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Towards an Integrated Performance Measurement System for Cellular Manufacturing: Insights from the Case of Volvo Aero Norway

Daryl Powell[1,3], Torbjørn Netland[2,3]

[1]Department of Production and Quality Engineering, and
[2]Department of Industrial Economy and Technology Management,
Norwegian University of Science and Technology, and
[3]Department of Industrial Management,
SINTEF Technology and Society,
S.P. Andersens Veg 5, N-7465 Trondheim, Norway

Corresponding author: daryl.j.powell@ntnu.no

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Abstract

Cellular manufacturing is a strategy that can be applied in order to increase productivity and foster continuous improvement activities. A performance measurement system for today's manufacturing environment must focus on monitoring and controlling processes as well as supporting improvement activity. This makes performance measurement systems complicated by their multi-dimensional nature. The purpose of this paper is to present a conceptual framework for an integrated performance measurement system for cellular manufacturing. Composed primarily of literature review, the paper also draws on insight from a practical case.

Keywords: cellular manufacturing; integrated performance measurement system; performance indicators; balanced scorecard; continuous improvement

Paper type: Conceptual paper

1. Introduction

The objective of this paper is to present a conceptual framework for an integrated performance measurement system (IPMS) for cellular manufacturing. In cellular manufacturing, machines, processes, and people are arranged into cells in order to support a smooth flow of materials with minimal transport or delay. Cellular manufacturing is a key enabler of increased production velocity and flexibility, as well as the reduction of capital requirements (United States Environmental Protection Agency, 2009). Companies can compete through cellular manufacturing as it provides the flexibility to vary product types on the production line in response to specific customer demands.

With performance measurement, Alexander (2007) suggests that although there has been substantial progress in measuring business performance over the past 15 years, performance measurement systems are still not fully integrated in many organizations. A performance measurement system (PMS) for today's manufacturing environment must be process orientated, should cut across functional boundaries and must also support improvement activity. This makes the design of a PMS complicated by its multi-dimensional nature (Neely et al., 1996). Bourne et al. (2000) suggest that the development of a PMS may conceptually be separated into phases of design, implementation, and use. This paper focuses on the design phase.

In this paper the design of an integrated performance measurement system (IPMS) for cellular manufacturing is demonstrated both through literature review and a case study. It presents a framework for an integrated performance measurement system for cellular manufacturing at Volvo Aero Norway (VAN). VAN is a producer of aero-engine components based in Kongsberg, Norway.

The paper is structured as follows: First of all, the research methodology is briefly explained. Then the paper introduces a review of the literature around two focal areas: cellular manufacturing and performance measurement. Performance measurement for cellular manufacturing is then considered, and a conceptual framework is presented. We then draw insight from a practical case, before final conclusions are drawn and the limitations and areas for further work are discussed.

2. Methodology

This paper is written as part of the Norwegian research program SFI Norman and the Norwegian research project Ideal Factory. The paper presents a conceptual framework for an IPMS for cellular manufacturing primarily through a literature review of cellular manufacturing and performance measurement. Electronic journal databases (e.g. - Science Direct, ISI Web of Knowledge, and EBSCO) were searched with the terms "cellular manufacturing" and "performance measurement". After presenting the conceptual framework, an IPMS for cellular manufacturing is designed and proposed from insight drawn from a practical case. The empirical data for this case was collected through observations, interviews, and written documentation at the case company.

3. Theoretical Background

There are two focal areas to this paper. The first is cellular manufacturing, which sets the boundaries for the research, and the second is performance measurement, which is the core topic. This section explores both concepts so that a conceptual framework for an integrated performance measurement system (IPMS) for cellular manufacturing can be presented.

Cellular Manufacturing

Cellular manufacturing involves the grouping of machines, processes and people into cells, and is based on the principles of Group Technology (see Burbidge, 1991). Burbidge (1991) suggests that the term cellular manufacturing can be used as a synonym for Group Technology (GT). Olorunniwo and Udo (2002) suggest that the implementation of cellular manufacturing involves the conversion to cells of all or a portion of a firm's manufacturing system, where each cell consists of a cluster of functionally dissimilar machines or processes that are placed in close proximity to one another and are dedicated to the manufacture of a set of part families. Greene and Sadowski (1984) define cellular manufacturing as the physical division of a functional job shop's machinery into production cells. With such a layout, machines and processes can be organized according to product types in order to create small organizational units that foster small batch production and continuous performance improvements.

Cellular manufacturing can be considered as a strategy for organizing work processes in order to shorten response times, improve quality in production, and drive down inventories and costs (Hyer and Wemmerlöv, 2002). Traditionally, shopfloor layouts have been functionally organized, grouping similar processes together regardless of product types, and transporting large batches of product from process to process. Greene and Sadowski (1984) suggest numerous advantages associated with cellular manufacturing, including reduced material handling, reduced tooling, reduced work-in-process (WIP) inventory and reduced set-up times. Shambu and Suresh (2000) agree that a major benefit of using cellular manufacturing is the resulting reduction in setup times because of the similarity of parts being processed on the machine/s.

Performance Measurement

Folan and Browne (2005) suggest that the ways and means of accurately measuring organizational performance is perceived as being an increasingly important field of research for both organizations and academics alike. Performance measurement provides information about how well an organization is progressing towards its targets, helps identify its strengths and weaknesses, and supports continuous improvement (Amaratunga and Baldry, 2002). However, performance measurement is not meaningful on its own. It is the actions taken as a result of the measures that are relevant (Busi, 2005).

Performance measurement systems succeed when the organization's strategy and performance indicators are in alignment and when senior management conveys the organization's mission, vision, values, and strategic direction to employees and stakeholders (Artley and Stroh, 2001). Bititci (1997) suggests that the performance management process can be seen as a closed loop control system which deploys policy and strategy, and obtains feedback from various levels in order to manage the performance of the business. Kaplan and Norton (2008) indicate that most companies' underperformance is due to breakdowns between strategy and operations. Therefore, once a company has formulated its business strategy at the top level, an appropriate operations strategy must then be developed by further defining strategic objectives and carefully selecting performance indicators and targets that can be clearly communicated across the organization.

Kaplan and Norton (2008) believe that if a firm does not measure its progress toward an objective, it can neither manage nor improve it. For example, the European Foundation for Quality Management (EFQM, 2003) suggests that excellent organizations comprehensively measure and achieve outstanding results with respect to the key elements of their policy and strategy. It is therefore of high importance for an organization to carefully select a balanced range of critical performance indicators that support and guide its progress toward common strategic objectives.

By categorizing performance indicators into performance objectives, it is simpler to identify which indicators an organization should measure in order to support its business objectives. Slack et al. (2007) suggest five generic performance objectives for performance measurement: quality; speed; dependability; flexibility; and cost. These are composites for many smaller measures, or indicators. Some typical performance indicators for each objective are shown in Table 1:

Table 1: *Some typical performance indicators* (adapted from Slack et al., 2007)

Performance Objective	***Typical Performance Indicators***
Quality	Number of customer complaints
	Scrap rate
	Rework rate
Speed	(Overall) lead time
	Throughput time
	Cycle time
Dependability	Mean time between failures
	Percentage of orders delivered late
	Schedule adherence
Flexibility	Range of products
	Machine changeover time
	Average batch size
Cost	Resource utilization (Downtime)
	Labour productivity
	Value added per person (VAPP)

An Integrated Performance Measurement System (IPMS)

The need for an integrated set of performance indicators which supports rather than contradicts business objectives is clearly established (Bititci, 1994). Franceschini et al. (2007) suggest that performance measures should be integrated in two directions: vertically and horizontally. Vertical integration motivates and improves operating performance by focusing employee efforts on common strategic objectives, whilst horizontal alignment assures optimization of work flow across all processes. The IPMS developed here considers the integration of both horizontal (functional) and vertical (management) measures. By integrating a PMS across an organization, it is possible for performance indicators to be effective agents for change. For example, Ghalayani et al. (1997) present an integrated dynamic performance measurement system (IDPMS) that integrates three key areas: management; process improvement team; and factory shopfloor. By taking this approach, they suggest that a PMS can explicitly consider the integration of continuous improvement.

Artley and Stroh (2001) suggest that there are a number of sources that should be examined as a first step in establishing an integrated performance measurement system (IPMS). They state that these sources typically provide a strategic perspective in developing the critical few performance indicators. These sources include:

- The strategic plan
- Key business processes
- Stakeholder needs
- The involvement of both senior management and employees
- Accountability for measures
- A conceptual framework
- Communication

Reflecting on Artley and Stroh (2001), we suggest that the key areas for the development of an IPMS for cellular manufacturing are the business and operations strategy (strategic plan) and a supporting conceptual framework for performance measurement. One of the most well-known and well-proven performance measurement frameworks is that of the balanced scorecard approach, which will now be briefly explained.

Balanced Scorecard

Chenhall and Langfield-Smith, (2007) suggest that management accounting has had a primary function in developing performance indicators to assist managers in planning and controlling their organizations. This paved the way to the traditional financial accounting model still evident in many performance measurement systems (PMSs). However, Chen (2008) suggests that PMSs based on traditional cost-accounting systems do not capture the relevant performance issues for today’s manufacturing environment.

The balanced scorecard approach (Kaplan and Norton, 1996) expanded the traditional model to consider non-financial performance indicators, and proposed a four perspective view of business performance: financial; customer; internal business processes; and learning and growth. Kaplan (1990) suggests that the traditional cost accounting measures fail in advanced manufacturing environments. He states that short-term, operational feedback for control (and learning) should be provided by direct physical measures, for example actual quantities of labor, materials, and machine time, or actual yields, defect rates, and throughput times. LaBarge (1999) suggests that a competitive performance measurement system should consist of the following characteristics:

- A balanced set of measures
- A selection of the “critical few” measures
- Accountability for all measures
- Vertical integration of measures
- Horizontal integration of measures.

Since the advent of the balanced scorecard framework (see Kaplan and Norton, 1996), a fully integrated approach is now considered the standard approach for performance measurement. This framework consists of a balanced set of measures based around the organizations vision and strategy. As was stated earlier, the balanced scorecard considers measures for four key areas:

- Financial (How do we satisfy the strategic financial objectives?)
- Customer (How do we satisfy customer needs?)
- Internal business process (How well do our internal business processes perform?)
- Learning and growth (How do we sustain innovation, change, and continuous improvement?)

However, the balanced scorecard approach is just a framework, and Folan and Browne (2005) state that no performance indicators are explicitly pre-defined by this approach, which relies upon the system design methodology to formulate the indicators during the design process.

It is clear that a balanced approach to performance measurement is an integral part in the design of an IPMS. The rest of this paper describes the process of designing of an IPMS for cellular manufacturing, with particular emphasis on the alignment of the strategic plan of the organization with a conceptual framework for performance measurement.

Performance Measurement for Cellular Manufacturing

Much of the literature around cellular manufacturing discusses the design of the manufacturing cells themselves, and typically involves some mathematical modeling. This leads to the conclusion that a gap exists in scientific knowledge as to how a performance measurement system (PMS) should look for cellular manufacturing. Hyer and Wemmerlöv (2002) suggest that a PMS for cellular manufacturing should consider five performance dimensions: quality and productivity (how well and how productive?); flow and inventory (how much and at what rate?); timeliness (how timely?); workplace environment (how safe and how satisfying?); and financial aspects (how much in monetary terms?). They suggest that this forms a similar balanced framework to the financial vs. customer vs. internal business processes vs. learning and growth dimensions of the balanced scorecard approach. The balanced scorecard approach remains the preferred method in this case as there is some confusion identified between the dimensions of timeliness and flow and inventory. In many cases, performance indicators can be placed into either of these dimensions. For example, Hyer and Wemmerlöv (2002) suggest that ‘response time to customer enquiries’ is a measure of flow and inventory, yet it could just as well be an indicator of timeliness.

One dimension of particular relevance to cellular manufacturing is the dimension that considers learning and growth (Kaplan and Norton, 1996). This is because a number of social changes occur when companies convert from functional, batch type production to manufacturing cells (Olorunniwo and Udo, 2002). This transformation shifts worker responsibilities from watching a single machine to managing multiple machines in a manufacturing cell. While shop floor operators may need to feed or unload components or products, they are generally empowered to focus on process improvement activities. United States Environmental Protection Agency, 2009). Cell team members have to work together, often with different skill sets, therefore cross-training and empowerment are key terms within the cell manufacturing movement. A key success factor for the development of a manufacturing cell is the ability to measure and improve the social performance of the cell. EFQM (2003) suggest that measuring involvement in suggestion schemes (e.g. – number of completed improvement activities per month) is an alternative to traditional measurements such as absenteeism and accident levels.

When designing an IPMS for cellular manufacturing, a selection of effective performance indicators from each of the five performance objectives (Slack et al., 2007) should be selected, based on the balanced scorecard approach, and used to align the individual production cells and workers with the organization's strategic goals (Artley and Stroh, 2001). The IPMS should also provide a mechanism for continuous improvement (Bond, 1999). In this respect, we can view the use of the PMS as a tool for performance management. Amaratunga and Baldry (2002) define performance management as the use of performance measurement information to effect positive change in organizational culture, systems and processes. Folan and Brown (2005) state that performance measurement precedes performance management, thus we can suggest that the application of a structured IPMS within a manufacturing cell will contribute towards improved performance management.

Based on the theoretical background, Figure 1 illustrates a conceptual framework for an IPMS for cellular manufacturing:

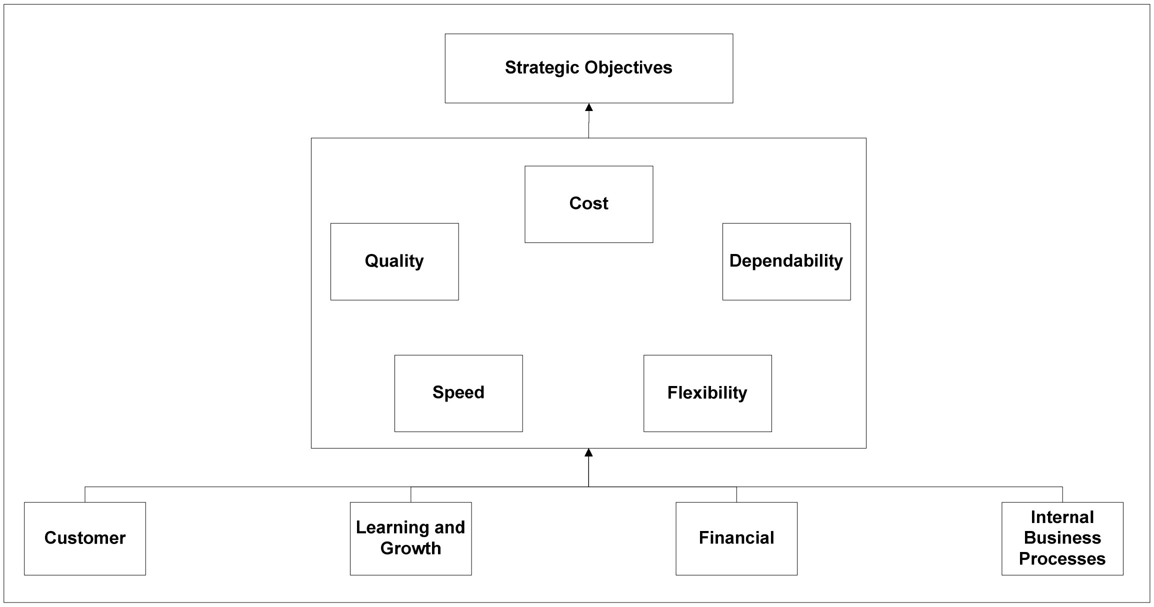

Figure 1: *A Conceptual Framework for an IPMS for cellular manufacturing (based on Kaplan and Norton, 1996; and Slack et al., 2007)*

It clearly shows how operations are aligned and integrated with the strategic objectives of the organization through a selection of appropriate performance indicators based on the balanced scorecard approach. Of particular relevance to application in the cellular manufacturing environment, the balanced scorecard approach ensures a balanced and integrated set of indicators, including those that reflect team learning and growth. The conceptual framework will now be applied to a practical case.

4. Case Study

This case study presents work from the research program SFI Norman and the research project Ideal Factory. Part-funded by the Norwegian Research Council, SFI Norman aims at securing the future of Norwegian manufacturing through innovative working practices, whilst Ideal Factory aims at creating the ideal factory and production system for high-tech manufacturing companies in Norway. The case itself draws on insight from Volvo Aero Norway (VAN) by first analyzing the company's current (AS-IS) performance management system, and then proposing an IPMS for cellular manufacturing (TO-BE).

VAN is a partner organization within both SFI Norman and Ideal Factory. With 3250 employees, VAN has locations in Sweden, Norway and USA, and produces components for 90% of all large commercial aircraft (Volvo Aero, 2008). This paper considers operations at the Kongsberg plant in Norway, where jet engine components for the world's largest aircraft engine manufacturers are produced. The company represents a technological competence center within advanced, mechanical production. Working for its customers, the strategic objectives of the Volvo Group are customer satisfaction, operational excellence and profitable growth (Volvo, 2009). In order to align manufacturing performance with these strategic objectives, VAN and SINTEF identified the need for a highly structured, integrated performance measurement system (IPMS).

VAN has recently applied cellular manufacturing principles to the production of turbine cases (T-Case). Before the conversion to cellular manufacturing, T-Case production took place on a production line. As of today, the T-Case manufacturing cell consists of four high-technology turning/milling machines. The aim of this case is to design and propose an IPMS for cellular manufacturing at VAN.

IPMS design for cellular manufacturing

Lohman et al. (2004) suggest that the complexity of a PMS can be reduced by clustering performance indicators into various perspectives. For this reason the balanced scorecard framework was used to identify indicators for the four key areas: financial; customer; internal business processes; and learning and growth. However, no performance indicators are explicitly pre-defined by this approach (Folan and Browne, 2005). Therefore the current performance measurement system at VAN was analyzed prior to the selection of performance indicators based on the balanced scorecard framework.

AS-IS Performance Measurement at VAN

Table 2 illustrates the current performance indicators that are measured in the T-Case cell at VAN, with reference to the balanced scorecard framework:

Table 2: *Current T-Case Performance Indicators with reference to balanced scorecard*

Customer	• N/A
Financial	• Value of quarantined parts (NOK)
Internal Business Processes	• Plan achievement (%) • Throughput time (days) • Indirect time (hours) • Lost time (hours) • Scrap rate (%) • Rework rate (%)
Learning and Growth	• Absenteeism (%)

It is clear that the indicators currently measured and displayed on the shopfloor have a strong influence towards the evaluation of internal business processes. Though this may deliver some horizontal integration, a more balanced and vertically integrated set of measures are required in order to focus employee efforts on achieving the organizations strategic objectives (Franceschini et al. 2007).

Proposed TO-BE Performance Measurement at VAN

By applying the conceptual framework for an IPMS for cellular manufacturing (Figure 1), we can conclude that the strategic objectives of VAN (customer satisfaction, profitable growth, and operational excellence) should be aligned with suitable performance indicators according to the balanced scorecard approach. Figure 2 illustrates the proposed IPMS for cellular manufacturing at VAN:

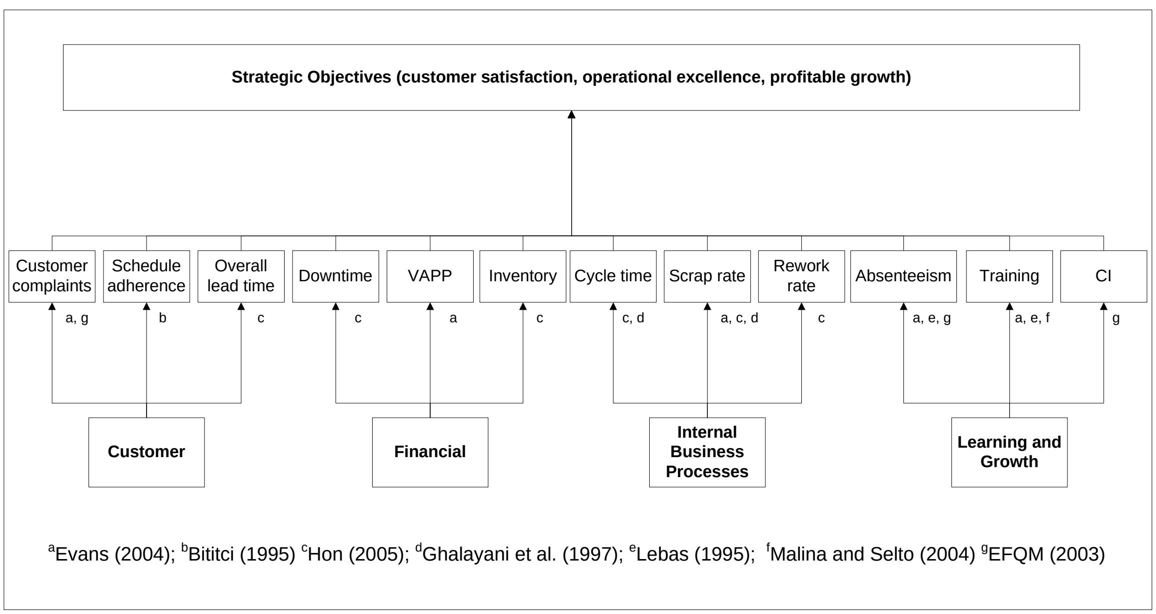

Figure 2: *Proposed IPMS for Cellular Manufacturing at VAN (based on Kaplan and Norton, 1996; and Slack et al., 2007)*

Appropriate measures were selected from relevant literature about performance measurement. For example, scrap rate has been suggested as a performance indicator by Evans et al. (2004); Hon (2005); and Ghalayani et al. (1997). In the framework, a selection of performance indicators addresses each of the four perspectives of the balanced scorecard approach (Kaplan and Norton, 1996) as well as the five performance objectives of Slack et al. (2007). For example, addressing the view of the customer, the selected performance measures are number of customer complaints, which reflects a quality measure, schedule adherence, which reflects a dependability measure, and overall lead time, which reflects a speed measure (see Table 1). The indicators chosen to address financial performance are downtime (hours), value added per person (VAPP), and the cost of inventory. The suggested indicators for internal business processes are cycle time, scrap rate and rework rate, and finally, learning and growth can be addressed through measures for absenteeism, training, and continuous improvement (CI). As was stated previously, of particular relevance to an IPMS for cellular manufacturing is the learning and growth perspective, and EFQM (2003) suggest that motivation and involvement of people can be measured through the success of suggestion schemes, for example, the number of CI suggestions made per month. VAN already use what they call a PUFF list, which stands for “Planlegge og Utføre, Følg opp og Forbedre”. Translated to English, this means plan and execute, follow up and improve, and can be considered in this case as a type of continuous improvement suggestion scheme which can be measured.

By using a structured selection of performance indicators in this manner, and through continuous learning within the cell environment, cell operators can be empowered to make quantifiable performance improvements that contribute towards the organization's strategic goals.

6. Conclusion

Performance measurement provides the essential links between strategic objectives and operational execution. The purpose of this paper was to present a conceptual framework for an integrated performance measurement system (IPMS) for cellular manufacturing. This has been achieved firstly by conducting a review of literature around the two focal areas (cellular manufacturing and performance measurement), and secondly through the application of theory to a case study example (Volvo Aero Norway (VAN)).

The theories of cellular manufacturing and performance measurement were considered and combined in order to evaluate the most critical aspects of a PMS for cellular manufacturing. It was also concluded that a PMS should be integrated both vertically and horizontally within the organization (Bititci, 1994; Franceschini, 2007). In order to define a balanced set of measures, the balanced scorecard approach (Kaplan and Norton, 1996) was taken. By applying the relevant theories from literature, a conceptual framework for an IPMS for cellular manufacturing has been presented (Figure 1).

In order to apply the theory empirically, VAN was chosen as a case company. VAN's strategic objectives are customer satisfaction, profitable growth, and operational excellence. The current performance indicators used in the T-Case cell fail to significantly address the dimension of customer satisfaction, but had a keen focus on the performance of internal business processes. In order to better measure performance against the strategic objectives, a balanced set of performance measures were selected by considering the five performance objectives (quality; speed; dependability; flexibility; cost) of Slack et al. (2007) and the four performance perspectives (financial; customer; learning and growth; internal business processes) of Kaplan and Norton (1996). This resulted in the IPMS framework for cellular manufacturing at VAN, illustrated in Figure 2. By employing such an IPMS, manufacturing cell operators can be empowered to contribute towards continuous improvements that help to satisfy the strategic objectives of the organization.

Limitations and Further Work

This work has been limited to one case within the scope of designing an integrated performance measurement system (IPMS) for cellular manufacturing. One limitation in particular was that a somewhat blinkered view of the individual cell was taken. Further work should consider the implications of not only intra-organizational integration of the IPMS, but also inter-organizational integration. For example, Goldratt (1994) suggests that a supply chain which limits itself to local performance does not work together in an integrated manner. Thus, performance measurement should be integrated across organisational boundaries as well as across intra-organizational, functional boundaries.

Further work will also evaluate the implementation and success of the IPMS for cellular manufacturing at VAN. Hyer and Wemmerlöv (2002) suggest that cell performance measures are presented most effectively through the use of a visual scoreboard. This is similar to the dashboard concept of Strandhagen et al. (2006). In order to ensure that the cell team members understand each performance indicator, it could also be suggested that the KPI sheet of Neely et al. (1997) be displayed within the manufacturing cell. It is proposed that by using the visual scoreboard in the cell, and by displaying information about the performance indicators on the KPI-Sheet, an effective IPMS for cellular manufacturing can be realized.

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