Operational implications of manufacturing outsourcing for subcontractor plants

An empirical investigation

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Abstract

Purpose – The objectives of this paper are: to identify the key defining elements of a subcontractor plant from an operations management perspective and examine whether there are differences between the operational contexts of such plants and original equipment manufacturer (OEM) plants; and to examine whether these differences should translate into different operational practices, addressing the specific case of process quality management practices.

Design/methodology/approach – The paper uses a multiple case study involving five plants in the electronics industry representative of the OEM and different subcontractor contexts.

Findings – Results suggest that the operational contexts of subcontractor and OEM plants are different and that, as a result, these types of plants should emphasize different sets of process quality management practices.

Research limitations/implications – Results are considered to be generalizable to most discrete goods industries. However, future research should ascertain whether these results replicate in industries other than electronics.

Practical implications – OEMs, who have a critical role in disseminating best practice within the supply chain, must recognize the differences between OEM and subcontractor environments and avoid pushing one-size-fits-all best practice programs along the chain.

Originality/value – Research in outsourcing to date has focused on the outsourcing decision *per se* and has mainly taken the perspective of the outsourcer firm. This study contributes to a better understanding of the operational implications of outsourcing decisions for subcontractor plants. It also responds to calls for more research linking quality management and supply chain management.

Keywords Outsourcing, Subcontracting, Quality management, Supply chain management

Paper type Research paper

Introduction

Original equipment manufacturer (OEM) companies have increasingly focused on their core competencies and outsourced part or all of their manufacturing operations to third party manufacturers (subcontractors). This is linked to the view that outsourcing can lead to overall increased competitiveness (Harrigan, 1984; Quinn and Hilmer, 1994) and has resulted in an enormous growth in the number of subcontractor plants and much academic and practitioner interest in such arrangements.

In this paper, we are interested in a particular case of outsourcing, manufacturing outsourcing, an arrangement in which the client outsources manufacturing-related processes (manufacturing *per se* as well as product design processes), resulting in the subcontractor plant performing all or part of the manufacture of the client's product. Subcontractor plants have branded themselves as "contract manufacturers" and "manufacturing service providers," implying a form of organization and service that is different from OEM plants. In particular, subcontractor plants have their operations organized specifically to provide routine manufacturing services to a range of external customers in the context of a web of complex supply chain relationships. Research in outsourcing to date has primarily focused on the decision of whether to outsource (the make-or-buy decision, including motivations and benefits), taking the perspective of the outsourcer firm (Canez *et al.*, 2000; Harland *et al.*, 2005; Ulrich and Ellison, 2005). Subcontract manufacture addressed from the subcontractor's perspective remains an under-researched topic (Webster *et al.*, 2000).

As a consequence, we lack knowledge about what characterizes a subcontractor (as opposed to an OEM) plant from an operations management (OM) perspective, as well as about the implications of such positioning for the operational context of such plants. By operational context we mean the variables that characterize manufacturing-related processes from an OM perspective, resulting from a given market positioning of a plant. This corresponds broadly to the subset of Hill's manufacturing strategy context variables that are specifically associated with the manufacturing-related processes (Hill, 1995, pp. 142-3). Therefore, a first objective of this paper is to identify the key elements defining a subcontractor plant and examine whether there are differences between the operational contexts of such plants and OEM plants.

If subcontractor and OEM plants exhibit different operational contexts, this raises the question of whether they need to employ different OM practices. This question is important because if that is the case, then supply chain improvement programs based on the adoption of best practices need to recognize these differences. As few studies have addressed this, a second objective of this study is to examine whether differences in operational contexts between OEM and subcontractor plants should translate into different operational practices.

In this paper, we focus on a specific set of practices, namely quality management (QM) practices associated with the management of manufacturing-related processes (from now onwards referred to as process QM practices). We focus on this area for two main reasons. First, past studies have found evidence that QM practices are context dependent (Benson *et al.*, 1991; Das *et al.*, 2000; Sousa and Voss, 2001; Sousa, 2003). In particular, process QM practices – also called "core" QM practices (Flynn *et al.*, 1995) – can be affected especially by a firm's operational context (Sousa and Voss, 2002). Second, processes are what clients actually outsource to subcontractor plants and, in recent years, these plants have increasingly become responsible for process QM activities within a supply chain (Quinn and Hilmer, 1994). At present, most of the interactions on quality between subcontractors and their customers refer to process management issues (e.g. SPC initiatives, ensuring product conformance quality, etc.).

This study sets out to develop and empirically test propositions related to:

- whether there are differences between the operational contexts of OEM and subcontractor plants; and
- if so, whether these translate into differences in process QM.

In addition, we also engage in a theory building mode to understand the mechanisms by which eventual differences in operational contexts influence process QM.

First, we characterize manufacturing outsourcing from an OM perspective and identify the typical forms of outsourcing arrangements that result in different types of subcontractor plants, as opposed to OEM plants. Second, we develop theory-based propositions related to contextual differences between OEM and subcontractor settings and the implications of such differences for the management of process QM. Third, we describe the research methodology, a multiple case study design. We then address the analysis of the case data. This comprises the uncovering of patterns in operational contexts and the use of process QM practices; and the use of the richness of the case data for the building of an explanatory model linking the two sets of variables. Finally, we present the overall conclusions and suggestions for future research.

The manufacturing outsourcing continuum

There is much debate in the management literature on defining outsourcing (Gilley and Rasheed, 2000; Harland *et al.*, 2005). We reviewed the definitions of outsourcing relevant to OM and propose the following key elements of outsourcing which emerge from those definitions:

- Outsourcing implies a business relationship between two parties: the outsourcing subject (also called the principal or the client) who makes the decision of whether to outsource or not; and an external outsourcing firm (also called the supplier or subcontractor) (Arnold, 2000).
- The objects of outsourcing are general business processes or processes' results which might be outsourced (Arnold, 2000; Kimura, 2002). This can include core (e.g. manufacturing, marketing, R&D) as well as support (e.g. maintenance, accounting, IT, logistics) processes (Gilley *et al.*, 2004).
- Outsourcing is not simply a purchasing decision. While all firms purchase elements of their operations, outsourcing is less common and represents the fundamental decision to reject the internalization of an activity (Gilley and Rasheed, 2000). Thus, outsourcing occurs in two situations. First, is when the client outsources objects that were originally sourced internally, resulting from a vertical disintegration decision (Gilley and Rasheed, 2000). Second, when the client sources objects that, although they have not been completed in-house in the past, are within the client's capabilities and hence could have been sourced internally notwithstanding the decision to go outside (Gilley and Rasheed, 2000; Van Mieghem, 1999).
- The outsourced objects are specific to the client. That is, the outsourced activities are performed according to a plan, specification, form, or design, of varying detail, provided by the client (Kimura, 2002; Van Mieghem, 1999; Webster *et al.*, 1997). Hence, a firm buying an off-the-shelf, standardized component or a supplier's proprietary part is not considered outsourcing, because no customization is performed for the buyer.
- The client may outsource all or part of a process or process result (Gilley *et al.*, 2004). For example, the outsourcing of manufacturing processes may take the form of a part, component, or a finished product (Harland *et al.*, 2005).

In this paper, we focus on a particular case of outsourcing, manufacturing outsourcing, an arrangement in which the client outsources manufacturing-related processes, resulting in the subcontractor plant performing all or part of the manufacture of the principal's product. Because, the subcontractor performs the manufacture of the items to a customized specification of varying detail provided by the client, the outsourced processes may include not only manufacturing processes, but also product design processes (Ulrich and Ellison, 2005). Within this definition, we can find a continuum of outsourcing intensities related to the scope of the product design processes that are outsourced by the client, which in turn gives rise to different types of subcontractor plants.

In the literature, we find two common types of subcontractors that serve as anchors along this continuum (Clark and Fujimoto, 1991; Kaufman *et al.*, 2000): "detailed-controlled parts" (DCP) and "black-box" (BB) subcontractors. These are based on the extent of control over two different aspects of product design: functional (conceptual) and physical design. As the name indicates, the functional design of a product specifies the functions or operations it should perform from the user's point of view (i.e. the way it should respond to external stimuli). The physical design is the concretization of the functional design by the combination of physical components with the appropriate technical characteristics configured in a suitable manner. Thus, a physical design is a blueprint for the manufacture of the product. In general, the same functional design can be concretized via several physical designs.

Thus, at one extreme of the outsourcing continuum, a DCP subcontractor is a plant which has no direct control over the design of its products (i.e. both the functional and physical designs are specified by the client) (Clark and Fujimoto, 1991). A BB subcontractor is a plant which has direct control over the physical but not the functional design of its products (Clark and Fujimoto, 1991). By exclusion, what we generally define as an OEM plant is a plant which does not perform manufacturing activities outsourced by a third party; such a plant has total control over the manufacturing and design of its products and is thus placed at the other extreme of the outsourcing continuum.

Differences in operational contexts along the manufacturing outsourcing continuum

In the literature, we found ample support for the existence of differences between the operational contexts (within the previously defined scope) of subcontractor and OEM plants in the following variables: extent of control over product design, rate of new product introduction, influence of customers over operational decisions, intensity of the exchange of information with customers, internal item variety and type of manufacturing process. In this section, we describe the identified differences between the extremes of the manufacturing outsourcing continuum (OEM vs DCP subcontractor, taking the OEM as the base model). We treat the BB subcontractor as an intermediate context between the two extremes.

A key operational difference between OEMs and subcontractors is the extent of control over product design, which has already been discussed in the previous section. Subcontractor plants are also expected to be subjected to a higher rate of new product introduction. In fact, one of the main reasons for clients deciding to work with a subcontractor is achieving a shorter time to market and being able to introduce new products more frequently (Clark and Fujimoto, 1991; Dyer and Ouchi, 1993), something which is typically considered as being as part of the subcontractor's intrinsic service offer.

Another characteristic of subcontractors is being subjected to a stronger influence of their direct customers (the clients) over operational decisions at various levels (Webster *et al.*, 1997), which is often linked to a power imbalance in favor of the client (Helper, 1991). One important area is the timing and lead times of new product introductions, which are often determined by the clients' marketing strategies to which the subcontractor needs to respond with high levels of flexibility. Another area of customer influence is in the selection of suppliers and product components. Frequently, clients wish to extend their control over product design to the selection and supply of actual components, on what is known as a "free issue" system (Webster *et al.*, 1997). Even if clients do not supply components themselves, they can impose component and supplier selection choices on the subcontractor, on what is known as "directed sourcing" (Park and Hartley, 2002). Finally, clients can have a strong influence on the subcontractor's production plans. With the proliferation of JIT arrangements, subcontractors often need to produce and deliver JIT, that is, to work with small lots and frequent deliveries working in conformity with the production plans elaborated by clients (Harrison and Voss, 1991; Villa and Panizzolo, 1996). The extended influence of clients at various levels, requires an intense exchange of data and information regarding product design issues, demand and production information, manufacturing processes, etc. (Villa and Panizzolo, 1996; Webster *et al.*, 1997).

From a strategic perspective, and because product designs remain under the control of clients, subcontractors avoid investing in client-specific processes in order to prevent dependency on a few clients (Kaufman *et al.*, 2000). Hence, subcontractor plants have their operations organized specifically to routinely provide manufacturing services to a range of clients and they tend to employ general assets and skills in order to meet diverse client specifications (Kaufman *et al.*, 2000). At an operational level, this strategic positioning results in having to deal with high levels of variety in processed items which tends to favor the adoption of jobbing processes.

Table I summarizes the hypothesized operational differences between OEM, BB and DCP subcontractors. Accordingly, we put forward the following research proposition:

Table I.
Hypothesized differences in the operational contexts of OEM, BB subcontractor and DCP subcontractor plants

Operational context characteristic	OEM	BB subcontractor	DCP subcontractor
Extent of control over product design	High	Medium	Low
Rate of new product introduction	Low	Medium	High
Influence of customers over operational decisions (timing and lead times of new product introductions, selection of suppliers and components, production plans)	Low	Medium	High
Intensity of the exchange of information with customers	Low	Medium	High
Internal item variety	Low	Medium	High
Manufacturing process	Closer to line	Closer to batch	Closer to jobbing

P1. Plants with different positions along the manufacturing outsourcing continuum (OEM vs DCP subcontractor) will exhibit different operational contexts. Specifically, these contexts will differ according to the pattern presented in Table I.

The manufacturing outsourcing continuum and process quality management

In this section, we hypothesize that the proposed differences between the operational contexts along the manufacturing outsourcing continuum will have implications for process QM. Based on a synthesis of several studies that attempted to identify the key QM-practice dimensions (Ahire *et al.*, 1996; Flynn *et al.*, 1995; Saraph *et al.*, 1989), we define process QM practices as the set of practices associated with ensuring good levels of internal process quality, comprising two subsets of practices: formalized new product introduction and statistical process control/feedback. The former are practices related to a formal and comprehensive introduction of a new product into production with the objective of minimizing the occurrence of problems during production. This includes thorough reviews of product designs before the product is produced, design for manufacturability, prototyping and trial runs, and special tools and techniques, such as process capability studies and failure mode and effects analysis. The latter are related to the collection and recording of data on the state of control of the process and subsequently comparing it with an "in-control standard" (e.g. SPC charts, defect levels at which the process is considered out of control). These practices provide timely feedback on the state of control of the process, enabling the adoption of corrective actions.

Process QM practices are closely associated with concepts of process design and control and are deeply rooted in classical control theory. Control theory prescribes different control methods depending on the degree of knowledge available about the systems or processes. In the following sections, we propose that:

- the operational context of a subcontractor plant is more complex than an OEM's, resulting in less available knowledge about processes; and
- according to control theory, this should lead to differences in the patterns of use of process QM practices between OEM and subcontractor plants.

Manufacturing complexity and process knowledge along the continuum

We found two main studies which support the notion that manufacturing complexity is higher in subcontractor plants than in OEM plants, thus resulting in less available knowledge about the processes for the former. Flynn and Flynn (1999) identified the sources of manufacturing complexity as:

- goal diversity (e.g. the variety of final products, individual product volumes, markets, etc.);
- manufacturing diversity (e.g. the instability of manufacturing schedules);
- process diversity (jobbing-type processes being more diverse than line-type processes);
- supplier diversity (e.g. the number of suppliers and extent of cooperation with the firm);

- customer diversity (e.g. the number of customers and extent of cooperation with the firm); and
- labor diversity (e.g. the number of job classifications).

Table I suggests that, with the possible exception of labor diversity, all the above causes of complexity would be typically stronger in a subcontractor environment than in an OEM environment.

Bohn's (1994) theory of process knowledge posits that knowledge of a process at the new product introduction phase is less than at later phases; that changes in the processes cause a regression of their effective knowledge to earlier stages; and that increasing knowledge is associated with converting exogenous variables into endogenously controlled variables. We have argued that subcontractor plants exhibit a higher rate of new product introduction and change in their processes and are subjected to more exogenous variables which cannot be internalized (e.g. resulting from the customer-controlled designs) (Table I). Therefore, it is expected that process knowledge will be lower than in OEM plants.

The impact of complexity and process knowledge on process quality management practices

Control theory prescribes two different types of control methods for systems: feedback and feed-forward control (Bishop and Dorf, 2004; Shinners, 1998). In a feedback system, the output of a process is compared to a standard and when a disturbance occurs that causes significant output deviations, the process is modified based on the observed deviations. This type of control is more appropriate for less well-understood systems subject to significant unknown disturbances. In QM, this control logic is implemented through statistical process control/feedback practices. Feed-forward control works by predicting deviations from the standard caused by a known disturbance and automatically adjusting the process in a predefined way (these controls are pre-defined and embedded in the process itself). This type of control is more appropriate for well-understood processes and requires a good prior understanding of a process's behavior and a prior reduction of the occurrence of significant process disturbances. In QM, this logic is implemented by several practices associated with the formalized introduction of new products into production with the objective of minimizing the occurrence of problems during the production stages, such as process capability studies and trial runs.

Therefore, considering the differences in manufacturing complexity and process knowledge along the manufacturing outsourcing continuum, we formulate the following proposition:

> *P2.* Plants in different positions along the manufacturing outsourcing continuum (OEM vs DCP subcontractor) will exhibit different patterns of use of process QM practices. Specifically, DCP subcontractor plants will emphasize statistical process control/feedback practices, while OEM plants will emphasize formalized new product introduction practices.

Methodology

To examine the two research propositions, we used case research to compare the operational context and degree of use of process QM practices across plants representative of the manufacturing outsourcing continuum. Case research is an appropriate method when contextual conditions are pertinent to the phenomenon of study and when the research questions include an explanatory, theory-building component (Yin, 1994).

Sample design and selection

Voss *et al.* (2002) emphasize the importance of control variables in case study research. In order to allow for meaningful comparisons between operational contexts (*P1*), and for the control of process technology, plants were selected from a single industry – the electronics industry in the UK, defined for the purposes of this study as the manufacture of products in which the core is one or several Printed Circuit Boards (PCBs). This is a highly competitive industry where subcontracting arrangements are widely employed and QM is strongly disseminated.

In order to isolate the effects of operational context on the degree of use of QM practices from implementation effects (*P2*), the study examined "quality mature" plants. All plants were involved in best practice benchmarking exercises, had been ISO9000 certified for at least seven years and were members of quality associations. All had a formal program of QM in place for an extended period of time (ranging from 7 to 20 years) and there were external indicators of successful QM implementation for all plants, including the winning of reputable quality awards and having been the object of academic case studies illustrating best practice in QM. We can thus conclude that the observation of different patterns of use of practices between plants does not simply result from plants being at different stages of the QM implementation process.

The data collected in the field supported this assumption. The plants had arrived at the current pattern of use of practices via a process of experimentation consisting of the adoption of new practices, the improvement of existing practices, and the discarding of unsuccessful practices. Plants were using certain practices because those practices were adequate to their context, having produced positive results for them over an extended period of time.

The target sample comprised two plants representing the DCP subcontractor context, two plants representing the OEM context, and one plant representing the BB subcontractor context. Using publicly available information, we compiled an initial list of 25 plants which were likely to comply with the research controls and covering the DCP, BB and OEM contexts. Next, we solicited participation of five plants from that list: two OEM and DCP and one BB plant (prioritizing what seemed the most promising plants among the initial 25). Those plants which declined participation were replaced by the next most promising plants in the list belonging to the same type. This process was repeated until the target sample was achieved. Overall, ten plants were contacted (three DCP subcontractors, two BB subcontractors and five OEMs), six of which agreed to participate in the study (three DCP subcontractors, one BB subcontractor and two OEMs). Of these six plants, one DCP subcontractor plant was dropped for being found not to comply with the research controls after two field visits and was replaced with a similar plant. Table II describes the final research sample.

Data collection

A case-study protocol was developed comprising a list of all the research variables to address (controls, operational context and process QM), and the respective indicative

Table II.
Research sample

	Plant				
	OEM		BB	DCP	
	1	2	3	4	5
Employees	450	123	226	170	224
Main products	Electricity and gas meters	Access control systems for buildings	PCBs for assembly into final products at the customer plants	PCBs, standalone for assembly into final product units by the customer or already incorporated into final product units	
Customers	Electricity and gas utilities	Dealers, selling products to hospitals, police forces, etc.	Plants part of the corporation the plant belongs to PCBs supplied on a free market basis	Companies in the industrial, instrumentation and communication segments	

questions, potential sources of information, and field procedures. Data collection focused on the formal research variables complemented with other issues enabling the understanding of the observed pattern of use of practices such as the history of use of the practices, the difficulties experienced by the plants in using them, and the factors which prevented plants from increasing or decreasing the use of some practices. The case-study protocol involved several data collection methods, including semi-structured interviews, direct observation (e.g. plant tours), a short questionnaire collecting descriptive plant data, and secondary data.

Each case study involved four visits to the manufacturing site on separate days. Across cases, informants included the managing director, the plant manager, shop floor supervisors and workers, and representatives from marketing/sales, customer service, engineering, manufacturing, quality, testing, and product design/introduction. Interviews were typically one hour long, ranging from 30 minutes to 4 hours. Each case involved around 20 interviews.

Data analysis

The first step in data analysis was data reduction which comprised two main stages:

(1) the organization and coding of the data that appeared in written-up field notes; and

(2) the characterization of plants across the several research variables.

Stage 1 followed the usual guidelines for qualitative research (Miles and Huberman, 1994). Stage 2 used the outcome of Stage 1 to construct tabular displays to manage and present qualitative data across the relevant research variables, an analysis strategy recommended by Miles and Huberman (1994). Two data displays – one comprising all the operational context variables and one comprising the two process QM practices – were constructed for each plant. These displays used a fixed set of items to characterize each variable – thus ensuring consistent and objective comparisons across the several cases – and were used to arrive at high, medium or low ratings for each variable. The templates that were used for the displays, including the variable rating rules, are shown in the Appendix.

The second step in the analysis was geared to examine the study's two propositions. We first present the several analyses that were performed and then discuss them jointly at the end.

Testing for differences between OEM and subcontractor plants: operational context (P1) and pattern of use of process quality management practices (P2)

Table III shows the ratings of the operational context variables across plants. With the exception of the rating for the rate of new product introduction in plant 4, the observed patterns match the hypothesized differences between contexts (Table I). Therefore, there is strong support for *P1*.

Table IV summarizes the degree of use of the several process QM practices across plants, ordered according to their relative positions along the manufacturing outsourcing continuum as in Table III. The patterns suggest that the use of practices follows a distinct trend as one moves across the manufacturing outsourcing continuum. We tested whether this trend is statistically significant by applying Cuzick's (1985) nonparametric test for trend to the degree of use of individual practices (high, medium or low) across the three operational context types, assumed to be equally spaced along the continuum. Thus, for each practice, the two polar groups comprised two observations each and the BB subcontractor group comprised a single observation.

The two practice trends were found to be significant at the 0.10 level. Given the small sample size, resulting in the reduction of the power of the test, this is considered to be adequate evidence of trend. Thus, the results provide support for *P2*.

Consistent with this result, the visual analysis of Table IV suggests that the patterns of use of practices in the two DCP subcontractor plants are similar to each other (literal replication) and in clear contrast with the patterns observed in the two OEM plants (theoretical replication), which are also similar to each other. However, the BB subcontractor exhibits a pattern similar to the OEM plants. Therefore, the results do not validate the hypothesized positioning of the BB subcontractor as an evenly spaced intermediate context between OEM and DCP subcontractor plants in terms of process QM practices. Rather, they suggest that process QM in BB subcontractors is managed in a similar fashion to OEM plants, despite the differences in operational contexts.

Explaining the differences in the pattern of use of practices

We adopted a theory-building mode to identify the mechanisms by which operational context influenced the use of process QM practices, thereby producing explanations for the empirical observations. The analysis consisted of building causal networks, i.e. "displays of the most important independent and dependent variables in a field study and of the relationships among them" (Miles and Huberman, 1994, p. 153).

We followed Miles and Huberman's (1994, pp. 245-62) guidelines to build one network for each case. This involved using the codes, the displays constructed in the data reduction stages and other case data to identify and validate patterns of relationships between the research variables (operational context and process QM practices).

Table III. Characterization of operational contexts of the plants in the research sample

Context variable/plant	1 OEM	2 OEM	3 BB	4 DCP	5 DCP
Extent of control over product design	H	H	M	L	L
Rate of NPI	L	L	M	M	H
Influence of customers	L	L	M	H	H
Exchange of information	L	L	M	H	H
Internal item variety	L	L	M	H	H
Manufacturing process	Line	Line	Batch	Jobbing	Jobbing

Notes: H – high; M – medium; L – low

Table IV. Degree of use of process quality management practices across plants

	Plants				
Practice	1 OEM	2 OEM	3 BB	4 DCP	5 DCP
Formalized new product introduction	H	H	H	L	L
Statistical process control/feedback	L	L	L	M	H

Notes: H – high; M – medium; L – low

The five individual case networks were then compared with each other in order to identify similarities and differences. These comparisons resulted in the extraction of relationships that were found to replicate across cases, abstracting from the peculiarities of individual cases and generalizing them to a broader theory. During this process, it became clear that the pattern of use of process QM practices across plants could be explained by a stable set of relationships among operational context variables and individual practices. In addition, it was found that the directions and strengths of these stable relationships in the two DCP subcontractor plants were similar to each other and were the reverse of the same relationships in the two OEM plants, which were also similar to each other. The BB plant exhibited a slightly different pattern of relationships, the main differences being in the strength of the effects of individual operational context variables. This led to the realization that, concerning process QM practices, the BB subcontractor could not be seen as an intermediate position between the polar extremes. This resulted in the building of two general (cross-case) causal networks for the two polar types, embodying generalizable relationships that were empirically grounded in the four individual case networks. Overall, we found that the operational context of a DCP subcontractor (OEM) plant results in more (less) complex processes, which in turn determines a lower (higher) use of formalized new product introduction practices (NPI) and a higher (lower) use of SPC/feedback practices. We next describe the meaning of the connections among variables in the networks for the DCP subcontractor and OEM contexts, taking the DCP subcontractor as the basis of our description. We will address the specific case of the BB subcontractor and its implications subsequently.

Management of process quality in DCP subcontractor and OEM plants

The DCP subcontractor's manufacturing task is inherently complex due to:

1. The reduced control over product design, which typically leads to designs which are more difficult to manufacture in the plant's specific processes (more on this below).
2. The high rate of new product introductions and product changes with very short lead times resulting from the volatility in the customers' markets. For example: while DCP subcontractor plants 3 and 4 had a few weeks from the availability of the physical design to shipping the product to customers, in the OEM plants 1 and 2 this period was in the order of a few months. In the introduction of a particular new product for one of its major customers, subcontractor plant 4 experienced a rate of 30 engineering change orders per week imposed by the customer during the first six months; in a similar situation, subcontractor plant 5 had an average of 150 change orders a week triggered by customers.
3. The strong influence of customers in such areas as:
    - Providing information necessary for manufacturing: often there are errors in the information supplied by customers and/or in the process of introducing this information into the subcontractor's internal systems (e.g. re-typing the information when the IT systems are not compatible, customer mistakes, different conventions and terminology, etc.).

  - Customer-supplied components and customer influence on the choice of component suppliers: in some cases, customers provide some of the components to be incorporated into their products. These may have characteristics which are unsuitable for the subcontractor's manufacturing processes. In other cases, although the customers may not provide components themselves, they may have a strong influence on the selection of the supplier to be used, either because there are links between the design of a product and the components it comprises; or because customers may have already worked with particular suppliers in the past when placing orders with other plants (for example, as part of the prototyping stages of the development of their designs) or when producing the product in-house (before deciding to outsource it). Because customers tend to have little manufacturing expertise, they are typically not sufficiently qualified to select good suppliers for volume production. This sometimes leads to the use of inadequate suppliers or suppliers with whom the DCP subcontractor plant has less well developed relationships, and is also an obstacle to component standardization efforts across different products.
  - The control over the timing and lead times of new product introductions. While a manufacturing department in an OEM can offer resistance towards a rushed introduction of a new product (or a request for a product design change) pushed by an internal development/marketing department, this is more difficult to accomplish when development is conducted by the customer who sees rapid new product introduction as part of the subcontractor's service offer and is less aware of the associated manufacturing issues.

(4) The very intense exchange of information with customers through interactions controlled by customers, which absorbs engineering resources and makes planning more difficult.

(5) The high internal item variety and associated use of jobbing processes. For example, DCP subcontractor plants 4 and 5 had over 180 different PCB board types and over 50 different types of components per board. OEM plants 1 and 2 had less than 25 different PCB board types and less than 13 different types of components per board.

The reverse arguments explain why the OEM plant exhibits simpler and well understood processes.

The more complex manufacturing environment of the DCP subcontractor places some obstacles to the use of formalized new product introduction practices (NPI):

- The reduced control over product design, with products being designed by customers, makes it difficult for the subcontractor to influence their manufacturability. Typically, customers have little knowledge of the specificities of the subcontractor's manufacturing processes and often have also reduced manufacturing expertise resulting from their focus on marketing and product development. In addition, even if a subcontractor is able to suggest improvements for the manufacturability of designs, customers typically resist incorporating such suggestions in a previously developed physical design that the customers may have already tested and proved to work (e.g. through prototyping)

(Engineering Manager, Plant 4: “Our customers typically require their designs to be set in stone right from the start”). This is especially true for new customers, who have less trust in the subcontractor’s capabilities and often consider that it is part of the subcontractor’s service offer to perform the adaptation of their manufacturing processes to the provided product designs.

- The very frequent new product introductions with very short lead times, lack of control over the timing of new product introductions, frequent changes to existing products, and delays in the processing of customer orders due to the intense exchange of information with customers that is needed, absorb engineering resources and create strong time pressures on new product introduction activities. This makes it difficult for a subcontractor to foolproof processes, conduct trial runs and accumulate knowledge about the manufacturability of designs to be incorporated in future products. For example, subcontractor plant 5’s Engineering Manager characterized their NPI process as “Production Engineering on the fly.” Trial runs were very rarely performed in subcontractor plants 4 and 5.

As a result of these obstacles, the emphasis of the NPI process in a DCP subcontractor plant is to get a product fit to be manufactured quickly, which contributes little to accumulating process knowledge. In contrast, in an OEM plant the NPI process is conducted internally with longer lead times and controlled timings, allowing for the use of a formal process with an emphasis on solving all problems before full scale production begins. For example, in OEM plant 1, the NPI process included, before full-scale production, systematic cycles of “trial runs – design improvement,” until the trial defect rate fell to 1 percent. In OEM plant 2, there were a series of cycles “trial runs – testing – design reviews” before full-scale production.

In the complex, less well understood processes of DCP subcontractors in which many things can go wrong, it pays to use a high degree of SPC/feedback to maintain the process in control and avoid the production of defects. For example: several of the subcontractor plants’ SPC/feedback points were analyzed real-time in an automated fashion and could trigger immediate line stoppage and/or corrective action. The reverse argument explains the lower use of SPC/feedback in an OEM plant (i.e. the reduced complexity of the processes and their increased stability mean that less feedback is needed for guiding corrective and improvement actions).

Discussion

The analysis of the observed patterns suggests that:

- there are differences in the operational contexts of plants across the manufacturing outsourcing continuum (Table III); and
- there is an association between the positioning along that continuum and the pattern of use of process QM practices (Table IV).

The causal network analyses provided evidence of a causal association between operational context and the patterns of use of practices, by uncovering mechanisms by which the detailed characteristics of the different operational contexts lead to different levels of manufacturing complexity and influence the adopted pattern of use of practices. These mechanisms are largely consistent with the theory-based arguments underlying

P2 and found replication both across similar contexts (i.e. their application to similar contexts explained the similarity observed in the patterns of use of practices – literal replication) and across the manufacturing outsourcing continuum (i.e. with the exception of the BB subcontractor plant, their application to different contexts explained the differences observed in the patterns of use of practices – theoretical replication) (Yin, 1994, p. 46).

The analyses did not validate the BB subcontractor as an intermediate position between the polar extremes in terms of process QM. Although, the causal network for the BB subcontractor plant validated the influence of operational context variables on process QM practices as sources of complexity, the data suggested that manufacturing complexity suffers a steep decrease when physical design is performed in-house by the subcontractor. In fact, if we refer to the causal network text above, we observe that the most important source of complexity is the lack of control over physical design. Although, there is strong support in the data for the influence of the other sources of complexity in OEM and DCP contexts, their compound effect in a BB case does not lead to a significant change in the logic underlying process QM, and hence to the pattern of use of practices. Therefore, the results seem to suggest that the degree of control over physical design is a key operational context characteristic for process QM in a BB subcontractor plant, the influence of which outweighs the influence of other variables. The degree of control over product design has been suggested before as a critical element in general buyer-supplier relationships (Wasti and Liker, 1999).

The study suggests that the manufacturing context of subcontractor plants is inherently more complex than that of OEM plants, and has identified several sources of complexity (low control over product design, high rate of new product introductions, high influence of customers over operational decisions, high intensity of exchange of information, high item variety and jobbing-type processes). These findings pave the way for future research into strategies that subcontractor plants may employ to deal with complexity. These strategies could be of two kinds. The first kind could be strategies trying to act on the supply chain positioning of the plant to effectively bring the subcontracting environment closer to an OEM environment where design and production are totally integrated. For example, subcontractor plants might try to forge stronger relationships with customers in order to increase the influence over product designs and develop integration mechanisms to reduce the exposure to externally induced errors (e.g. integration of IT systems for seamless information exchange, more control over material and supplier selection, testing strategies, etc.).

The second kind could be strategies that accept the complexity of the subcontractor context as a given, and develop internal organizational structures specialized in dealing with complexity. For example, subcontractor plants could invest in information systems able to process a large amount of customer supplied inputs and able to cope with the strong influence of customers on manufacturing activities. Alternatively subcontractors could adopt the use of lateral forms of communication and joint decision-making processes.

Conclusions

Our study contributes to a better understanding of the operational implications of outsourcing decisions for subcontractor plants, at two levels. The first relates to the implications for a subcontractor's operational context. In this connection, the study has clarified and enriched existing definitions of manufacturing outsourcing from an OM perspective, setting the stage for a better understanding of a subcontractor's context. In addition, it has conceptually identified and empirically validated a set of operational context attributes that are different in a subcontractor plant, when compared to an OEM plant taken as the base model.

The second contribution relates to a better understanding of the implications of the uncovered contextual differences for process QM, a key area of interaction between supply chain players. In this way, this study also responds to calls for more research linking QM and supply chain management (Foster, 2005; Jack *et al.*, 2001). Our results suggest that subcontractor plants may benefit from placing a different emphasis on the several process QM practices, compared to OEM plants: subcontractors might emphasize statistical process control/feedback practices while OEMs might emphasize NPI practices (see discussion on the limitations of the study below). Therefore, there does not seem to be a one-size-fits-all QM approach that applies uniformly across different supply chain players: a plant's position along the manufacturing outsourcing continuum seems to influence its operational context, which, in turn, seems to influence the degree to which the several process QM practices are used.

The findings can inform the implementation of QM programs along the manufacturing outsourcing continuum. In many industries (e.g. automotive, electronics), OEM companies often use their clout as customers to drive QM initiatives to the subcontractor plants with whom they work (Park and Hartley, 2002), for example, by promoting supplier selection policies which require adherence to standardized supplier certification schemes. Typically, OEM plants have little awareness of the operational context of subcontractor plants and design these initiatives from the perspective of their own operational context. Our study suggests that this will be counter-productive, and may lead to difficulties on the part of the subcontractor and to the OEM firm not deriving the expected benefits from the outsourcing decision. In addition, it may result in reduced trust and co-operation levels between the two parties. The increased knowledge about subcontractor operations that our study brings can contribute towards a better mutual understanding and cooperation between OEM and subcontractor plants, a critical issue for improving overall supply chain effectiveness (Kumar, 1996; Gulati and Singh, 1998).

The replication logic allows us to make theoretical – as opposed to statistical – inferences about other industries based on this single industry study. We believe that the study's findings can be the object of reasonable generalization to manufacturing plants in discrete goods industries. In fact, one would expect to observe the same positioning of plants in terms of the manufacturing outsourcing continuum in most discrete good industries and one would also expect that the forces shaping process QM practice identified under carefully controlled conditions in the electronics industry would also be in play in other industries (although its effects might be felt alongside other industry specific variables). Nevertheless, it may be important for future research to ascertain whether these results replicate in other industries.

The small sample size did not allow for the testing of whether a fit (as suggested by the study's findings) among the positioning of a plant along the manufacturing outsourcing continuum, its operational context and the pattern of use of process QM practices results in superior overall plant performance. Future large-scale cross-sectional studies should investigate this. It would also be important to study the effects of the "improper" use (as suggested by this study's findings) of practices in relation to a plant's context.

The light that this study sheds on the implications of differences in operational contexts along the manufacturing outsourcing continuum on the selection and use of process QM practices fosters the notion that practices may need to be tailored across the continuum. Future research should examine whether the identified differences in operational context have implications for other QM and OM practices in general (e.g. Lean production). We hope that this will contribute to the most powerful players within a supply chain, often being OEMs with a critical role in disseminating best practice within the chain, gradually coming to recognize these differences and resist the temptation to push one-size-fits-all best practice programs along the chain.

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Appendix. Templates used for data reduction

Variable rating rules

The rules employed by the researchers (joint rating) to rate the several research variables making up the data displays were as follows:

Rule 1. Rule for arriving at high, medium, low ratings for individual information items. For each item, the decision was taken as to whether there were "significant and clearly identifiable differences" across plants. In case, the conclusion was that there were no such differences, all the plants were rated as medium on that item by default. Otherwise, this rule took different formats depending on the nature of the items:

R1.1 Quantitative items (numerical values). The interval (minimum observed numerical value across plants; maximum observed numerical value across plants) was divided into three equally sized intervals, each corresponding to the low, medium, and high ratings.

R1.2 Qualitative items (textual descriptions). The plants were ranked according to the item in question with the level high being attributed to the plant ranked the highest and the level low to the plant ranked the lowest. A notional item was considered in between these two extremes as an exemplar of the medium rating. These three items (two real and one notional) then acted as the anchor points for the rating of the remaining plants. The remaining plants were attributed the rating high, medium and low according to the anchor item they most resembled. This procedure is exactly equivalent to the one followed for the quantitative items.

Rule 2 (R2). Rule for arriving at a high, medium, low rating for an aggregate variable made up of several individual items (dimensions), each rated as high, medium or low. The ratings of high, medium and low corresponding to the individual items making up the aggregate variable for a plant were assigned the values 3, 2, and 1, respectively. These values were added to arrive at a numerical score for the variable. This score was compared with the other plants' scores to arrive at a high, medium, low rating using rule R1.1.

The reliability of the ratings was ensured by adopting a conservative policy of only differentiating plants if there are "significant and clearly identifiable differences" between them, thus reducing the chance of spurious results. In addition, the ratings being relative to other plants, thus independent of the researchers' realm of experience, and the study controls for industry and process technology, allowed for simple comparisons of like with like.

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Table AI.
Display for operational context

Ctx. Var	Unit of Meas.	Measurement items/characterization of the context variable (a)	Rating
DSG	Main product line	H – total control over design; M – control over physical, but not functional design; L – no control over functional and physical design	L-H, rule R1.2
RNPI	Plant	(1) Instability of product designs, both across new product introductions (L-H, Rule R1.2) and during a product's life cycle (L-H, rule R1.2). Overall item rating is determined by the application of rule R2 to the two individual ratings (2) Consequences of new product introductions to manufacturing. Application of rule R1.1 to the ratio "internal item variety rating (see below)/average product life cycle rating (applying rule R1.1.)" to yield a L-H rating. The more products a plant produces and the shorter are their life cycles, the more manufacturing is subject to new product introductions	L-H, applying rule R2 to the two individual items
CUST_INFL	Plant	Extent of customer influence on: (1) Timing and lead times of new product introductions: H – decisions mostly imposed by customers; later involvement of the plant in the new product design and introduction process; M – some negotiation with the plant, earlier involvement of the plant in the new product design and introduction process; L – little influence (L-H, rule R1.2) (2) Selection of components and suppliers: H – free issue system often used; customers frequently take control of the relationship with chosen suppliers; M – some influence, but plant assumes direct control of the relationship with chosen suppliers; L – little influence (L-H, rule R1.2)	L-H, applying rule R2 to the three individual items

(*continued*)

Ctx. Var	Unit of Meas.	Measurement items/characterization of the context variable (a)	Rating
		(3) Production plans: H – strong customer influence leading to unstable production plans, production of small volumes based on make-to-order; M – some influence, but higher volumes and less frequent customer-determined schedule changes; L – little influence, typically make-to-stock production (L-H, rule R1.2)	
INFO_EXCH	Plant	H – frequent and rich exchanges of information about physical and functional product designs, components and suppliers, delivery times, etc.; M – exchange of design information limited to functional design, reduced information exchange on components and suppliers; L – little exchange of information	L-H, rule R1.2.
IIV	Domin. Process (b)	(1) Number of unique board types (different part numbers) (L-H, rule R1.1) (2) Number of different board sizes (L-H, rule R1.1) (3) Average number of components per board: this is a measure of the size of the differences between individual boards (L-H, rule R1.1)	L-H, applying rule R2 to the five individual items

(*continued*)

Table AI.

Table AI.

Ctx. Var	Unit of Meas.	Measurement items/characterization of the context variable (a)	Rating
		(4) Average number of different types of components per board: same as previous (L-H, rule R1.1) (5) Difficulty of the set-up operations: this is a combination of the sheer item variety and the plant's ability and resources put into simplifying set-ups. This item captures variety as "experienced" by the process (L-H, rule R1.2)	
PROC	Domin. Process (b)	Layout (line vs functional), product routes (fixed vs variable). L – represents the extreme "line layout, fixed routes" (line process); H – the extreme "functional layout, variable routes" (jobbing process); and M – a high volume batch process	L-H, rule R1.2

Notes: Context variables: DSG – degree of control over product design, RNPI – rate of new product introduction, CUST_INFL – influence of customers over operational decisions, INFO_EXCH – intensity of the exchange of information with customers, IIV – internal item variety and PROC – manufacturing process. (a) (L-H): indicates that the measurement item is classified into one of three levels (low, medium and high) by the application of an appropriate rule to the observations made across all cases; (b) The dominant process comprises the PCB assembly lines used to produce the main product line

Table AII.
Display for the use of process quality management practices

Pract.	Unit of Meas.	Description of practice	Measurement items/characterization of the practice (a)	Rating
New product intro.	Main product line	A rich and detailed textual description of the steps undertaken in the new product introduction process	Based on the previous column, a characterization of the new product introduction process along the following items: (1) Formalization of the process (L-H, rule R1.2) (2) Existence of and adherence to design for manufacturability guidelines (L-H, rule R1.2) (3) Extent to which the emphasis is on solving all problems before production begins (L-H, rule R1.2) (4) Extent of use of special tools and techniques (L-H, rule R1.2)	L-H, applying rule R2 to the four individual items
SPC/feedback	Domin. Process (b)	A rich and detailed textual description of the SPC/feedback points in the dominant process, comprising The number and location in the process of these points The analyses performed on the data collected from the feedback points The corrective action mechanisms in place to respond to the feedback	Based on the previous column, an SPC/feedback intensity figure is calculated by dividing the number of SPC/feedback points (adjusted for whether sample or "population" process data was used) by the number of steps in the dominant process	L-H, rule R1.1

Notes: (a) (L-H): indicates that the measurement item is classified into one of three levels (low, medium and high) by the application of an appropriate rule to the observations made across all cases; (b) The dominant process comprises the PCB assembly lines used to produce the main product line