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A Systematic Literature Review of Design-Manufacturing Integration for Sustainable Products

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Functional integration in Operations Management (OM) is long recognized as a key driver for new product development and manufacturing performance. Design-manufacturing integration (DMI) aspects related to people, technology, and tools occupy the centre stage in New Product Development (NPD) debate, extending beyond the factory walls to the Supply Chain (SC). More recently, the design of environmentally conscious products is gaining prominence in DMI/NPD performance research. However, despite the relevance of the subject, there is still a paucity of rigorous and systematic literature reviews relating DMI and NPD to environmental, economic, and social sustainability. This paper aims to contribute to close this gap through a rigorous research synthesis. The Web of Sciences (WoS) database was searched with predefined and reproducible keywords, adhering to a strict protocol. Citation network analysis (CNA) was applied to the selected studies and updated with a search for the process industry in papers from the Chemical Engineering Transactions (CET) and Clean Technology Environmental Policy (CTEP) Journals. Two major research streams were identified through main path analysis. Both research streams underpin the relationships between internal cross-functional coordination, product life-cycle management, and supplier involvement in green products, reverse logistics, and the environment. Searches in keywords of 2013-2014 articles in CET and CTEP Journals confirmed a sustained number of environment-related publications. Directions for future research and an extension of the research to demonstration projects in the process industry are proposed.

1. Introduction

Nowadays being sustainable and profitable is necessary, but it is still a constant challenge facing manufacturing (Pujari et al., 2003) and service providers alike (Pujari, 2006). There is a quest to create 'shared values' for the company and the society at large (Porter and Kramer, 2011), under the "triple bottom line" of economic, societal and environmental achievements (Mattioda et al., 2013). Sustainable development often goes beyond the boundaries of the firm and into the Supply Chain (Deutsch et al., 2013). This challenge is even more pressing in the process industry, in which "targeted properties involve a combination of chemical, mechanical and thermal behaviour resulting from the structural and compositional nature of the product", with important implications for the environment (Seferlis and Varbanov, 2014). The issue of sustainability is even more acute when facing new product development (NPD) uncertainties and market competition pressuring for short time-to-market, reliability, and conformance quality at low cost. However, despite the recurrence of the theme there is not a recipe for integrating sustainability in the design and manufacturing phases of NPD (Petala et al., 2010). This paper reviews the extant literature in an attempt to describe the main paths of influential publications shaping the field of sustainable NPD. Two research questions guide this study: (i) "who are the prominent authors/what are their publications in sustainable NPD?" and (ii) "what are the prevailing themes in sustainable NPD?" Despite recent literature reviews in both NPD and sustainability – e.g.(Arnete et al., 2014) review of design for sustainability, and (Lockrey, 2015) review of life cycle management in NPD, there was no attempt to bridge the fields with an integrative review focusing on main research streams on the confluence of NPD and the environment, as the one proposed here. Given these premises, the rest of this paper is structured

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as follows: first, the paper presents the methodology used for the systematic literature review. Then the paper outlines and discusses the main findings. Finally, there is the conclusion including recommendations for future research.

2. Methodology

Systematic literature reviews (SLRs) are research endeavours by themselves seeking to provide transparent and reproducible processes of locating, selecting, analysing, and reporting relevant research in a given subject (Denyer and Tranfield, 2009). The seven steps of the approach of Cooper (2010) are: (i) planning; (ii) searching; (iii) data gathering; (iv) quality evaluation of primary research; (v) analysis; (vi) interpretation; and (vii) reporting. This study adopts this approach to select, to describe, and to report the findings. This paper uses the searching and data gathering steps adapted from Thomé et al. (2012) and Thomé et al. (2014). The ISI Web of Science (WoS) database was selected in the first step. Second, the paper searched WoS with the following structure of keywords and Boolean operator: “TOPIC: ("design-manufacturing integration" OR "new product development") AND TOPIC: ("Green" OR Sustainab* OR Environment* OR "Social Corporate Responsibility"). Then to refine the search, the paper restricted results to peer reviewed research papers and reviews as a quality check for primary research published only in the English language with no restrictions regarding time span. Third, the authors of this paper manually reviewed all abstracts and they dropped the papers not corresponding to the criteria for inclusion. They ensured reliability of the selection process by repeating the manual selection process in three different occasions, with same results. All papers indexed by SCI-EXPANDED, SSCI, A&HCI, CPCI-S, and CPCI-SSH and conforming to the selection criteria were included. The search results, the criteria to exclude papers, and the total number of papers selected appear in Table 1. All papers from the 42 selected abstracts were full text reviewed. The complete bibliographic reference is available upon request.

Table 1: Selection of papers for the systematic literature review

Exclusion Criteria	Number of selected records
None	759
Proceedings Papers, Editorial Material, Meeting Abstracts	499
Language other than English	495
Agriculture (e.g., farm animals (DMI), "green beans"), non-permanent disability (NPD), Optics and electronics (e.g., "green lights"), Environment as in contingency theory, e.g. contextual variables. Sustainable, sustainability and its derivatives not having an ecological meaning (e.g., synonym of bearable, maintainable, sustainable competitive advantage)	42

The analysis phases combined the SLR technique with citation network analysis (CNA) to locate the main paths or main research streams based on the number of citations paper receives using Pajek software (De Nooy et al., 2005) to apply graph theory to CNA (Colicchia and Strozzi, 2012). It applies systematically forward snowball search to the main research streams identified.

As CNA is based on the articles cited in current literature, it refers to past trends reflecting the basis of a given research field. However, CNA might not cover actual trends adequately. In an attempt to circumvent this limitation for the chemical engineering field, the titles of articles from Chemical Engineering Transactions (CET) and Clean Technologies and Environmental Policy (CTEP) Journals were also searched for the 2013-2014 period. The prevalent themes were derived from the frequencies of occurrence of words in titles, user keywords and abstracts, using BibExcel software (Persson et al., 2009). All 2,007 published articles, Conference Proceedings and Reviews appearing in 2013 - 2014 in CET and CPET Journals were included in the analysis.

3. Results

The theme of sustainable NPD is being increasingly researched, as depicted in Figure 1 with a constant increase in the number of publications per year, accentuated after 2010. The ten top journals, as ranked by WoS Global Citation Score (GCS) appear in Table 2.

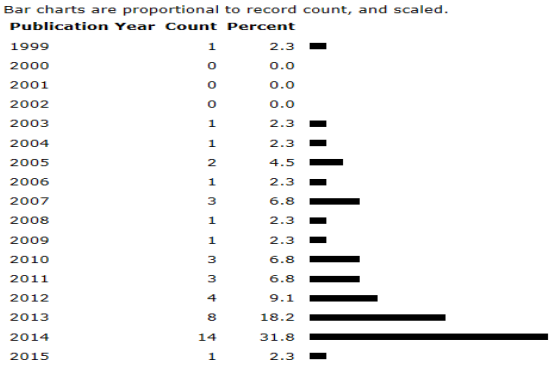

Figure 1: Number of publications on sustainable NPD per year

Table 2: High impact journals in Sustainable NPD

Journal	GCS	# of papers
Computers & Industrial Engineering	356	1
Journal of Business Research	74	1
Journal of Cleaner Production	72	8
Industrial Marketing Management	51	2
Journal of The Academy of Marketing Science	50	1
International Journal of Production Research	29	1
Business Strategy aAnd The Environment	14	2
Journal of Engineering and Technology Management	8	2
Management Decision	8	1
Journal of Product Innovation Management	6	4

GCS: Global citation score

Two main streams of research were identified: the influential early work of Gungor and Gupta (1999), which appeared in Computers & Industrial Engineering, Pujari et al.'s (2003) framework for environmental new product development, Pujari et al. (2004) analysis of the antecedents of new product development, and Pujari (2006) on greening of product innovation, published in the Journal of Business Research, Industrial Marketing Management, and Technovation. In summary, while the former introduces the basic concepts, models, and frameworks for sustainability in NPD, the later three papers are more concerned with the empirical consubstantiation of findings about the effects of sustainable NPD in performance. The Journal of Cleaner Production has the largest amount of papers published on the subject of sustainability and NPD interface, although the most influential paper in this area appeared in Computer & Industrial Engineering (Gungor and Gupta, 1999).

3.1 Gungor and Gupta (1999) research stream

The forward search on Gungor and Gupta's (1999) paper appears in Table 3, where the ten most cited papers that cite Gungor and Gupta (1999) are classified in descending order of impact (measured by GCS). Although it is somehow arbitrary to select a cutting point of 10 most cited articles, it is consistent with CNA call for parsimony (Colicchia and Strozzi, 2012) and is a common practice in bilbiometrics (Persson et al., 2009). It does not intend to be an exhaustive list of papers but to guide the identification of prevalent themes in the research stream. It is readily apparent from Table 3 that four influential papers are literature reviews (LR), three are conceptual papers (CP), and three are conceptual papers associated with modelling (CP-M). The main sustainability themes interfacing with NPD were sustainable supply chains (Linton et al., 2007), product recycling (Sodhi and Reimer, 2001), reverse logistics (Ravi et al., 2005), disassembling (Lambert, 2002), and product manufacturing (Sundin and Bras, 2005).

3.2 Pujari et al. (2003) main path

Pujari et al. (2003) main path is depicted in Figure 2 which for simplicity presents the first authors of each paper. Pujari et al. (2003) propose an environmental NPD (ENPD) framework comprised by the integration into traditional NPD of product life cycle assessment, design for the environment, and supplier evaluation. Applying the framework to survey research in the British industries, Pujari et al. (2004) conclude that there

are synergies between traditional NDP and ENPD. Top management support, DMI, and environmental product policies are antecedents to move from NPD to ENPD. Pujari (2006) applies the ENPD framework to the US industries finding that factors influencing market performance of greener products are “cross-functional co-ordination between new product development professionals and environmental specialists, supplier involvement, market focus and life cycle analysis”.

Table 3: The ten most cited papers referencing Gungor and Gupta (1999)

Author (date)	Journal	GCS	Method
Srivastava, 2007	International Journal of Management Reviews	402	LR
Cui and Forssberg, 2003	Journal of Hazardous Materials	266	LR
Linton et al., 2007	Journal of Operations Management	209	CP
Ilgin and Gupta, 2010	Journal of Environmental Management	169	LR
Ravi et al., 2005	Computers & Industrial Engineering	127	CP
Lambert, 2003	International Journal of Production Research	124	LR
Lambert, 2002	Computers & Industrial Engineering	79	CP-M
Sundin and Bras, 2005	Journal of Cleaner Production	76	CP
Schultmann et al., 2006	European Journal of Operational Research	73	CP-M
Sodhi and Reimer, 2001	Or Spektrum	69	CP-M

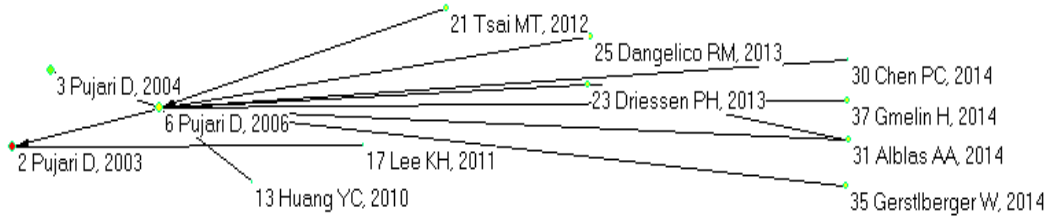

Figure 2: The main citation path for Pujari et al. (2003)

Huang and Wu (2010) apply survey research to a sample of 181 hi-tech companies in Taiwan. The study corroborates Pujari et al. (2003) and Pujari et al. (2004) results regarding the effect of cross-functional integration, market focus, and corporate commitment in green performance and it finds a positive relationship between green performance and financial performance. Lee and Kim (2011) explore further the linkage between supplier involvement and ENDP in a case study in Korea, confirming Pujari et al. (2003) and later Pujari et al. (2004) early findings of a positive relationship with green performance.

Tsai et al. (2012) survey both manufacturers and customers for green toys. The buying of green toys increases as more people tend to buy green because of economic trends and childhood education. Manufacturers would be willing to respond to the customer-perceived value of green toys, if they succeed in meeting the obstacles encountered for green supplies. Dangelico et al. (2013) study 102 manufacturing firms in Italy and find out that there are ENDP gains from SC integration with suppliers for both design and manufacturing, although contrary to Huang and Wu (2010) ENDP do not appear to contribute to increase financial performance. Driesen et al. (2013) conduct a multiple case study in eight firms from the chemical and food industries and they propose an ENDP framework rooted in green products and green marketing combined with a traditional NPD perspective. Alblas et al. (2014) find out in a multiple-six case studies research that incentives for green products were fuzzy or absent, companies did not know how to deal with introducing environmentally sustainable products, and that methods, metrics, and tools of life cycle assessment and design-for-sustainability were not a sufficient condition for success. Alblas et al. (2014) advocate for further research on proactive management of sustainability incentives and information.

Chen and Liu (2014) re-join the earlier Gungor and Gupta’s (1999) research stream on design for recycling, but through the theoretical lenses of a duopoly market of both green and non-environmentally conscious consumers’ under-price leadership. Gerstlberger et al. (2014) explores energy efficiency in a Danish sub sample of 335 manufacturing firms from the 2009 European Manufacturing Survey, concluding that green and efficiency aspects of innovation are keys, but complex and intertwined process driving towards the desirable goal of achieving sustainable energy efficiency. Gmelin and Seuring (2014) extend current life-cycle framework research linking NPD and sustainability based on “cross-departmental and cross-company processes, data, and people”, aiming at reducing complexity, harmonization of processes,

and technology. The vitality of the field in the process industry is further confirmed by the recent burgeoning of related articles in CET and CTEP Journals, where the themes of production and the environment are intertwined with discussions related to methodological appraisals and methods, decision support, waste disposal and environmental impact. The main research streams described in this paper expand to new horizons in the process industry, including demonstration projects (Bossink, 2015). The five most prevalent user keywords in CET and CTEP during 2013-2014 period were “optimization”, “sustainability”, “adsorption”, “process integration” and “biosorption”, which clearly refers to the convergence among sustainability, the environment and performance, consolidating earlier findings from CNA results.

4. Conclusions

The SLR identified two main research streams through the application of CNA to the confluence of sustainability and NPD themes. The more traditional and consolidated stream of research is Gungor and Gupta’s (1999) sustainability and NPD framework, which was the basis for a diversified array of high impact literature reviews and conceptual and modelling papers. The predominant themes in this research area are product manufacturing, sustainable supply chains, product recycling, reverse logistics, and disassembling. A second research stream relates more to the development of ENPD application frameworks and empirical verification of theories through survey research and case studies. Pujari et al.’s (2003) framework of product life cycle assessment, design for the environment and supplier evaluation and its impact upon green performance are implicit or explicitly present in most empirical research of this stream. Not all results are conclusive (e.g., Alblas et al., 2014) and further research on sustainable SC, product life cycle and design-for-sustainability tools are necessary. The future trend of research in this area probably lies in the development of mechanisms and practical tools to enhance design for sustainability and its integration in the manufacturing, post selling services, distribution, and reverse logistics phases of NPD. In addition, the SLR use of WoS alone, not including Scopus or Google Scholar, are limitations of this study and should be further researched. A detailed analysis of the specificities of NDP interface with the environment in process industries deserves further investigation, as prompted by recent studies from 2013-2015 published in CET and CTEP Journals.

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