Measuring Maintenance Performance: A Holistic Approach

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Abstract

Performance measures should be linked to an organization's strategy in order to provide useful information for making effective decisions and shaping desirable employee behaviour. The pitfalls relating to the indiscriminate use of common maintenance performance indicators are discussed in this paper. It also reviews four approaches to maintenance performance measures. The value-based performance measure evaluates the impact of maintenance activities on the future value of the organization. The Balanced Scorecard (BSC) provides a framework for translating strategy into operational measures that collectively capture the critical requirements for sustaining the organization's success. System audits are the tool for measuring organizational culture, which in turn determines the appropriate approach to the organization of maintenance functions. The operational efficiency of an organization's maintenance function can be benchmarked with those of its counterparts in other organizations by using Data Envelopment Analysis (DEA) . Among these approaches, the one which builds on the BSC embraces the design principles of a good performance measurement system. To smoothen the adoption of the BSC approach to managing maintenance operations, a related research agenda is proposed in the concluding section.

Keywords: Maintenance, Performance Measurement, Balanced Scorecard

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Introduction

Maintenance spending accounts for a significant part of the operating budget in organizations with heavy investments in plant, machinery and equipment (Cross 1988 and Dekker 1996). Tracking the performance of maintenance operations should be a key management issue in these organizations. This paper examines the various approaches to measuring maintenance performance with a view to identifying an appropriate methodology that embraces the design principles of a good performance measurement system.

The first part of this paper defines the maintenance function. It is followed by a review of the theory and practice of measuring organizational performance in general and maintenance performance in particular. The pitfalls of utilizing the commonly used maintenance performance indicators are also examined. In the subsequent section, various approaches to establishing maintenance performance measures that would lead to effective decisions in today's turbulent and highly competitive environment are discussed. These approaches include the use of a single measure, multiple measures and system audits for performance evaluation. Also presented is a method for comparing the operational efficiencies of multiple maintenance organizations. In the concluding section, recommendations for a research agenda are made for applying a holistic approach to maintenance performance measurement.

The Maintenance Function

Before something can be measured, it must be defined. The traditional perception of maintenance's role is to fix broken items. Taking such a narrow view, maintenance activities will be confined to the reactive tasks of repair actions or item replacement. Thus, this approach is known as reactive maintenance, breakdown maintenance, or corrective maintenance. A more recent view of maintenance

is defined by Geraerds (1985) as: "*All activities aimed at keeping an item in, or restoring it to, the physical state considered necessary for the fulfilment of its production function*." According to this definition, maintenance also includes the proactive tasks such as routine servicing, periodic inspection, preventive replacement, and condition-monitoring. When the strategic dimension is taken into account, making decisions that will shape the future maintenance requirements of the organization should also fall into the domain of maintenance operations. Equipment replacement decisions and design modifications to enhance equipment reliability and maintainability are examples of these activities. The Maintenance Engineering Society of Australia (MESA) recognizes this broader perspective of maintenance and defines the function as: "*The engineering decisions and associated actions necessary and sufficient for the optimization of specified capability*." 'Capability' in this definition is the ability to perform a specific function within a range of performance levels that may relate to capacity, rate, quality and responsiveness. The scope of maintenance management, therefore, should cover every stage in the life cycle of *technical systems* (plant, machinery, equipment and facilities): specification, acquisition, planning, operation, performance evaluation, improvement, replacement and disposal (Murray *et al.* 1996). When perceived in this wider context, the maintenance function is also known as *physical asset management.*

The EUT-maintenance model developed at Eindhoven University of Technology, the Netherlands (Geraerds 1990) provides a conceptualisation of the processes involved in the maintenance function. Its main focus is on meeting the maintenance needs of *technical systems* already in place. This is achieved by utilising internal maintenance capacity and external services, with the support of spare parts inventory management and performance measurement. There are two cycles of management processes embedded in the maintenance function. The first cycle consists of the managerial processes of formulating maintenance policies, establishing objectives, planning, auditing, and measuring performance that apply to the entire function. The issues addressed in the planning process include organizational structure, manpower, resource allocation, action plans, etc. The second cycle is

concerned with technical planning and operation of maintenance activities for individual *technical systems*. These involve the selection of maintenance regimes (reactive, preventive, condition-based, TPM, etc.), planning and optimization of maintenance decisions, scheduling and execution of work. The cycle is closed by providing feedback through capturing and analysis of performance data (see **Fig.1**, Coetzee 1997).

The Theory of Performance Measurement

Neely, Gregory and Platts (1995) provide a comprehensive literature review of performance measurement that addresses two distinct aspects, namely levels and concepts. They examine performance measurement at three different levels: (a) the individual performance measures, (b) the performance measurement system (PMS), and (c) the relationship between the PMS and its environment. Three of the key concepts identified in the review are highlighted below:

(1) Performance measures can be classified in a number of ways according to their perspective, namely financial and non-financial measures, outcome measures and performance drivers, internal and external measures. Another classification, suggested subsequently by Kaplan and Norton (1996b), is linked to the level of focus of the measures: *diagnostic measures* are used to monitor and control day-to-day operations and *strategic measures*, on the other hand, are selected to inform the stakeholders of the organization's strategic intent and the progress that has been made in achieving it.

(2) Performance measures need to be positioned in a strategic context, as they influence what people do. Peters and Waterman (1982) explain this succinctly — "*What gets measured gets done*." The pattern of decisions and action within an organization defines the strategy in practice. Thus, performance measurement should not be considered purely as a means to provide information for management control and decision making; it can also serve as a powerful motivational tool driving decisions and action that are consistent with the espoused strategy.

(3) The PMS does not exist in isolation. The effectiveness of the PMS in shaping behaviour depends

on the support of a matching organizational infrastructure relating to issues such as resource allocation, work structuring, management information, reward and recognition in addition to technical or operational activities such as maintenance operations. For example, there is a need to link performance measurement to reward systems because, as Hammer and Stanton (1995) state, "*The way to people's hearts and minds is not through their ears but through their wallets*." As such, work in the organization should be structured to achieve joint optimization of the social and technical subsystems, or at least a good fit between them, and there is choice in developing such organizational designs (Gerwin and Kolodny 1992). The organization in which the PMS is embedded must also be understood as an open system that is in continuous interaction with its environment. When that environment is turbulent, organization designs must repeatedly change to best adapt to the uncertainty of the environment. This perspective is referred to as a *Sociotechnical Systems* (STS) approach.

If performance measures are to trigger effective beneficial change, they have to fulfill two conditions. First, they should relate to what is controllable by the unit to be evaluated. Second, favourable results on these measures will contribute to specific Business Success Factors. The level of analysis (for instance, organization versus the maintenance department), and the agreed sphere of influence of the function being measured, will significantly influence the measures used. If average equipment life is used as a measure of performance, maintenance must have an input in equipment purchase decisions. When the lost time for repair is monitored, the organization being measured should have jurisdiction over staffing decisions and stocking of spare parts (Dwight 1994).

The widely used performance measures were developed on the premises of the scientific management movement pioneered by Frederick Taylor about a century ago, a period when demand far exceeded supply, the operating environment was very stable, and labour intensive operations were the norm. The conventional wisdom of management evolved from such a background is characterised by a preoccupation with maximizing the utilization of resources. Thus, in assessing maintenance

performance, various efficiency indicators (equipment availability and labour utilization, etc.) and financial measures (such as repair and preventive maintenance costs) are routinely tracked.

Assessments in terms of financial measures are typically performed through variance analysis, which breaks a variance down into its constituent parts such as price variance and usage variance to determine the causes of the discrepancy. It has been shown that variance analysis is dysfunctional to global optimization because it focuses on minimization of within-department costs (Kaplan 1990). Here is a likely scenario in an industrial organization:

- The Maintenance unit is reluctant to introduce condition based maintenance even though it will prevent unplanned outages due to machine breakdowns, a major benefit manifested in the Production Department. The resistance exists because when compared to the "do nothing" option embodied in the standard cost, it will give rise to unfavourable usage variance in the cost of planned maintenance, an indicator commonly used to measure maintenance performance.

Furthermore, the notion of comparing the actual cost to a 'static' standard cost in variance analysis is incompatible with the philosophy of continuous improvement. Trends as well as deviations from the 'standard' should be tracked to motivate favourable change as an on-going process. If a 'standard' is to be established, it should be based on the best-in-class benchmark instead of the organization's historical performance level.

Apart from the above problems relating to variance analysis, Kaplan (1989) also points out that the 'numbers' produced by traditional management accounting systems are:

(a) too aggregate to provide relevant information for operational control,

(b) available too late for corrective action to be taken, and

(c) too distorted by the standard overhead absorption method.

Equipment maintenance is a key process in industries such as transportation, utilities, mining, and manufacturing. It represents a significant component of the operating cost in these industries. Much of these expenses are consumed by non-value adding management control or logistics related activities.

Through the application of business process reengineering (BPR) pioneered by Hammer and Champy (1993), maintenance processes can be streamlined to eliminate waste and produce breakthrough performance in areas valued by customers. Activity-based costing (Kaplan 1988), being an effective tool for capturing all the end-to-end expenses associated with a process, will provide the financial measures for determining the outcome of such changes.

Various aspects of performance measurement have been extensively discussed in the literature. Atkinson, *et al.* (1997) identify that there are three roles in performance measurement, namely *coordinating*, *monitoring*, and *diagnostic.* Poirier and Tokarz (1996), Neely *et al*. (1997) offer suggestions on the design of good performance measures. Cameron (1986), Keegan *et al.* (1989), Maskell (1991), Bevan and Thompson (1991), Lockamy and Cox (1995), Kaplan and Norton (1996b) provide their sets of guidelines for design of performance measurement systems that would lead to excellent performance in today's highly turbulent and competitive business environment. The principles shared by most of these prescriptions are:

(a) Measures are organization-specific — they are linked to the organization's strategy.

(b) Multiple measures — internal and external, financial and non-financial measures, performance drivers and outcome measures — should be used to achieve balance in perspective, and to communicate the causal relationships for achieving business success.

(c) Measures should be user-friendly — simple, easy to use, available promptly.

(d) Measures at different levels of the hierarchy are aligned and they are integrated across an organization's functions.

(e) Involve employees in formulating strategies and identifying the related performance measures.

(f) The organization's infrastructure encourages desired behaviour and supports operation of the measurement system.

(g) Effectiveness of the system and its contribution to overall organizational performance

are reviewed periodically to allow changes and improvements to be made.

The Practice of Performance Measurement

In a review of the performance literature, Cameron (1986) finds that measures of organizational performance are often selected on the basis of convenience. Typically, the measures used are either too narrowly or too broadly defined. This is a problem related to level of analysis; measures of individual, group, and organizational performance are not necessarily the same. In fact, focusing on a biased set of lower level measures may encourage sub-optimization. Other common features of performance measures identified in the review are:

- proxies of measures selected on the basis of convenience are often unrelated to organizational performance;
- a single measure is commonly used to assess performance which is a multidimensional construct;
- *Outcome measures* are the dominant type of indicators for evaluating performance, whereas *effects* are most frequently used in policy decisions and by the public. *Outcome measures* reflect short-term results, but sustainable performance depends on the *long-term effects* of strategies pursued by the organization.

Results of a KPMG survey (1990) of 150 of *The Time* 1,000 companies, excluding the top 200, found that the information used to monitor performance was rated poor or average by close to half of the respondents in terms of relevance, accuracy, timeliness, completeness, cost effectiveness and presentation. Internal information and past financial performance appeared to dominate the information set. External information was not reported as being widely used in strategy formulation or monitoring. In fact, information available to formulate and review strategy was rated poor or average by the majority of respondents.

A large scale postal survey of almost 12,800 organizations both in the private and public sectors in the UK was conducted in 1991 to determine the state of practice of performance management in industry (Bevan and Thompson 1991). With a response representing a fifth of the total UK workforce, the survey

results indicated that just under 20 percent of respondents claimed to be operating a formal PMS, but that a further two-thirds did have policies for managing employee performance generally. Evidently, there was a patchy and incomplete uptake of performance management techniques in the UK. The main reasons employers gave for introducing performance management included improving organizational effectiveness and increasing employee motivation. It was also found that organizations with a formal PMS were more likely to have a performance-related reward system.

In 1995, another survey on performance measurement was conducted in the US, covering over 200 organizations (APQC 1996). It can be observed from the results that "*Overall, the majority of management systems are designed around short-term, control-oriented financial frameworks that are fundamentally tactical*." The characteristics of performance measurement in participating organizations are as follows:

- dominated by financial or other backward-looking indicators;
- failure to measure all the factors that create value;
- little account taken of asset creation and growth;
- poor measurement of innovation, learning and change;
- a concentration on immediate rather than long-term goals.

In its conclusion, the survey report states: "*Despite reasonably high level use, non-financial measures and targets are frequently treated in isolation from strategic objectives. They are not reviewed regularly, nor are they linked to short-term or action plans — they are largely ignored or 'for interest' only*."

Maintenance practices of small and medium sized enterprises (SME) is the focus of a recent survey conducted in Australia (De Jong 1997). It is found that the main measure of maintenance performance used in the responding companies is the ratio of the total cost of the maintenance system to estimated equipment replacement value (ERV). Other measures are chosen according to the priorities of the company and they may include number of accidents, value of spare parts to ERV, maintenance cost to production cost. Two other significant observations made from the study are:

(1) Companies which have equipment performance goals and maintenance performance goals in place show both lower maintenance cost and lower proportions of reactive maintenance.

(2) As the practice moves more towards proactive and relies less on reactive maintenance, the direct cost of maintenance will tend to reduce.

In an on-going project to study the current practice of maintenance operations, the first author interviewed senior executives with maintenance responsibilities in six large-scale organizations in Hong Kong and Canada. The companies included in the study are in the steel, public utility, transportation, and process industries and all of them have significant maintenance budgets. The findings from these interviews so far are generally in agreement with those reported in the relevant literature as reviewed above. It is observed that among the companies studied, their maintenance performance management system share the following characteristics:

(1) It is an exception rather than the norm that the maintenance organization uses a structured process to identify measures of its performance. Management is typically not aware of the part that the measurement system can play in achieving vertical alignment of goals and horizontal integration of activities across organizational units.

(2) The performance measures are primarily used for operational control purposes.

(3) The commonly used measures are financial indicators such as Operation & Maintenance (O&M) costs, and equipment-based or process-oriented measures such as equipment availability, labour productivity, and number of incidents caused by in-service failures.

(4) Benchmarking is gaining acceptance as a methodology to evaluate performance and establish targets by making reference to the achievements of best-in-class organizations.

Classifying Maintenance Performance Measures

Arts and Mann (1994) use the time horizon to classify maintenance decisions into three categories, namely strategic, tactical, and operational. Strategic maintenance decisions are made in the selection of design options for management systems or products to be developed, or plant and machinery to be

acquired that will be compatible with the organization's business strategy. Tactical maintenance decisions relate to the formulation of policies for effective and efficient use of available resources. Operational decisions are made to achieve a high level of effectiveness and efficiency in maintenance activities.

Maintenance plans are often established with a view to achieving a quantified objective. However, the objective is usually chosen by 'gut feel' rather than by careful analysis. In a study done during the Second World War it was discovered that aircraft of the UK's Coastal Command was prevented from maximizing their flying time since a wrong objective (maximizing serviceability) was used (Crowther and Whiddington 1963). Serviceability, defined as the ratio of the number of aircraft on the ground available to fly plus those flying to the total number of aircraft, was initially used as the measure of performance for these aircraft. With the technology in those days, for every hour spent flying, two hours would be required for maintenance. Thus, aiming for a high level of serviceability would be in conflict with Coastal Command's wartime requirement of maximizing the flying time of aircraft. On the other hand, in situations where aircraft are called upon only on emergencies, a high serviceability objective may be appropriate.

Many indicators of maintenance performance discussed in the literature are developed to support operational decisions. Armitage and Jardine (1968) note that these indicators are, at best, descriptive signalling that some action need to be taken. To be more useful, decision rules which are compatible with organizational objectives should also be in place such that the preferred course of action can be determined on the basis of the indicators' values.

To facilitate detection of trends when the level of activities may vary over time, or comparisons are made between organizations of differing scales of operation, indices are often used as measures of maintenance performance. Campbell (1995) classifies these commonly used performance measures into three categories on the basis of their focus:

(1) Measures of equipment performance — e.g. availability, reliability, overall equipment

effectiveness

(2) Measures of cost performance — e.g. Operation & maintenance (O&M) labour and material costs

(3) Measures of process performance — e.g. ratio of planned and unplanned work, schedule compliance

However, the underlying assumptions of these measures are often not considered when the results are interpreted.

Dwight (1994) proposes to classify performance measures into a hierarchy according to their implicit assumptions regarding the impact of the maintenance system on the business. There are five levels in the hierarchy, indicating a progression in awareness of the Business Success Factors that are controllable or influenced by maintenance. Some details of the classification are shown in Fig. 2.

The measures in the fifth level recognize that expenses include depletion of the fixed asset resource, the value of which depends on future demand, technological changes, and the appropriateness of the various maintenance actions. They also allow maintenance actions to be judged against factors like the remaining life of the equipment, process or product.

Level	Assumptions	Typical Measures
1. Overt Bottom-Line impact	• Impact of maintenance actions on down-time, quality, yield and future maintenance costs are negligible. • Causes of maintenance costs arise and are controllable within the accounting period.	• Direct Maintenance Cost
2. Profit-Loss and Overt Cost Impact Performance	• Impact of maintenance actions on quality, yield and future maintenance costs are negligible. • Causes of maintenance costs and down-time arise and are controllable within the accounting period.	• Direct Maintenance Cost • (Delay Time) × $/hr.
3. Instantaneous Effectiveness Measures	• Causes of maintenance impacts on the business arise and are controllable within the accounting period. • Only the events occurring now will occur in the future	• Overt Maintenance Action Cost • Utilization • Availability • Reliability • Overall Equipment Effectiveness

Level	Assumptions	Typical Measures
4. System Audit Approach	• System excellence implies the best possible performance. • Strategies and current techniques are effective.	• Planned/Unplanned Work Ratio • Actions carried out compared with strategy • Backlog trends • % Maintenance Induced Failures • System Audit
5. Time Related Performance Measurement	• Projections for future demand and obsolescence are accurate.	• Value-based measurement

Fig. 2 Levels of Performance Measures

Maintenance is an essential support function in an organizations's value chain. Dwight states that its contribution to the organization's business success can be analysed as a function of four variables:

- the cost of the action,
- the effect of disruption caused by the required maintenance actions,
- the effect of equipment performance between maintenance actions, and
- the ability of the action to affect the life of the asset.

An assessment of the situation with respect to these dimensions determines the appropriate maintenance actions that will affect the bottom line. This analysis, in turn, will determine the relevant measures of performance that should be used. For example, when a company has surplus productive capacity, disruption may have a low correlation with success. In such a case, any measure that relates to disruption will not be appropriate.

Whilst these four variables relate to the impact of maintenance at the equipment level, other indicators that measure performance of the maintenance system should also be in place. These measures of system performance are typically designed to detect if planned work had been done and completed on time, or to track resources consumed by the system. Again, these measures are appropriate only if they have a cause-and-effect relationship with business performance.

Approaches to Measuring Maintenance Performance

A Value-Based Performance Measure

Maintenance activities determine the future options available to meet demand. The readiness to deal with uncertain events, such as equipment breakdown, is also influenced by maintenance management decisions. In the light of these characteristics, Dwight (1995) identifies the following shortcomings of performance measures currently used in industry:

(a) The concept of accumulation of risk is not captured.

(b) The focus is on the immediate rather than the overall requirement.

(c) The measures are not related to business requirements.

A performance measure that takes into account the impact of maintenance activities on the future value of the organization has been proposed by Dwight (1994) as follows:

$$\text{Performance} = \frac{V_r - V_l}{V_r^*}$$

where V_r is the value realized in the period, which is equivalent to CF (t - 1, t), the cash-flow during the interval (t - 1, t). V_l is the future value lost compared with the known best value, V_r^*, which, in turn, is given by: $V_r^* = V^*(t-1) - V^*(t)$ where $V^*(t)$ is the estimated best attainable sum of future real cash flows, or 'residual value' in the system at time t . $V^*(t)$ and V_l must be calculated *ex poste* by considering the circumstances prevailing during that period. In this calculation of value, it is assumed that the best available option will be taken up in the next period.

An alternative definition of performance, which deals with 'residual value' in the system, is:

$$\text{Performance} = \frac{CF(t-1,t) + V^*(t)}{V^*(t-1)}$$

The data required in determining the above performance measure can be collected from an existing system using a conceptual model known as the "Incident Evaluation Approach" (see Fig. 3, Dwight 1995). This approach involves the compilation of a library of possible primal incidents and their associated actions, leading to secondary incidents. An incident is a failure mode of the system which will reduce the potential output of the system. The expected residual value of an action policy is determined by the expression:

$$\sum_{i=1}^{N}(p(C_i)CF_i)|A$$

where $p(C_I)$ is the probability of occurrence of incident C_i as a function of time. CF_i is the expected cash flow as a result of C_i occurring at its expected time, given the available resources implied by action set A. The optimal action policy and $V^*(t\text{-}1)$ are determined *ex poste* by taking into account the involuntary incidents that actually occurred during the interval (t - 1, t).

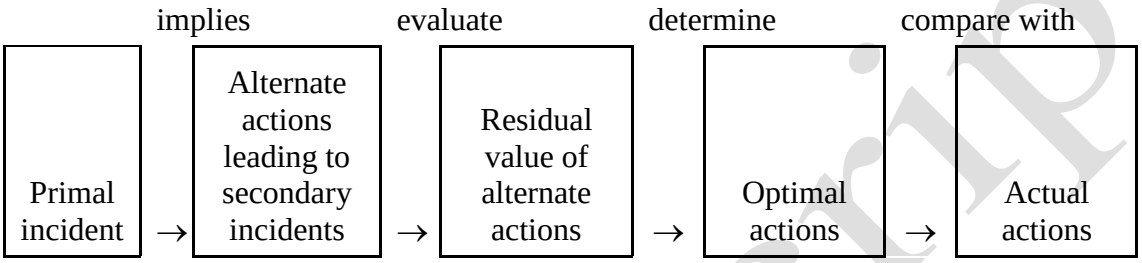


Fig.3 The incident evaluation approach to collecting data for performance measurement

This is a labourious procedure which only focuses on the financial impact of decisions associated with system failures. If other dimensions of performance measures, such as customer perception and contribution to meeting the future business needs of the organization, are to be assessed, a more comprehensive approach to performance measurement has to be used.

The Balanced Scorecard

Some of the shortcomings of using financial measures as performance indicators have been discussed in the section on "The Theory of Performance Measurement". Even if those flaws can be eliminated, financial measures still have the drawback that they tend to shape managers' behaviour to focus on short-term results. The short-term thinking is driven by the investment community's short-term perspective. As a result, very few managers will choose to make capital investments or pursue long-term strategic objectives that will jeopardize quarterly earnings targets.

Income-based financial figures are lag indicators. They are better at measuring the consequences of yesterday's decisions than at indicating tomorrow's performance. Managers are willing to play the earnings game. For instance, investment in maintenance can be cut back to boost the quarterly earnings.

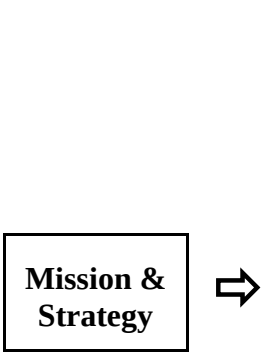
The detrimental effect of the cut back will only show up as increased operating cost in some future periods, by which time the manager making the cut back decision may have already been promoted because of the excellent earnings performance. In view of these deficiencies, customer oriented measures such as response time, service commitments, and customer satisfaction have been proposed to serve as lead indicators of business success (Eccles 1995).

To assure future success, organizations nowadays must be financially sound and customer oriented. This is possible only if their internal processes can provide a set of distinctive core competencies that will enable them to achieve their business objectives. Furthermore, they also need to have the capability to improve and create value continuously, through development of their most precious assets — the employees. An organization which excels in only some of these dimensions can, at best, be a mediocre performer. Improvements in operational capabilities such as faster response, better quality of service, reduced waste, etc. will not lead to better financial performance unless the spare capacity created by the operational improvement is utilized or the operation is downsized. Also, maintenance organizations that are efficient in delivering high quality services will not remain viable for long if they are slow in developing new expertise that will meet the emerging needs of the user departments. For example, electro-mechanical systems are being phased out by electronic and software systems in many automatic facilities. In the face of the new demand, the maintenance service provider has to transform the profile of its expertise from one that is primarily in the electrical and mechanical trades to one that is more focused on electronics and information technology.

Obviously, relying on a few measures that represent a narrow perspective will not be able to capture all these requirements. A balanced presentation of results is therefore the preferred approach to measuring maintenance performance. The ***Balanced Scorecard*** (BSC) proposed by Kaplan and Norton (1992) offers the template for the balanced presentation. The BSC is a vehicle that translates a business unit's mission and strategy into a set of objectives and quantifiable measures built around four perspectives: ***Financial*** (the investor's views), ***Customer*** (the performance attributes valued by

customers), ***Internal Processes*** (the long- and short-term means to achieve the financial and customer objectives), and ***Learning & Growth*** (capability to improve and create value). It directs managers to focus on a handful of measures that are most critical for the continual success of the organization.

The Balanced Scorecard had been implemented in a number of major corporations in the engineering, construction, microelectronics and computer industries (Kaplan and Norton 1993). Experience in these pioneering organizations indicates that the Scorecard will get its greatest impact on business performance only if it is used to drive a change process. The development of a Balanced Scorecard also engenders the emergence of a strategic management system that links long-term strategic objectives to short-term actions (see Fig. 4, Kaplan and Norton 1996a, 1996b)



Strategic Objectives	Measures (KPIs)	Targets	Action Plans	Perspective
				Financial
				Customer
				Internal Processes
				Learning & Growth

Fig.4 The Balanced Scorecard links strategic objectives to short-term actions

A strategic management system that builds around a Balanced Scorecard is characterised by three keywords — focus, balance and integration. Ashton (1997) explains these three attributes as follows:

> "*Focus* has both strategic and operational dimensions in defining direction, capability and what the business or its activities are all about, while *balance* seeks an equilibrium for making sense of the business and to strengthen focus. *Integration* is critical, ensuring that organizational effort knits into some form of sustainable response to strategic priority and change."

The BSC approach provides a holistic framework for establishing performance management systems at the corporate or business unit level. When the approach is applied to managing the performance of maintenance operations, a process involving the following steps can be followed (see **Fig. 5**, Tsang 1998):

(1) Formulate strategy for the maintenance operation — Strategic options such as developing in-house capability, outsourcing maintenance, empowering frontline operators to practise autonomous maintenance, developing a multi-skilled maintenance workforce, and implementing condition-based maintenance are considered and decisions made through a participative process.

(2) Operationalize the strategy — The maintenance strategy is translated into long-term objectives. The relevant *Key Performance Indicators* (KPIs) to be included in the BSC are then identified and performance targets established. Suppose outsourcing the maintenance and repair of generic and common equipment and vehicle fleets has been chosen as a strategy to allow an electric utility company to focus on its core competencies of managing its transmission and distribution system. The KPIs and performance targets that relate to this strategic objective are "outsource 20% of maintenance work" and "reduce maintenance costs by 30%" in two years. The former indicator belongs to the "Internal Processes" perspective and the latter the "Financial" perspective. To achieve vertical alignment, these objectives, KPIs and targets are cascaded into goals for teams and individuals.

(3) Develop action plans — These are means to the ends stipulated in the targets established in step (2). To achieve the targets relating to outsourcing of non-core maintenance works given in the above example, the company may have decided to develop capabilities in the following three areas which are needed in the outsourcing process: contract negotiation, contract management, and the ability to capitalize on emerging opportunities arising from changing technology and the changing competitive environment in the maintenance field. These action plans should also encompass any necessary changes in the organization's support infrastructure, such as structuring

of maintenance work, management information systems, reward and recognition, resource allocation mechanisms, etc.

(4) Periodic review of performance and strategy — Progress made in meeting strategic objectives is tracked and the causal relationships between measures are validated at defined intervals. The outcome of the review may necessitate the formulation of new strategic objectives, modification of action plans and revision of the scorecard.

Some of the KPIs featured in the Scorecard for measuring the maintenance performance of an electricity transmission and distribution company may include the following items (Tsang & Brown 1998):

Perspective	Strategic Objectives	Key Performance Indicators (KPIs)
Financial	Reduce operation & maintenance (O&M) costs	O&M costs per customer
Customer	Increase customer satisfaction	Customer-minute loss Customer satisfaction rating
Internal Processes	Enhance system integrity	% of time voltage exceeds limits Number of contingency plans reviewed
Learning & Growth	Develop a multi-skilled & empowered workforce	% of cross-trained staff Hours of training per employee

Since these measures are derived from the organization's strategic objectives, the Balanced Scorecard is specific to the organization for which it is developed.

By directing managers to consider all the important measures together, the Balanced Scorecard guards against sub-optimization. Unlike conventional measures which are control oriented, the Balanced Scorecard puts strategy and vision at the centre and its emphasis is on achieving performance targets. The measures are designed to pull people toward the overall vision. They are identified and their stretch targets established through a participative process which involves the consultation of internal and external stakeholders — senior management, key personnel in the operating units of the maintenance function, and the users of the maintenance service. This way, the performance measures for the

maintenance operation are linked to the business success of the whole organization.

The theoretical underpinning of the Balanced Scorecard approach to measuring performance is built on two assertions:

(1) Strategic planning has a strong and positive effect on a firm's performance.

(2) Group goals influence group performance.

The link between strategic planning and a firm's performance has been the subject of numerous research studies. By applying the meta-analytic technique to analyse the empirical data drawn from planning-performance studies published in the last two decades, Miller and Cardinal (1994) are able to establish a strong and positive correlation between strategic planning and growth. They also show that a similar link between planning and profitability exists when the firm is operating in turbulent environments.

The existence of group goal effect is also established in a similar study on previously published research findings relating to goal setting in groups (O'Leary-Kelly *et al*. 1994).

Although it is a common belief in industry that strategic planning is important for ensuring an organization's future success, very often the performance measures and the actual company improvement programs are inconsistent with the declared strategy. Such a discrepancy between strategic intent and operational objectives and measures is reported in a recent survey conducted in the Belgian manufacturing industry (Gelders *et al*. 1994). This unsatisfactory situation can indeed be avoided by introducing the Balanced Scorecard.

System Audits

An organization's maintenance capability can be inferred from an audit of its maintenance system. The audit is a thorough and comprehensive review of the various dimensions in the maintenance system, such as organization, personnel training, planning and scheduling, data collection and analysis, control mechanisms, measurement and reward systems, etc. To get unbiased findings, the reviewer should have no direct responsibility or accountability for performance of the system under review. The audit is

usually conducted by using a questionnaire designed to provide a profile of the maintenance system. Typically, the questionnaire is structured to address specific key areas in the system to be audited. Responses to these questionnaires may take one of these forms:

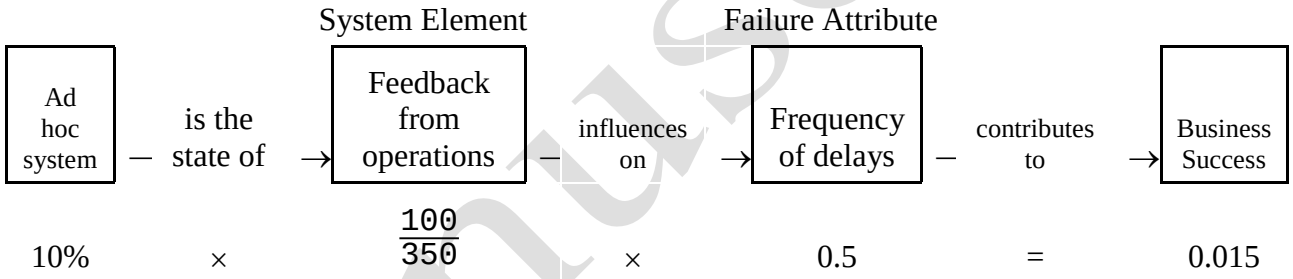
(a) either “yes” or “no”;

(b) choose one or more of the available options;

(c) on a Likert-type scale of, say, 1 to 5, to indicate different degrees of agreement or lack of it.

Different weights may also be assigned to different questions to reflect their relative contributions to system performance. Even though they may use sophisticated assessment schemes, the underlying theory of system audits is obscure.

Dwight (1994) suggests a procedure that relates the state of a system element, such as “feedback from operations”, to its contribution to the system’s overall performance.



In the example given in Fig. 6, an organization’s maintenance function only obtains feedback from operations on an ad hoc basis. Suppose the *standard* state (the best practice) for this system element is to empower the operator to be the maintainer. When compared to the *standard* , the observed state scores 10% of the maximum rating. *Feedback from operations* is recognized as one of the system elements that have an influence on the failure attribute *Frequency of delays* (scoring 100 points out of a total of 350). With *Frequency of delays* contributing to 50% of business success, the overall performance contribution of the observed state of *Feedback from operation* is computed as:

$$10\% \times \frac{100}{350} \times 50\% = 0.015$$

The overall performance of the maintenance system can be determined by aggregating the

contributions to business success of the observed states of all the system elements that have an influence on a relevant failure attribute.

In this procedure, mutually exclusive and collectively exhaustive *Failure attributes* that contribute to business success have to be identified. The same requirements also apply to the *System elements* that have an influence on a *Failure attribute*.

The more typical system audit tends to focus on the issue of conformance to a *standard* model both in system design and execution. It is assumed that the *standard* can be universally applied to achieve superior performance. The maintenance system audit questionnaires in Westerchamp (1993) and Wireman (1990) are developed on the basis of this concept. This approach to system audits fails to recognize that different organizations operate in different environments. Product, technology, organizational culture and the external environment are some of the key variables in an organization's operating environment and they may be in a state of constant change. Superior performance will be achieved only if the internal states and processes of the organization fit perfectly in the specific operating environment. Sociotechnical System (STS) analysis provides a methodology to design a system that will achieve this fit (Taylor and Felten 1993). Thus, the basic assumption of a *standard* reference model implicit in the design of the typical audit questionnaire is problematic.

An effective system audit that focuses on the organization's social systems can be designed on the basis of the Parsonian paradigm, which postulates that people are organized into groups to fulfill these four (GAIL) functions (Parsons and Smeler 1956):

- attaining goals that legitimize the group's existence (G);
- adapting to external circumstances (A);
- integrating activities for survival (I).
- maintaining the possibility to function in the longer term (L);

In the context of maintenance management, these functions relate to four roles, namely user, designer, manager, and maintainer, respectively. Running through these roles are three macro processes that

collectively contribute to achieving the goals of the organization:

- Producing (products).
- Maintaining (equipment).
- Modifying and building (new facilities)

The equipment can be in the *start-up*, *stabilising*, or *stable* phase. The interface between the roles and processes must be managed and controlled in ways which are appropriate to the equipment's phase of existence. For example, when the equipment is in the *start-up* phase, Engineering (the designer) and Production (the user) should play a leading role in maintenance. However, when the equipment is in the *stable* phase, Maintenance and Operations Management should become the driving force.

Organizational culture, the *softer* aspect of the organization, is an important element that can also be assessed by a culture audit. Scores relating to various dimensions of the organization's culture can be plotted on a multifactor chart developed from the competing values model (Quinn and Rohrbaugh 1983). The four quadrants in the chart defines four orientations of cultural dimensions: innovative, supportive, rule-oriented, and goal-oriented, which correspond to the adaptive, pattern maintenance, integrating, and goal-attainment functions, respectively in the Parsonian paradigm. A culture audit can bring out the cultural differences, if any, between various parties in the organization. It can also detect mis-matches between an organization's culture and its approach to maintenance management, such as introducing *self-directing teams* in a Production Department which has a very low level of innovative and goal orientations (Rensen 1995).

The alignment between strategy, actions and performance measures, a basic principle in the design of performance measurement systems, can be audited using the Performance Management Questionnaire (PMQ) developed by Dixon *et al*. (1990). The tool can also be applied to perform a reality check on the performance measurement in practice rather than the one on paper. Any deficiencies identified from these processes will become the driver for realigning perceptions, or changing the

measurement system.

Performance Analysis

Performance analysis is the measurement and comparison of levels of achievement of specific objectives. To evaluate the overall performance of maintenance operations across organizations in a specific industry, the measures of achievement must not be influenced by matters unrelated to operational issues, such as accounting and taxation rules, or financing arrangements. In single-input, single-output cases, productivity defined as the ratio of output to input is an adequate measure of operational performance. However, the analysis becomes more complex when multiple inputs and multiple outputs are involved. These multiple inputs could have different units of measures and the same situation may also apply to the multiple output measures. Consider the case of comparing the maintenance performance of railway systems. The inputs can include available kilometres, passenger trips per day, rolling stock and station facilities, etc. O&M costs per car operating kilometre, and car operating kilometre per total staff plus contract hours are examples of the multiple outputs.

Data Envelopment Analysis (DEA), developed by Charnes, Cooper and Rhodes (1978), is a non-parametric approach that can be used to compute multiple-input, multiple-output productivities. It does not require preassigned weights for inputs and outputs; these are implicit in the data set. Performing DEA requires the solution of a linear programming (LP) model for each decision-making unit (DMU) in the peer group. The set of solutions of the LP models in the data set will define the *data envelopment surface*, a piecewise empirical extremal surface, in a hyperspace with $m + s$ dimensions where m is the number of inputs and s is the number of outputs. DMUs which are on the data envelopment surface, also known as the *efficient frontier*, are considered top performers amongst their peers.

A review of the various basic DEA models and their extensions to deal with complications such as inputs and outputs that are non-discretionary, or have categorical values can be found in Charnes *et al*. (1994).

DEA is often supplemented with multiple regression analysis to identify the significant factors

contributing to superior performance of the DMUs on the frontier.

The procedure has been used to compare the operational performance amongst airlines (Schefczyk 1995), hospitals (Ozcan and McCue 1996), schools (Thanassoulis 1996), and special economic zones in China (Zhu 1996). An example illustrating the use of DEA to study the performance of a number of aircraft maintenance operations over multiple time periods can be found in Charnes *et al*. (1985).

Concluding Remarks

Performance measures will only provide useful information for guiding management decisions and shaping desirable employee behaviour if they are appropriately selected to fit the operating environment peculiar to the organization. The indiscriminate use of commonly employed performance measures without regard to their underlying assumptions and their adequacy in reflecting the organization's strategic focus may lead management astray by providing misleading information for management decisions or giving incoherent signals to employees on what factors are important to the organization's success.

Maintenance performance measurement is a complex task since multiple inputs and multiple outputs are involved in the process. Various approaches to measuring maintenance performance have been reviewed. The value-based performance measure attempts to assess the impact of maintenance activities on the future value of the associated assets. However, the procedure involved is labourious and it has a limited focus — the measure is a financial indicator expressed in terms of future cash flows. The Balanced Scorecard provides an alternate and holistic approach to measurement which is developed on the notion that no single measure is sufficient to indicate the total performance of a system. It translates the organization's strategy on maintenance into operational measures in multiple dimensions that collectively are critical indicators of current achievements and powerful predictors of future maintenance performance. While some of the indicators featured in the Balanced Scorecard are easily quantifiable (these are known as hard measures), some others are soft measures which lend themselves to evaluation by using the system audit approach. Examples of soft measures include the fit between

organizational culture and the structuring of maintenance work, the vertical alignment of objectives at different levels of the hierarchy, and horizontal integration across multiple functions that interact with maintenance. System audits designed on the basis of STS analysis provide an approach to predicting future maintenance performance with particular focus on interactions between the social system in the organization and its operating environment. The extent of alignment within the organization can be surveyed by using instruments such as PMQ.

Value-based measures, the Balanced Scorecard, and system audits are approaches to measuring the maintenance performance of an organization. When the operational efficiencies of multiple maintenance organizations are to be compared quantitatively, however, the DEA approach will be appropriate.

Recommendations for Future Research

The Balanced Scorecard has received increasing acceptance in industry as the model for measuring overall performance of business units. Despite such interest in industry, the feasibility of applying the BSC model for managing performance of a specific function, maintenance for instance, is still an uncharted area which needs researching. In this context, the specific issues are:

(a) What processes should be in place to:
- implement a BSC-based performance management system for maintenance operations?
- match the strategy, as manifested in the measures of the BSC, with the culture and the prevailing operating environment of maintenance operations?
- ensure vertical alignment and horizontal integration?

(b) A typical BSC for a business unit has measures representing four perspectives: financial, customer, internal processes, learning and growth. Are these perspectives still appropriate for the BSC of maintenance operations?

(c) What is the optimum number of performance measures to be included in the maintenance BSC?

(d) How to validate that the BSC reflects the declared strategy of the maintenance operation? The

following questions are relevant:

- How to ensure that the various performance measures used are associated with each other and linked to the strategy?
- How to ascertain the completeness of the measures in the BSC?

(e) When problems are identified in the periodic reviews, how to ensure that the system will regulate itself, such as modifying the strategy, fine-tuning the action plans, or replacing inadequate performance measures with better ones ?

(f) Are there generic measures for evaluating maintenance performance?

(g) How to analyse the costs and benefits of a maintenance performance management system?

(h) In measuring maintenance performance, what are the measures that relate to:

- the learning and growth perspective?
- the performance drivers that can be used as lead indicators (predictors of performance)?

(I) What elements of organizational infrastructure are mandatory to support the BSC-based maintenance performance measurement system?

(j) What are the success factors and common pitfalls in implementing the BSC-based performance measurement system?

The performance of maintenance operations can be enhanced only to the extent that the stakeholders concerned behave in an orchestrated manner that will ensure availability of productive assets to meet demands at minimum life cycle cost to the organization. The framework built around a Balanced Scorecard as outlined in Fig. 5 provides a model for achieving this goal. Investigation into the issues listed above will surely shed light on the contributing factors to ensure success of the maintenance performance measurement system.

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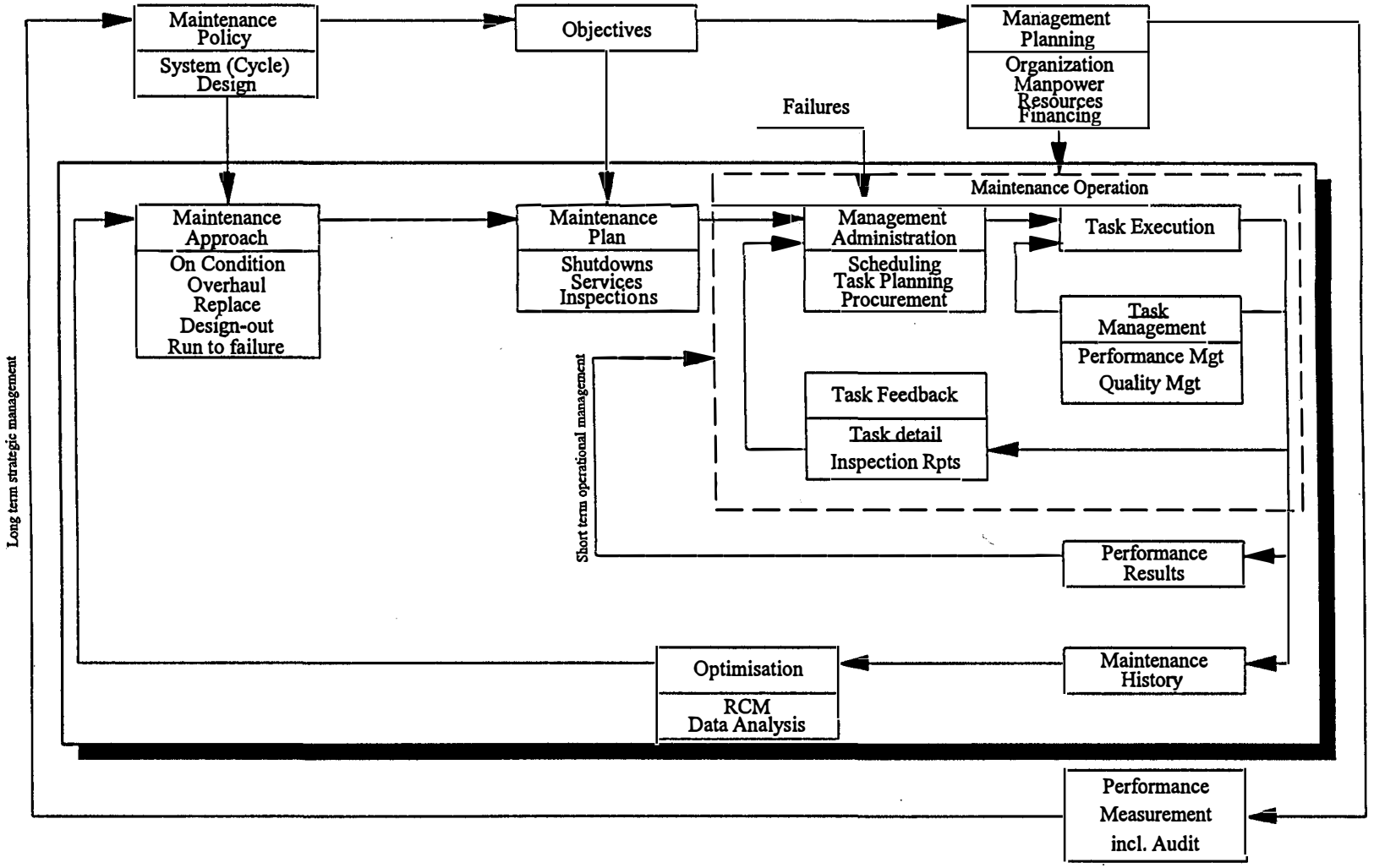

Fig. 1 The General Maintenance Model

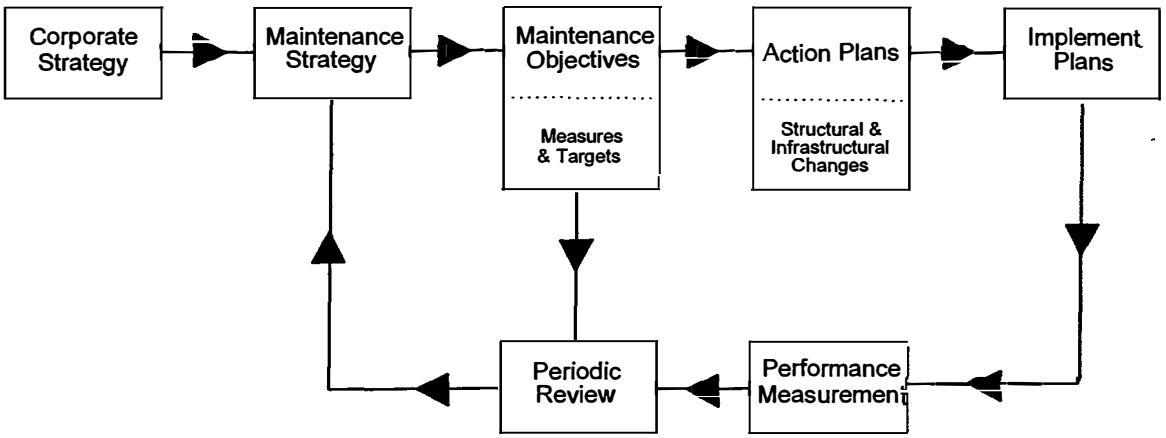

Fig. 5 Strategic Maintenance Performance Management Process

Perspective	Strategic Objectives	Key Performance Indicators (KPIs)
Financial	Reduce operation & maintenance (O&M) costs	O&M costs per customer
Customer	Increase customer satisfaction	Customer-minute loss Customer satisfaction rating
Internal Processes	Enhance system integrity	% of time voltage exceeds limits Number of contingency plans reviewed
Learning & Growth	Develop a multi-skilled & empowered workforce	% of cross-trained staff Hours of training per employee