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Design-manufacturing integration and manufacturing complexity

A contingency investigation of job rotation and co-location

Antônio Márcio Tavares Thomé
Industrial Engineering Department,
Pontifícia Universidade Católica do Rio de Janeiro, Rio de Janeiro, Brazil, and
Rui Sousa
Universidade Católica Portuguesa, Católica Porto Business School and CEGE,
Porto, Portugal

Abstract

Purpose – The purpose of this paper is to propose that the effectiveness of organizational design-manufacturing integration (ODMI) practices is contingent upon the degree of complexity of the manufacturing environment. The paper submits that the level of use of ODMI ought to match the level of complexity of the manufacturing environment. The paper puts forward the hypothesis that when a misfit occurs between ODMI and complexity (high use of ODMI practices in low complexity environments or low use of ODMI practices in high complexity environments) manufacturing operational performance declines.
Design/methodology/approach – The paper tests the hypothesis based on a survey database of 725 manufacturers from 21 countries. The measurement model was assessed with confirmatory factor analysis and the hypothesis was tested with linear regression.
Findings – A misfit between the level of ODMI use (job rotation and co-location) and manufacturing complexity (product and process complexity) has a negative effect on manufacturing operational performance dimensions of quality, delivery and flexibility. *Post hoc* analyses also suggest that firms that operate in different environments in what concerns the rate of change in process technologies suffer differentiated negative impacts of ODMI-complexity misfit.
Research limitations/implications – Future studies could extend this research to other dimensions of design-manufacturing integration, such as technological practices.
Practical implications – Manufacturers with high levels of complexity should invest strongly in ODMI practices. However, manufacturers with low levels of complexity should invest in these practices with caution since the expected payoffs may not outweigh the effort.
Originality/value – The study assesses fit as a simultaneous set of contingency factors, applying profile-deviation analysis to ODMI and operational performance relationships. By focusing on plant-level manufacturing complexity, this study complements existing studies of product development complexity which tend to focus on project-level complexity.

Keywords Manufacturing strategy, Structural equation modelling, Engineering management, Manufacturing complexity, Process integration
Paper type Research paper

1. Introduction

Short product life cycles, more informed and demanding customers, and increased competition are pressuring firms to shorten time-to-market for new and innovative products. New product design and development (NPD) requires highly specialized knowledge and expertise, which are often concentrated in specialized organizational units or functions. These functions require organizational integration due to the interdependency of tasks and responsibilities (Lawrence and Lorsch, 1967;

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Thompson, 1967; Vandevelde and Van Dierdonck, 2003). Product design and manufacturing have been recognized as two key functions that need to be integrated (Griffin and Hauser, 1992; Adler, 1995). The sequential logic of designing first and producing later is long questioned (Adler, 1995). Instead, the development of new products and their introduction into production requires the mutual adaptation of product designs and manufacturing processes.

The integration of the design and manufacturing functions can be achieved by organizational practices (e.g. direct contacts, job rotation, co-location) and/or by technological practices (e.g. collaborative information technologies, such as e-mail or decision rules software) (Twigg, 2002). In this paper, we focus on organizational integration practices, namely, job rotation and co-location, from here onwards referred to as organizational design-manufacturing integration (ODMI). Reported ODMI benefits include reduced time-to-market, increase in the quality of final products and cost reductions (Dekkers *et al.*, 2013), as well as increased profit and market-share, higher product effectiveness and better production outcomes (Troy *et al.*, 2008). Although cross-functional integration can be achieved in a number of ways, such as better communications, matrix organizations, reward systems and top management involvement (Mintzberg, 1979), job rotation and co-location are two practices long recognized as being key for the success of NPD projects (Allen, 1977; Dougherty, 1992; Griffin and Hauser, 1996; Browning, 1998). These practices address the reciprocal interdependencies between design and manufacturing, and are able to foster the exchange of tacit knowledge. They are a key element of concurrent engineering (Youssef, 1994), driving cross-functional integration early in the product development project, which is paramount as most NPD costs are committed early in the process (Liker *et al.*, 1999).

Despite extensive research in the past 20 years and substantial progress in understanding the effects of ODMI on manufacturing performance, there is still a lack of comprehension about the contextual conditions under which ODMI is beneficial, as consistently evidenced in recent literature reviews (Troy *et al.*, 2008; Dekkers *et al.*, 2013). Complexity has been proposed as a relevant ODMI contingency (Adler, 1995), with some authors suggesting that a high level of use of ODMI practices may not be effective in low complexity environments (Duysters and Lokshin, 2011). Our study empirically examines the complexity of the manufacturing environment as a contingency factor affecting the impact of ODMI on manufacturing operational performance. By manufacturing environment we mean the plant level, manufacturing setting in which the design and manufacturing functions interact throughout the product development process, from product design to the introduction of a product into production. Complexity is analysed as a contextual variable, grounded on the framework of contingency theory (Lawrence and Lorsch, 1967; Thompson, 1967).

We submit the hypothesis that in order to positively affect performance, the level of ODMI use ought to match the level of complexity of the manufacturing environment. Two basic notions underlie the research: there is an ideal profile of fit between the level of ODMI use and the level of manufacturing complexity; manufacturers that deviate from the ideal profile of fit will exhibit inferior performance than manufacturers that are closer to the ideal profile. We test the hypothesis based on survey data from 725 manufacturing firms.

The study makes four major contributions. First, it enriches our knowledge about the contingencies affecting the use of design-manufacturing integration (DMI). Specifically, we find that while for high complexity manufacturing environments ODMI use enhances performance, for low complexity environments the high use of ODMI may actually hinder performance. Second, we employ a profile-deviation methodology for measuring fit that allows for a novel and systemic examination of ODMI contingencies. Third, by drawing on a large international sample with a wide geographical scope (725 manufacturers in 21 countries), the study provides a rigorous empirical examination of ODMI contingencies that has been lacking in past research. Fourth, we complement existing studies of product development complexity in novel ways. These studies have often focused on the project as the unit of analysis, emphasized product-related complexity and addressed NPD performance. In our study, we take a different focus by addressing plant-level manufacturing complexity dimensions (determined both by product-related and manufacturing process-related aspects) and addressing overall manufacturing performance.

The structure of the paper is as follows. In Section 2, we review the concepts of contingency theory/fit, DMI and manufacturing complexity, resulting in the development of a theoretical framework for ODMI-manufacturing complexity fit. Section 3 develops the research model and hypothesis. Section 4 addresses the methodology of the study, including data and measures. Section 5 presents the results and discussion. Section 6 concludes with a discussion of the contributions to research, implications for practice, limitations and suggestions for future research.

2. Theoretical foundations

2.1 Contingency theory and complexity

In its simpler expression, structural contingency theory (SCT) states that organizations adapt their structures and processes to their environment (or context), in order to attain high performance (Drazin and van de Ven, 1985; Donaldson, 2001). A "contingency" or "contextual variable" is defined as "any variable that moderates the effect of an organizational characteristic on organizational performance" (Donaldson, 2001, p. 7). Of paramount relevance for our study is SCT's postulate that there ought to be some level of fit between the organizational characteristics and each level of the contingency, whereby high levels of fit causes effectiveness and low fit (misfit) causes ineffectiveness (Donaldson, 2001).

One prominent contingency studied by SCT has been organizational complexity. SCT posits that organizational complexity results from organizations adding more subunits specialized in specific tasks, thereby increasing the level of differentiation of its constituent parts (Thompson, 1967). Differentiation is defined as "the state of segmentation of the organizational system into subsystems, each of which tends to develop particular attributes in relation to the requirements posed by its relevant external environment" (Lawrence and Lorsch, 1967, p. 3).

According to SCT, the greater the differentiation the more complex the organization (Hall, 1979). Complexity results from the increase in the number of functions and their interdependencies. Thompson (1967) defines three types of inter-functional dependencies, with increasing levels of complexity: pooled, sequential and reciprocal. Pooled interdependency is present in every organization as each function contributes to the whole; sequential interdependency is related to the ordering of the tasks performed by different functions; reciprocal interdependency occurs when one task executed by a function is dependent on the output of a task executed by another function. These three types of interdependencies are present in product development.

According to Lawrence and Lorsch's (1967) differentiation-integration framework, the greater the differentiation, the greater the organizational complexity and the need for integration. Integration is defined as "the process of achieving unity of effort among the various subsystems in the accomplishment of the organization's task" (Lawrence and Lorsch, 1967 p. 4). SCT posits that highly complex organizations benefit from integration mechanisms such as coordinating departments, task forces, cross-functional coordinating teams, liaison positions and ad hoc committees (Lawrence and Lorsch, 1967; Mintzberg, 1979). On the other hand, in low complexity organizations, information gathering and processing are expected to be minimal, perceived uncertainty is low, decisions are likely to be routine, high standardization and formalization are feasible, and participatory decision making and specialization of functions can be kept to a minimum (e.g. Burns and Stalker, 1961; Woodward, 1965; Thompson, 1967; Perrow, 1970). In this context, a high level of organizational integration is deemed unnecessary and dysfunctional (Tung, 1979).

Our study will adopt the theoretical lens of SCT. Specifically, it will be underpinned by SCT's notion that the adoption of integration mechanisms among functions should match the level of organizational complexity (Hall, 1979; Thompson, 1967). Figure 1 shows the adopted conceptual framework for SCT and complexity.

2.2 DMI

For the purpose of our study, we borrow from Pagell's (2004) definition of integration, to define DMI as the interaction and collaboration between design/engineering and manufacturing managers, who work together to arrive at mutually acceptable outcomes for their organization. The integration between design and manufacturing should occur throughout the several stages of product development, including pre-project, product and process design and manufacturing (Adler, 1995). A number of practices (or mechanisms) have been proposed in the literature for the purpose of integrating the design and manufacturing functions.

Twigg (2002) classifies DMI practices into two broad categories: organizational (e.g. direct contacts, liaison roles, secondment, task forces, project team, role combination, permanent team or cell, integrator function, combined department, matrix organization); and technological (e.g. decision rules software, e-mail, video conferencing, advanced manufacturing technologies). This classification is consistent with those of other studies, whose categories can easily be related to organizational- or technological-related practices. For example, Boyle *et al.* (2006) enlist 12 process-related, 15 people-focused and three information technology DMI practices. Thompson (1967) considers the coordination

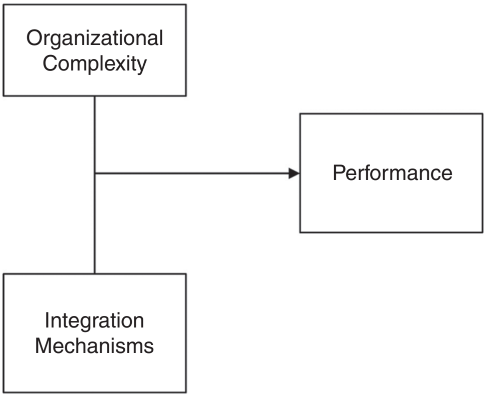

Figure 1. Conceptual framework for structural contingency theory and complexity

mechanisms of standardization or rules, plans and schedules, and mutual adjustments. Van de Ven and Koenig (1976) added the coordination mechanisms of integrated design-manufacturing teams, which demands "the simultaneity of multilateral interactions and which typically requires physical proximity" (Adler, 1995, p. 152). Finally, Adler (1995) proposes four coordination mechanisms: standards, schedules, mutual adaptations and teams.

Our study focuses on organizational (people-related) DMI practices (ODMI), namely, job rotation and co-location. Design/manufacturing job rotation (i.e. having design people work in the manufacturing function and vice versa) is expected to enhance the ability of individuals to serve as gatekeepers and foster interdepartmental integration (Hauptman and Hirji, 1999; Liker *et al.*, 1999; Rusinko, 1999). Physical co-location (i.e. physically locating project personnel in a single area) is expected to enable more rapid and frequent decision making and communication between the two functions (Liker *et al.*, 1999; Rusinko, 1999). According to Browning (1998, p. 103), co-location leads to more expedient resolution of low level issues, as well as an increase in cross-functional awareness and appreciation.

2.3 Complexity of the manufacturing environment

During the development of new products, the design of the products needs to be coordinated with the design and operation of the processes in which they will be manufactured (e.g. Clark and Fujimoto, 1991). Not only the products need to offer desirable functionality to customers, but also the processes in which they will be manufactured need to be capable of meeting adequate operational performance targets such as quality, delivery, flexibility or cost. Thus, the development of new products encompasses the development of manufacturing processes, in a cycle of mutual adaptation of products and processes. Accordingly, a number of initiatives to support this mutual adaptation are usually adopted, such as design for manufacturing, failure mode and effects analysis, prototyping, process capability studies, etc. (Otto and Wood, 2001).

In this context, we argue that in order to understand manufacturing complexity contingencies in ODMI, we need to consider both product-related and process-related sources of complexity. Thus, for the purposes of our paper, we define manufacturing complexity as comprising product and process complexity dimensions. This definition draws on prior conceptualizations of manufacturing complexity that associate complexity with the existence of diverse products/components and process subsystems (e.g. work centres, machines), that are inter-related (Gabriel, 2013; Bozarth *et al.*, 2009). For example, Bozarth *et al.* (2009) define system complexity as comprising the distinct number of components or parts that make up a system as well as their interconnectedness. We next discuss in more detail product and process complexity in the context of the development and introduction of new products into production.

Product complexity has been substantially researched in NPD (e.g. Lebcir, 2006; Grussenmeyer and Blecker, 2013). It has been defined by the number of parts (Murmann, 1994), the number of functions embedded in the product (Griffin, 1997) and the interdependence of parts and functions (Ulrich, 1995). Lebcir (2006) notes that the number of parts and multi-functionality are usually correlated. Ulrich (1995) combines these dimensions in his definition of "integral products" (many inter-related parts and functions), as opposed to simpler "modular products" (few parts/functions). According to Gabriel (2013), the number of product parts and components is a key driver of manufacturing complexity. Consistent with these definitions, we define product complexity in terms of the number of parts and its interdependencies.

Process complexity has not received the same degree of attention as product complexity in the NPD literature. In general, the NPD literature on complexity adopts the NPD project as the unit of analysis and, as a result, tends to emphasize product-related aspects. Process-related aspects are addressed somewhat tangentially by arguing that there are interdependencies between products and process technology that lead to increased complexity in product development. For example, Wheelwright and Clark (1992), consider product newness as a source of NPD project complexity, and state that one of the dimensions of newness is the degree of required change in the process technology. Lebcir (2006) argues that an important driver of NPD project complexity is the existence of reciprocal interdependence between project's elements. In NPD projects, this type of interdependence occurs between products and processes, and leads to snowball effects, by which changes in one project element trigger changes in several other elements, making the effective coordination between functions very complex and hard to achieve (Lebcir, 2006). For Williams (1999), organizational interdependency of the reciprocal type is an important driver of NPD complexity, as each output from one function becomes the input to another function and vice versa. Reciprocal interdependence between products and processes also leads to a higher number and higher complexity interactions between design and manufacturing, an aspect which has been considered as an important driver of NPD project complexity (Tatikonda and Rosenthal, 2000, p. 78).

In summary, studies of complexity in NPD usually adopt the NPD project as the unit of analysis and recognize there are reciprocal interdependencies between products and processes that lead to higher complexity in product development. However, they stop short of discussing the detailed characteristics of the manufacturing processes that affect the complexity associated with the introduction of a new product in the manufacturing processes. In order to close this gap, we take a manufacturing/operations perspective of process complexity. We consider the detailed characteristics of manufacturing processes and recognize that not all manufacturing processes are alike from a product development perspective. Specifically, we draw on Woodward's (1965) contention that process complexity is associated with the technology being used, ranging in an increasing order of complexity from job-shop (low level of automation) to mass production (high level of automation). Thus, we define process complexity in terms of the intensity of use of technology in the manufacturing process and the level of interdependencies across these technologies. This aspect of complexity is consistent with one of the key drivers of manufacturing complexity identified by Gabriel (2013), namely, the existence of different process subsystems and their interdependencies. The more intense and integrated the technology in a manufacturing process is the higher are the changes required when introducing a new product (i.e. reciprocal interdependence increases), corresponding to a more complex product development environment (Wheelwright and Clark, 1992; Williams, 1999; Lebcir, 2006).

2.4 Theoretical framework for ODMI-complexity fit

SCT postulates that there ought to be some level of fit between organizational complexity and integration mechanisms (Section 2.1). ODMI, and in particular job rotation and co-location, can be viewed as an integration mechanism, in accordance with the structural contingency differentiation and integration framework (Lawrence and Lorsch, 1967). Based on this theoretical lens, we posit that in order to positively impact on manufacturing performance, the level of use of ODMI should fit the level of manufacturing complexity. Our overall argument is that as manufacturing complexity increases, reciprocal interdependencies between the design and manufacturing functions also increase, leading to the need for higher integration between the two functions. Consistent with SCT, the reverse argument also applies, so that we posit that when manufacturing complexity is low, the marginal costs of managing ODMI may be higher than the expected benefits. Thus, an ideal profile of ODMI-complexity fit will be attained when both ODMI and complexity are high or when both are low. Accordingly, integration efforts off the diagonal would be dysfunctional and would affect performance negatively. Figure 2 shows the associated framework.

In the next section, we discuss the research model in the specific context of the ODMI and manufacturing/operations literatures.

3. Research model and hypotheses

Many studies have found support for the positive effect of ODMI practices on performance (Griffin, 1997; Koufteros *et al.*, 2002; Swink and Calantone, 2004; Moses and Ahlstrom, 2008; Ernst *et al.*, 2010; Engelen *et al.*, 2012). Examples of studied ODMI practices include cross-functional teams, task forces, integrator roles, recreational activities or collective lunches, co-location, multifunctional design teams, among others (Vandevelde and Van Dierdonck, 2003).

Despite findings of a positive effect of ODMI on performance, Homburg and Kuehnl (2013) argue that the effect of these practices on performance is not clear-cut, and suggest that in some cases the costs of ODMI can outweigh the benefits. Among the drawbacks of ODMI, one could enlist the organizational costs, time and efforts for collaboration (e.g. meetings, workflow coordination, handling decision making by teams with conflicting goals), conflicts over resources and technical issues, budget overruns and project failure (De Luca and Atuahene-Gima, 2007; Troy *et al.*, 2008; Ernst *et al.*, 2010; Cuijpers *et al.*, 2011). These drawbacks are likely to affect several manufacturing performance dimensions negatively. In a similar vein, Turkulainen and Ketokivi (2012) reported mixed empirical evidence concerning the impact of cross-functional integration on NPD lead times. Likewise, Parente (1998) argues that the mere use of cross-functional teams does not automatically lead to successful cross-functional integration. Finally, Jayaram and Malhotra (2010) found that five contextual factors (location of products in a family stream, project size, stage in the product life cycle, innovativeness of the product and predictability of market demand) significantly affected the relationship between DMI-related practices (interactive routines, cross-functional coordination, downstream

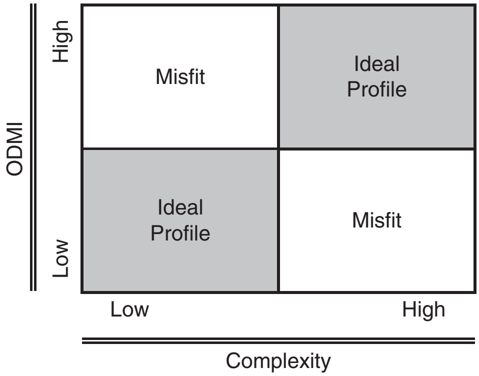

Figure 2.
Fit between levels of ODMI use and manufacturing complexity

coordination and computer-based integrated design tools) and NPD project performance. We submit that the existence of contingency effects emerges as a promising explanation for the mixed findings reported in the literature and merit further study. The contingency view of NPD is consistent with Loch's (2000) argument that Stage-Gate™ processes must fit the environment to succeed and with Davidson *et al.*'s (1999) view that the flexibility of the NPD processes should match organizational needs in NPD projects.

Complexity has consistently been suggested as a relevant ODMI contingency in the organizational and operations management literatures. The higher the complexity and uncertainty of product and technology, the more difficult it is to have a smooth production start-up (Vandevelde and Van Dierdonck, 2003). Adler (1995) posits that the higher the complexity, the higher the need for mechanisms of coordination of design-manufacturing teams. Swink and Calantone (2004) find that ODMI is important at the NPD project level, as "an effective means for coping with technological uncertainty and project organization complexity". However, Duysters and Lokshin (2011, p. 570) have noted that despite the advantages of integration, firms will at a certain stage reach a specific inflection point after which the marginal costs of managing integration are higher than the expected benefits from this increased integration.

Consequently, based on the earlier discussed theoretical framework for ODMI-complexity fit, as well as the organizational and operations management literatures, we posit that a misfit, or deviation from the ideal profile of fit, will negatively affect manufacturing performance (Figure 3). Because our unit of analysis is the manufacturing plant, and as manufacturing plants do not control directly financial or market-share performance, we concentrate on the operational performance of plants. Accordingly, we put forward the following hypothesis:

H1. Misfit to an ideal profile of ODMI use and manufacturing complexity will negatively affect manufacturing operational performance.

We submit that deviations from an ideal fit ODMI-complexity have an adverse effect on a broad range of operational performance dimensions. We concentrate on the dimensions of quality, delivery and flexibility, which are largely controlled at plant level (Akyuz and Erkan, 2010; Hill, 1994) and have been widely used in previous research (e.g. Schmenner and Swink, 1998; Schroeder *et al.*, 2002). Inadequate levels of ODMI are expected to lead to a mismatch between product designs and manufacturing processes, which have adverse impacts on quality, delivery and flexibility performance. We present a number of examples. If product specifications are not adequate to the capability of the manufacturing process technology, both conformance quality and product reliability will suffer. In turn, higher defect rates lead to the increase of

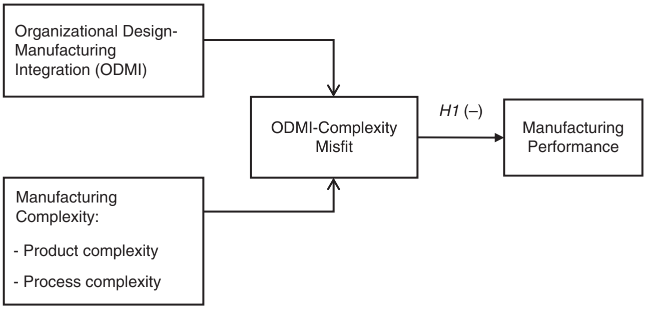

Figure 3.
Research model

manufacturing lead times, harming delivery reliability and delivery speed. Product components set at the design stage which have long or unreliable procurement lead times will also hurt delivery performance. A mismatch between product design and manufacturing processes may also lead to increased changeover times, hurting mix and volume flexibility, as well as delivery speed (Blackburn, 1991). As a final example, exaggerated levels of ODMI resulting in long development cycles may hurt delivery speed and time-to-market.

Thus, we break *H1* into the following three sub-hypotheses: H1.1/H1.2/H1.3 – misfit to an ideal profile of ODMI use and manufacturing complexity will negatively affect quality/delivery/flexibility performance.

Based on a contingency logic (Sousa and Voss, 2008), it is conceivable that the adverse effect of misfit on each individual performance dimension may itself vary according to certain contextual traits of the NPD environment. We explore these detailed contingency aspects *post hoc*, rather than specifying them in our hypotheses.

4. Methods

4.1 Data

The study draws on data from the fifth round of the International Manufacturing Strategy Survey (IMSS-V). The IMSS project periodically collects data on strategies, practices and performance of manufacturers around the world classified in ISIC 3.1 codes 28-35 (metal products, machinery, semiconductor, transportation, advanced instruments and audio-video). The unit of analysis is the manufacturing plant and its dominant activity. The survey was centrally coordinated to maximize consistency in data collection procedures across countries. Country offices translated the questionnaire into the local language when needed and were responsible for local data collection and verification. The director of operations or equivalent from the companies in the 21 countries filled-out the questionnaire in 2009-2010. Out of 4,457 questionnaires sent, 725 valid questionnaires were returned (16.3 per cent response rate). No systematic biases were found in comparing early and late respondents in key characteristics, such as company size and ISIC codes, suggesting the absence of non-response bias (for additional information see Laugen and Boer, 2009; www.manufacturingstrategy.net).

Table I characterizes the sample according to production process, firm size, ODMI level and country. Most plants employed batch production (48 per cent), followed by one-of-a-kind (26 per cent) and mass production (23 per cent). Make-to-order producers were 48 per cent, with 19 per cent of assemble-to-order, 15 per cent of engineered-to-order and 14 per cent of make-to-stock (3 per cent did not declare). The average firm size for the whole sample is 1,849 employees. As expected, mass producers exhibit larger size (3,046) than one-of-a-kind (1,965) and batch producers (1,079). Average ODMI levels were calculated based on answers to a five-point Likert scale measuring job rotation and co-location, as described further in Section 4.2. Table I provides the average ODMI scores by production process, because it is an important descriptor of manufacturing firms in the sample. The average ODMI score for the whole sample was 2.37. Firms classified as mass producers exhibit higher average ODMI scores (2.66), while one-of-a-kind and batch producers have similar ODMI scores (2.23 and 2.29, respectively).

Table II shows the distribution of the sample firms by industrial sector (ISIC codes). Approximately 33 per cent of the sample falls under ISIC code 28, which deals with the manufacture of "pure" metal products (such as parts, containers and structures), usually with a static, immovable function. This is followed by the manufacture of machinery and equipment (ISIC code 29; 25 per cent of the sample), which includes

	Production process				Global sample	
Characteristics	One-of-a-kind	Batch	Mass	Missing	Total	*n*
Average firm size (no. employees)	1,965	1,079	3,046	4,277	1,849	725
Average ODMI	2.23	2.29	2.66	2.63	2.37	698
Country						
Belgium	19%	44%	31%	6%	5%	36
Brazil	22%	46%	30%	3%	5%	37
Canada	63%	32%	5%	0%	3%	19
China	14%	42%	39%	5%	8%	59
Denmark	28%	56%	17%	0%	2%	18
Estonia	41%	44%	15%	0%	4%	27
Germany	18%	58%	24%	0%	5%	38
Hungary	28%	58%	14%	0%	10%	71
Ireland	0%	67%	33%	0%	1%	6
Italy	39%	54%	7%	0%	8%	56
Japan	21%	29%	39%	11%	4%	28
Korea	39%	15%	44%	2%	6%	41
Mexico	12%	24%	53%	12%	2%	17
The Netherlands	27%	57%	16%	0%	7%	51
Portugal	30%	50%	20%	0%	1%	10
Romania	29%	42%	26%	3%	4%	31
Spain	28%	63%	8%	3%	6%	40
Switzerland	26%	58%	16%	0%	4%	31
Taiwan	19%	55%	26%	0%	4%	31
UK	23%	47%	17%	13%	4%	30
USA	21%	48%	27%	4%	7%	48
Total	26%	48%	23%	3%	100%	725

Table I. Characterization of the research sample

ISIC codes	Description	*n*	%
28	Fabricated metal products, except machinery and equipment	242	33
29	Machinery and equipment	185	25
30	Office, accounting and computing machinery	12	2
31	Electrical machinery and apparatus	92	13
32	Radio, television and communication equipment and apparatus	42	6
33	Medical, precision and optical instruments, watches and clocks	42	6
34	Motor vehicles, trailers and semi-trailers	52	7
35	Other transport equipment	34	5
	Not reported	24	3
	Total sample	725	100

Table II. Distribution of manufacturing firms by industrial sector (ISIC codes)

domestic appliances, motors (except electric motors), turbines, pumps, compressors, ovens, burners, agricultural machinery, machine tools, civil engineering, machinery for other industries, weapons and munitions. The third group in importance is ISIC 31 (13 per cent of the sample), which deals with the manufacture of electrical machinery and apparatus, including products such as power generators, motors, insulated wire and cables, electrical lighting and signalling equipment, accumulators, cells, batteries and lamps. Together, these three industrial groups represent about 71 per cent of the total sample.

4.2 Measures

Theory and statistical reasons guided the selection of scale items. The scales were first built based on content validity or conformance with similar constructs in the literature (Ping, 2004).

The construct of ODMI pertains to organizational (people-related) practices. We drew on van de Ven and Koenig's (1976) construct of DMI teams and earlier research on job rotation (Dougherty, 1992; Griffin and Hauser, 1996) and co-location (Allen, 1977; Griffin and Hauser, 1996; Browning, 1998) in NPD projects. Accordingly, ODMI was measured by two items associated with the extent to which the plant organizationally coordinated design and manufacturing by employing: job rotation between design and manufacturing; co-location of design engineers and manufacturing managers.

Consistent with the conceptual framework of Section 2, we considered two constructs pertaining to the complexity of the manufacturing environment of plants: product complexity and process complexity. In order to have a reliable measure of these constructs at the aggregate plant level, we focused on the dominant manufacturing activity of the plants.

Product complexity was measured by three items associated with: the complexity of the manufactured items in terms of the associated product functions (single components vs finished assembled products); the complexity of the bill of materials (number of parts and their interdependencies); the number of steps/operations required in production. This construct is aligned with our discussion of the conceptual domain of product complexity in Section 2.3 and is consistent with earlier research on the subject (e.g. Murmann, 1994; Ulrich, 1995; Griffin, 1997).

Process complexity was measured by four items associated with the core process technology of the dominant activity: extent of automation (manual operations vs highly automated machine tools); extent of systems integration; extent of adoption of process automation programs; and extent of adoption of flexible manufacturing/cell systems. This construct is aligned with our discussion of the conceptual domain of process complexity in Section 2.3, namely, the intensity and interdependencies of the technology used in the manufacturing process.

Operational performance includes the dimensions of quality, delivery and flexibility (Akyuz and Erkan, 2010; Hill, 1994), which have been widely used in previous research (e.g. Schroeder *et al.*, 2002), including those using IMSS data sets. Specifically, we adopted the exact scales and items used previously in the IMSS studies by da Silveira and Sousa (2010) and Thomé *et al.* (2014a, b).

Scales were validated for unidimensionality, validity and reliability using confirmatory factor analysis. Table III shows descriptive statistics for the scale items and the measurement model. All scale items were assessed on a five-point Likert scale response format. The scale items had factor loads on or about 0.6 (Chin, 1998), each contributing to the increase in overall measurement model fit and loading in one dimension only (Anderson and Gerbing, 1988). The scales also passed rigorous tests for convergent and discriminant validity, with CR well above 0.6, AVE over or about 0.5 and AVE's square root higher than inter class correlation (Fornell and Larcker, 1981; Anderson and Gerbing, 1988).

We adopted three criteria to define the acceptance of the measurement model: the normed-χ^2 (χ^2/df) should be close to or higher than 1 and close to or lower than 3 (Jöreskog and Sörbom, 1993); the root mean square error of approximation (RMSEA) should be close to or lower than 0.05 and pclose should be higher than 0.05; and the comparative fit index (CFI) should be close to or higher than 0.95

Table III. Research variables and measurement model

Construct	Items	Factor loads	CR	AVE	1 ODMI	2 PROC	3 PROD	4 QUAL	5 DELI	6 FLEX
Fit variables										
1. Organizational design-manufacturing integration (ODMI)	How do you organizationally coordinate design and manufacturing? (1 – no use; 5 – high use) (2.37, 1.04, 698)		0.68	0.52	*(0.72)*					
	Job rotation between design and manufacturing (2.16, 1.09, 694)	0.735								
	Co-location of design engineers and manufacturing managers (2.57, 1.28, 694)	0.707								
2. Product complexity (PROD)	How would you describe the complexity of the dominant activity? (3.76, 1.03, 714)		0.76	0.53	0.17***	*(0.73)*				
	1 – single manufactured components; 5 – finished assembled products (3.72, 1.42, 707)	0.550								
	1 – very few parts/materials, one-line bill of material; 5 – many parts/materials, complex bill of material (3.72, 1.31, 713)	0.923								
	1 – very few steps/operations required; 5 – many steps/operations required (3.84, 1.09, 711)	0.663								
3. Process complexity (PROC)	How advanced is the core process technology of your dominant activity? (2.68, 0.95, 711)		0.74	0.50	0.52***	0.05	*(0.71)*			
	1 – mostly manual operations; 5 – highly automated machine tools (3.00, 1.10, 707)	0.670								
	1 – mostly standalone machines; 5 – fully integrated systems (2.80, 1.20, 705)	0.764								
	Indicate the effort put into implementing the following action programs in the last three years									
	Extent of adoption of process automation programs (1 – none; 5 – high) (2.50, 1.20, 696)	0.718								
	Extent of adoption of flexible manufacturing/assembly systems – cell programs (1 – none; 5 – high) (2.70, 1.30, 701)	0.664								

(continued)

Table III.

Construct	Items	Factor loads	CR	AVE	1 ODMI	2 PROC	3 PROD	4 QUAL	5 DELI	6 FLEX
Performance variables: how does your current performance compare with your main competitor(s)? (1 – much worse; 5 –much better)										
4. Quality (QUAL)			0.73	0.58	0.29***	0.13**	0.35***	*(0.76)*		
	Manufacturing conformance (3.49, 0.72, 596)	0.763								
	Product quality/reliability (3.63, 0.79, 601)	0.757								
5. Delivery (DELI)			0.82	0.54	0.34***	0.08*	0.32***	0.69***	*(0.74)*	
	Delivery speed (3.44, 0.79, 584)	0.743								
	Delivery reliability (3.49, 0.81, 586)	0.757								
	Manufacturing lead time (3.36, 0.72, 563)	0.762								
	Procurement lead time (3.16, 0.71, 556)	0.678								
6. Flexibility (FLEX)			0.78	0.64	0.30***	0.06	0.31***	0.57***	0.69***	*(0.79)*
	Volume flexibility (3.58, 0,81, 579)	0.787								
	Mix flexibility (3.51, 0.79, 582)	0.815								

Notes: CR, composite reliability; AVE, square roots in the main diagonal, in italics and parentheses. Factor loads and correlations obtained with Amos 19; means, standard deviations and number of cases provided in parenthesis after definition of variables. Calculated with SPSS-20. all items measured in a five-point 1-5 scale (endpoints shown above). $*p < 0.1$; $**p < 0.05$; $***p < 0.01$

(Browne and Cudeck, 1993; Hu and Bentler, 1999; Schermelleh-Engel *et al.*, 2003). According to these criteria, the overall fit of the measurement model was good (χ^2/df = 2.8; CFI = 0.95; RMSEA = 0.05 in the interval of 0.044 and 0.057; pclose = 0.457).

4.3 Ideal profiles and profile deviation

The concept of fit is not straightforward (da Silveira and Sousa, 2010). Sousa and Voss (2008) combined the typologies of Drazin and van de Ven (1985) and Venkatraman (1989) into three broad classes of fit: selection (matching), interaction (moderation, mediation) and systems (gestalt, profile deviation and covariation). In our study we adopt the systems approach, in which fit is a holistic concept asserting that context-structure-performance relationships are multi-faceted and require simultaneous analyses that consider several contingencies at the same time.

Fit is defined here in accordance with configurational theories, which typically posit higher effectiveness for organizations that resemble an ideal profile of fit. The increased effectiveness of the ideal profile is attributed to the "internal consistency, or fit, among the patterns of relevant contextual, structural, and strategic factors" (Doty *et al.*, 1993, p. 1193). In this connection, fit can be assessed based on the deviation that a firm exhibits from the ideal profile. A challenge with testing fit as profile deviation is to find the "ideal profile". Within the systems approach, the computation of ideal profiles can be done in a number of ways, including being based on the average of a firm's own fit dimensions (da Silveira, 2005), on a sample of top performers (e.g. Venkatraman and Prescott, 1990; Das and Narasimhan, 2001) or by comparison with best systems defined a priori based on the literature (e.g. Ahmad and Schroeder, 2003).

In our study, we followed da Silveira's (2005) approach to compute the ideal profile from the average of a firm's own fit dimensions, namely, the manifest variables of ODMI and manufacturing complexity (product complexity and process complexity). This was for two reasons. First, this approach is aligned with Lawrence and Lorsch's (1967) contingency framework, according to which each organization attains its ideal profile by matching its own structure with its own managerial processes and with the environment. The assumption implied in this "measure by average" is that departure from the average would represent a misfit and impact negatively on operational performance. Conversely, different organizational arrangements (not specified a priori by theory or by comparison with specific top-performers' profiles) could equally and effectively drive higher performance in case of fit, or proximity to the average. This definition is consistent with the concept of "equifinality" in SCT, which implies that there could be multiple "ideal profiles" and that multiple organizational forms could be equally effective (Drazin and Van de Ven, 1985; Doty *et al.*, 1993; da Silveira, 2005). From a theoretical stand point there is no reason to expect a priori that a particular type of ODMI profile would result in superior performance, but the fit of ODMI with the contextual factors of the firm can take upon different and equally effective configurations.

The second reason for our choice of ideal profile was its consistency with Hill's (1994) definition of the ideal profile of manufacturing organizations in the orders winners' framework. According to this framework, the ideal profile for each plant, against which each individual variable is compared, is given by the average of the variables that should exhibit fit (fit variables).

Da Silveira (2005) measures deviations (distances) from the ideal profile based on the Euclidian distance, as depicted in Equation (1). The equation computes the level of deviation of organization i ($MISFIT_i$) from its ideal profile $\overline{X}_i$. As explained above, a firm's ideal profile $\overline{X}_i$ is computed as the average of the fit variables ($\overline{X}\mathrm{i} = \sum_{j=1}^{9} X_{ij}/9$), in which X_{ij} represents each of the nine manifest fit variables (variables corresponding to constructs 1 to 3 in Table III). The use of the square root of the Euclidian distance instead of the Euclidean distance is because it produces scores that are close to a normal distribution, which is an assumption for regression analysis (da Silveira, 2005). Because there is no reason to suppose a priori that one fit variable is more important than another, they all received equal weights:

$$MISFIT_i = \sqrt{\frac{\sum_{j=1}^{9} \left(X_{ij} - \overline{X}\mathrm{i}\right)^2}{8}}. \tag{1}$$

5. Results and discussion

5.1 Hypothesis test

H1 states that ODMI-complexity misfit will negatively affect performance. Following da Silveira (2005), *H1* is tested with a simple linear regression of misfit on manufacturing operational performance, with the following equation:

$$Y = \alpha + \beta_1 \, MISFIT_i + \xi_{,i}. \tag{2}$$

where Y represents the performance measures of quality, flexibility and delivery, calculated in three separate equations. *H1* is supported if β_1 is negative and statistically significant.

Data analysis started with the computation of the ideal profile and the index of "misfit" of ODMI-complexity for each plant in the sample (Equation (1)). We then regressed the misfit variable on the three manufacturing operational performance dimensions (Equation (2)). Table IV shows the results. All regression coefficients are negative and statistically significant ($p < 0.10$ for quality and delivery; $p < 0.05$ for flexibility). Thus, *H1* is supported for quality (H1.1), delivery (H1.2) and flexibility (H1.3).

In summary, the results show a negative effect of ODMI-complexity misfit upon all three dimensions of manufacturing operational performance (quality, delivery, flexibility). These results are consistent with both the literature on ODMI and contingency theory.

Concerning the literature on ODMI, the results are consistent with earlier findings of a non-linear relationship between ODMI and performance (Homburg and Kuehnl, 2013). Our findings support the notion that, depending on the level of manufacturing complexity, there is a turning point beyond which the advantages of increased levels of use of ODMI might not overcome the costs (Adler, 1995; Duysters and Lokshin, 2011;

Variables	Quality	Delivery	Flexibility
n	541	497	523
Constant	*3.708 (0.000)*	*3.514 (0.000)*	*3.721 (0.000)*
MISFIT	*−0.075*	*−0.084*	*−0.090*
R^2	0.006	0.007	0.008
F	*3.036*	*3.506*	*4.254*
df	(1,539)	(1,495)	(1,521)
p-value	*0.082*	*0.062*	*0.040*

Notes: *p*-values for unstandardized parameter estimates are in parenthesis. Significant estimates and *F* are set in italics ($p < 0.10$)

Table IV. Regression analysis of misfit on performance

Homburg and Kuehnl, 2013). However, for complex environments, ODMI may contribute to easing the process of product introduction and manufacturability, contributing to higher levels of product conformance and reliability, on time and reliable delivery, product volume and mix flexibility.

Concerning contingency theory, our results are in accordance with Lawrence and Lorsch's (1967) framework of differentiation and integration in complex organizations. Consistent with this framework, our study suggests that in complex manufacturing environments, the integration mechanisms of job rotation and co-location may contribute to closing the gap between departments and personnel with different professional cultures and knowledge (e.g. design vs manufacturing engineers), thereby leading to improved manufacturing performance.

5.2 Consequences of misfit under different environments of process technology change

The results revealed a uniform negative impact of misfit on all three dimensions of performance (quality, delivery, flexibility). As mentioned in Section 3, based on a contingency logic (Sousa and Voss, 2007, 2008), it is useful to further analyse *post hoc* whether the adverse effect of misfit on each individual performance dimension varies for different NPD environments. As discussed in Section 2.3, a significant contribution of our study is to understand the fit between ODMI and manufacturing complexity by including process-related sources of complexity. Thus, it is of particular interest to explore the consequences of misfit under different degrees of technological change in manufacturing processes. While research in NPD has emphasized the degree of technological change in products as an important attribute of the NPD environment, it has paid relatively less attention to the extent of technological change in manufacturing processes. Accordingly, we examine in detail the adverse effects of misfit on performance (quality, delivery, flexibility) for two groups of firms: low levels of change in process technology (stable process technology) vs high levels of change in process technology (volatile process technology).

A subgroup analysis was performed using the same methodology that was applied to the overall sample. Misfit was calculated with Equation (1) and regressions with Equation (2). The subgroups were based on a median half-sample split of a perceptual variable in the IMSS questionnaire characterizing the degree of technological change in core production processes (1 – slowly to 5 – rapidly). Each group represents a more homogeneous environment in terms of process technology change than the overall sample. The Appendix shows the characterization of the two groups (Table AI) and the detailed regression results (Table AII). The volatile process technology group exhibits higher average firm sizes, higher levels of ODMI use, a slightly larger proportion of mass producers and higher proportions of manufacturers of electrical machinery and apparatus (ISIC code 31). Table V summarizes the negative impact of misfit on each dimension of performance. The results show that misfit has differentiated negative impacts on performance in the two groups.

Table V.
Effect of misfit on performance under different environments of process technology change

		Impact of misfit on performance (p-values)		
Process technology change	Median	Quality	Delivery	Flexibility
Please indicate what characterizes technological change in your business (1 – slowly; 5 – rapidly)				
Core production processes change	Slow (< 3)	*0.016**	*0.072**	0.451
	Rapid (⩾3)	0.765	0.235	*0.034**

Note: *p-values in italic indicate a significant negative effect of misfit on performance ($p < 0.10$)

For firms in stable process technology environments, the distinguishing impact of misfit occurs for quality and delivery. In other words, firms in this group which show deviations from adequate levels of fit will be at a disadvantage on quality and delivery relative to their counterparts. Deviations from fit seem to be more forgiving in what concerns flexibility, since they do not lead to significant adverse impacts on this performance dimension. For firms in volatile process technology environments, the distinguishing impact of misfit occurs for flexibility. That is, firms in this group which show misfit will be at a disadvantage on flexibility relative to their counterparts. Deviations from fit in these firms seem to be more forgiving in what concerns quality and delivery, since they do not lead to significant adverse impacts on these performance dimensions.

A possible explanation for these results may be that the benefits of ODMI-complexity fit (implying an effective coordination between product design and manufacturing) on different performance dimensions take place in different ways. The impact of ODMI fit on quality and delivery is expected to occur over time, as learning about the processes takes place during their operation. Over time, a better fit between products and processes is achieved through mutual adaptations of both, leading to improved "steady-state" operation of the manufacturing processes, reflected in higher levels of quality and delivery. On the other hand, the impact on flexibility may be more heavily determined at the time the processes are commissioned, as it is strongly influenced by structural decisions such as process layouts and technology traits. At this early stage, ODMI fit is important to ensure that the new processes are well matched with the product designs.

Therefore, in firms with stable process technology there is a sufficient period of time (before technology changes) for adequate levels of fit to produce positive impacts on quality and delivery performance. However, in firms with volatile process technology there may not be sufficient time before technology changes for significant learning during process operation to occur. Regarding flexibility, in firms with volatile process technology, a very effective design-manufacturing coordination is needed to achieve flexibility whenever technology changes and new processes are installed. However, in firms with stable process technology, flexibility may be already naturally imbedded in the existing process technology from knowledge acquired in the past, leading to less differentiation of the impacts of ODMI fit on flexibility across firms.

These results suggest that the fit between ODMI and complexity when considered within more homogenous groups in terms of changes in process technology, produces differentiated performance advantages. In volatile process technology environments, fit provides a competitive advantage based on flexibility, while in stable process technology environments fit provides a competitive advantage based on quality and delivery. These impacts are theoretically meaningful and in line with prior literature (e.g. Narasimhan *et al.*, 2012), providing a deeper understanding of the competitive implications of ODMI-complexity fit.

6. Conclusions

6.1 Contributions to research

Our study found that a misfit between the level of ODMI use (job rotation and co-location) and manufacturing complexity (product and process) has a significantly negative effect on the manufacturing operational performance dimensions of quality, delivery and flexibility. The study makes several important contributions to research.

First, our study provides evidence of a contingent effect of manufacturing complexity on the ODMI-performance relationship and thus contributes to the on-going debate about the conditions under which ODMI can be beneficial to performance. Consistent with contingency theory and our proposed theoretical framework, the results show that those manufacturers that conform to an ideal profile of ODMI-complexity fit (by which high complexity should correspond to higher use of ODMI, and vice versa), outperform those manufacturers that operate farther from this profile. In other words, ODMI is context dependent and, as such, there is no such thing as "one size fits all" or universal approach to DMI.

Second, we complement existing studies of product development complexity in novel ways. In general, these studies adopt the NPD project as the unit of analysis, tend to emphasize product-related aspects of complexity and address NPD performance. Our study takes a different focus by addressing plant-level manufacturing complexity dimensions (determined both by product-related and manufacturing process-related aspects) and addressing overall manufacturing performance. A key implication of our study is that not all manufacturing processes are alike from a product development perspective. Specifically, complex manufacturing processes (i.e. with high levels of automation and systems integration) lead to higher levels of interdependencies with product design, thus requiring higher levels of ODMI. Thus, future research on NPD complexity should explicitly address process complexity alongside product complexity, as key attributes of the NPD environment. In addition, such research should extend the performance impacts of NPD activities beyond the NPD project, to encompass manufacturing performance. This will require studies that have the manufacturing plant as the unit of analysis and, accordingly, that look at representative sets of NPD projects as a whole, rather than at each project in isolation. While it is important that each project is successful *per se* (e.g. meeting time-to-market goals), it is also important that the manufacturing plant where those products are manufactured will exhibit sustainable and competitive levels of manufacturing performance across a range of new products.

Third, the study addresses multiple manufacturing performance dimensions individually, going beyond research that often measures performance as a single aggregate performance construct. The finding that ODMI-complexity misfit impacts multiple performance dimensions (quality, delivery and flexibility) highlights the importance of pursuing a contingency approach in the design of ODMI initiatives. Our *post hoc* analyses provide additional insights on the effects of fit on different performance dimensions. Specifically, they suggest that, when considered within more homogenous groups of firms in terms of change in process technology, the fit between ODMI and complexity produces differentiated performance advantages. In volatile process technology environments, fit provides a competitive advantage based on flexibility, while in stable process technology environments fit provides a competitive advantage based on quality and delivery. These impacts are theoretically meaningful and provide a deeper understanding of the competitive implications of ODMI-complexity fit.

Fourth, the empirical examination involved a large set of manufacturers from countries at different levels of development, employing a diversified array of production processes (from one-of-a-kind products to batch and mass production), and originating from different industries (metal products, machinery, semiconductor, transportation, advanced instruments and audio-video). This level of diversity enhances the generalizability of the findings, enriching the contribution to contingency research on DMI.

Finally, our study also effects a methodological contribution by successfully applying Venkatraman's (1989) Euclidean distance approach and da Silveira's (2005) suggested measurement technique of profile deviation to analyse fit in ODMI. This approach is simple and parsimonious, because it requires a single predictor of misfit and the use of simple regression analyses of misfit on performance. Alternative approaches to analysing fit would be typically more complex. For example, the test of compliance of different and simultaneous fit configurations to a set of possible ideal profiles, would require simultaneous equation modelling or multiple regression techniques (Doty *et al.*, 1993). Thus, we contribute to the generalization of a simple profile-deviation method to assess fit as a simultaneous set of contingency factors. Future research might employ this method to study ODMI contingencies beyond manufacturing complexity.

6.2 Implications for practice

Our findings suggest that manufacturers should adapt the level of use of ODMI to the level of complexity of their manufacturing environments, in order to attain high performance. Thus, manufacturers with high levels of manufacturing complexity should invest strongly in ODMI practices, including job rotation and co-location of manufacturing and design engineers. However, manufacturers with low levels of complexity should invest in these practices with caution since the expected payoffs may not outweigh the effort and may actually hurt performance. The need for fit between complexity and ODMI use also needs to be observed dynamically along time. For example, if manufacturers undertake manufacturing complexity reduction initiatives (e.g. reduction of number of product components and manufacturing steps) they may benefit from subsequently relaxing their ODMI efforts accordingly. Thus, it is important that when manufacturers apply lean thinking or similar approaches to reduce manufacturing complexity, they recognize that such initiatives have positive spill-overs for the simplification of DMI activities.

Our results also suggest that firms that operate in different environments in what concerns the rate of change in process technologies suffer differentiated negative impacts of ODMI-complexity misfit. Specifically, firms operating in industries with volatile process technologies which do a poor job in seeking ODMI-complexity fit, will suffer an adverse impact on flexibility *vis-à-vis* their counterparts, while those that operate in industries with stable process technologies will be at a disadvantage in terms of quality and delivery.

The profile-deviation approach that we developed in our research could be used for performance benchmarking with useful practical implications. One possibility would be to calculate the ideal ODMI-complexity profile within a given industry, and employ this profile as a benchmark to assess a specific firm's profile. Another practical extension of our approach could be for a multi-plants manufacturer to compare individual plant profiles with their own average "ideal" profile.

6.3 Limitations and future research

This study has some limitations that open opportunities for future research. Our study addressed long used ODMI practices associated with organizational integration (people related), namely, job rotation and co-location. Future studies might extend this research to other ODMI practices (e.g. concurrent engineering or mechanisms to manage cross-functional teams), as well as to technological DMI practices (e.g. the use of computer-aided design and manufacturing tools). They might also identify the most effective DMI practices in different contexts. Future studies could also use the case study method to examine in more detail the adverse consequences of ODMI-complexity misfit, namely, the mechanisms by which misfit negatively affects different performance dimensions. Our *post hoc* analyses revealed a differentiated impact of misfit on individual performance dimensions for stable and volatile process technology environments, and we advanced possible explanations for this differentiated impact. Case-based studies would be especially useful to validate and enrich these explanations.

Finally, although our study has examined a diverse set of industries, future studies should examine DMI-complexity contingencies in additional industries. To contrast high clock-speed and low clock-speed industries would be of particular interest, as these should exhibit very diverse product development environments.

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Appendix. Consequences of misfit under different environments of process technology change

Sample characteristics	Process technology change groups[a] Group 1 – stable (< 3)	Group 2 – volatile (≥ 3)	Total
Average firm size (no. employees)	885	2,442	1,849
Average ODMI	2.09	2.53	2.37
Production process			
One-of-a-kind (%)	28	26	27
Batch (%)	50	46	48
Mass (%)	18	26	23
Missing (%)	4	2	2
Industry sector (ISIC codes)			
28 – fabricated metal products, except machinery and equipment (%)	37	31	33
29 – machinery and equipment (%)	32	22	25
30 – office, accounting and computing machinery (%)	2	2	2
31 – electrical machinery and apparatus (%)	6	17	13
32 – radio, television and communication equipment and apparatus (%)	5	6	6
33 – medical, precision and optical instruments, watches and clocks (%)	6	5	6
34 – motor vehicles, trailers and semi-trailers (%)	5	9	7
35 – other transport equipment (%)	3	5	5
Not declared (%)	4	3	3
Grand total (%)	100	100	100

Note: [a] Please indicate what characterizes technological change in your business (1 – slowly; 5 – rapidly)

Table AI. Characterization of the groups of process technology change

Table AII.
Regression results for the groups of process technology change

Variables	Quality	Delivery	Flexibility	Variables	Quality	Delivery	Flexibility
Group 1: stable process technology				*Group 2: volatile process technology*			
n	186	177	183	*n*	348	313	332
Constant	3.870 (0.000)	3.619 (0.000)	3.685 (0.000)	Constant	3.623 (0.000)	3.481 (0.000)	3.769 (0.000)
MISFIT	*−0.177*	*−0.136*	−0.056	MISFIT	−0.016	−0.067	*−0.116*
R^2	0.031	0.018	0.003	R^2	0.000	0.005	0.014
F	*5.960*	*3.276*	0.570	F	0.089	1.413	*4.528*
df	(1,184)	(1,175)	(1,181)	df	(1,346)	(1,311)	(1,330)
p-value	*0.016*	*0.072*	0.451	p-value	0.765	0.235	*0.034*

Notes: p-values for unstandardized parameter estimates are in parenthesis. Significant estimates and F are set in italics ($p < 0.10$)

About the authors

Antônio Márcio Tavares Thomé is a Professor in the Industrial Engineering Department at the Catholic University of Rio de Janeiro, where he obtained his Doctoral and Master Degrees. He graduated at the Political Sciences Institute of Bordeaux, France and obtained a Master Degree in Demography at the Sorbonne-Nouvelle, University of Paris I. His interests in the field of engineering and organizational sciences are operations strategy and planning, supply chain management, manufacturing strategy and research methods in operations management. He was formerly with Westinghouse Electric Corporation, The Population Council, Cambridge Consulting Corporation and BEMFAM. He has published in international journals as *Population Studies*, *Population et Société*, *Studies in Family Planning*, *International Journal of Production Economics*, *International Journal of Production Research*, *Industrial Management and Data Systems*, *International Journal of Production and Productivity Management*. Professor Antônio Márcio Tavares Thomé is the corresponding author and can be contacted at: marcio.thome1@gmail.com; mt@puc-rio.br

Rui Sousa (PhD, London Business School) is a Professor of Operations Management at the Catholic University of Portugal (Porto). His research has won several awards and has been published in leading international journals, including the *Journal of Operations Management, Production and Operations Management, Decision Sciences, Journal of Service Research* and *the International Journal of Operations & Production Management*. Rui serves on a number of editorial review boards (e.g. *JOM, IJOPM*) and is an Invited Lecturer at the European Institute of Advanced Studies in Management (EIASM, Belgium). Rui is also the Director of the Service Management Lab (SLab) and a member of the Portuguese Scientific Council of Social Sciences. His present research interests include service operations, multichannel services and operations strategy.