Trying to Resolve Manufacturing Performance Trade-Offs: The Case of British Contract Electronics Assemblers

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Abstract
The changing nature of competitive pressure now requires companies to compete on several aspects of performance simultaneously. This reality departs from the traditional idea that organizations must find a specific area of competency and choose between objectives such as low cost, quality, or flexibility. Hence, the degree to which companies resolve manufacturing performance trade-offs, and the understanding of the processes whereby companies manage to achieve this, emerge as a set of research questions. This paper presents the results of a benchmarking study carried out to assess and compare the levels of manufacturing performance achieved by 16 British contract electronics assemblers. Case studies conducted in three of these companies highlighted structural and cultural aspects that may explain inter-company differences in the resolution of manufacturing performance trade-offs.

Résumé
La nature changeante des règles de la compétition oblige les entreprises à maîtriser simultanément plusieurs aspects de la performance manufacturière. Cette réalité diffère de l'idée reçue selon laquelle les organisations doivent choisir entre des objectifs tels la réduction des coûts, la qualité, ou la flexibilité. Ainsi, l'évaluation du degré de résolution des arbitrages traditionnels entre les objectifs de performance manufacturière et la compréhension des facteurs favorisant cette résolution constituent des thèmes de recherche pertinents. Les résultats d'une étude de benchmarking menées auprès de 16 sous-traitants électroniques britanniques et ayant pour but de comparer leur performance manufacturière sont présentés dans cet article. Trois études de cas ont ensuite permis d'identifier différents aspects structurels et culturels qui semblent expliquer les différents niveaux de résolution des arbitrages opérationnels.

In many industrial sectors, competitive pressure now requires companies to compete on several dimensions simultaneously. Rather than choosing between an ensemble of key performance criteria, manufacturers should aim at achieving them all. Indeed, from a customer's point of view, the obvious choice would be, for example, audio equipment offering both performance and ease of use or cars offering both speed and safety. Similarly, when given the choice, an original equipment manufacturer will opt for an electronics subcontractor that is able to offer high quality, short lead-time, and low price all at once.

These examples illustrate the perspective that has shaped into a critique of the traditional trade-off model in the manufacturing strategy literature. This is echoed in the field of competitive strategy where Porter's (1985) "stuck in the middle" prescription that is the argument that inherent contradictions exist between the generic competitive strategies, namely the cost leadership, cost focus, differentiation, and focused differentiation strategies, is questioned. Meanwhile, the concept of paradox in organizations, which presents interesting similarities with the new approaches to manufacturing and competitive strategies, is gathering momentum.

After reviewing the current debate in the field of manufacturing strategy, this paper will present the result of a benchmarking study carried out in the British contract electronics manufacturing industry to measure the level of trade-offs resolution in the industry. The paper also presents three case studies that were carried out to identify inter-company differences that might explain the resolution of manufacturing trade-offs.

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New Approaches to Manufacturing Strategy

After Skinner's (1969) seminal article was published, the field of manufacturing strategy was for a long time dominated by the trade-off model: the manufacturing function should not try to be all things to all people and structural decisions (capacity, equipment, and processes, etc.) should be taken with a limited set of criteria in mind. As a result, a factory designed to achieve low cost could not be flexible and a lower quality could also be expected. The manufacturing strategy formulation process proposed by Skinner was in tune with Harvard Business School tradition and the SWOT (strengths, weaknesses, opportunities, and threats) framework. Moreover, manufacturing strategy was instrumental in character as part of a hierarchy of corporate, competitive, and functional strategies. The production function should select one or two competitive priorities and develop manufacturing capabilities accordingly, in order to support the choice between a cost and a differentiation strategy made at business level. Indeed, the trade-off model content is very much in line with Porter's generic competitive strategies. Interestingly, both were questioned in recent years (Hayes & Pisano, 1996).

"Stuck in the Middle" Revisited

Porter's (1985) "stuck in the middle" prescription has generated many debates. For example, although they recognize that high value and low cost are the only possible competitive moves, Gilbert and Strebel (1988) suggest that they are not mutually exclusive ones. Cronshaw, Davis, and Kay (1994) revisit Porter's prescription and their analysis is refreshing. They suggest that "stuck in the middle" is less a prescription than a way to analyze strategic outcomes. Companies who cannot achieve lower cost or differentiated products rarely succeed but, reciprocally, being stuck in the middle is a very good thing if a firm is good at both efficiency and differentiation. Interestingly, Porter's (1990) more recent discussion of the importance of distinct sources of advantage in order to sustain competitiveness is consistent with this. He gives the example of successful Japanese small copier manufacturers who combine advanced features, low costs, flexible automation, and high levels of reliability.

The "stuck in the middle" prescription is a perfect example of what is being challenged in the literature on paradox and dilemma in organizational settings (Hampden-Turner, 1990; Pascale, 1990; Quinn & Cameron, 1988). These authors point out the contradictory elements or competing forces present in a paradox and put forward the idea that organizations are pulled in several different directions simultaneously. This literature is for the most part prescriptive as many authors associate paradox with excellence. They argue that the recognition of paradox favours major organizational changes or quantum leaps that lead to superior performance. While Porter argues that contradictions exist between the generic competitive strategies, Quinn and Cameron (1988) or Pascale (1990) suggest that it is possible to reach a higher level of performance where contradictions cease to exist. Therefore, instead of depicting the decision-maker as a hero courageous enough to choose between two courses of action, one can argue that managers are required to learn to reconcile the competing forces present in their organizations (Hampden-Turner, 1990). A similar message is conveyed by some authors in manufacturing strategy, a message that suggests that factories should learn to resolve manufacturing performance trade-offs.

Competing Schools of Thought

Skinner's "Missing Link" paper (1969) is unanimously considered as the paper that has initiated the development of manufacturing strategy as a field. Similarly, Ferdows and De Meyer's (1990) article, in which they introduced the sandcone model, is increasingly referred to as the first formal proposition of an alternative approach to manufacturing strategy. Most authors in the field now recognize the trade-off model and the *cumulative approach*[1] as two competing schools of thought (Clark, 1996; Collins, Cordon, & Julien, 1998; Corbett & Wassenhove, 1994; Noble, 1995). If the two perspectives were placed on a continuum, Skinner's early ideas would be found at one end. Schonberger, whose comments on the damage done by MBA graduates who "have taken the trade-off baggage into the world and presumably have made strategy accordingly" (1986, p. 203) make him the most severe critic of the traditional model, would be placed at the other end. Ferdows and De Meyer's position is slightly more moderate than this as they do not wish to invalidate completely the trade-off theory but to propose an alternative viewpoint to it. They believe that the trade-off model can apply in many cases but not all. They report that some manufacturers "have better quality, are more dependable, respond faster to changing market conditions and, in spite of all that, achieve lower cost" (1990, p. 168). These authors express the view that these achievements can be best explained using a model based on the notion of lasting manufacturing capabilities.

The notion of *sequence* is a key element in Ferdows and De Meyer's model which is illustrated by a sandcone: pouring sand to build a cone is like putting in managerial effort and resources. The authors argue that it is because improvements in quality precede successive improvements in dependability, speed of response, and cost, that all these improvements can last. It appears that specific actions aiming at improving the next capability will also enhance the previous one. Similarly, actions that aim at developing a capability pave the way for the improvement of the next one. The right sequence of improvement enables manufacturers to reach a point where a high level of performance is achieved simultaneously on all four criteria. While this concept of a fixed sequence may be considered as constraining (Collins, Cordon, & Julien, 1998), it has found some supporters. Describing the evolution of various European manufacturing firms in response to the evolution of market pressures from the 1960s to the 1980s, Boljwin and Kumpe (1989) have proposed their own sequence, moving from efficiency to quality, flexibility and finally innovation. Corbett and Wassenhove (1994) support Ferdows and De Meyer's sequence although they consider that in reality each competing dimension is composed of many subdimensions, adding complexity to the process by which companies build capabilities in response to competitive pressures. This idea of subdimensions was also proposed by New (1992). Further support for the sandcone model can be found in Noble (1995), although she modifies the sequence by distinguishing between dependability and delivery. The six stages of her sequence end with flexibility and innovation; cost reduction precedes these two last stages and is therefore not seen as a result of all other improvements.

Dynamic Trade-offs

A special issue of *Production and Operations Management* published in 1996 gives a good idea of how the trade-off argument has recently evolved to what may be seen as a more moderate trade-off perspective. Contributions to this special issue came from Skinner himself and from those that have followed his footsteps in the development of the concept of manufacturing strategy. There is a unifying theme across the articles of this special issue; most authors notice the undeniable popularity of manufacturing best practices that have gained wide acceptance in industry and have had a noticeable impact on manufacturing performance, allowing companies to "violate many of the prescriptions in the manufacturing strategy literature" and to "have it all—quality, dependability, flexibility, high variety, and low cost" (Clark, 1996, p. 43). Whether the authors refer to these as "advanced manufacturing techniques" (Skinner, 1996b), "tools" (Wheelwright & Bowen, 1996), or "advanced manufacturing systems" (Clark, 1996), the message is the same: these manufacturing practices are powerful but they should be encompassed within the framework of a coherent and unique manufacturing strategy. This prescription was formulated earlier by Hayes and Pisano (1994).

The apparent violation of the manufacturing strategy prescriptions has forced Skinner and his followers to revisit their trade-off argument. The main defender of the argument had already started this in an article published in 1992, in which he was slightly critical of his early ideas. He had then stated that operations systems are technologically limited and, as such, they "need to be designed to maximize performance on a few success criteria of strategic importance because a system which is technologically constrained cannot perform superbly on every measure" (1992, p. 21). Interestingly, it was through the ideas of technological constraint and technological development that Skinner revised the notion of trade-off. He argued that technical developments can lead to a shift in the relation between some performance criteria, causing opposite functions (such as cost and quality) to "turn out to be positive concurrently over a span of time" (1992, p. 20). However, his discussion did not truly challenge his earlier ideas because he stated that changes in trade-offs do not mean the disappearance of them; it means that a new set of curves needs to be drawn. This argument was used again when Skinner (1996a) suggested that although the content of the model may have changed (i.e. the criteria to be traded-off) the manufacturing strategy formulation process remains the same.

Clark (1996) and Hayes and Pisano (1996) both offered some support to this revised approach to manufacturing trade-offs by introducing the concept of *performance frontier*. They used various sets of curves to illustrate that a performance frontier may move over time offering various improvement paths that factories may follow to reach higher levels of performance on two competing criteria. A similar idea was found in Slack (1991) who used the metaphor of a seesaw to explain how improvements can move the pivot upwards so that "both sides of the seesaw can be raised while preserving the ability to trade-off between them" (1991, p. 11).

In line with Skinner, Clark (1996) and Hayes and Pisano (1996) slightly challenged the trade-off approach but did not refute altogether the existence of trade-offs. Moving along a new curve—either raised seesaw or higher performance frontier—still means trading-off one criterion against the other. However, this revised perspective is more dynamic than the traditional one as it integrates the notion of performance improvement trajectories as Clark (1996) and Hayes and Pisano (1996) put it. For authors such as Corbett and Wassenhove (1993) a dynamic approach to manufacturing strategy is crucial in a changing competitive environment where order-winning criteria become qualifying ones. Interestingly, this revised approach to manufacturing trade-offs offers some similarities with the capabilities-building process described by Ferdows and De Meyer (1990). It is also very much in line with the dynamic theory of strategy (Porter, 1991) that has emerged in recent years, a theory that may be used as a common label for concepts and approaches such as organizational learning (Argyris & Schön, 1978; Senge, 1990), resource-based theory (Barney & Zajac, 1995; Grant, 1991), and capabilities-based approach to strategic planning (Hayes & Pisano, 1996; Prahalad & Hamel, 1990; Stalk, Evans, & Shulman, 1992).

Empirical Studies

The above review of the literature has shed light on various theoretical positions on the trade-off theory/cumulative perspective continuum and the dynamic trade-off perspective has emerged as a possible unifying theme between the two schools of thought. But the debate does not rage solely at the theoretical level as empirical work has contributed to fuel it in recent years. The International Motor Vehicle Program (IMVP) that aimed at assessing productivity and quality performance in car assembly plants around the world and whose results were presented in the book *The Machine that Changed the World* (Womack, Jones, & Ross, 1990), provided evidence of companies achieving competing manufacturing objectives in a simultaneous way. This was supported by Oliver, Delbridge, Jones, and Lowe (1994) who have identified some world class autocomponents plants able to achieve high levels of performance on both productivity and quality.

Ferdows and De Meyer (1990) have used the European Manufacture Futures Project data to test their sand-cone model. Significant results were obtained with the first layer of their model as manufacturing companies having implemented quality programs achieved high performance on a large number of indicators. However, evidence was scant for the remaining stages of their proposed sequence. Having tested her seven stages cumulative model on a large sample of North American, European, and Korean factories, Noble (1995) has found some support for it and has confirmed Ferdows and De Meyer's view on quality being the basis of improvements in all other performance areas. In the same vein, recent work by Flynn, Schroeder, and Flynn (1999) supports what they label as the *synergies perspective.*

It should be noted, however, that other empirical work has led to results that are far from challenging the trade-off perspective. For example, Mapes, New, and Szwejczewski (1997) positioned themselves among those believing that some trade-offs always remain, arguing that it is harder to control cost and deliver on time in a context where product features and product variety is high. Their research results did show that a gain in flexibility led to a loss in other aspects of performance but, surprisingly, the expected synergies between quality and cost were not supported by their data. Similarly, Collins, Cordon, and Julien (1998) did not find any empirical support for Ferdows and De Meyer's view on quality. However, they did not find any support for the trade-off model either, as their results did not indicate any trade-off between quality and dependability.

Many researchers in the field of manufacturing strategy often equate empirical research with quantitative approaches in an apparent urge to get away from the anecdotes on which early theories have been built. For example, most of the authors surveyed above used large samples of manufacturing companies who were asked about programs and practices implemented in the factory and the level of manufacturing performance achieved before and after the implementation. Interestingly, while statistical investigations are very thorough, data validity can be questioned because they are mainly based on self-assessment. Moreover, most of these results presented snapshots of particular points in time. A dynamic trade-offs perspective calls for a longitudinal research approach (Porter, 1991) to shed light on the processes whereby capabilities can be developed and manufacturing performance trade-offs can be resolved. This was the aim of the benchmarking exercise and case studies carried out in the electronics industry whose results are presented next.

Choice of Industrial Sector

Contract electronics manufacturers (CEMs) typically assemble printed circuit boards (PCBs) to order. The range of services that they can offer varies from product engineering and board design to finished product assembly and distribution. In the mid-1990s, the British CEM industry was presented as a growing and promising sector, but one having to gain ground as market figures suggest that original equipment manufacturers (OEMs) still did the larger part of their assembling operations in-house (*Financial Times*, 1993). An initial analysis of the industry offered some evidence that contract electronics manufacturing is a sector where competitive pressures require contractors to compete on several dimensions. This provided a justification for carrying out this research in this specific industrial context.

From the mid-1980s to the beginning of the 1990s, life became more difficult for UK CEMs due to the joint effects of the recession and the intensification of both domestic and foreign competition. On top of the decrease in the number of orders, the recession resulted in the entry of OEMs with spare capacity into the CEM business. At the same time, more firms became familiar with surface mount technology (SMT)—an assembly technology whose popularity started to increase in the mid-1980s—which was no more the exclusive domain of a few specialists. It was believed that the UK CEM industry had excess capacity and, as a result, a shakeout was expected. This could lead to a reorganization resulting in two types of companies sharing the market: large volume CEMs and very small specialist companies (*Financial Times*, 1993, p. 33). One manager interviewed saw the future CEM industry populated with "on one hand fewer and larger global scale CEMs having strong links with OEMs and on the other hand very small CEMs." Actors in the industry who perceived this trend knew that they would have to work hard in order to be among surviving firms.

In the face of the intensification of competition, it appeared that some sources of competitive edge were now "given" in the CEM industry. Negotiations between subcontractors and their clients could no longer be based only on low price or short delivery (*Financial Times*, 1993, p. 35). Interestingly, not all members of the industry agreed on which sources of competitive edge were given and which were the ones that allowed a company to differentiate itself enough to see quotations becoming firm orders. "Quality, time and flexibility are given; you have to offer low price," said one manager. Conversely, another said "quality, delivery and cost are no more a base of differentiation, now they are given." These differences in opinion as to which sources of competitive advantage come first challenged the hypothesis of a unique sequence in the development of lasting manufacturing capabilities (Ferdows & De Meyer, 1990).

No matter in which order they were presented, the same sources of competitive edge were always mentioned in the industry: cost efficiency, quality, dependability, and flexibility. Interestingly, they are the traditional competitive priorities (Wheelwright, 1984) that are seen as being achieved at the expense of one another, according to the trade-off model. Ferdows and De Meyer (1990) also define them as the four manufacturing capabilities that can be cumulated over time. The results of a benchmarking study conducted to objectively measure and compare the level of performance achieved by 16 CEMs on these four manufacturing performance criteria is presented next.

Benchmarking Study

The research sample was constructed using a list of 164 companies published in 1993 by the British Association of Contract Electronics Manufacturers (ACEM). The sample target size was between 15 and 20 companies. The reason for this was that the research process involved a visit to each company to introduce the project, carry out a plant inspection and brief the respondents on the completion of the questionnaire which was then left to be completed off-line. Twenty-one companies showed an interest in the study and were visited and 16 completed the questionnaire.

In this research, the term *benchmarking* is used in reference to the process by which a systematic performance evaluation and comparison is carried out (Delbridge, Lowe, & Oliver, 1995; Sweeney, 1994). The questionnaire that was constructed for this study was based on the one developed for the Lean Enterprise Benchmarking Project (LEBP) (Andersen Consulting, 1993, 1994) which was an extension of the International Motor Vehicle Program (IMVP) (Womack, Jones, & Ross, 1990).

Choosing a product sector is a decision of paramount importance in the context of a benchmarking study as it is the primary path to comparable results. Finding a base of comparability in the context of contract electronics manufacturing was challenging as contractors may assemble various types of finished products for various industrial sectors. However, most of them do place components on printed circuit boards. PCB assembly therefore appeared to be the relevant focus for this benchmarking study.

The questionnaire was designed mainly to measure the level of achievement of four manufacturing performance indicators: cost, quality, dependability, and flexibility. These measurements were based on objective indicators and were not self-assessed by respondents. Drawing on the IMVP and LEBP studies, productivity was used as a proxy for cost. As traditional cost accounting systems are increasingly questioned, mainly because of fixed costs being arbitrarily charged to individual products, physical indicators appear to be more valid measures for manufacturing performance evaluation. In this context, productivity was defined as the annual units of output divided by annual labour hours adjusted for vertical integration, overtime and absenteeism. It was not possible to adjust for product differences because printed circuit boards vary a lot in terms of size and number of components. However, it was decided that the annual units of output would be the total number of components placed. Careful attention was given to the annual labour hour's calculation to make sure that only the actual working time of direct employees involved in PCB assembly was taken into account.

The quality measure used was the external defect rate, represented in parts per million (ppm). Respondents were asked to indicate the number of PCBs claimed to be defective by their clients. To ensure that CEMs were indeed responsible for these defects,

Table 1
Benchmarking Results

Companies	Annual Productivity (components/hour)	External Defect Rate (ppm)	Late Deliveries	Modified Orders	Number of indicators above average
A	53	**5467**	25%	15%	1
B	253	**2347**	20%	30%	1
C	101	**176**	60%	**80%**	2
D	117	12,527	**10%**	15%	1
E	16	23,223	37%	12%	0
F	**451**	**1,350**	**1%**	**50%**	4
G	**476**	7,500	**15%**	30%	2
H	163	7,161	32%	24%	0
I	**463**	12,957	19%	**80%**	2
J	146	**87**	**13%**	**87%**	3
K	**597**	**2,598**	**15%**	18%	3
L	**400**	**3,943**	20%	20%	2
M	**474**	**362**	**5%**	20%	3
N	219	**4,364**	**10%**	**80%**	3
O	48	**1,800**	**10%**	**60%**	3
P	**865**	**1,662**	**3%**	**50%**	4
Average	303	5,470	18%	42%	

Note: Bold numbers indicate a performance level above average.

respondents were also asked to indicate the distribution of the claims in terms of their typical nature. Claims which were outside the companies' control, such as incorrect handling during shipping, or for which no fault was found were taken out of the total number of defective PCBs. Dependability was represented by the percentage of on-time delivery, while flexibility was defined as the number of orders which were modified either in terms of specifications, quantity, or delivery date. This indicator is a measure of the ability to react to various types of change and, as such, it covers many aspects of flexibility.

After each questionnaire was completed and returned, an initial calculation of performance was carried out. These initial results and the details of how they had been calculated were then sent back to each participating company for verification. Errors in the original data were sometimes detected and corrections were made accordingly. The last step of the benchmarking process was the provision of a feedback report to each company. The report summarized the performance and characteristics of each company against approximately 70 measures of performance.

The benchmarking results are summarized in Table 1, which indicates the manufacturing performance of each of the 16 companies in the research sample. The levels of performance that are above average are indicated in bold numbers. Performance levels varied considerably across the sample. Productivity ranged from 16 to 865 components placed per annual hour, with an average of 303. Intuitively, it can be argued that factors such as automation, product complexity, production volume and company size should explain these differences. These manufacturing characteristics were measured in the study and correlated with physical productivity. Broadly, the relationships were all in the direction that one would expect, although only half achieved statistical significance. It was therefore decided not to make any adjustment to the original productivity data.

Quality performance ranged from 87 ppm, which was the top position, to 23,223 ppm, which was the worst one. The average external defect rate was 5,470 ppm. The fact that the most productive CEM in the sample (Company P) occupies the fifth position for quality with 1,662 ppm—which is above average but not outstanding—suggests that a trade-off between productivity and quality is partly avoidable. However, the two top performers on quality (Company J and C with external defect rates of 87 and 176 ppm and productivity levels of 146 and 101 components per hour respectively) are

Table 2
Overall Performance (Case Studies)

Performance indicators	Company P	Company N	Company D
Number of employees	341	56	45
Sales	£39,056,000	£3,314,000	£1,691,000
Profit margin	3.19%	3.16%	2%

Note: £ = $2.25

clearly trading off one criterion against the other. The percentage of late deliveries varied from 1% to 60% across the sample with an average of 18%. Again, Company P appears as a high performer with only 3% of deliveries that were not on time. Interestingly, the two other most dependable companies in the sample, Companies F and M, also have levels of productivity and quality that are above average. This is in line with the cumulative perspective.

Between 12% and 87% of the orders delivered by companies in the sample during the 12-month period covered by the benchmarking study have been modified either in terms of quantity, delivery date, or specifications. Based on the benchmarking results, the most flexible CEMs in the sample are those that faced changes in more than 42% of the cases. The positions of Companies F and P are particularly interesting as the manufacturing performance of these two companies is above average on all indicators. However, their level of flexibility is good but not outstanding. One can wonder if their productivity, dependability, or quality levels would have been as high if their planning environment had been even less stable. Indeed, companies where the proportion of modified orders was 60% and over appear to have been trading off flexibility against either productivity (Company C, J, N, and O), or quality (Company I). This is in line with Mapes, New, and Szwejczewski's findings (1997).

Case Studies

Case studies have been conducted in companies P, N, and D, which ranged from higher to lower manufacturing performance. Company P is one of the two companies in the benchmarking sample having achieved an above average performance on all four indicators. Five companies had an above average performance on three indicators and Company N is one of these. Lastly, like three other CEMs, Company D had a better than average performance, and yet not an outstanding one, on only one indicator. Measures of overall performance for the three companies are presented in Table 2. They show some congruence between manufacturing performance and overall performance. It is interesting to note that while Companies N and D have a similar size in terms of number of employees, Company P is seven times larger than Company D. Company P's sales figure is also higher than the figures of the other two. Moreover, with the lowest profit margin of the three companies and half the sales of Company N, Company D's overall performance appears to reflect its manufacturing performance.

The aim of the case studies was to explain intercompany differences in levels of achievement of the four manufacturing performance indicators. The methodology used for the case studies was designed around the concept of activities. This follows from Porter's proposition that a network of discrete activities lies under any competitive advantage (1985, 1991). Ten working days were spent in each of the three companies to look at the specific ways in which they perform the various printed circuit board assembly activities that start when an order is received and end when the boards are shipped. At Company P, 19 interviews were carried out, a materials meeting and a claims meeting were attended, and four assembly operators, two inspectors, and one store employee were observed. At Company N, 20 interviews were carried out, one production meeting and two contract review meetings were attended, one hand assembly operator, one pick-and-place machine operator, one line driver (on three occasions), one inspector, one test operator, and one store employee were observed. At Company D, 20 interviews were carried out, two management meetings and one production liaison meeting were attended, three inspectors, one hand assembly operator, and two store employees were observed. Some of the interviews were scheduled, semi-structured sessions, while others were essentially extended conversations prompted by shop-floor observations. The interviews and conversations took place either in a meeting room, at the respondent's desk, on the shop-floor, or in the store.

Most interviews in offices and meeting rooms were tape-recorded, extensive notes were taken and comments were recorded verbatim as much as possible. Field notes were usually reviewed and supplemented right after the interviews, conversations, and periods of observation, sitting down in empty meeting rooms when possible. Field notes were typed during the days following each visit. Interviews were not transcribed but notes of relevant elements were taken while listening to the tapes.

The case study results are presented in the following section. Specific factors that appear to distinguish the top performance company from the others can be highlighted. These factors give an insight into how manufacturing performance trade-offs may be resolved or avoided.

A Closer Look at Some Companies

Company P grew from an electronics components operation founded in the 1940s. Subcontracting work began in 1981, initially for one large OEM. The company has had a few owners in its history and since 1990 has been part of a public company owned by a diversified group. At the time of the benchmarking study, it employed 341 people and had sales amounting to £39,056,000 ($87,876 million). The company then had seven clients and its initial and main client accounted for 43% of its sales. During the 12-month period covered by the benchmarking study, Company P had assembled 3,292,924 PCBs and its level of automation for components placement was 75%. Recent years had been quite successful and when the case study started, Company P had just increased its work force by 15%. However, the company went through hard patches in the past. An initial period of growth ended around 1989, at which time the company had a large number of employees. In subsequent years, the work force was significantly reduced. They eventually went through a major reorganization and became very committed to Total Quality Management (TQM).

Two partners founded Company N in 1983 and enjoyed an early success until competition became more intense and the recession started to hit. At the time of the benchmarking study, the company employed 56 people and had sales amounting to £3,314,000 ($7,456.5 million). The company had 51 clients and its main client accounted for 14% of its sales. Fifteen months later, at the time of the case study, Company N was going through a growth period and the number of employees had doubled. Two new major clients, accounting for two-thirds of the business, were recently added to the client base. Company N was moving from low volume to medium volume business and the annual volume figure of 220,000 PCBs—90% of these assembled automatically—picked up at the time of the benchmarking study had probably increased.

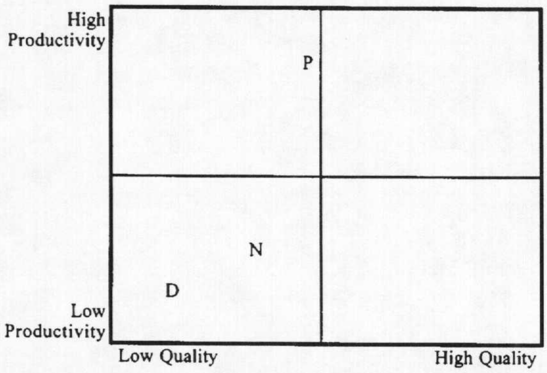
Company D is the smallest of the three companies studied with 45 employees and sales of £1,691,000 ($3,804.75 million). During the 12-month period covered by the benchmarking study, the company had assembled 57,797 PCBs and its level of automation for components placement was 58%. A former defense engineering technician, who initially obtained a contract to design and assemble a medical instrument, founded Company D. Although the initial client had remained the main client, accounting for 63% of sales, Company D had managed to increase its client base. However, like many subcontracting companies, it had experienced hard times in the early 1990s because of the recession. The relationship with the initial client was described as "not a happy one" and although the managing director had hoped that it would eventually come to an end and that the sales to this client would be replaced by other subcontracting business, he was very concerned when the news came that his client wanted the end of the relationship much sooner than he expected.

The following sections discuss the resolution of two trade-offs—productivity and quality, and dependability and flexibility—illustrated by Figures 1 and 2. The scale of these scattergrams is based on the complete benchmarking sample, although only the position of the three companies where case studies were conducted is presented. The productivity and quality trade-off is the first to be explored, followed by the dependability and flexibility trade-off. Specific themes that have emerged from the analysis of the research material and that give an insight into how the two trade-offs may or may not be resolved or avoided are covered. These themes are related to various managerial, structural, and cultural aspects of the three companies. The case studies show how these aspects have evolved in recent years and how they are related to manufacturing performance trade-offs resolution.

Trying to Resolve the Productivity and Quality Trade-off

As illustrated in Figure 1, Company P has a much higher productivity level and better quality than the three others do. This company came out of the benchmarking study in first position for productivity and fifth position for quality. Companies N and D are lower performers, but Company N has a slightly higher performance than Company D in both criteria. Interestingly, the line along which the three companies are positioned in Figure 1, from lower productivity/lower quality to higher productivity/higher quality, suggests the absence of a trade-off

Figure 1
Productivity and Quality



between the two manufacturing performance criteria. Indeed, the PCBs assembled at Company P are not of lesser quality because the work is done more rapidly than at Company N or M.

The general differences between the three companies in terms of size, volume, level of automation, and perhaps number of clients suggest a correlation between these factors and the levels of productivity achieved. However, size, volume, and automation do not explain everything. Ensuring that the flow is not interrupted is crucial. This can be achieved by minimizing downtime and making sure that machines are running most of the time. This was challenging for both Company P and N. Indeed, at the time of the case studies, both companies had recently acquired a new surface mount assembly line and both were experiencing problems with them. On many occasions, during periods of observation on the shop floor, various set-up problems were witnessed. In fact, these machines seemed so complex that neither manufacturers nor users appeared to know them very well. However, both companies had a history of keeping records of past problems and this appeared to help. Company N used a "History of Break Downs" book, which was started by a technician after the first surface mount assembly line was installed. This book contained information about the faults that had occurred, the date, the solution found, and how long the repair took. Similarly, a maintenance technician from Company P talked about a "communication book" used by the maintenance team in which adjustments made during any shift are recorded. He was proud to say that machines' manufacturers were not called very often. In line with this, Company P's SMT and auto insertion manager commented, "We try to recover problems ourselves with our knowledge, our enthusiasm and our experience."

Knowledge Capture

Since Companies N and P experienced similar problems with their newest assembly lines, how can Company P's relatively higher productivity be explained? Perhaps by the fact that Company P has learned "the lessons from the past," as was often mentioned by various people in the company, and has safeguarded the learning passed on from its initial client. The shop floor at Company P is organized in two distinct divisions: Continuous Flow Manufacturing (CFM) and Batch Flow Manufacturing (BFM). Before the CFM and BFM divisions were created, Company P was doing most of its assembly work for the large OEM who was the initial client when the company started subcontracting work in 1981. The creation of the divisions solved the problem of attracting new business and prevented all the engineering resources from being pushed towards one client. It appears that Company P learned a lot from this client and then from creating two divisions. As one manager explains, "Lessons from CFM were picked up by BFM; handling bigger volume, ways of doing engineering, organizing work, using our information system." The result of this learning process is a shop-floor—including both automated and hand assembly area—organized like a "pipeline from supplier to dispatch," a pipeline in which assembly of work orders is not interrupted very often.

This learning process was less present in Company N in this respect. As a result of the growth period through which the company was going at the time of the case study, the company was experiencing a break in the continuity of what had been learned over the years. While a second surface mount assembly line was being implemented to cope with the increasing demand, building on the apparent success of the implementation of the first surface mount assembly line earlier seemed difficult. During the fieldwork at Company N, many operators mentioned that the first line ("Line One") worked very well, that breakdowns were not frequent, and that most problems were solved quickly.

Three electronics engineers were hired when the assembly line was purchased. They were appointed right after they had completed their degree and this was their first job in the industry. They seemed to enjoy considerable status; the production director praised them, saying how much they had developed since they started to work and, according to the supervisor quoted above, many people in the surface mount area were "aware that they would not be able to do the job that these engineers are doing." Interestingly, when the engineers spoke about the new surface mount assembly line ("Line Two"), they called it "our machine," while Line One was referred to as "their machine." This suggested that a boundary existed between the two lines, that collaboration between the two groups of

Canadian Journal of Administrative Sciences
Revue canadienne des sciences de l'administration
17(3), 255-268

operators was limited, and that experience was not shared and passed on like it was at Company P. For example, no "History of Break Downs" book existed for Line Two.

As far as knowledge retention was concerned, Company D was far behind the two others. Moreover, the company's overall performance suggested that it had problems to solve in many areas. The company owned two pick-and-place machines that were idle on most days during the study of Company D. According to the post-solder inspector whose work station was in the automated assembly room, the machines were in operation half of the time. This was explained by the fact that the present demand for conventional assembly was higher than the demand for surface mount at Company D. The operators were trained to program the machine but had not had the chance to experiment with it: "Now they don't remember how to program the machine," commented the production engineer.

Sending the Right Message

Contradicting the trade-off theory, Company P did not have to sacrifice quality to obtain a higher level of productivity. One reason this could be achieved was that workers who saw productivity as a consequence of quality operated the "pipeline from supplier to dispatch." Comments such as "achieve good quality and then you'll get the numbers out of the door" were heard on many occasions during the fieldwork at Company P. The situation was rather different at Company D where there was a post-soldering inspection that was crucial because of the inadequacies of the soldering machines. During the fieldwork, some time was spent observing the post-soldering inspector who needed to rework most of the boards that she inspected. This is certainly one of the factors explaining why Company D could not achieve high productivity.

Company P appeared to be very committed to its TQM program. In the context of the TQM philosophy, the workforce at Company P had received a clear message. This was not the case in the other two companies. In the downstream operations area of Company N, where the pressure to work fast was felt most acutely, quality could hardly be built in the product and operators relied on inspection. Similarly, the operator working at the post-soldering inspection and rework station at Company D mentioned that her supervisor was sometimes putting pressure on her to work faster. She commented that this was something she "did not need." She believed that taking regular breaks was important. "If you don't, you can miss things."

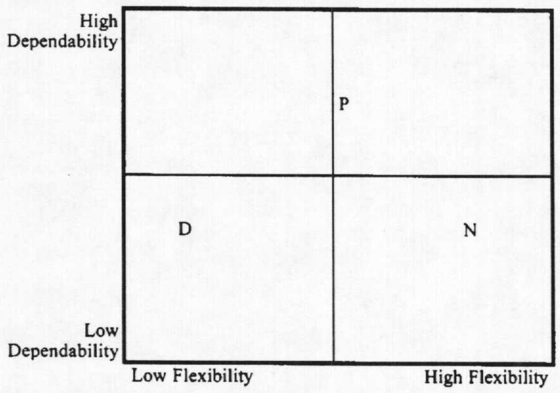
Rewards and Punishments

Managers at Company P mentioned on many occasions that they had access to a pool of reasonably well educated people and they obviously took pride in this "excellent work force." Workers were willing to work hard and well, possibly because they did not have a choice as the level of unemployment in the region where Company P was located was quite high. This might have been a reason why higher levels of productivity and quality could be achieved. Moreover, rewards and punishments seemed to be used as a guardian of the TQM culture; they were used to reinforce the message about the supremacy of the quality objective. For example, an employee working in the quality department had won an award for the speed at which changes were now made in the technical manufacturing instructions used on the shop floor. She said proudly, "Before, engineers would not put anything in here because it would get lost." Similarly, an inspector observed on one of the surface mount assembly lines was proud to mention the quality award (a plaque and gift vouchers from Marks & Spencer) she won for a suggestion that she made and which has been implemented in each area of the shop-floor. She was referring to a box containing "product history" index cards where any problems related to various products were recorded.

An incident that took place during the fieldwork illustrated that punishment was also used at Company P. One evening, when there was less supervision, a product was built using the wrong components. It was decided that an investigation would be carried out and a warning issued. One of the managers commented that having TQM in place did not prevent the need for rules. "Any system needs a certain amount of discipline." Indeed at Company P, workers seemed to feel the need to protect themselves. Putting "their" number on the board was a way to trace their errors but also a guarantee that they could not be accused of someone else's mistakes. Comparatively, the attitude at the two other companies and especially at Company D appeared to be more relaxed. When asked about the changes she had seen in Company D through the years, a hand assembly operator said that the standards had improved: "We have to be more careful, to be extra cautious when we put the boards to QC otherwise we can get told off." She explained that any faulty board came back from inspection accompanied by an "inspection report" saying that she had been "naughty, naughty." She added that "someday it's a good day, someday it's a bad day but then you say 'what the hell'." It would have been impossible to hear such a comment at Company P where workers seemed to be much more concerned about their own performance.

It can be gathered from the above discussion that while certain factors appear to be linked with productivity and others with quality, productivity-quality trade-off can be resolved if quality is the first objective that people have in mind. Interestingly, this partly confirms the

Figure 2
Dependability and Flexibility



cumulative theory put forward by Ferdows and De Meyer (1990) and supported by empirical research that provided evidence that quality can possibly be the base on which other improvements can be achieved (Flynn, Schroeder, & Flynn, 1999; Noble, 1995).

Trying to Resolve the Dependability and Flexibility Trade-off

As illustrated in Figure 2, Company P had a higher level of dependability but a lower level of flexibility than Company N. With 3% of late deliveries, Company P was the second most dependable of all 16 companies in the benchmarking sample. Company P had to deal with less modified orders compared to Company N which had 10% of late deliveries. It can therefore be suggested that both companies might be trading-off one objective for the other. Interestingly, Company D had the same level of dependability as Company N but was much less flexible, with only 15% of modified orders.

During the fieldwork at Company D, a management meeting was held to discuss the contract review procedure. Somehow, the discussion held during this meeting destroyed the myth of small companies being synonymous with simplicity of processes and reaction speed. The discussion clearly indicated that the complex contract review procedure used in the company was not well understood by everyone. Instead of trying to simplify things and to make sure that managers understood the contract review process, the group almost succumbed to the temptation of making it even more complicated by adding a temporary step to it.

Business Team Structure

One of the most striking differences between the three companies studied is that the higher performance companies (A and N) had recently adopted a business team structure. This was a very sensible choice in an industry where companies need to be closely connected to their clients. Company N, for example, was organized in four teams composed of a leader, a buyer, and an engineer and each of these teams was centred on six or seven clients. The four teams shared the same room, and the three members of each team (leader, buyer, and engineer) were working in the same island, their desks facing one another. This favoured constant exchanges between them.

This work organization appeared to help CEMs gain more speed. Company N's managing director commented on how files would take a long time to travel from one department to the other, from the engineers to the buyers and back to the engineers again. This was exactly what was observed at Company D where a functional structure was used. However, a business team organization would not be appropriate at Company D where the materials function, with one manager and one buyer, was too small to justify it.

Production and Inventory Control

Although they both had a team organization, other aspects of Companies P and N helped to explain the fact that they appeared to be trading-off one performance criterion for the other. Company P benefited from years of experience in using its integrated production and inventory control system that helped to achieve higher dependability but maybe at the expense of flexibility. Changes asked for by the customer were perceived as disturbing the schedule generated by the system. During a meeting with the managing director, he mentioned that the company was not as flexible as he would have liked it to be. "It takes more time that I would like to respond to customer changes and the company does not appear flexible to others," he said. As a matter of fact, an existing customer had recently taken one of their products from Company P to another subcontractor partly because they "were not giving them positive answers" about changes of schedule, as the systems manager explained.

While Company P's integrated production and inventory control system might have favoured dependability at the expense of flexibility, Company N was in a different situation. The production planning and control system was manual enough to accommodate many changes. Both initial and modified orders went through the same channel. The system, which generated product-related documents, was another feature that seemed to favour Company N's flexibility. When interviewed, Company N's managing director mentioned that even when the company went through a difficult time they "managed to keep the infrastructure there." The system was developed a few years earlier and appeared to have survived well, and providing it was operated with enough discipline so that accurate information was disseminated, it could be used as one of the bases on which Company N could grow.

It is interesting to see that, out of the three companies, the highest level of flexibility was achieved by the medium-sized company where the infrastructure to deal with engineering changes was in place and where the planning system was formalized but not enough to refuse to be pushed around. Indeed, Company N's production plan could be updated "each minute if the situation is critical," according the production director. Paradoxically, this suggests the idea of a balance; the planning system must be formal but not too formal. It also suggests that at a certain level of dependability, a trade-off against flexibility is unavoidable. While this proposition supports Mapes, New, and Szwejczewski's (1997) argument, it appears to contradict Ferdows and De Meyer's (1990) sandcone model as well as Slack's idea that a flexible operation enhances dependability (1991, p. 80). This, however, depends on how manufacturing flexibility is defined.

Conclusion

This research comes within the scope of new approaches to manufacturing strategies that challenge the operations management traditional trade-off model by examining the processes whereby manufacturing performance trade-offs may be resolved. A benchmarking study was carried out to evaluate if British CEMs are actually able to face the new demands in terms of low price (or high productivity), high quality, high dependability, and high flexibility. The results indicated that a few companies were better than others at resolving the productivity-quality and the dependability-flexibility trade-offs. The analysis of the three case studies carried out to understand the reasons behind this suggested that when the right message is sent throughout the company making quality the prime objective, improvements in productivity might follow. It also suggested that a high level of formalism, discipline, and control is required for flexibility to be achieved. A similar concept was proposed by Collins, Cordon, and Julien (1998) who use the oxymoron "rigid flexibility" to convey the idea that simplicity and discipline favour manufacturing flexibility.

This last proposition questions the flexibility assumption to which small CEMs appeared to subscribe. They tended to picture larger companies as being highly productive, assembling a lot of simple boards, trading off volume against flexibility and they believed that their small size favours simplicity of processes and reaction speed, giving them an advantage over larger CEMs dedicated to high volume assembly. Comments of this nature were heard frequently during the interviews carried out in the industry. The research results question this opinion by suggesting that organizations that are more productive do not necessarily have to be less flexible. Moreover, the conditions needed for productivity might even favour flexibility. It must be said, however, that dependability and flexibility remain a trade-off that is difficult to resolve. This is in line with what was proposed by New (1992) and Mapes et al. (1997).

Key structural and cultural aspects also help explain why some companies achieve higher performance than others do. The business team organization is one of these factors as well as the approach to quality control. The ability to safeguard knowledge has also emerged as a crucial factor. Clark (1996) suggested that the implementation of manufacturing best practices could contribute to move the performance frontier by increasing knowledge. The present results suggest that generating new knowledge might not be enough and should be combined with formal means to record knowledge for further retrieval.

The exploratory nature of the approach and the small size of the research sample mean that these findings can only be generalized with caution and that they constitute some tentative conclusions. However, the combination of a rigorous benchmarking process derived from well-known studies from the automotive industry (Andersen Consulting, 1993, 1994; Womack, Jones, & Ross, 1990) with case studies allowing processes to be detected enhances the validity of the research findings. Moreover, it offers an alternative perspective as it differs from the quantitative approaches correlating performance and program indicators currently favoured by many researchers in the field of manufacturing strategy. Elements such as knowledge capture, formalism, discipline, and control that have emerged during this research as having an impact on trade-offs resolution could be further investigated in a more deductive manner in further steps of the theory-building cycle.

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Notes

1. Flynn, Schroeder, and Flynn (1999) have recently labelled the latter the *synergies perspective*.