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CROSS-FUNCTIONAL INTEGRATION IN PRODUCT DEVELOPMENT PROCESSES IN THE ERA OF INDUSTRY 4.0

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ABSTRACT

Industry 4.0 covers the use of technologies such as: internet of things, cloud computing, machine-to-machine integration, communication, 3D printing and big data. In this context, cross-functional integration is essential for the product development. The objective of this paper is to characterize the literature on cross-functional integration in product development processes in the context of the technologies of Industry 4.0. A systematic literature review was carried out to analyze the literature on this topic. There is a growing trend of publications mentioning cross-functional integration in product development, in the studied context. The mainstream of cross-functional integration research focuses on cooperation between people, in the sense of integrating structures of function and power. However, in the context of Industry 4.0, there is a shift in this emphasis on people. People continue to be oriented to cooperate with each other to obtain joint results at the firm level. However, this cooperation is more related to the development of skills to deal with cyber-physical processes and with the knowledge produced by machines and information systems. This kind of interaction ability between human, machine and system, can generate a new way to study cross-functional integration.

KEYWORD: Cross-functional integration; Product development; Industry 4.0

INTEGRAÇÃO INTERFUNCIONAL EM PROCESSOS DE DESENVOLVIMENTO DE PRODUTOS NA ERA DA INDÚSTRIA 4.0

RESUMO

A Indústria 4.0 abarca o uso de tecnologias como: internet das coisas, computação em nuvem, integração maquina a máquina, comunicação, impressão 3D e big data. Nesse contexto, a integração interfuncional é essencial para o desenvolvimento de produtos. O objetivo deste trabalho é caracterizar a literatura sobre a integração interfuncional em processos de desenvolvimento de produtos no contexto das tecnologias da Indústria 4.0. Foi realizada uma revisão sistemática de literatura que permitiu analisar a literatura deste tema. Há uma tendência de crescimento das publicações que mencionam integração interfuncional no desenvolvimento de produtos, no contexto estudado. O mainstream da pesquisa em integração interfuncional possui foco na cooperação entre pessoas, no sentido de integrar estruturas de função e de poder. Porém, no contexto da Indústria 4.0 há uma mudança nessa ênfase dada às pessoas. Estas continuam sendo orientadas a cooperar entre si para a obtenção de resultados conjuntos no nível da firma. Porém, essa cooperação está mais relacionada ao desenvolvimento de habilidades para lidar com os processos cyber-physical e com o conhecimento produzido pelas máquinas e sistemas de informação. Esse tipo de habilidade de interação entre humano, máquina e sistema, pode gerar uma nova forma de se estudar a integração interfuncional.

PALAVRAS CHAVE: Integração interfuncional; Desenvolvimento de produtos; Indústria 4.0

1. INTRODUCTION

The paradigm of Industry 4.0 includes the use of technologies such as the Internet of things, cloud computing, machine integration engine, communication, 3D printing and big data. The integrated use of these tools can generate flexibility, economy and sustainability in the production, and the processes become intensive in communication, automation, storage and processing of data (Wang; Wang, 2016). Oesterreich and Teuteberg (2016) categorize key technologies of Industry 4.0 on: statistical tools for simulation and modeling of data, smart factories technologies (e.g. cyber-physical systems, additive manufacturing and internet of things), technologies of scanning and virtualization (e.g. Big data and cloud computing.).

However, not all projects use these technologies to their full potential. Müller, Buliga and Voigt (2018) identified four levels of users of these technologies: *Craft manufacturers*, have motivation to implement Industry 4.0. *Preliminary stage:* there are implementation of ideas and innovation, but not practiced yet. *Industry 4.0 users:* there are innovations in production, equipment, people and interaction with consumers. *Full-scale adopters*: which have also implemented all of these technologies, but they are leaders of their industries in terms of competitiveness and implementation of the concept. From a managerial point of view, the information systems are now linked to cyber-physical systems of production and datamining capabilities of senior management, generating the digitization of processes and results (CANDI; BELTAGUI, 2018).

In this context, the development of new products faces the need to reduce time to market, design and complex products that require high flexibility in production (VYATKIN et al., 2017). To assist in this task, the Industry 4.0 technologies help to enhance the product development process (PD) through information sharing and processing, virtual design and product testing systems (HEHENBERGER et al., 2016; MAUERHOEFER; STRESEE; BRETTEL, 2017; MÜLLER; BULIGA; VOIGT, 2018).

DP process has always been influenced by the need for cross-functional integration because of its multidisciplinary nature in terms of specific methods and application of knowledge from different areas (CALANTONE; DROGE, VICKERY, 2002;. JUGEND, et al, 2013;. BERTAN et al, 2016). Integration is the state of cooperation between functions to work together to meet the environmental requirements (LAWRENCE; Lorsch, 1967). Specifically in the context of industry, 4.0, Candy and Beltagui (2018) emphasize that the integration is essential for the PD. In complex PD processes, from a technological point of view, companies need to make greater use of intelligence systems, involving knowledge from many areas. This scenario requires the integration of efforts between technologies, internal functions, partners and customers (NEIROTTI; RAGUSEO; PAOLUCCI, 2018). This integration is necessary both between departments and among the company, its suppliers and customers (HEHENBERGER et al., 2016).

However, the literature on the PD in the context of Industry 4.0 is not clear with regard to the cross-functional integration practice, in order to provide cooperation synergies and states required to support its multifunctional aspect (MOEUF et al., 2018). The objective of this study is to characterize the literature on functional integration initiatives in product development processes in the context of the Industry 4.0 technologies.

This introduction presents preliminary points of contacts between Industry 4.0 and integration in PD processes. After it, the methodology brings about the procedures adopted for the literature review and the criteria for selecting papers. The results show bibliometric information and a content analysis of the selected papers. Finally, the conclusion highlights the main research trends and proposals for future studies.

2. METHODOLOGY

In order to characterize the literature on functional integration initiatives in product development processes in the context of Industry 4.0 technologies, a systematic review was performed. Google Scholar was used as a search engine and refining the results. Initially, a search was made containing the following keywords: 1) "Industry 4.0" "product development" "cross-functional integration"; 2) " Industry 4.0", "product development", "functional integration"; 3) "Industry 4.0", "product development" "Information Sharing". Only papers from the first 5 pages, ordered by relevance, were considered. The survey was conducted in June 2018 and 125 documents were obtained.

The first criterion of selection of items was the exclusion of 66 papers published in conferences (18), theses and dissertations (18), book chapters (22), citations (2), patents (1) and working papers (5). The remaining 59 papers were added to a single folder, and thus 9 repeated papers were eliminated, resulting in 50 remaining.

The next filter was the relevance checking. Papers with less than 10 citations in Google Scholar were excluded. Two exceptions to this rule were placed: articles from 2017 must have at least five citations, from 2018 must have JCR above 1 or at least 5 citations. Thus, 22 studies were excluded, remaining 28.

The last selection criterion was the suitability of the subject in relation to the main purpose of this article. The abstracts of the 28 selected articles were analyzed to see if their objectives were directly related to the Industry 4.0 context or related to at least one of its technologies: internet of things, cyber-physical systems, big data, cloud computing. The application of this criterion resulted in the exclusion of 9 studies. After the implementation of these actions, the final sample consisted of 19 articles, all published in journals, peer-reviewed through blind review, with relevance indicated by JCR or minimum number of citations.

The content analysis technique was performed in the articles, following these steps: 1) *Filling of an Excel® spreadsheet*, containing one row for each paper being filled in the following fields: Year, Authors, Objective, Theoretical Contributions, Relationship with product development process, Method, Industry, Country, Integration factors, Integration type (Internal / External); 2) *Open coding to define the research streams.* This step is about about the content analysis of the following fields in the articles: "Objective", "Theoretical Contributions", "Integration Factors". The other fields, were related to numeric/objective data, which were simply filled in the table without qualitative analysis; 3) *Categorization of information:* through the toll ‘PivotTable’, from Excel®, data were consolidated to generate relationships between fields and to quantify the codes resulting from content analysis.

3. RESULTS

Through the content analysis of the selected articles, seven categories were obtained: publication type, context of the objective, theoretical contribution, cross-functional integration factors present in PD processes, type of integration method, country, journal of the publication and area of the journal. These categories are explained below.

3.1 Publication type

The initial search, before filters application, showed a variety of types of publications through the researched keywords. Figure 1 shows the amount of each type.

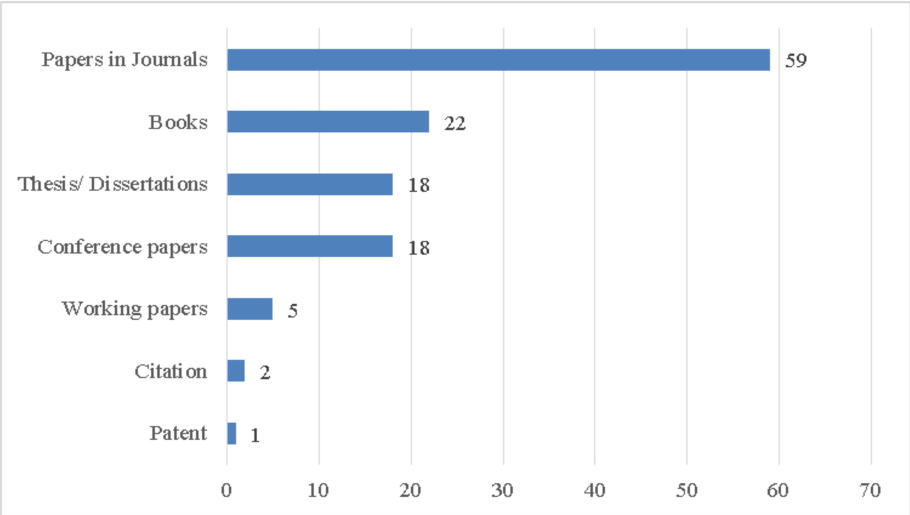

Figure 1 - Types of studies found before filter application

The 125 studies in the preliminary stage were mostly published in journals. However, nearly half of these papers are theses, dissertations, working papers and conference articles. This may indicate that, at the time of the data collection, there was a considerable amount of ongoing studies for future publication in journals in the specific field of study.

3.2 Year of publication

During the search of the studies, no restriction on publication year was made. However, only papers from 2014 were found after the filters. It may indicate that the theme cross-functional integration in PD processes has been studied for a long time (COOPER; KLEINSCHMIDT, 1986; CLARK; FUJIMOTO, 1991 JUGEND, et al, 2013; BERTAN et al, 2016). However, only a few years ago, there was a greater interest in studying these processes in the context of Industry 4.0, as shown in Figure 2. There is also a growing trend of publications that mention cross-functional integration in PD, specifically in the context of Industry 4.0.

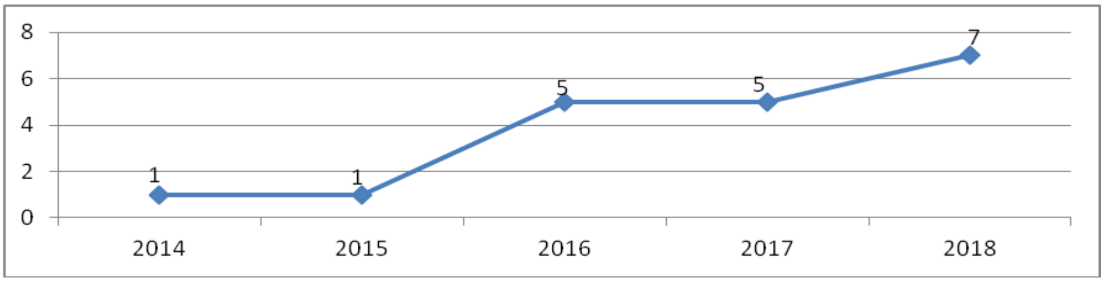

Figure 2 - Publications per year

3.3 Context of the objective

Table 1 shows the amount and the authors of each context found through the analysis of the objectives of the selected articles. Only 3 papers present objectives specifically related to PD.

Table 1 - Contexts of the objectives

Context of the objective	Amount	Authors
Cyber-physical systems	4	Hehenberger et al, (2016).; Wang and Wang (2016); Liu et al (2017).; Feather et al. (2017)
Product development	3	Mauerhoefer, Stresee Brettel (2017); Candy and Beltagui (2018); Rashid et al. (2018)
Industry 4.0 on small and medium enterprises	3	Moeuf et al (2017).; Müller, Buliga and Voigt (2018); Neirotti, and Raguseo Paolucci (2018)
Smart factory	2	Li (2016); Chen et al. (2018)
Conceptualization of Industry 4.0	2	Brettel et al, (2014).; And oesterreich Teuteberg (2016)
Maintenance	1	Roy et al., (2016)
Internet of Things	1	Rymaszewska, Heloa, Gunasekaran (2017)
Industry 4.0 and lean production	1	Tortorella and Fettermann (2018)
Integration of product and customer development team	1	Papazoglou, van den Heuvel and Mascolo (2015)
Industry 4.0 and sustainability	1	Jabbour et al. (2018)
Total	**19**	

Source: Author

A highlight on the analysis of these objectives is the emphasis of the literature on technical aspects related to the cross-functional integration between the various stages of the production processes, or the integration for the development of a new production line. From the 10 types of objectives found, 7 are related to the integration of physical processes and data. This is a type of cross-functional integration that not specifically brings about the cooperation between people from different departments, as defined by Lawrence and Lorsch (1967). These contexts are: cyber-physical systems, Industry 4.0 on small and medium enterprises, smart factory, maintenance, internet of things, industry 4.0 and lean production, and industry 4.0 sustainability.

3.4 Area of theoretical contribution

Through the analysis of the discussions and conclusions of the papers, seven distinct areas of contribution were generated, as shown in Table 2.

Table 2 - Contexts of the goals of the selected works

Contribution area	Amount	Authors
Automatic integration processes between production stages	5	Brettel et al, (2014).; And oesterreich Teuteberg (2016); Wang and Wang (2016); Liu et al (2017).; Chen et al. (2018)
Cooperation	4	Hehenberger et al, (2016).; Li (2016); Feather et al (2017).; Candy and Beltagui (2018)
Integration of teams through information systems	3	Mauerhoefer, and Stresee Brettel (2017); Moeuf et al (2017).; Neirotti, and Raguseo Paolucci (2018)
Relationship between Industry 4.0 and value creation	3	Papazoglou, van den Heuvel and Mascolo (2015); Rymaszewska, Heloa, Gunasekaran (2017); Müller, Buliga and Voigt (2018)
Lifecycle of new product design	2	Roy et al, (2016).; Rashid et al. (2018)
Sustainable production	1	Jabbour et al. (2018)
Relationship between Industry 4.0 and lean production	1	Tortorella and Fettermann (2018)
Total	**19**	

Source: Author

The most frequent code from this category was "automatic integration processes between production stages". Perhaps, due to the characteristic of the analyzed journals, which are mostly technical, these articles are more closely related to the solution of operational difficulties for implementation of integrated production lines. This integration occurs internally (between machines from different functions, data systems and cloud computing) and externally (among machines, customer data systems and suppliers).

The codes Cooperation and Integration of teams through information systems are those that come closest to the mainstream research in cross-functional integration, which is focused on cooperation between people, to integrate function and power structures (KAHN, 1996; PIMENTA, SILVA, TATE, 2016). However, there is a change in this emphasis on people. The functions remain oriented to cooperate with each other to achieve joint results at the firm level. However, such cooperation is more related to the development of skills and capabilities to deal with cyber-physical processes and with the knowledge produced by machines and information systems. This type of interaction ability between human, machine and systems can generate a new way of studying cross-functional integration,

The code "Life cycle of new product designs" presents new ways of designing products and production lines running through integrated cyber-physical systems. Finally, the codes "Sustainable production" and "Relationship between Industry 4.0 and lean production" introduce the capability of technologies used in industry 4.0 on improving processes and performance in diverse perspectives of production, such as: sustainable production, lean production and consumer value creation.

3.5 integration factors present in the product development process

Integration factors are management mechanisms or informal states of cooperation involving different departments in an organization toward the fulfillment process (KAHN, 1996; PIMENTA, SILVA, TATE, 2016). The analysis of the work allowed to find 7 categories of integration factors, as shown in Table 3.

Table 3 - Integration factors

Integration factors	Amount	Authors
Information systems connected to machines	6	Roy et al, (2016).; Wang and Wang (2016); Liu et al (2017).; Moeuf et al (2017).; And oesterreich Teuteberg (2016); Candy and Beltagui (2018)
Shared virtual PD systems	5	Papazoglou, van den Heuvel and Mascolo (2015); Hehenberger et al, (2016).; Mauerhoefer, Stresee Brettel (2017); Müller, Buliga and Voigt (2018); Neirotti, and Raguseo Paolucci (2018)
Information Sharing	4	Brettel et al, (2014).; Li (2016); Rymaszewska, Heloa, Gunasekaran (2017); Rashid et al. (2018)
Cross-functional training	1	Tortorella and Fettermann (2018)
Shared problems solution systems	1	Chen et al. (2018)
Mutual understanding between the functions	1	Feather et al. (2017)
Communication, support from top management, teamwork, trust	1	Jabbour et al. (2018)
Total	**19**	

Source: Author

The literature on cross-functional integration has already mentioned some elements identified in Table 3: communication, teamwork (CHERNATONY; COTTAM, 2009; MOLLENKOPF; GIBSON; OZANNE, 2000); trust, cross-functional training (KAHN, 1996; PIMENTA; SILVA, TATE, 2016), top management support (MURPHY; POIST, 1996) mutual understanding between the functions (STANK; DAUGHERTY; ELLINGER, 1999).

The other factors mentioned in Table 3 show great conceptual and practical difference in relation to the integration factors present in the prior literature on cross-functional integration. These studies were more related to the integration of people, within structures of power and function, than to the integration between technology and people. The information systems connected to machines provide the integration of operations and information between machines of the production line, as well as between the line and the data analysis systems. These data systems operate in clouds, often integrated with customers and suppliers.

Shared virtual PD systems are factors that help to integrate internal functions responsible for the various phases of new product design (e.g. product design, test, release). These systems work based on simulation of information from previous projects, data accumulated about production line and insertion of new ideas obtained by members of several functions. Shared problem solution systems automate and manage the participation of various people, from various functions, in the solution of problems that emerge in the physical or virtual field.

The integration factor "information sharing" is also known in the literature on integration (ELLINGER; DAUGHERTY; KELLER, 2000). However, the context of Industry 4.0 changes the way of how this integration factor works, due to the new ways of information sharing provided by big data technologies, cloud computing, additive manufacturing and cyber-physical systems.

3.6 Research methods and geographical distribution

In terms of methods, the selected articles present a balance between theoretical research (10 articles) and empirical research (9 articles), as shown in Table 4. This may indicate that the literature on integration in PD processes in the context of Industry 4.0, although recent, already have enough theoretical constructs to be investigated through empirical qualitative and quantitative research.

Table 4 - Research methods of the selected articles

Method	Amount	authors
Systematic Review / Theoretical / Documentary	9	Brettel et al, (2014).; Hehenberger et al, (2016).; Jabbour et al (2018).; Li (2016); Moeuf et al (2017).; And oesterreich Teuteberg (2016); Papazoglou, van den Heuvel and Mascolo (2015); Roy et al, (2016).; Wang and Wang (2016)
Survey	4	Candy and Beltagui (2018); Mauerhoefer, Stresee Brettel (2017); Neirotti, and Raguseo Paolucci (2018); Tortorella and Fettermann (2018)
Case Study / Multicase	3	Müller, Buliga and Voigt (2018); Feather et al (2017).; Rymaszewska, Heloa, Gunasekaran (2017)
Experimental	2	Chen et al, (2018).; Liu et al. (2017)
Focus Group	1	Rashid et al. (2018)
Total	**19**	

Source: Author

The 9 studies that present field research are distributed among various countries: Germany (2) USA (2), Brazil (1), China (1), China, Turkey and Pakistan (1), Finland (1), France (1), Italy (1). Regarding the industries studied, these empirical studies are distributed in: Aerospace (1) Electronics (1), Metalworking (1), Power generation and distribution (1), Candy wrappers (1) several industries (5). These numbers may indicate that the cross-functional integration in the PD, in the context of Industry 4.0, is being studied in various countries and industries, indicating the potential scope of this topic.

3.7 Journals

The selected articles are not concentrated in few journals, but distributed in several. Table 5 presents the journals in which the articles were published.

Table 5 - Journals of the selected articles

Journal name	Amount	Authors
Computers in Industry	3	Hehenberger et al, (2016).; And oesterreich Teuteberg (2016); Feather et al. (2017)
International Journal of Production Research	2	Moeuf et al (2017).; Tortorella and Fettermann (2018)
Technological Forecasting & Social Change	2	Jabbour et al (2018).; Müller, Buliga and Voigt (2018)
Journal of Manufacturing Systems	1	Liu et al. (2017)
Computers and Chemical Engineering	1	Li (2016)
CIRP Annals - Manufacturing Technology	1	Roy et al., (2016)
International Journal of Production Economics	1	Rymaszewska, Heloa, Gunasekaran (2017)
Enterprise Information Systems	1	Rashid et al. (2018)
Journal of Enterprise Information Management	1	Neirotti, and Raguseo Paolucci (2018)
IEEE Access	1	Chen et al. (2018)
Journal of Product Innovation Management	1	Mauerhoefer, Stresee Brettel (2017)
IEEE Software	1	Papazoglou, van den Heuvel and Mascolo (2015)
Technovation	1	Candy and Beltagui (2018)
International Journal of Engineering and Manufacturing	1	Wang and Wang (2016)
International Journal of Information and Communication Engineering	1	Brettel et al. (2014)
Total	**19**	

Despite this distribution mentioned, most journals are technical, and not managerial in nature. Eight of them are from engineering and six from the technical area of operations. Only 5 articles were published in journals related to fields of operations management: Technology Environment and Society (2), Information Management (2), Innovation Management (1). This indicates the need to develop research on cross-functional integration in PD in a more managerial perspective of Industry 4.0, because there is more focus on developing technologies than in generating cooperation between the different components of the process.

4. CONCLUSION

The literature of cross-functional integration presents studies on cooperation between people, to integrate functional and power structures. However, the current technological landscape of Industry 4.0 requires other types of cross-functional integration, such as people with people, machines with machines, machines with people, people with big data analytics / cloud computing / internet of things. The integration of equipment and people requires new skills to deal with automation and data analysis. These are skills necessary for the development of automated production lines and for the new products development, as they will be produced in these systems and production lines.

The cross-functional integration in PD processes in the context of Industry 4.0 has been studied in various countries and industries, indicating the potential scope of this topic. Nevertheless, most journals are technical, and not managerial, in nature, indicating the need to develop research in a more managerial perspective of Industry 4.0. This is because there is more focus on developing technologies than in generating cooperation between the different components of the process.

This article has limitations in relation to its research focus, which is restricted to articles that study product development and integration as a practice within this process. This option resulted in a low number of articles in the final sample. Future research can explore the cross-functional integration from the perspective of various objects of study, such as: between different departments, different hierarchical levels, different skills, different companies.

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