve an integrated system, these three areas are linked through dynamically defined performance measures and performance standards from production planning to customer. The indicators are transformed into quantitative just-in-time parameters that are utilized with management by objectives (MBO) principles to develop a manufacturing PMS that satisfies both internal and external customers. An example is given that illustrates how the IDPMS addresses current PMS requirements.

Keywords: Performance measurement; Management by objective; Process improvement; Customer satisfaction; Manufacturing

1. Introduction

In today’s highly competitive business environment, product manufacturers need to provide customized and innovative products. To achieve this, they require innovative methods of performance measurement. In measuring manufacturing performance, manufacturers usually compare their own plants with other manufacturing plants in the industry in terms of such parameters as customer satisfaction, product quality, speed in completing manufacturing orders, productivity, diversity of product line, and flexibility in manufacturing new products (Cordero et al., 2005). The essential function of a performance measure is to assess how well the activities within a process, or the outputs of a process, achieve specified goals. This involves a comparison of actual results with a predetermined goal and an assessment of the extent of any deviation from that goal. A target level of performance is usually expressed as a quantitative standard, value, or rate (Ahmad et al., 2005).

The selection of a range of performance measures appropriate to a particular company should be made in the light of the company’s strategic intentions, and should suit the competitive environment in which the company operates. For example,
if technical leadership and product innovation represent the basis of a manufacturing company’s competitive advantage, performance in these areas must be measured relative to the competitors. Similarly, if a service company differentiates itself in the marketplace on the basis of quality of service, it should be monitoring and controlling the desired level of quality (Ahmad and Dhafr, 2002). Whether the company is in the manufacturing sector or the service sector, it is necessary to choose an appropriate range of performance measures, and these measures must be balanced to ensure that one performance or set of performance dimensions is not stressed to the detriment of others. The mix that is chosen will differ from case to case. Incomplete metrics can lead to inappropriate action (Ahmad and Dhafr, 2002), and performance areas must therefore be operationalized (that is, made measurable) in a way that allows performance to be adequately measured against relevant performance indicators (Jose et al., 1999). To achieve this, many companies have adopted modern management strategies—such as total quality management (TQM), just-in-time (JIT), computer-integrated manufacturing (CIM), and optimized production realization (OPR).

A business can achieve success only by understanding and fulfilling the needs of its customers. A failure to recognize this can cause huge potential losses (Ernst and Young, 1992). A customer focus involves the establishment of links between customer requirements and internal processes (Sousa, 2003; Reiner, 2005), and implies a shifting of company goals from the maximization of company profits in one project to the optimization of the value of the customer’s project by meeting jointly agreed objectives (Cova and Salle, 2005). However, having adopted such a customer focus, many companies use performance measures that are based on outdated management cost systems that are incompatible with their new operating philosophies. Consequently, many researchers are suggesting new comprehensive approaches to performance measurement—approaches that support day-to-day operations by providing managers, supervisors, and operators with timely and relevant information (Shah and Ward, 2003).

To provide a comprehensive overview of company performance, researchers have tried to combine more than one performance measurement through the development of integrated performance-measurement systems (PMSs). These integrated systems address many of the shortcomings of older PMSs; however, there are still issues associated with today’s manufacturing environment that must be considered. For example, these systems work primarily as monitoring-and-controlling tools, and most have not incorporated an explicit feedback loop that supports improvement in performance measurement. In addition, these systems are not dynamic, and they cannot therefore provide mechanisms for adapting to a changing manufacturing environment.

To address these shortcomings, this paper presents an integrated dynamic performance-measurement system (IDPMS), which has been developed in collaboration with an international electronics firm (‘D company’) in Taiwan. The proposed system focuses on improving manufacturing competitiveness by overcoming the limitations of existing PMSs and by facilitating continuous improvement (Ghalayini et al., 1997). To this end, the system incorporates interaction among three groups: (i) management (production planning); (ii) manufacturing; and (iii) customers. Having proposed the system and having discussed the indicators used in it, the present paper presents a case simulation to verify the practical suitability of the proposed system.

The remainder of this paper is arranged as follows. Following this Introduction, the next section of the paper reviews the literature pertaining to performance measurement. Section 3 then presents the proposed IDPMS. Section 4 illustrates how the system would be applied. Sections 5 and 6 provide a result comparison and summarize the benefits of IDPMS with respect to existing PMSs.

2. Literature review

2.1. Overview

An effective PMS should include the traditional financial and cost-accounting criteria used by senior management and also the tactical-performance criteria that are used in assessing a firm’s current level of competitiveness. Such tactical-performance measures vary according to the needs of the various management levels and functional areas within the organization. Each functional area should develop and utilize a set of performance criteria consistent with its particular operating characteristics and strategic objectives. An effective PMS should lead
to the integration of operations, marketing, finance, engineering, and accounting to ensure that they act as a unified and coordinated value-adding system. The system must have a long-term orientation such that continual improvement in both product and process leads to a sustainable competitive advantage (Wisner and Fawcett, 1991).

In designing a PMS to support strategy implementation, particular challenges in modern manufacturing industries must be addressed. The rapid escalation in global competition has brought new doctrines (for example, JIT, TQM, and the ‘flexible factory’), and this has necessitated new approaches to performance measurement—including the expansion of traditional efficiency-focused manufacturing PMSs to embrace new manufacturing-performance measures (Abernethy and Lillis, 1995; Chenhall, 1997; Perera et al., 1997). However, the widespread use of multiple measures has raised several implementation issues, including the potential problem of inadequate managerial commitment (Ittner and Larcker, 1998; Lillis, 2002). Because companies operate in dynamic environment, and because performance measurement is thus a dynamic process, Suwignjo et al. (2000) developed a quantitative model for performance-measurement system (QMPMS), which used the analytic hierarchy process (AHP) to quantify the effects of various factors on performance. The system allowed for the fact that performance measures will change over time and vary between companies. In a similar vein, Hayes and Wheelwright (1984) noted that management must make decisions in a variety of areas (such as capacity, facilities, technology, quality, and so on), each of which presents a variety of choices and each of which can have an effect on the manufacturing function’s ability to implement the organization’s business strategy. Senior management therefore needs to consult closely with its manufacturing function to obtain its perspective on the major issues that are facing the business. In this regard, Choe (2004) has noted that advanced manufacturing technology (AMT) can achieve low cost, improved quality, increased flexibility, and dependability of supply, and that the measurements of manufacturing performance in AMT should reflect these four strategic goals. The works of Gunasekharan et al. (2005) and Gupta and Galloyway (2003) are two examples of scholarly work (among a plethora of articles) that has focused on the use of financial and cost-based performance measures in manufacturing operations.

A ‘customer orientation’ has been variously defined. For example, it has been defined as “the set of beliefs that puts the customer’s interest first” (Desphande et al., 1993) or, alternatively, as a “firm’s ability and will to identify, analyze, understand, and answer user needs” (Gatignon and Xuereb, 1997; Matsuo, 2006). Yet another definition was supplied by Narver and Slater (1990), who defined ‘customer orientation’ as “the sufficient understanding of one’s target buyers to be able to create superior value for them continuously”. According to Liu et al. (2002), a ‘customer orientation’ is a set of beliefs that places customers’ needs and satisfaction as the priority of an organization; it focuses on dynamic interactions among the organization, its customers, its competitors in the market, and its internal stakeholders. In summary, the term ‘customer orientation’ refers to an organization (and individuals within the organization) focusing their efforts on understanding and satisfying customers (Huff and Kelley, 2005).

Given these definitions, a customer-focused manufacturing strategy should include the dimensions of cost, quality, flexibility, and dependability of supply (Ahmad and Dhafr, 2002). In this context, it is important to note that a focus on the customer is the underpinning principle of the TQM philosophy, which is concerned with how an organization designs and introduces products and services, integrates production-and-delivery requirements, and manages supplier performance (Evans and Lindsay, 1999). From a total quality perspective, all strategic decisions that a company makes should be ‘customer-driven’ (Evans and Dean, 2000). Knowing the customer begins with a detailed evaluation of what is known about the customer, which is essentially an exercise in measuring customer satisfaction (Player and Keys, 1999).

Mohr-Jackson (1991) proposed an extended concept of customer orientation to include internal customers, noting that this requires additional activities. These include: (i) understanding internal customers’ requirements for the effective delivery of needs and preferences of external customers; (ii) obtaining information about external customers’ needs and preferences through effective interdepartmental communication; and (iii) creating additional final buyer value by increasing internal customer benefits. According to this view, the provision of superior value to the external customer requires superior value to be provided at each point in the value chain. Internal suppliers therefore need to
demonstrate an internal-customer orientation by focusing on satisfying the requirements of their internal customers, thus ensuring that a customer orientation is developed throughout the organization (Hauser et al., 1996), rather than limiting this orientation to the point of customer contact (Conduit and Mavondo, 2001). In this respect, Breyfogle et al. (2001) noted that a good PMS addresses both external quality and internal quality.

Bhote (1991) has asserted: “If performance isn’t being measured, it isn’t being managed”. In this regard, ‘management by objectives’ (MBO), which was introduced to industry in the early 1950s by Drucker (1954), has been used effectively by senior management. The first step is to establish objective measurements, and the best measures are customer-focused and goal-oriented. They help people to learn how to improve their performance by pointing out where they are deficient and by establishing achievable timetables to reach desired levels. In this way, they can be used as a basis for improved performance (George and Weimerskirch, 1998).

Ahmad et al. (2005) noted that performance measurement involves a comparison of actual operation results with established performance targets. In this regard, Six-Sigma (Gack and Robinson, 2003) and Balanced Scorecard (BSC) (Kaplan and Norton, 2001) offer frameworks for business improvement. Both approaches begin with goal definition, and both are based on a quantitative measurement of performance using pre-defined business goals and pre-defined metrics (Trienekens et al., 2005).

2.2. Recent concepts and practices in manufacturing performance

The manufacturing performance assessment and analysis introduced in Ahmad and Benson (1999) covered the areas of quality, delivery reliability, cost (price minus profit margin), and delivery lead time. The KPIs within manufacturing strategy are cost, quality, inventory, flexibility, and delivery (Corbett, 1998). A part of a project survey was carried out to identify which performance indicators companies’ use and which ones they characterize as important. The top five were: profitability, conformance to specifications, customer satisfaction, return on investment, and materials/overhead cost. When looking at the performance areas to which the specific indicators are related and considering their relative importance it was also possible to rank the importance of these performance areas (from top to bottom): efficiency, quality, competence (technical), flexibility, innovativeness, speed, and capacity (Jose et al., 1999). The measured KPIs are normally split into six sections: (1) safety and environment, (2) flexibility, (3) innovation, (4) performance, (5) quality, and (6) dependability. The focus was on the KPI of the dependability which consist of: (1) customer complaints, (2) on-time-in-full delivery to customers (OTIFc), (3) on-time-in-full delivery from suppliers (OTIFs), and (4) overall equipment effectiveness (OEE) = product rate x quality rate-availability (Ahmad and Dhafr, 2002). A six-item scale is used to measure the operational performance of a manufacturing plant after different levels’ lean manufacturing practice. The items include 5-year changes in scrap and rework costs, manufacturing cycle time, first pass yield, labor productivity, unit manufacturing cost, and customer lead time (Shah and Ward, 2003). Global competition demands the manufacturing organizations improve quality, reduce delivery time, and minimize costs. In response to this, many manufacturing organizations have implemented different excellence programs to improve their performance. Lean manufacturing techniques, performance measurement, and benchmarking, were included in many of those excellence programs (Ahmad et al., 2005).

2.3. Popular model review

D Company was supported to establish the manufacturing performance evaluation through integrating ‘quality’, ‘cost’, and ‘delivery’ by the Corporate Synergy Development center (CSD), Taiwan. The manufacturing performance ($Y$) is measured by

$$Y = W_q Q + W_c C + W_d D,$$

where

$$Q : \text{score of quality} = \frac{\text{good production}}{\text{good production + failed QC}},$$

$$W_q : \text{weight of quality},$$

$$C : \text{score of cost} = \left| \frac{\sum (\text{actual cost} - \text{target cost})}{\sum \text{target cost}} - 0.60 \right|,$$

$$\frac{\sum \text{target cost}}{\sum \text{target cost}}.$$
$W_c$: weight of price,  

$$D : \text{score of delivery} = 1 - \frac{\text{number of delayed lots}}{\text{number of delivered lots}},$$  

(4)

$W_d$ is the weight of delivery, and $W_q + W_c + W_d = 100$.

From the rating system defined by the D Company, we can find three factors are usually considered when the manufacturer adopts the formula of grading to measure the manufacturing performance.

(a) Quality ($Q$)—quality of product,  
(b) Cost ($C$)—price of product,  
(c) Delivery ($D$)—delivery time of product.

The weight of each factor can be adjusted when we apply the calculations of grading that depend on the needs of manufacturers. Some specific manufacturers just consider quality, while others put quality and cost into consideration. Some of them consider all three, quality, service, and delivery. Two example equations are provided for the score calculations of manufacturing performance:

Score of manufacturing performance  

$$= 40Q + 35C + 25D \quad \text{or} \quad (5)$$

$$= 40Q + 40C + 20D.$$  

(6)

In practice, these manufacturing PMSs were unable to quantify the customer orientation and objective orientation requirement levels in the past decade. These measurement systems cannot highlight the quality or business concerns in a JIT manner that will promote the effectiveness of improvements. The advantages of establishing a new model is obvious after analyzing the concerns listed below.

(a) Internal failure: These models do not reflect the rework, scrap, and sorting that could occur on the production line due to manufacturing quality problems.  
(b) Customer voice: These models do not help highlight customer complaints and their possible impact on the organization.  
(c) Equipment effectiveness and engineering efficiency: These models do not evaluate the efficiency of engineering maintenance programs caused by poor manufacturing management. Potential programmatic impacts, such as schedule and cost impacts, should also be brought to management’s attention.

(d) Quality level: The percentage of defects inside lots from various process stages are sometimes extremely different and may significantly impact profits.  
(e) Customer orientation: These models do not involve full satisfaction levels or views from actual product users.  
(f) Objective orientation: If indicators are applied to manufacturing project performance measures with different characteristics, arguments will always ensue. Setting a target for each performance measurement using `achievement level’ or ‘AL’ will be one of the solutions.

This study attempts to highlight suitable factors that if applied to day-to-day, year-to-year, and product-to-product in industry PMSs that could help transform these factors into measurable, quantitative, and JIT parameters. These parameters could be utilized in planning and establishing a manufacturing performance rating system based on our work with an international electronics firm (D company). The relevance of the proposed system to a manufacturing team, product line (internal customer), and external customers is presented. The system logic is then detailed. In addition to describing the system, applications and conclusions are drawn.

3. A new model with a customer focus

To address the above-mentioned concerns, the present study set out to develop an integrated and dynamic manufacturing performance-measurement model. Two central concerns for all measurement systems are: (i) what to measure and (ii) how to weight the various performance categories. Most of the objective and quantifiable variables in manufacturing performance have been previously specified, but management might also wish to use a number of qualitative factors in assessing manufacturing performance—including problem-resolution ability, technical ability, and corrective-action response. Although these factors are somewhat subjective in nature, management can still assign each factor a score or rating.

3.1. Satisfaction indicators in manufacturing

An IDPMS (Ghalayini et al., 1997) was developed in conjunction with the ‘D Company’ of Chungli, Taiwan. The IDPMS integrated three
main areas of the company: (i) management; (ii) the process-improvement team; and (iii) the factory shop floor. To achieve an integrated system, these three areas were linked through the specification, reporting, and updating of certain defined performance measures.

The four main indicators established in this study were adapted from Ahmad and Dhafr (2002):

- Cc (customer complaint);
- Od (on-time delivery);
- Ee (equipment effectiveness); and
- Cq (cost of quality).

These performance indicators were selected because: (i) they indicate important manufacturing performance areas; (ii) provide critical links among business strategy, internal organization, and technology; and (iii) are fairly easy to measure or estimate. The company’s relative performance in each area of the plant (or specific product line) can be assessed by comparing the relevant performance indicators with internal goals/standards, competitors, and customer demand. After comparisons are made for all performance areas, an overview of the performance gaps can be made.

3.1.1. Customer complaint (Cc)

A ‘customer complaint’ was defined as a quality or reliability issue occurring with an external customer and confirmed as being caused by manufacturing failure. Normally, a formal notification from the customer and a formal ‘corrective action report’ (CAR) are required to confirm that an issue exists. These complaints might arise from any business area.

A measurement can be made to identify operational problems that might be avoided in future. This measurement is determined by the number (and nature) of customer’s complaints. Written, verbal, and anecdotal information are all recorded. These data are then shared to avoid repeat problems at other sites. The quality-assurance department is responsible for the provision of the required information on a regular basis.

The KPI to be measured is the number of customer complaints received—expressed as an absolute number or as a percentage of the dispatches. The goal is to achieve fewer than \( x \)% complaints on dispatches (with an \( x \) value of less than 1 being suggested).

3.1.2. On-time delivery (Od)

This indicator measures the delivery of product on time and in full—with no errors in product, packaging, transport, or supporting documentation. The commonly used performance measures in this area are ‘unit penalty’, ‘mean tardiness’, ‘maximum lateness’, and ‘minimum lateness’. Tardy jobs can incur costs, such as contractual penalties, depending on how late they are (Lengyel et al., 2003).

Such a measure requires a rigorous recording system by the plant (or by the distribution company if this aspect is out-sourced). The KPI goal of this measure is to achieve a value greater than \( y \)% (with a \( y \) value greater than 99 being suggested).

3.1.3. Equipment effectiveness (Ee)

This measure is designed to determine the reliability of assets and their capability to deliver the desired performance. This measure is assessed by taking the product of two sub-measures—‘quality rate’ and ‘availability’. Equipment effectiveness (Ee) is thus obtained as follows:

\[ Ee = \text{quality rate} \times \text{availability}. \]

The quality rate is the amount of product that is right the first time—without adjustment, recycles, and so on. To achieve a satisfactory performance in this regard, it is necessary to achieve a very high first-time-right rate. Quality rate is calculated as follows:

\[ \text{Quality rate} = \frac{\text{good production}}{\text{good production} + \text{failed QC}}. \]

The availability is defined in terms of the number of hours the plant actually operates divided by the number of hours in a month. For example, if a factory plans to operate for 22 hours per day for 25 days per month, the maximum available number of hours is 550. If so, availability is calculated as follows:

\[ \text{Availability} = \frac{550 - (\text{number of hours of total shutdown})}{550}. \]

Ee rests on the principle that the best manufacturing performance occurs when a plant operates to full capacity, always produces a perfect product, and never breaks down. Data on capacity usage, quality performance, and equipment breakdown are therefore required to determine the Ee. The manufacturing manager at the site is responsible for providing the required information on a timely basis.
It is suggested that an Ee of 99.5% on critical equipment should be the target. This can be achieved if quality rate is greater than 99.9%, and availability is greater than 99.6%.

To achieve this goal, the following practices should be implemented: six-sigma performance; fully automatic start-up; shutdown and fail-safe; intelligent measurement; total accurate dynamic models; multivariate statistical process control; design for success not failure; and predictive maintenance.

3.1.4. Cost of quality (Cq)

Cost of quality (or, more accurately, cost of poor quality) is invisible and seldom pursued; it is often referred to as a ‘hidden’ quality cost (Dahlgaard et al., 1998; Krishnan et al., 2000). It is effectively an ‘opportunity cost of sales lost’ brought about by a customer’s experience of a poor-quality product or poor delivery service.

The consequential costs of such failure include engineering time, management time, shop and field downtime, delivery problems, lost orders, lost market share, customer dissatisfaction, and decreased capacity generally. Some companies have found a ‘multiplier effect’ between the measured costs and the ‘true’ failure costs (Chen and Yang, 2003).

The measure is defined in terms of a comparison between actual cost and target cost in completing a specific manufacturing task. The goal is to achieve a measure of \( z \% \) consequential loss on sales revenue as a result of failure (with a \( z \) value less than 3 being suggested).

3.2. Target values for manufacturing performance

At the end of each year, senior management in a manufacturing enterprise measures the performance of each manufacturing team or product line and sets target values for the following year. These targets are announced as a management ‘commitment’ or ‘pledge’ for all customers of various product lines.

An example case study will be discussed. This case study examines a manufacturer whose actual values for the year 2004 and target values for the year 2005 for each performance indicator are given in Tables 1 and 2.

3.3. New performance measurement model

The present study developed a new model through the integration of the four indicators discussed above (Cc, Od, Ee, and Cq), with appropriate weights of \( r_1, r_2, r_3, \) and \( r_4 \), respectively. Performance \( (P) \) was obtained by matching AL through comparisons of a range of percentages from actual values and target values for each indicator. That is,

Actual Cc is compared with target Cc to get an AL, which is used to obtain a PCc, Cc performance value through matching.

(1) The performance of Od, Ee, and Cq (‘POd’, ‘PEe’, and ‘PCq’, respectively) can be measured in the same way.

Formula example 1: \( PCc—Cc \) performance depends on the AL of target Cc.

Formula: \( PCc = \text{achievement level of target Cc, } AL \)

\[1.00 = AL_1: Cc \text{ lower than target above } 60\%\]
\[0.95 = AL_2: Cc \text{ lower than target } 41–60\%\]
\[0.90 = AL_3: Cc \text{ lower than target } 21–40\%\]
\[0.85 = AL_4: Cc \text{ lower than target } 6–20\%\]
\[0.80 = AL_5: Cc \text{ equivalent to target } \pm 5\%\]
\[0.75 = AL_6: Cc \text{ higher than target } 6–20\%\]
\[0.70 = AL_7: Cc \text{ higher than target } 21–40\%\]
\[0.65 = AL_8: Cc \text{ higher than target } 41–60\%\]
\[0.60 = AL_9: Cc \text{ higher than target above } 60\%\]

<table>
<thead>
<tr>
<th>B.U. Indicator</th>
<th>Desktop power</th>
<th>Adaptor power</th>
<th>Telecom. power</th>
<th>Server power</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cc—customer complaint</td>
<td>3.6% on dispatches</td>
<td>2.2% on dispatches</td>
<td>7.3% on dispatches</td>
<td>3.8% on dispatches</td>
</tr>
<tr>
<td>Od—on-time delivery</td>
<td>96.6%</td>
<td>97.8%</td>
<td>94.2%</td>
<td>97.1%</td>
</tr>
<tr>
<td>Ee—equipment effectiveness</td>
<td>94.6%</td>
<td>97.1%</td>
<td>81.7%</td>
<td>95.9%</td>
</tr>
<tr>
<td>Quality rate</td>
<td>97.6%</td>
<td>99.1%</td>
<td>93.3%</td>
<td>98.5%</td>
</tr>
<tr>
<td>Availability</td>
<td>96.9%</td>
<td>98.0%</td>
<td>87.7%</td>
<td>97.4%</td>
</tr>
<tr>
<td>Cq—cost of quality</td>
<td>8.1% of sales</td>
<td>4.7% of sales</td>
<td>13.6% of sales</td>
<td>8.5% of sales</td>
</tr>
</tbody>
</table>
Or we may have many kinds of values set either in
the number of achievement levels or in the actual
output vs. target degree range depending on the
organizational requirements. Two additional value-
setting examples are shown as below:

Formula example 2: PCc—Performance of Cc.

Formula: PCc = achievement level of target Cc,

\[ AL_n \]

\[ 1.00 = AL_1: \text{Cc lower than target above 80\%} \]
\[ 0.90 = AL_2: \text{Cc lower than target 61–80\%} \]
\[ 0.80 = AL_3: \text{Cc lower than target 41–60\%} \]
\[ 0.70 = AL_4: \text{Cc lower than target 21–40\%} \]
\[ 0.60 = AL_5: \text{Cc equivalent to target } \pm 20\% \]
\[ 0.50 = AL_6: \text{Cc higher than target 21–40\%} \]
\[ 0.40 = AL_7: \text{Cc higher than target 41–60\%} \]
\[ 0.30 = AL_8: \text{Cc higher than target 61–80\%} \]
\[ 0.20 = AL_9: \text{Cc higher than target above 80\%.} \]

Formula example 3: PCc—Performance of Cc.

Formula: PCc = achievement level for target Cc, AL_n

\[ 1.00 = AL_1: \text{Cc lower than target above 80\%} \]
\[ 0.90 = AL_2: \text{Cc lower than target 61–80\%} \]
\[ 0.80 = AL_3: \text{Cc lower than target 41–60\%} \]
\[ 0.70 = AL_4: \text{Cc lower than target 21–40\%} \]
\[ 0.60 = AL_5: \text{Cc equivalent to target } \pm 20\% \]
\[ 0.50 = AL_6: \text{Cc higher than target 21–40\%} \]
\[ 0.40 = AL_7: \text{Cc higher than target 41–60\%} \]
\[ 0.30 = AL_8: \text{Cc higher than target 61–80\%} \]
\[ 0.20 = AL_9: \text{Cc higher than target above 80\%.} \]

Similarly, value-setting flexibility can be applied
for all other indicators (Od, Ee, and Cq), or only
some of them. The maintenance of performance-
measurement consistency, continuity, and flexibility
is necessary. The weights \( r_1, r_2, r_3, \) and \( r_4 \), can be
set by constructing a scale—rating these perfor-

Table 2
The target value for various power supply product business units (B.U.), year 2005

<table>
<thead>
<tr>
<th>B.U. Indicator</th>
<th>Desktop power</th>
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<th>Telecom. power</th>
<th>Server power</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cc—customer complaint</td>
<td>Less than 2% on dispatches</td>
<td>Less than 1% on dispatches</td>
<td>Less than 5% on dispatches</td>
<td>Less than 2% on dispatches</td>
</tr>
<tr>
<td>Od—on-time delivery</td>
<td>Higher than 98.5%</td>
<td>Higher than 99.5%</td>
<td>Higher than 96%</td>
<td>Higher than 99%</td>
</tr>
<tr>
<td>Ee—equipment effectiveness</td>
<td>Higher than 98.0%</td>
<td>Higher than 99.0%</td>
<td>Higher than 85.0%</td>
<td>Higher than 98.0%</td>
</tr>
<tr>
<td>Quality rate</td>
<td>Higher than 99.0%</td>
<td>Higher than 99.8%</td>
<td>Higher than 95.0%</td>
<td>Higher than 99.0%</td>
</tr>
<tr>
<td>Availability</td>
<td>Higher than 99.0%</td>
<td>Higher than 99.2%</td>
<td>Higher than 90.0%</td>
<td>Higher than 99.0%</td>
</tr>
<tr>
<td>Cq—cost of quality</td>
<td>Lower than 6.0% of sales</td>
<td>Lower than 3.0% of sales</td>
<td>Lower than 10.0% of sales</td>
<td>Lower than 6.0% of sales</td>
</tr>
</tbody>
</table>

decision-makers approximate the importance of
each indicator using AHP and pairwise compar-
sions (Saaty, 1980).

(2) Manufacturing performance measurement formula

(a) If a manufacturing team organizes just one
product group, the manufacturing performance
value (Pm) will be the same as the product performance value (Pp). This value is given by

\[ Pm = Pp = 100 \times (r_1 \times PCc + r_2 \times POd + r_3 \times PBe + r_4 \times PCq), \]

where \( r_1 + r_2 + r_3 + r_4 = 1 \), \( r_i \geq 0 \), \( 1 \leq i \leq 4 \).

(b) If a manufacturing team organizes several
groups of products (more than one type), the
Pm is obtained using:

\[ Pm = \frac{Pp_1 + Pp_2 + \ldots + Pp_n}{n} \text{ where } n > 1. \]

(c) The parameters in this formula are applied
flexibly to cover all kinds of manufacturing
projects with different characteristics. For in-
stance,

(1) If a manufacturing project is not suitable for
the Ee measurement, the parameter weights

\[ r_1 + r_2 + r_4 = 1. \]

(2) If another manufacturing project has been
adopted for a program-support role, and is
not suitable for Cq’s control, the formula
weights can be expressed using

\[ r_1 + r_2 + r_3 = 1. \]
4. Results comparison

An example is presented to demonstrate how the proposed model of formula (7) can be applied to performance measurement of a manufacturing team, and to compare it with the popular model of formula (5). The proposed method can be compared with different AL and weight values for each performance indicator. Formula example 1 is used in this comparison.

The basic manufacturing data from two product groups (Desktop power and Telecom. power) are given in Tables 3 and 4. The results from the proposed model of formula (7) and the popular model of formula (5) are shown in Tables 3 and 4, respectively.

Compared with formula (5), the application of the new model of formula (7) has produced sensitive, accurate, and effective manufacturing performance rating results for different achievement levels.

5. Conclusions

The proposed manufacturing performance-measurement model with a customer-satisfaction orientation could be applied by firms in different industries to address all kinds of manufacturing management situations. The proposed model can assist firms in selecting and rewarding the best manufacturing teams and integrating their capabilities to develop an appropriate profit-improvement program for meeting and exceeding specific customer requirements.

The merits of the proposed model are that it is complete, flexible, and effective.

In terms of completeness, the model integrates four performance indicators and covers three stages (planning, production, and customer). The main manufacturing activities in industry are horizontally involved in this system. The system also extends the customer-satisfaction concept vertically from manufacturing to include the user and customer.

In terms of flexibility, the model provides four flexible weights to combine performance parameters linearly in a manner that assists management in formulating the most suitable measurements for several kinds of manufacturing projects/teams in different industries. To ensure accuracy and effectiveness, and different weight combinations \( r_1, r_2, r_3, \) and \( r_4 \) can be set in this system.

In terms of effectiveness, the proposed model addresses the same manufacturing performance requirements as are found in the ISO-9000 and QS-9000 quality-management systems. The main purpose of these requirements is to generate effective quality improvement. The system presented in this study provides an effective method for measuring manufacturing quality improvement (PCc, PCq, and PEe) with measurable, JIT aspects.

Grades for manufacturing performance can be developed after the performance measurement. This supports senior management in adopting suitable strategic actions to promote manufacturing-team

| Table 3 | Comparison in desktop power performance measurements using two different formulas, (5) and (7), time: January–March, year: 2005 |
|-----------------|------------------|------------------|-----------------|-----------------|
| Indicator       | Target (%)       | Actual value (%) | Weight of formula (7), \( r_1, r_2, \ldots, r_4 \) | Score using formula example 1 |
| PCc             | \( \leq 2.0 \)   | 2.3              | 0.3             | 0.75            |
| POd             | \( \geq 98.5 \)  | 98.3             | 0.3             | 0.75^a          |
| PEe             | \( \geq 98.0 \)  | 98.5             | 0.2             | 0.90^b          |
| Quality rate    | \( \geq 99.0 \)  | 99.4             | —               | —               |
| Availability    | \( \geq 99.0 \)  | 99.1             | —               | —               |
| PCq             | \( \leq 6.0 \)   | 9.1              | 0.2             | 0.65^c          |
| Total           | 76.0%^d          |                  |                  | 88.39%^e        |

^aOn-time delivery rate \( \geq 98.5% \) means delinquency of delivery against customer requirements <1.5%. The calculation of achievement level (AL) should be \((98.3\%−98.5\%)/(1−98.5\%×100)=−13.3\%)—higher delinquency than target value 13.3%.

^bSimilarly, Ee’s achievement level is \((98.5\%−98.0\%)/(1−98.0\%×100)=25.0\%)—better than target value 25.0%.

^cThe calculation of Cc’s achievement level is as same as Cq’s which is \((9.1\%−6.0\%)/6.0\%×100=51.7\%)—worse than target value 51.7%.

^d\( [0.75 \times 0.3] + [0.75 \times 0.3] + [0.90 \times 0.2] + [0.65 \times 0.2] \times 100\% = 76.0\%.

^e\( [0.983 \times 0.35] + [0.994 \times 0.4] + [0.569 \times 0.25] \times 100\% = 88.39\%.


