World class manufacturing: an investigation of Hayes and Wheelwright’s foundation

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Abstract

Although Hayes and Wheelwright originally coined the term ‘world class manufacturing’, the global manufacturing environment has undergone many changes since their work. In the study, we seek to determine whether the practices which they described are still relevant in today’s manufacturing environment. We also look at their list of competitive priorities and examine whether they function as tradeoffs, as Hayes and Wheelwright suggested, or whether there are synergies between them. The World Class Manufacturing (WCM) Project data set, comprised of plants in the machinery, electronics and transportation components industries, was used to construct measures to correspond to the practices and performance measures suggested by Hayes and Wheelwright. The results indicated that Hayes and Wheelwright’s practices were related to competitive performance, and that the addition of new manufacturing practices resulted in further improvements in competitive performance. Thus, Hayes and Wheelwright’s practices are robust and have provided a foundation for the use of new manufacturing practices. In addition, there was strong support for the notion that the use of world class manufacturing practices, alone and in combination with new manufacturing practices, leads to the achievement of simultaneous competitive advantages, supporting the synergies perspective. © 1999 Elsevier Science B.V. All rights reserved.

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1. Introduction

The term ‘world class manufacturing’ was first used by Hayes and Wheelwright in 1984. Since then, the concept has been embraced, expanded and enhanced by a number of authors, who have reinforced some of Hayes and Wheelwright’s ideas, added some new practices and ignored others. In this paper, we analyze the foundation provided by Hayes and Wheelwright’s work, to determine whether it remains relevant in today’s environment.

Hayes and Wheelwright’s work on world class manufacturing is important to the field of operations strategy for several reasons. First, Hayes and Wheelwright were the first authors to use the term ‘world class manufacturing’, laying the foundation for the work of countless future authors. This is particularly
important due to the credibility associated with the work of Hayes and Wheelwright because of their seminal work in the area of operations strategy (Hayes and Wheelwright, 1979, 1984).

Second, Hayes and Wheelwright described world class manufacturing as a set of practices, implying that the use of best practices would lead to superior performance. This practice-based approach to world class manufacturing has been echoed by numerous authors since then. For example, Voss (1995) describes world class manufacturing as a subset of the ‘best practices’ paradigm of operations strategy. Much of the study of Japanese manufacturing in recent years has also focused on the discernment and use of best practices.

Third, Hayes and Wheelwright were among the first authors in the operations management arena to address the issue of tradeoffs vs. synergies in manufacturing performance, building on the earlier work of Skinner (1969). They made a substantial contribu-

Table 1
Summary of Hayes and Wheelwright’s practices

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Rationale</th>
<th>Practices</th>
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<tbody>
<tr>
<td>Workforce skills and capabilities</td>
<td>U.S. firms have neglected development of workforce skills and capabilities; this should not be left to the schools</td>
<td>• Apprenticeship programs&lt;br&gt;• Cooperative arrangements with vocational technical institutes&lt;br&gt;• Internal training institutes&lt;br&gt;• Extensive advanced training and retraining beyond entry level, focusing on skills, work habits and motivation</td>
</tr>
<tr>
<td>Management technical competence</td>
<td>U.S. firms experience technical weakness among their managers</td>
<td>• Ensure a significant number of managers have engineering or technical degrees&lt;br&gt;• Train potential managers, early in their careers, in a variety of technologies important to the firm&lt;br&gt;• Rotate managers through various functions, to broaden their experience</td>
</tr>
<tr>
<td>Competing through quality</td>
<td>U.S. firms need to focus on what is important to customers</td>
<td>• Seek to align products and processes to meet needs that are important to customers&lt;br&gt;• Long-term commitment to quality&lt;br&gt;• Strong attention to product design&lt;br&gt;• Involvement of all functions in product design and quality improvement</td>
</tr>
<tr>
<td>Workforce participation</td>
<td>Real participation is more than simply putting employees into teams</td>
<td>• Develop a culture of trust between workers in various departments and between workers and management&lt;br&gt;• Routine, close contact between management and workers&lt;br&gt;• Develop participation policies to ensure that ‘We’re all in this together’</td>
</tr>
<tr>
<td>Rebuilding manufacturing engineering</td>
<td>Unique capabilities of equipment can’t be copied</td>
<td>• Invest in proprietary equipment&lt;br&gt;• Bolster ability to perform sophisticated maintenance, process upgrades and continuous improvement of existing equipment</td>
</tr>
<tr>
<td>Incremental improvement approaches</td>
<td>Win the race by creating a constantly escalating standard</td>
<td>• Continuous improvement in small increments&lt;br&gt;• Continually adapt to changes in customer needs</td>
</tr>
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</table>

tion to this debate by arguing that it was important to have a clear set of priorities between the dimensions of competitive performance because it was potentially dangerous to try to achieve superior performance on multiple dimensions simultaneously. This debate continues to rage, particularly in the strategic management field.

In this paper, we address both the robustness of Hayes and Wheelwright’s original set of practices and the issue of tradeoffs vs. synergies between dimensions of competitive performance by testing a set of propositions in a sample of manufacturing plants in the machinery, electronics and transportation components industry in the U.S. We begin by comparing the practices suggested by Hayes and Wheelwright with current descriptions of practices associated with world class manufacturing, pointing out departures from Hayes and Wheelwright, as well as consistencies. We then turn to a summary of the debate about whether the dimensions of competitive performance represent tradeoffs or synergies, citing support for each perspective from both the operations management and strategic management literatures. Finally, the empirical testing and results are described.

2. Hayes and Wheelwright’s foundation for world class manufacturing

2.1. Practices

Although Hayes and Wheelwright are primarily known for their set of stages of manufacturing’s strategic role in the organization (1984), their framework for manufacturing strategy structure and infrastructure (1984) and their product-process matrix (1979), they were also the first to use the term ‘world class manufacturing’. Since then, the term has been used and popularized by many other authors. Hayes and Wheelwright’s description of world class manufacturing focuses on six practices, some of which are taken for granted today and others which seem fairly unique.

There are marked differences between Hayes and Wheelwright’s set of practices and those described by recent researchers in this area. Given the dramatic changes which have taken place in the global manufacturing arena since 1984, is Hayes and Wheelwright’s set of world class manufacturing practices still relevant? Will they be more effective if used in concert with additional, more recently popularized practices?

2.1.1. Hayes and Wheelwright’s perspective

Hayes and Wheelwright (1984) developed their concept of world class manufacturing based on in-depth analysis of the practices implemented by Japanese and German firms, as well as U.S. firms which had competed equally with the Japanese and German firms. The term ‘world class manufacturing’ was used because these firms were associated with outstanding performance in their global industries, resulting in their being described as ‘world class’. Hayes and Wheelwright found that there were many commonalities between these highly successful firms, arguing that the key to building competitive strength is related to six world class manufacturing practices, summarized in Table 1.

Hayes and Wheelwright found that, relative to firms in Germany and Japan, U.S. firms had neglected workforce skills and capabilities. They recommended a proactive stance on the part of U.S. manufacturers, focusing on apprenticeships, internal training institutes and cooperative arrangements with vocational technical institutes. They also found management technical competence lacking, relative to Japan and Germany, making management of cutting edge manufacturing a significant challenge. In addition to providing technical training for managers, they suggested developing more managers with engineering or technical degrees, and rotating managers through technical functions in their organizations.

Although Hayes and Wheelwright called the third practice competing through quality, their definition is substantially narrower than recent definitions of quality management, focusing primarily on the product design function, with customers as the drivers of quality. In terms of workforce participation, Hayes and Wheelwright emphasized that development of true worker participation moves beyond simply putting employees into teams, focusing on culture change and policies which support employee participation.

Hayes and Wheelwright’s fifth practice, rebuilding manufacturing engineering, describes the inter-
nal development of equipment with unique characteristics, which is difficult for competitors to copy. They also stressed the importance of developing employees' ability to maintain and improve their own equipment. Finally, Hayes and Wheelwright speak of 'Tortoise and Hare' approaches to competition, or incremental improvement approaches. While U.S. firms have traditionally pursued strategic leaps as a means of manufacturing improvement, Hayes and Wheelwright suggest that world class competitors pursue continuous improvement in small increments, winning the race by creating a constantly escalating standard.

2.1.2. Recent Perspectives

More recent authors have developed their own descriptions of world class manufacturing practices, often building on new manufacturing practices, such as quality management and JIT. In the following section, we examine two recent descriptions of world class manufacturing, both based on extensive observation in world class firms, representing the state of the art in world class manufacturing practices.

The first was developed by Schonberger (1986, 1990a,b, 1996), who provides a list of 16 principles of world class manufacturing. Many of these correspond to Hayes and Wheelwright’s practices, although not necessarily directly. A comparison of Hayes and Wheelwright’s prescriptions with Schonberger’s principles is contained in Table 2. In addition, we consider the work of Giffi et al. (1990), who summarizes the attributes of world class organizations. Those which are related to Hayes and Wheelwright’s practices are also summarized in Table 2.

2.1.2.1. Workforce skills and capabilities. Schonberger emphasizes the importance of employee development, focusing primarily on internal means of development, such as cross-training, job rotation and reinforcement of employee development accomplishments, through rewards and recognition. Giffi, Roth and Seal’s attributes are somewhat broader, suggesting that employee skill development should progress in tandem with technology development, and that rewards should be based on the ability to achieve meaningful goals. Thus, employee development continues to be an important part of world class manufacturing practices. However, its focus has moved beyond training to include job rotation, cross-training, rewards and recognition, and linkages with the firm’s strategy.

2.1.2.2. Management technical competence. Although Hayes and Wheelwright emphasize the importance of having managers with a technical background, this practice is largely ignored by Schonberger. Giffi, Roth and Seal approach this practice only in the broadest sense, stating that a new knowledge base is required as advanced technology is installed. Thus, recent descriptions of world class manufacturing practices lack the suggestion that management would benefit from an engineering or technical background, acquired through education, training or job rotation.

2.1.2.3. Competing through quality. The maxim of designing for customer needs has become a cornerstone of most quality management approaches. Likewise, it is supported by recent descriptions of world class manufacturing. However, while Hayes and Wheelwright focus exclusively on developing products and processes that meet customer needs and involving all functions in product design, Schonberger adds the importance of producing at close to the customers’ rate of use. He also takes the concept of cross-functional design a step further, suggesting organizing the firm by families of customers or products. Giffi, Roth and Seal extend this to the notion of ‘customer closeness’, where every employee has a customer whom he or she personally relates to. They also emphasize the strategic goal of making customers the core of an organization’s existence. Thus, the concept of designing for customer needs continues to be an important world class manufacturing practice. However, it has moved beyond the design function to have organizational and strategic implications.

2.1.2.4. Workforce participation. Hayes and Wheelwright express concern that many efforts at worker participation are superficial, stressing the need for culture change and policies to ensure that, ‘We’re all in this together’. Schonberger, however, remains at a fairly superficial level in discussing worker participation. He prescribes that employees should be involved in activities such as recording their own
Table 2
Comparison of recent descriptions of world class manufacturing with Hayes and Wheelwright’s world class manufacturing practices

<table>
<thead>
<tr>
<th>Hayes and Wheelwright’s world class manufacturing practices</th>
<th>Corresponding Schonberger principles</th>
<th>Corresponding Giffi, Roth and Seal attributes</th>
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<tbody>
<tr>
<td>Workforce skills and capabilities</td>
<td>• Principle 8: Continually enhance human resources through cross-training, job and career-path rotation and improvements in health, safety and security</td>
<td>• Promote and measure knowledge and skill development</td>
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<td></td>
<td>• Principle 9: Expand the variety of rewards, recognition, pay and celebration—to match the expanded variety of employee contributions</td>
<td>• Invest in people; develop a pattern for updating workforce skills and capabilities consistent with the evolution of technology within the organization</td>
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<tr>
<td></td>
<td></td>
<td>• Seek ways to liberate the teams from traditional organizational controls, and reward and motivate, based upon ability to achieve meaningful goals</td>
</tr>
<tr>
<td>Management technical competence</td>
<td></td>
<td>• Identify the competitive advantage of the knowledge base that advanced technology can create; simultaneously implement new technology and develop the new knowledge base</td>
</tr>
<tr>
<td>Competing through quality</td>
<td>• Principle 1: Team up with customers, organizing by families of customers or products (what customers buy/use)</td>
<td>• Define quality in terms of the customers’ needs. Make customer closeness the number one priority</td>
</tr>
<tr>
<td></td>
<td>• Principle 7: Operate close to customers’ rate of use or demand</td>
<td>• Integrate the concept of customer closeness into the organization so that everyone in the organization has a customer, and everyone’s goal is to provide quality product and service to his or her customer</td>
</tr>
<tr>
<td>Workforce participation</td>
<td>• Principle 4: Frontline employee involved in change and strategic planning—to achieve unified purpose</td>
<td>• Dissolve the boundaries between management and worker and between functionally segregated staff units, to create dynamic cross-functional teams charged with resolving both strategic and operational issues</td>
</tr>
<tr>
<td></td>
<td>• Principle 11: Frontline teams record and own process data at the workplace</td>
<td>• Empower teams of workers to carry out the mission of the organization</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Eliminate the terms ‘supervisors’ and ‘supervision’. Develop leaders who can create and execute the strategic vision through the teams</td>
</tr>
<tr>
<td>Rebuilding manufacturing engineering</td>
<td>• Principle 14: Improve present equipment and human work before considering new equipment and automation</td>
<td>• Develop an investment strategy for the continual enhancement of technology throughout the organization, based on a clearly defined vision of future competitive requirements</td>
</tr>
<tr>
<td></td>
<td>• Principle 15: Seek simple, flexible, movable, low-cost, readily available equipment and work facilities—in multiples, one for each product/customer family</td>
<td>• Carefully plan technological upgrades to be consistent with infrastructural upgrades. Benefits can be achieved only when the infrastructure is capable of integrating and exploiting the technology advantage offered</td>
</tr>
<tr>
<td>Incremental improvement approaches</td>
<td>• Principle 3: Dedicate to continual, rapid improvement in quality, response time, flexibility and value</td>
<td>• Develop manufacturing operations that are flexible and able to respond rapidly to changes in products and markets</td>
</tr>
<tr>
<td></td>
<td>• Principle 5: Cut to the few best components, operations and suppliers</td>
<td>• Develop measurement systems that encourage continual learning</td>
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</tbody>
</table>
process data and in continuous improvement, but offers no suggestions for ensuring genuine involvement. Giffi, Roth and Seal are more specific, suggesting the development of cross-functional teams, elimination of supervisors and other practices for breaking down barriers between workers and management. They also emphasize the important role of good leaders in the development of team members. Thus, worker participation remains intact in recent world class manufacturing practices. Like Hayes and Wheelwright, Giffi, Roth and Seal express concern that developing genuine worker participation is a challenge, moving beyond the implementation of superficial programs.

2.1.2.5. Rebuilding manufacturing engineering. Hayes and Wheelwright consider the development of proprietary equipment to be critical to becoming a world class manufacturer. In fact, it is one of their ‘litmus tests’ of whether an organization has truly achieved world class status, because organizations that develop and maintain their own equipment know more about what is critical to their business than their suppliers.

Neither Schonberger nor Giffi, Roth and Seal explicitly address proprietary equipment. Both, however, do address issues related to technology. Schonberger has a strong bias against investments in overly-sophisticated equipment, suggesting investing in the simplest equipment possible and improving present equipment before considering new equipment and automation. This is somewhat consistent with Hayes and Wheelwright’s proprietary equipment practice; by developing proprietary equipment, a firm can customize it to its unique needs, rather than purchasing unneeded capabilities. Giffi, Roth and Seal, on the other hand, do not discuss the level of sophistication of technology investments. Rather, their attributes focus on appropriate ways for developing the infrastructure to support technology, at whatever level it may be. Thus, proprietary equipment, per se, is not a part of recent descriptions of world class manufacturing. This represents a major departure from Hayes and Wheelwright’s practices, since they consider it to be a cornerstone of world class manufacturing.

2.1.2.6. Incremental improvement approaches. Hayes and Wheelwright are quite vague in their discussion of incremental improvement approaches. Schonberger and Giffi, Roth and Seal build upon Hayes and Wheelwright’s foundation by providing very specific suggestions about ways in which improvement can be pursued. Schonberger focuses on the continuous improvement of information, performance improvements and quality. He also stresses the importance of simplification as a form of improvement. Giffi, Roth and Seal discuss improvement in terms of flexibility, rapid response, measurement systems, human assets and learning programs. Thus, both Schonberger and Giffi, Roth and Seal include incremental improvement approaches in their description of world class manufacturing, providing details about areas of implementation not described by Hayes and Wheelwright.

2.1.3. Summary

In looking at Hayes and Wheelwright’s practices, it is interesting to note that some continue to be integral to descriptions of world class manufacturing, while others have dropped out. In particular, workforce skills and capabilities, competing through quality, worker participation and incremental improvement approaches have been strongly supported by
recent accounts of world class manufacturing, and in most cases, further elaborated upon. This is supported by numerous anecdotal accounts of the effectiveness of such practices. On the other hand, recent accounts of world class manufacturing have largely ignored prescriptions for management technical competence and rebuilding manufacturing engineering.

This is supported by recent empirical work. For example, Voss and his colleagues visited over 500 manufacturing plants to assess progress on practices and performance measures (Hanson and Voss, 1993; Voss, 1995; Voss and Blackmon, 1996; Voss et al., 1997). They list 46 practices and performance measures related to world class manufacturing, including practices related to workforce skills and capabilities, competing through quality and worker participation. Although they don’t explicitly include incremental improvement approaches as a practice, many of their practices are elements of incremental improvement, as well. However, like Schonberger and Giffi, Roth and Seal, Voss, et al. does not include practices related to management technological competence or rebuilding manufacturing engineering.

2.1.4. New manufacturing practices
Recent work by Schonberger, Giffi, Roth and Seal and Voss, et al. differs from the work of Hayes and Wheelwright by its inclusion of two other key constructs, described by Clark (1996) as ‘new manufacturing practices’. Use of new manufacturing practices, such as quality management and JIT, has led to impressive results during the past decade (Clark, 1996). Manufacturers which applied these approaches noted significant improvements in competitive position and increases in productivity and reliability of their products.

‘Concepts such as TQM, JIT and continuous improvement are not simply new techniques; taken together, they represent a new conceptualization of the manufacturing system (Clark, 1996, p. 47).’

Thus, the question of whether these new manufacturing practices have become elements of world class manufacturing can be raised.

The first is a broader definition of practices associated with quality management. Although quality management has been defined many ways by various authors, the definitions appear to be coalescing into a three-pronged definition. Both academics and practitioners have described quality management as a set of practices related to three elements: customer focus, employee involvement and process focus (Dean and Bowen, 1994). Hayes and Wheelwright took a narrow approach, focusing primarily on customer focus in their definition of quality management. However, they also included employee involvement in their conceptualization of world class manufacturing. Thus, only process focus was notably lacking from Hayes and Wheelwright’s work.

Second, the use of JIT has become widespread in recent years. Its influence is particularly evident in Schonberger’s work on world class manufacturing. The domain of JIT practices can be divided into two sets: core JIT practices, such as use of a demand pull system and setup time reduction, and practices which comprise the infrastructure for supporting the use of those practices, such as workforce involvement in scheduling and improving the production process (Flynn et al., 1995). Infrastructure practices are well represented in Hayes and Wheelwright’s world class manufacturing practices, however this set lacks practices related to the core practices of JIT.

2.2. Competitive performance

2.2.1. The tradeoffs perspective
Hayes and Wheelwright (1984) defined competitive priorities as the ways in which a firm chooses to compete in the marketplace and the types of markets it pursues, defined in Table 3. It is reasonable to infer that the use of world class manufacturing practices will led to superior performance in some subset of these competitive priorities.

Hayes and Wheelwright stress that, within an industry, different firms or business units differ in the emphasis given to each competitive priority, thus creating their own unique strategic profile. However, they explicitly advise against the pursuit of multiple competitive priorities, stating,

‘It is difficult (if not impossible), and potentially dangerous, for a company to try to compete by offering superior performance along all of these dimensions simultaneously, since it will probably end up second best on each dimension to some other company that devotes more of its resources to developing that competitive advantage (p. 41).’
Table 3  
Operationalization of dependent variables

<table>
<thead>
<tr>
<th>Dependent variable</th>
<th>Hayes and Wheelwright’s definition</th>
<th>Operationalization</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost</td>
<td>Unit cost</td>
<td>Cost improvement = two-year change in cost</td>
</tr>
<tr>
<td>Quality—performance</td>
<td>High reliability or performance in a standard product</td>
<td>Mean of two perceptual items which measured perceived customer satisfaction with performance</td>
</tr>
<tr>
<td>Quality—features</td>
<td>Features or capabilities unavailable in competing products</td>
<td>Percent of sales from products introduced in the last five years</td>
</tr>
<tr>
<td>Dependability—specifications</td>
<td>Doing the work as specified</td>
<td>Percent of items shipped without requiring rework</td>
</tr>
<tr>
<td>Dependability—on-time delivery</td>
<td>Delivery of products on time</td>
<td>Perception of customer relations, relative to the industry</td>
</tr>
<tr>
<td>Dependability—service</td>
<td>Being ready to mobilize resources instantly to ensure that any failures are corrected immediately</td>
<td>Perception of customer relations, relative to the industry</td>
</tr>
<tr>
<td>Product flexibility</td>
<td>Ability to handle difficult, nonstandard orders and to take the lead in new product introduction</td>
<td>Perception of plant’s product flexibility, relative to its global industry</td>
</tr>
<tr>
<td>Volume flexibility</td>
<td>Ability to accelerate or decelerate production very quickly and juggle orders so as to meet demands for unusually rapid delivery</td>
<td>Perception of plant’s volume flexibility, relative to its global industry</td>
</tr>
</tbody>
</table>


Instead, they suggest that a firm must attach a clear set of priorities among the dimensions, which is supported over time by various decisions about resource allocation, rewards, competitive profiles, research and development, etc.

The idea of tradeoffs among competitive priorities echoes the well-known work of Porter (1981, 1985), who divided competitive priorities into cost and differentiation, which included quality dependable, flexibility and other attributes. He referred to attempting to simultaneously pursue both competitive priorities as being a ‘recipe for mediocrity’, describing such a firm as ‘stuck in the middle’. Kotha and Orne (1989) attribute the lack of success of mixed approaches to two causes. First, firms which pursue multiple competitive priorities simultaneously lack critical focus, producing neither effective reduction in costs nor differentiation which is sufficient to attract a premium price. Second, organizations which follow a mixed approach are positioned in the middle of their industry, close to competitors which have strengths resulting from their product and process characteristics. Empirical support for Porter’s perspective is provided by Dess and Davis (1984) and replicated by Robinson and Pearce (1988), whose work provided construct validity of Porter’s typology. They found that firms which pursued generic strategies, rather than mixed strategies, exhibited superior performance.

The tradeoffs perspective can be traced back to the seminal work of Skinner (1969), who described the diversity of strengths and weaknesses of organizations and how they can be used as a means of differentiation from competitors. Likewise, production systems have different operating characteristics. Thus, Skinner states that the task of manufacturing strategy is to configure production systems to reflect the priorities and tradeoffs inherent in an organization’s competitive situation and strategy.

Hayes and Pisano (1994) describe the fundamental robustness of the tradeoffs perspective over time. Many common practices today can trace their roots to it. For example, the focused factory concept is based on the premise that no single organization can do all things equally well. Process choice (Hill, 1989) which prescribes matching product and market evolution with manufacturing process characteristics, is based on the idea of shifting competitive priorities as a product matures.

Clark (1996) describes two central propositions of manufacturing strategy represented by the tradeoffs perspective. First, there are many ways for an organization to compete, including low cost, rapid delivery, superior performance, etc. Second, organizations
cannot be all things to all people. While an organization must meet minimum standards on all dimensions of customer choice,

‘...firms that try to do everything exceptionally well and fail to develop competitive priorities will end up second best to those firms that concentrate their efforts (Clark, 1996, p. 45).’

The work of a number of more recent authors, including Hill (1989), Anderson et al. (1989), and Miller and Roth (1994) continues to support these propositions.

2.2.2. The synergies perspective

A number of authors have questioned whether there are necessarily tradeoffs between competitive priorities. Ferdows and DeMeyer (1991), although acknowledging that tradeoffs sometimes exist, argued that they can be avoided through the use of a cumulative approach, which begins by establishing a strong foundation of high quality operations. This should be followed by developing capability in dependability, flexibility and, finally, cost. Thus, pursued in a specific order, competitive priorities can reinforce each other, rather than functioning as tradeoffs.

Hill (1988) observed two weaknesses in the tradeoffs perspective. First, many industries do not have a unique low cost position. This is particularly true of mature industries, where most firms have already achieved minimum-cost structures. In these industries, firms which also differentiate are rewarded by superior economic performance because their products have more value. Hill also demonstrated that differentiation can be a means to achieve an overall low cost position. Although the immediate effect of differentiation may be to increase unit costs, there is frequently a long-run reduction of cost as demand for a more valuable product increases, due to learning effects and economies of scale and scope. This is consistent with the ‘quality is free’ discussion of quality by Crosby (1979).

More recently, D’Aveni (1994) criticized the tradeoff perspective for being static and presenting a ‘simple accounting-based view of where profits come from’ (1994, p. 3). He noted that a dynamic approach should incorporate how competitors would react and maneuver all four bases of competition: (1) cost and quality, (2) timing and know-how, (3) strongholds, and (4) deep pockets. This results in hypercompetition, where a firm’s goal is to achieve a temporary advantage and continuously disrupt the market, in order to destroy the advantage of competitors.

Kotha and Vadlamani (1995) found Porter’s typology inadequate as they attempted to fit it to the strategies of a sample of discrete parts manufacturers. They speculated that their findings differed from earlier empirical work because of changes in the competitive environment caused by increased global competition and changes caused by the introduction of new manufacturing practices, such as JIT and quality management, which may have increased the complexity of the competitive environment.

According to Schonberger (1986), the tradeoff theory has been outdated by world class manufacturing, in which the adoption of world class practices stimulates solutions to quality problems, thus, eliminating unnecessary stocks, reducing waste and processing. This is reflected in a compression of costs and a reduction of lead time. The resulting absence of tradeoffs requires that a world class manufacturer modify its managerial focus so that it no longer analyzes and chooses which types of performance to focus on, but rather, achieves high level performance, across the board. This is supported by the empirical work of other authors (Ferdows and DeMeyer, 1991; Vickery et al., 1993; Ward et al., 1994).

Womack et al. (1990) supported this approach in The Machine That Changed the World, using the term ‘lean producer’ to describe an organization which pursued multiple competitive priorities simultaneously.

‘The lean producer combines the advantages of craft and mass production, while avoiding the high cost of the former and the rigidity of the latter...it requires keeping far less than half the needed inventory on site, resulting in fewer defects and producing a greater and ever-growing variety of products (p. 13).’

New (1991, 1992) attempted to integrate the tradeoff and synergy approaches. He criticized Schonberger’s (1986) position, pointing out that little research evidence has been offered in support of the
abandonment of the tradeoffs model, other than case examples, which are almost universally taken from high volume, repetitive manufacturing plants (New, 1991). However, he also pointed out that a great deal of the empirical research which supports the tradeoffs theory was completed before the widespread growth of innovative managerial practices such as JIT and quality management. According to New, the radical changes which have taken place in the definition of performance, the use of production technologies and the organization of management and human resources have dramatically changes the context of these performance areas. The result is that some classical tradeoffs can be overcome today, whereas others remain unaltered and some new tradeoffs have been created. For example, while quality defined as conformance is no longer considered a tradeoff with cost, delivery time and flexibility, quality defined as ‘features’ will have a negative impact on delivery times.

2.3. Hypotheses

This discussion leads to a number of hypotheses. The first tests whether there is a relationship between Hayes and Wheelwright’s world class manufacturing practices, taken as a set, and competitive performance. Support of this hypothesis would indicate that Hayes and Wheelwright developed a robust set of practices that lead to improvements in competitive performance.

H1: Hayes and Wheelwright’s world class manufacturing practices will be related to competitive performance.

The second and third hypotheses are designed to test whether the addition of new manufacturing practices will lead to better performance than Hayes and Wheelwright’s world class practices, alone. This will help in determining whether Hayes and Wheelwright’s practices form a foundation for the implementation of other practices, as well as whether there are any key constructs missing from their conception of world class manufacturing. The second hypothesis tests the incremental effect of quality management practices which focus on process improvement. It suggests that these practices, combined with Hayes and Wheelwright’s world class manufacturing practices, will be more strongly related to competitive performance than Hayes and Wheelwright’s world class manufacturing practices in isolation. Similarly, the third hypothesis tests whether the addition of core JIT practices to Hayes and Wheelwright’s practices and quality management process improvement practices will lead to further performance improvements.

H2: Quality management process improvement practices will be related to competitive performance, given the use of Hayes and Wheelwright’s world class manufacturing practices.

H3: Core JIT practices will be related to competitive performance, given the use of Hayes and Wheelwright’s world class manufacturing practices plus quality management process improvement practices.

Taken together, these hypotheses test whether Hayes and Wheelwright’s world class manufacturing practices form a foundation upon which other practices can effectively build. Conversely, they also test whether there were missing constructs in Hayes and Wheelwright’s original conception of world class manufacturing.

The fourth hypothesis addresses the tradeoffs vs. synergies debate by testing whether the use of these practices leads to improved performance on more than one dimension of competitive performance simultaneously. Support of this hypothesis would refute the assertion of Hayes and Wheelwright and other authors that the competitive priorities necessarily represent tradeoffs and would support the work of more recent authors, such as Schonberger (1986, 1990a,b, 1996) who believe that synergies between competitive priorities can be achieved through the use of world class manufacturing practices.

H4a: Hayes and Wheelwright’s world class manufacturing practices will be simultaneously related to more than one dimension of competitive performance.

H4b: Quality management process improvement practices will be simultaneously related to more than one dimension of competitive performance, given the
use of Hayes and Wheelwright’s world class manufacturing practices.

**H4c:** Core JIT practices will be simultaneously related to more than one dimension of competitive performance, given the use of Hayes and Wheelwright’s world class manufacturing practices and quality management process improvement practices.

**3. Method**

**3.1. Sample**

The data used for this study was gathered as part of the WCM Project (Flynn et al., 1996). The level of analysis was the plant, because the plant is where best practices are implemented and their effect is most strongly evidenced. For example, Schonberger (1986) described some John Deere plants as world class, while others were quite traditional. Thus, a corporate level sample would not allow accurate assessment of the impact of practices on performance.

The research design was a stratified sample of three plant types: world class reputation, traditional and Japanese-owned. The world class reputation plants were randomly selected from a master list of world class manufacturers, compiled from several sources, including Schonberger’s Honor Roll and industry experts. The traditional plants were randomly selected from Dunn’s Guide: The Metalworking Directory, a source of plant-level information about manufacturing plants. The third type of plant consisted of Japanese-owned plants operating in the U.S. These were randomly selected from a Japanese-language source published by JETRO. Within each of these strata, plants were randomly selected in three industries: machinery, electronics and transportation components.

**3.2. Data collection**

The plant manager of each sampled plant was contacted by telephone to solicit the firm’s participation. Participating plant managers each appointed a plant research coordinator to serve as liaison with the research team. The packet of questionnaires was sent to the plant research coordinator. It included 21 questionnaires, targeted at various respondents in the plant. For example, the accounting questionnaire requested performance information, while the direct labor questionnaire contained a set of scales designed to determine workers’ perceptions of practices and culture at the plant. The research coordinator distributed to questionnaires to the named managers and a random sample of 10 direct laborers. Respondents were asked to return their questionnaires to the plant research coordinator in sealed envelopes. When the entire set had been received, the plant research coordinator returned the packet of sealed envelopes to the research team. A subset of the information gathered through the questionnaires was used for this study.

In return for participating, each firm was provided with a detailed profile of its practices and performance, as well as benchmark data on practices and performance in its industry. This yielded a response rate of 60% of the firms that were contacted. Analysis of the industry, size and location of responding and nonresponding firms did not indicate any significant differences; although it was not possible to question nonrespondents on items more relevant to the hypotheses, there was not a respondent bias indicated in this basic analysis.

**3.3. Variables**

**3.3.1. Independent variables**

There were ten independent variables, corresponding to Hayes and Wheelwright’s six world class manufacturing practices, plus four variables which measured quality management process improvement and core JIT practices. The measures for these variables were constructed after the WCM Project data had been collected, by selecting the perceptual and objective measures which corresponded most closely to Hayes and Wheelwright’s description of world class practices from the existing WCM Project data set. In some cases, this meant selecting items from several of the original WCM Project scales and combining them to develop a new scale which more accurately measured a construct as Hayes and Wheelwright described it. The complete measures are listed in Appendix A. The quality management process focus and core JIT scales were not modified from the original scales in the WCM Project data set.
Worker development was an eight-item scale which focused on training, skill level and criteria for employee selection, measuring Hayes and Wheelwright’s ‘workforce skills and capabilities’. Management technical competence was measured by the objective measure of the percentage of the staff having engineering or technical degrees. Competing through quality was operationalized as design for customer needs, to reflect Hayes and Wheelwright’s narrow focus within the domain of quality management. The scale contained items drawn from scales measuring customer orientation and coordination among functional areas in designing new products. Worker participation was measured by a scale which contained items which measured team problem solving and the environment for team problem solving, including communication, supervisory support and performance evaluation. Rebuilding manufacturing engineering was operationalized as proprietary equipment, an objective item which measured the percentage of the plant’s equipment which was vendor equipment modified for the plant’s use, proprietary equipment designed by the plant or proprietary equipment designed and built by the plant. Finally, incremental improvement approaches was operationalized as continuous improvement, measured by a scale which contained items which measured belief in and support for continuous improvement. On all scale variables, lower values indicate better performance (a value of 1 indicates ‘strongly agree’).

Quality management process focus was operationalized with two scales. Process control deals with techniques to control process variability, including the use of SPC, foolproofing, inspection and the use of standardized process instructions. Feedback of information describes the extent of process feedback received by employees, including defect rates, schedule compliance, machine breakdown frequency and quality performance. Two scales were selected to represent core JIT practices. Pull system describes the extent to which production is driven by customer demand, and JIT supplier relations describes the extent of coordination with suppliers to ensure JIT deliveries.

Table 4 contains descriptive statistics on the independent variables, indicating that there were none with extreme values. Table 5 describes the sample in terms of average response to the independent and dependent variables. Although the purpose of this paper was not to compare responses between world class, Japanese-owned and traditional plants, nor is the sample size sufficient for such a comparison, this table describes the variability of the sample.

Table 6 contains intercorrelation matrices between variables, illustrating a broad range of relationships, from −0.31 to 0.85, with many of the relationships significant at \( p < 0.05 \). Lewis-Beck (1990) describes several indicators of high multicollinearity, including a substantial \( R^2 \) value for the regression equation, combined with statistically insignificant coefficients, and coefficients which change greatly in value when independent variables are dropped or added to the equation. Both of these existed, to some extent, in the original regression analysis. Using the test sug-
Table 5
Description of sample

<table>
<thead>
<tr>
<th>Variable</th>
<th>‘Best’ value</th>
<th>Plant type</th>
<th>Traditional</th>
<th>World class</th>
<th>Japanese-owned</th>
</tr>
</thead>
<tbody>
<tr>
<td>Independent variables</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Employee development</td>
<td>Low</td>
<td>2.39</td>
<td>2.18</td>
<td>2.25</td>
<td></td>
</tr>
<tr>
<td>Management technical competence</td>
<td>High</td>
<td>5.08</td>
<td>6.82</td>
<td>6.48</td>
<td></td>
</tr>
<tr>
<td>Design for customer needs</td>
<td>Low</td>
<td>2.41</td>
<td>2.27</td>
<td>2.21</td>
<td></td>
</tr>
<tr>
<td>Worker participation</td>
<td>Low</td>
<td>2.61</td>
<td>2.33</td>
<td>2.40</td>
<td></td>
</tr>
<tr>
<td>Proprietary equipment</td>
<td>High</td>
<td>22.36</td>
<td>41.09</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>Continuous improvement</td>
<td>Low</td>
<td>2.66</td>
<td>2.48</td>
<td>2.47</td>
<td></td>
</tr>
<tr>
<td>Process control</td>
<td>Low</td>
<td>3.19</td>
<td>2.84</td>
<td>2.91</td>
<td></td>
</tr>
<tr>
<td>Feedback of information</td>
<td>Low</td>
<td>2.91</td>
<td>2.54</td>
<td>2.58</td>
<td></td>
</tr>
<tr>
<td>Pull system</td>
<td>Low</td>
<td>3.18</td>
<td>2.71</td>
<td>2.56</td>
<td></td>
</tr>
<tr>
<td>JIT supplier relationship</td>
<td>Low</td>
<td>3.53</td>
<td>3.07</td>
<td>3.16</td>
<td></td>
</tr>
<tr>
<td>Dependent variables</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cost improvement</td>
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<td>1265.21</td>
<td>8916.06</td>
<td>49,360.19</td>
<td></td>
</tr>
<tr>
<td>Quality–performance</td>
<td>Low</td>
<td>3.79</td>
<td>3.89</td>
<td>2.93</td>
<td></td>
</tr>
<tr>
<td>Quality–features</td>
<td>High</td>
<td>63.13</td>
<td>59.53</td>
<td>87.24</td>
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</tr>
<tr>
<td>Dependability–on-time delivery</td>
<td>High</td>
<td>75.92</td>
<td>89.75</td>
<td>89.09</td>
<td></td>
</tr>
<tr>
<td>Dependability–specifications</td>
<td>High</td>
<td>91.87</td>
<td>89.54</td>
<td>93.37</td>
<td></td>
</tr>
<tr>
<td>Dependability–service</td>
<td>Low</td>
<td>2.38</td>
<td>1.97</td>
<td>1.93</td>
<td></td>
</tr>
<tr>
<td>Product flexibility</td>
<td>Low</td>
<td>3.12</td>
<td>2.81</td>
<td>3.14</td>
<td></td>
</tr>
<tr>
<td>Volume flexibility</td>
<td>Low</td>
<td>2.42</td>
<td>2.41</td>
<td>2.57</td>
<td></td>
</tr>
</tbody>
</table>

Table 6
Intercorrelation matrices

a. Independent variables

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
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</thead>
<tbody>
<tr>
<td>1. Employee development</td>
<td>–</td>
<td>0.06</td>
<td>0.41</td>
<td>0.65</td>
<td>–0.07</td>
<td>0.56</td>
<td>0.36</td>
<td>0.41</td>
<td>0.28</td>
<td>0.50</td>
</tr>
<tr>
<td>2. Management technical competence</td>
<td>–</td>
<td>0.05</td>
<td>0.03</td>
<td>0.28</td>
<td>–0.08</td>
<td>–0.18</td>
<td>–0.06</td>
<td>–0.07</td>
<td>0.11</td>
<td></td>
</tr>
<tr>
<td>3. Design for customer needs</td>
<td>–</td>
<td>0.60</td>
<td>0.12</td>
<td>0.63</td>
<td>0.36</td>
<td>0.59</td>
<td>0.44</td>
<td>0.47</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Worker participation</td>
<td>–</td>
<td>0.06</td>
<td>0.78</td>
<td>0.32</td>
<td>0.64</td>
<td>0.57</td>
<td>0.85</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Proprietary equipment</td>
<td>–</td>
<td>0.12</td>
<td>–0.05</td>
<td>0.14</td>
<td>–0.05</td>
<td>0.12</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. Continuous improvement</td>
<td>–</td>
<td>0.44</td>
<td>0.64</td>
<td>0.44</td>
<td>0.69</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. JIT supplier relations</td>
<td>–</td>
<td>0.56</td>
<td>0.12</td>
<td>0.30</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8. Pull system</td>
<td>–</td>
<td></td>
<td>0.47</td>
<td>0.71</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9. Process control</td>
<td>–</td>
<td></td>
<td></td>
<td>0.45</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10. Feedback of information</td>
<td>–</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

b. Dependent variables

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Cost</td>
<td>–</td>
<td>–0.17</td>
<td>0.14</td>
<td>0.24</td>
<td>0.09</td>
<td>–0.17</td>
<td>–0.13</td>
<td>–0.11</td>
</tr>
<tr>
<td>2. Quality–performance</td>
<td>–</td>
<td>–0.08</td>
<td>–0.16</td>
<td>–0.13</td>
<td>–0.01</td>
<td>0.09</td>
<td>–0.14</td>
<td></td>
</tr>
<tr>
<td>3. Quality–features</td>
<td>–</td>
<td>–0.17</td>
<td>0.12</td>
<td>–0.14</td>
<td>–0.35</td>
<td>–0.19</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Dependability–specifications</td>
<td>–</td>
<td>0.16</td>
<td>–0.21</td>
<td>–0.21</td>
<td>–0.33</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Dependability–on-time delivery</td>
<td>–</td>
<td>–0.31</td>
<td>–0.16</td>
<td>–0.30</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. Dependability–service</td>
<td>–</td>
<td>0.21</td>
<td>0.24</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. Flexibility–product</td>
<td>–</td>
<td></td>
<td>0.47</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8. Flexibility–volume</td>
<td>–</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

Correlation coefficients listed in bold type are significant at \( p < 0.05 \).
gested by Lewis-Beck, each independent variable was regressed on all other independent variables. The majority of the $R^2$ values approached 1.0, indicating that high multicollinearity exists. Thus, the analysis was limited to describing the effects of the interrelated independent variables as a set, rather than as individual variables. This is theoretically appropriate, since we are considering the effects of three interrelated sets of variables: world class manufacturing practices, quality management process focus practices and core JIT practices.

Table 7 summarizes the reliability and validity analysis of the independent variables. The Cronbach’s alpha values were all in excess of 0.70, indicating that the scales are reliable. Support for construct validity is provided by the remaining columns of the table. The alpha values were higher than the average interscale correlation, providing evidence of divergent validity. Further evidence of divergent validity is provided in the item/total correlations, which indicate a higher correlation between items and the scales they are associated with than the correlation between items and the remaining scales. Although unidimensionality is also a part of construct validity, it was not tested for because the world class manufacturing scales were constructed to specifically measure Hayes and Wheelwright’s practices which, as they stated, were clearly not unidimensional. For example, Hayes and Wheelwright’s description of worker skills and capabilities includes both worker training and apprenticeship programs, and worker training is broken into three practices: content, motivation and work habits.

3.3.2. Dependent variables

There were seven dependent variables, corresponding to Hayes and Wheelwright’s description of the dimensions of competitive priorities. They include a mix of objective and perceptual measures, summarized in Table 3. Like the independent variables, the dependent variables were operationalized by selecting the measure which most closely corresponded to Hayes and Wheelwright’s definition from the WCM Project data set. Although some of the operationalizations do not correspond perfectly to Hayes and Wheelwright’s definitions, the measures used were the best approximations of Hayes and Wheelwright’s definitions available. Cost was operationalized as cost improvement, since absolute measures of cost would be difficult to interpret, due to size differences within the sample. Descriptive statistics on the dependent variables are provided in Tables 4 and 5, while Table 6 contains their intercorrelation matrix.

3.4. Analysis

The standard assumptions of multiple regression were verified prior to conducting the analysis. The assumptions of constant variance, no influential outliers and normality were verified using the following

Table 7

<table>
<thead>
<tr>
<th>Reliability and validity of independent variables</th>
<th>Cronbach's alpha</th>
<th>Average interscale correlation</th>
<th>Item/total correlation Scale items</th>
<th>Non-scale items</th>
</tr>
</thead>
<tbody>
<tr>
<td>Employee development</td>
<td>0.78</td>
<td>0.36</td>
<td>0.64</td>
<td>0.24</td>
</tr>
<tr>
<td>Management technical competence (objective)</td>
<td>n.a.</td>
<td>0.03</td>
<td>n.a.</td>
<td>0.04</td>
</tr>
<tr>
<td>Design for customer needs</td>
<td>0.80</td>
<td>0.41</td>
<td>0.59</td>
<td>0.24</td>
</tr>
<tr>
<td>Worker participation</td>
<td>0.92</td>
<td>0.50</td>
<td>0.75</td>
<td>0.38</td>
</tr>
<tr>
<td>Proprietary equipment (objective)</td>
<td>n.a.</td>
<td>0.009</td>
<td>n.a.</td>
<td>0.09</td>
</tr>
<tr>
<td>Continuous improvement</td>
<td>0.88</td>
<td>0.46</td>
<td>0.58</td>
<td>0.35</td>
</tr>
<tr>
<td>Pull system</td>
<td>0.72</td>
<td>0.24</td>
<td>0.57</td>
<td>0.39</td>
</tr>
<tr>
<td>JIT supplier relationship</td>
<td>0.72</td>
<td>0.27</td>
<td>0.61</td>
<td>0.21</td>
</tr>
<tr>
<td>Process control</td>
<td>0.76</td>
<td>0.20</td>
<td>0.46</td>
<td>0.26</td>
</tr>
<tr>
<td>Feedback of information</td>
<td>0.90</td>
<td>0.59</td>
<td>0.73</td>
<td>0.31</td>
</tr>
</tbody>
</table>
plots: residuals by predicted values, rankits plot of residuals, studentized residuals by case number, Cook’s distances by case number and Leverage values (hat matrix diagonal). The Shapiro–Wilk statistic provided a further test for normality. Neither the plots nor the Shapiro–Wilk statistic indicated any potentially significant departures from assumptions.

The hypotheses were tested using hierarchical regression analysis, where groups of independent variables were entered cumulatively, according to the logic dictated by the sequence of the hypotheses. At each step, analysis of variance was used to determine the statistical significance of the regression equation. At steps following the first, the change in the cumulative $R^2$ was reported and tested for significance using a $t$-test (Cohen and Cohen, 1987) to determine whether the set of variables added at that step added to the predictive power of the regression equation.

The first hypothesis tested the relationship between each of the dependent variables and the set of world class manufacturing practice variables, taken as a group, by constructing eight regression equations, one for each dependent variable. The second and third hypotheses were tested by adding the set of quality management process focus and core JIT practice variables, respectively, to each of the equations and assessing their incremental impact. The fourth hypothesis was resolved by examination of the results of the tests of the first three hypotheses to determine if the sets of practices were simultaneously related to more than one dimension of competitive performance.

4. Results and discussion

Table 8 shows the results of the regression analysis. It indicates that the set of world class manufacturing practices was significantly related to cost, quality–performance, product flexibility and volume flexibility. This provides support for the first hypothesis, indicating that the world class manufacturing practices described by Hayes and Wheelwright are related to competitive performance.

The test of the second hypothesis indicates that the addition of quality management process focus variables led to several results. First, it led to the significance of the regression equations which had dependent variables related to dependability. This was not surprising, given that the scales which were added dealt with the process focus dimension of quality management. Although the world class manufacturing practices included the quality management dimensions of customer focus and employee involvement, process focus measures had been absent. Explicitly focusing on reducing process variability by a number of means would be expected to be related to improved dependability. This is consistent with the cumulative model described by Ferdows and DeMeyer (1991), where there are synergies between dependability and quality management, provided that the foundation of quality management is established before dependability is pursued.

In addition, support was provided for the inclusion of additional quality management variables by the $t$-test results. They indicated that the addition of the quality management process focus variables increased the predictive power of six of the eight regression equations. Thus, it can be concluded that, although the set of world class manufacturing practices described by Hayes and Wheelwright provides a strong foundation for competitive performance, the addition of new manufacturing practices focusing on process improvement offer opportunities for even better performance.

The test of the third hypothesis was also supported, with the addition of variables related to core JIT practices having a similar effect. All regression equations were statistically significant, with the exception of quality–features. Further, the addition of the JIT practice variables led to increased predictive power for the equations related to quality and dependability. This supports the work of Flynn et al. (1995), which suggests that the use of JIT practices leads to improved quality performance. Although quality management practices provide tools and approaches for solving quality problems, the problems are not always readily apparent. Through inventory reduction (the ‘rocks and river’ effect), JIT provides a potent means of finding quality problems, which can then be solved using quality management tools and approaches. This may also provide support for the proposition of Flynn et al. (1995) that there is a common infrastructure which supports the successful implementation of both JIT and quality management.
<table>
<thead>
<tr>
<th>Quality Management Variables</th>
<th>JIT Variables</th>
<th>( R^2 ) (Adj. ( R^2 ))</th>
<th>( F )</th>
<th>( p )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost</td>
<td>0.05 0.21 3.34</td>
<td>0.43 0.23 2.29*</td>
<td>0.01 0.90</td>
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</tr>
<tr>
<td>Dep. Hayes and Wheelwright</td>
<td>0.05 0.22 2.39*</td>
<td>0.42 0.24 2.29</td>
<td>0.00 0.00</td>
<td></td>
</tr>
<tr>
<td>Quality features</td>
<td>0.05 0.22 2.39*</td>
<td>0.42 0.24 2.29</td>
<td>0.00 0.00</td>
<td></td>
</tr>
<tr>
<td>Dependability on time delivery</td>
<td>0.05 0.22 2.39*</td>
<td>0.42 0.24 2.29</td>
<td>0.00 0.00</td>
<td></td>
</tr>
<tr>
<td>Dependability specifications</td>
<td>0.05 0.22 2.39*</td>
<td>0.42 0.24 2.29</td>
<td>0.00 0.00</td>
<td></td>
</tr>
<tr>
<td>Dependability specifications</td>
<td>0.05 0.22 2.39*</td>
<td>0.42 0.24 2.29</td>
<td>0.00 0.00</td>
<td></td>
</tr>
<tr>
<td>Dependability specifications</td>
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<tr>
<td>Dependability specifications</td>
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</tr>
<tr>
<td>Dependability specifications</td>
<td>0.05 0.22 2.39*</td>
<td>0.42 0.24 2.29</td>
<td>0.00 0.00</td>
<td></td>
</tr>
</tbody>
</table>

* \( df = 40 \) for all models.
** \( p < 0.01 \)
*** \( p < 0.001 \)
practices. The practices suggested by Hayes and Wheelwright may function most effectively as that infrastructure, providing the foundation for the use of quality management and JIT.

Examination of the results provides evidence supporting the fourth hypothesis. The set of world class manufacturing practice variables was simultaneously related to cost, quality and flexibility. When the set of quality management process focus practices was added, the combined set of practices was simultaneously related to cost, quality, dependability and flexibility. With the addition of JIT practices, all dimensions of competitive performance continued to be statistically significant, with significantly increased predictive power for the equations related to quality and dependability. Combined, this provides strong support for the notion that the employment of world class practices leads to the achievement of simultaneous competitive advantages related to cost, quality, dependability and flexibility.

5. Conclusions

Three issues drove the analysis described in this paper. First, although Hayes and Wheelwright’s thoughts about world class manufacturing practices were developed in the early 1980s, have they been robust to the changes that have taken place since then in the global manufacturing arena? We found strong support that this is true. The use of the practices which Hayes and Wheelwright described was strongly related to competitive performance. Furthermore, this relationship was robust to differences in measurement of competitive performance, with the world class manufacturing practices significantly related to cost, quality—performance, product flexibility and volume flexibility. Thus, we have concluded that Hayes and Wheelwright’s set of world class manufacturing practices have stood the test of time.

Second, will the use of these practices be more effective if they are used in concert with new manufacturing practices? To that we can also answer a resounding yes. When quality management practices which emphasize process focus were added to the set of world class manufacturing practices, predictive power increased significantly, across most of the measures of competitive performance. The addition of quality management practices also allowed competition on the basis of dependability, which the world class manufacturing practices, alone, were not able to achieve. The addition of JIT practices further increased the explanatory power. This suggests that Hayes and Wheelwright’s conception of world class manufacturing, although robust in and of itself, can be improved through the addition of new manufacturing practices. Thus, it forms a foundation for the implementation of other practices, functioning as a supportive infrastructure.

Third, are there tradeoffs between dimensions of competitive performance, as Hayes and Wheelwright, Porter and other authors have contended? To the contrary, we found strong evidence of synergies. The combination of Hayes and Wheelwright’s world class manufacturing practices, quality management process focus practices and JIT practices was simultaneously related to competitive performance, in terms of cost, quality, dependability and flexibility, on seven out of eight measures. This is not to say, however, that the potential for tradeoffs does not exist. The findings discussed here are limited to organizations which employ world class practices. This is consistent with the work of Schonberger, who describes synergies between quality and cost, for example; as the number of defects is reduced through quality management, the amount spent on rework and warranty work is reduced. Our findings suggest that there are synergies between most dimensions of competitive performance possible to organizations which employ world class manufacturing practices.

There are many opportunities for future research suggested by this paper. For example, the findings were interpreted only by sets of practices, rather than by individual practices, due to multicollinearity between the independent variables. Better articulation of which specific practices are most critical to world class manufacturing would be valuable, as well as guidelines for which practices are related to synergies between particular dimensions of competitive performance. The predictive power of the regression equations was increased by the addition of quality management and JIT practices. Are there other new manufacturing practices which should also be included? Suggestions include practices related to
strategic management, international supply chain management, fast product development strategies, etc.

In this paper, we have sought to determine whether Hayes and Wheelwright’s foundation for world class manufacturing is relevant in today’s manufacturing environment. We also sought to determine how world class manufacturing practices functioned in the achievement of competitive performance, examining whether they supported dimensions of competitive performance which were tradeoffs or synergies. We found strong support for Hayes and Wheelwright’s set of world class manufacturing practices. Thus, we can conclude that the work of Hayes and Wheelwright provides a solid foundation for ensuing and future work in the area of world class manufacturing. We expect that the practices associated with world class manufacturing will continue to evolve, as Hayes and Wheelwright’s have, both in type and content.

Appendix A. Scale contents

A.1. World class manufacturing practices (Hayes and Wheelwright)

A.1.1. Dimension 1: workforce skills and capabilities

Expanding the nature of worker training and other approaches, to include motivation and work habits, as well as the development of technical skills.

A.1.1.1. Employee development.

1. Direct labor undergoes training to perform multiple tasks in the production process.
2. Plant employees are rewarded for learning new skills.
3. R: Our plant has a low skill level, compared with our industry.
4. Direct labor technical competence is high in this plant.
5. We use knowledge and skill level as a criterion in selecting employers.
6. We use ability to work in a team as a criterion in employee selection.
7. We use problem solving ability as a criterion in selection of employees.
8. We use work values and ethics as a criterion in employee selection.

A.1.2. Dimension 2: management technical competence

Technical literacy as a prerequisite for management careers.

A.1.2.1. Management technical competence. Percentage of the staff having engineering or technical degrees (objective item).

A.1.3. Dimension 3: competing through quality

True customer orientation and coordination among functional areas in designing products. This construct is not all encompassing, like TQM, but rather focuses on the design process and how the customer is integrated into it.

A.1.3.1. Design for customer needs.

1. We frequently are in close contact with our customer.
2. R: Our customers seldom visit our plant.
3. A very important objective is to obtain satisfied customers.
4. Our customers give us feedback on quality and delivery performance.
5. Customer requirements are thoroughly analyzed in the new product design process.
6. There is a strong customer focus in our design process.
7. Direct labor employees are involved to a great extent (on teams or consulted) before introducing new products or making product changes.
8. Manufacturing engineers are involved to a great extent before the introduction of new products.
9. R: There is little involvement of manufacturing and quality people in the early design of products, before they reach the plant.
10. We work in teams, with members from a variety of areas (marketing, manufacturing, etc.), to introduce new products.

Items 1, 2, 3, 4, 5, and 6 measure customer orientation, while items 7, 8, 9 and 10 measure coordination among functional areas in designing products.

A.1.4. Dimension 4: Workforce participation

Real worker participation, including the use of teams and the culture change which accompanies it. This includes close contact between managers and
workers, a ‘we’re all in this together’ attitude and worker-management cooperation.

A.1.4.1. Worker participation.
1. Quality of team participation is a significant part of performance evaluation at this plant.
2. R: Strategies and goals are communicated primarily to managers.
3. I know how we are planning to be competitive at this plant.
4. Supervisors encourage the persons who work for them to work as a team.
5. Supervisors encourage people who work for them to exchange opinions and ideas.
6. Supervisors frequently hold group meetings where the people who work for them can really discuss things together.
7. R: Managers here are more likely to send a memo than to tell us something face-to-face.
8. During problem solving sessions, we make an effort to get all team members’ opinions and ideas before making a decision.
9. Our plant forms teams to solve problems.
10. In the past three years, many problems have been solved through small group sessions.

A.1.5. Dimension 5: rebuilding manufacturing engineering
Ability to design and manufacture equipment for their own factories, as well as perform major repairs and modifications. Ability to compete on the basis of unique process technology.

A.1.5.1. Proprietary equipment. Objective variable, the sum of the percentage of the plants’ equipment which is: vendor equipment which we modified for our use, proprietary equipment designed by the company and proprietary equipment designed and built by the company.

A.1.6. Dimension 6: incremental improvement approaches
Ability to survive and thrive in a competitive environment where success is based on a series of small steps, rather than on a few dramatic breakthroughs. Steady improvement of ‘competitive effectiveness’. Small steps, whose cumulative impact can be just as great as strategic leaps (breakthroughs).
Continually striving to strengthen competitive position

A.1.6.1. Continuous improvement.
1. All employees believe that it is their responsibility to improve quality in the plant.
2. Continuous improvement of quality is stressed in all work processes throughout our plant.
3. I am constantly working to improve quality.
4. R: Quality improvement is not a high priority for me.
5. Workers are rewarded for quality improvement.
6. Supervisors are rewarded for quality improvement.
7. If I improve quality, management will reward me.
8. Managers are rewarded for making continuous improvements.

A.2. Core quality practices
These scales represent the dimension of process focus, since Hayes and Wheelwright’s practices already adequately represent the dimensions of customer focus and continuous improvement.

A.2.1. Process control
1. Processes in our plant are designed to be ‘fool proof’.
2. We have standardized process instructions which are given to personnel.
3. A large percent of the equipment or processes on the shop floor are currently under statistical quality control.
4. We make extensive use of statistical techniques to reduce variance in processes.

A.2.2. Feedback of information
1. Charts showing defect rates are posted on the shop floor.
2. Charts showing schedule compliance are posted on the shop floor.
3. Charts plotting the frequency of machine breakdowns are posted on the shop floor.
4. Information in quality performance is readily available to employees.
5. Information on productivity is readily available to employees.
A.3. Core JIT practices

A.3.1. Pull System
1. We have laid out the shop floor so that processes and machines are in close proximity to each other.
2. Direct labor is authorized to stop production for quality problems.
3. We use a pull system to control our production.
4. We use a Kanban pull system for production control.
5. We use kanban squares, containers or signals for production control.

A.3.2. JIT supplier relations
1. Our vendors supply us on a just-in-time basis.
2. We receive daily shipments from most suppliers.
3. Our suppliers are certified, or qualified, for quality.
4. We have long-term arrangements with our suppliers.

References

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