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An Analysis of Flexible Manufacturing on the Support of the Development of Smart Product-Service Systems

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Abstract. Currently, changes in the customer’s mindset and increased flexibility in manufacturing shifted competition between companies to focus on the product’s value rather than its cost. In this context, Product-Service Systems (PSSs) are an alternative to traditional value propositions (i.e. pure products, pure services) by combining services with products and providing an experience to customers. In recent decades, PSSs were expanded from solely business aspects to engineering aspects and technical considerations in their scope, such as the paradigms of Technical PSS, Industrial PSS, Digitalized PSS and Cyber-Physical PSS. More recently, due to the application of Industry 4.0 concepts, there is a significant increase of “smart technologies”, i.e. sensors; connectivity; mobile application, in PSSs, naming it a new paradigm on the field, known as Smart PSSs. In this context, this research aims to explore and discuss current issues related to the integration of flexible manufacturing processes and Smart PSSs through a literature review and analysis, regarding information sharing, traceability and system reconfiguration based on customer’s requirements. Found literature points to gaps in the theme related to semantic issues and design issues regarding the dynamic reconfiguration of the manufacturing process and the Smart PSS. The modern approaches to the theme, as found in literature, are still not able to cope with the semantic barriers and high volume of heterogeneous information in a holistic manner. Conclusions point that further investigation of the cited issues is required in a systematic manner, as well as the development of models that can cope with the presented issues.

Keywords: Smart PSSs, Process Flexibility, Semantic Heterogeneity, Dynamic System Reconfiguration.

1 Introduction

In past decades, the increased competitiveness in markets was characterised mostly by a competition related to product's cost instead of product's value, due, in part, to the massification of manufacturing of consumer goods [1]. With the trend shift to flexible manufacturing and new market needs, an alternative to improve the value offer of the product was to add services to increase it, a phenomenon known as Servitisation, which can be represented as the origin of the Product-Service Systems (PSSs) [2][3][4]. These systems are achieved through a combination of products and services to better fulfil user's needs, by a single organisation or a joint effort between organisations [4]. In recent decades, research found on [5] points to further increase of “smart technologies” in Industry 4.0 scenarios, i.e. sensors; connectivity; mobile applications; e-services, in PSSs, naming it a new paradigm on the field, known as Smart PSSs.

The Smart PSSs development are characterised as a combination, in different degrees of depth, of Smart Products and E-Services [4][6]. Due to the current development scenarios being shorter than before, more methodologies and technologies are being combined to improve the ‘time and resources’ management on those types of system [6]. This can be exemplified in the increasing connections between the development of the concept of Smart PSSs and the current trends on integrated and flexible manufacturing systems, smart factories, and Service 4.0 [5][6][7].

In another aspect, the systems’ interoperation in the Fourth Industrial Revolution tends to generate a large amount of data and dynamic requirements during development cycles, in order to attend more needs from stakeholders [8]. In this context, Smart PSSs, aided by flexible manufacturing techniques, need to cope with dynamic stakeholder’s needs, which contributes to the aspect of a Co-creative Value Proposition in it, but increases the number of unclear information and ambiguous interpretations, reducing the interoperability capability on its development [4][6].

This research has as its main goal to study and analyse literature on the current issues regarding the development of Smart PSSs with the aid of flexible manufacturing techniques, and analyse, in a qualitative manner, some of the gaps and areas of interest approaching the research themes.

1.1 Materials and Methods

The research is considered to have a basic nature, with a qualitative approach. Its scientific objectives are exploratory, using as procedure an introductory literature review, followed by an analysis based on synthesis and reflection.

The expected result of the review is a discussion on the themes, represented through a schema, which serves as the starting point to expose the current issues on the continuous development and flexibilization related to Flexible Manufacturing in the context of Smart PSSs. A summarization of the method for the Literature Review is depicted in Figure 1.

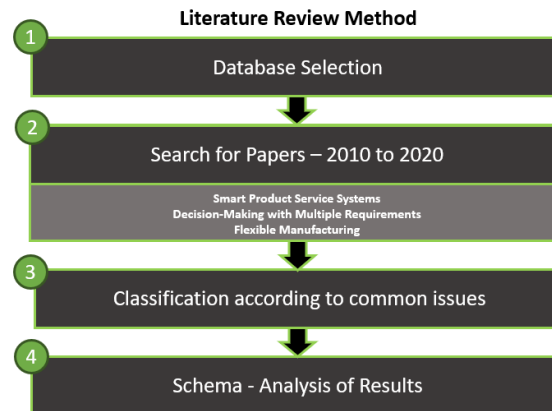


Fig. 1. Method for the Literature Review

The research has as its starting point the definition of the scientific database (Detail 1 of Figure 1) in which the review will be conducted, followed by the search (Detail 2 of Figure 1) and categorisation of the research in found issues (Detail 3 of Figure 1). The review focuses on establishing a conceptual link for the themes, as well as to improve understanding of the areas and their intricate relations. The final analysis will be represented in a schema that represents the issues in the domains of research (Detail 4 of Figure 1).

2 Literature Review

As the starting point for the literature review, this research defined the main database for research as the Brazilian CAPES scientific database (an aggregator of more than 519 research databases, including the bases from Elsevier, IEEE, Emerald, Taylor & Francis, Springer, among others). In sequence, papers from 2010 to 2020 were searched, using the keywords of:

- Smart Product-Service Systems
- Decision-Making with Multiple Requirements
- Flexible Manufacturing.

As Smart PSS is a recent theme, later research found on PSS and its varieties were also considered, as some of the issues are common between the different terminologies. The topic of Decision-Making with Multiple Requirements was also approached as Multi-Criteria Decision-Making, which turned out as a more fruitful search in terms of available literature.

The selected literature for this research were classified in a content analysis based on the nature of issues and current solutions in the context of Smart PSSs and Flexible Manufacturing, as follows, (i) Issues on Semantic Interoperability, (ii) Issues on Decision-Making Process with Multiple Requirements and (iii) Issues on Flexibility on System's Development.

2.1 Issues on Semantic Interoperability

The occurrence of semantic issues in the development of products, services and systems, as pointed out by literature, relates to the representation of requirements by developers [9]. Specialists tend to focus on a single phase of development; single domain; and/or single way to represent knowledge, based on self-expertise. Three aspects compose the Semantic Interoperability issues, as defined by [8][10][11], detailed as follows:

- i. Domain: reflects multiple knowledge domains, necessary to develop products, services and systems, and their particularities;
- ii. Knowledge Representation: represents the taxonomies and modelling of knowledge from different requirement sources (Design, Manufacture, ISO, among others). This difference has a significant impact on a programming level, as there are different notations to represent these requirements (XML models, RDF schema, for instance) and their conceptual structure (representation of product's features) across different phases and domains;
- iii. Development: reflects the whole process of development. Each phase may approach different domains of knowledge and their representations.

The different kinds of knowledge of multiple domains imply in heterogeneous information that may cause semantic inconsistencies along the development process. In another perspective, the communication between different phases of development might present divergent information, resulting in semantic issues related to information transfer, its uniqueness and traceability, among others [11].

Within a domain and a phase of development, there are various notations of representing knowledge, presenting semantic interoperation issues on conceptual and computational levels [8]. Furthermore, semantic issues related to knowledge structures communicating without any similarity, which imply in lack of trustworthy, verifiable, unique, coherent, complete and traceable information [8].

Currently, ontologies are one of the most popular tools for representing and sharing knowledge across different systems and domains [5][12][13], being a viable solution on the formalization of common information models and sharing of the formal information throughout the stages of the development process, which, consequently, provides increased knowledge in the domains of application [14][15][16].

In [17], the author affirms that with the rapid advance and development of semantic technologies based on ontologies, there has been a shift towards more complex and better semantic modelling of manufacturing processes. This process culminates in the insertion of machining features in the semantic technologies to retrieve the considerable machining knowledge and shape semantics presented in these features.

In [18], the authors assert that ontology technology has great advantages in improving the semantic consistency of multi-source heterogeneous data. However, for complex dynamic decision-making problems, there are some limitations in the mining of ontology relations and the establishment of inference rules.

2.2 Issues on Decision-Making Process with Multiple Requirements

The complexity of current stakeholders' needs demands the participation of specialists from multiple backgrounds, providing a holistic view that ensures the best solution to fulfil customers' needs [19]. Although this approach increases value, it ends up generating a set of heterogeneous information, which may not have the same meaning, representing interests and the background of different groups of stakeholders. As globalization, collaboration, and cooperation contribute to a more connected and integrated competitive environment for the manufacturing industries, they have also made the decision-making process more complex whilst reducing the time for the decision to be made [15].

Recently, few models consider the consistency of requirements and performance in dynamic environments. In [15], the authors explain a design framework for cyber-physical systems, based on Design Rationale, connecting different design parameters and requirements from varied sources. In [9], the authors explore the Manufacturing domain and requirement's gathering from different domains. Both pieces of research have combined different models to achieve verifiably and validated information within the context of dynamic requirements, but still, there is a significant presence of specialist's decisions during the process of translating the requirements.

In another aspect, prioritization of criteria is of high importance, as demonstrated in [20]. To aid in an environment that is dynamic and has multiple requirements, research has been made on the use Multi-Criteria Decision Making (MCDM) algorithms, aiding in the decision-making process [20][21][22]. Furthermore, current trends on the theme, as shown by [23][24], present the use of machine learning techniques and algorithms to solve multi-criteria problems. This happens due to the inherent ability of these methods to judge different alternatives through several criteria (attributes or requirements) to provide the most suitable alternative.

Over the last decades, several MCDM methods have been proposed, the most popular of which are AHP (Analytic Hierarchy Process), ANP (Analytic Network Process), TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution), ELECTRE (ELimination and Choice Expressing REality), and PROMETHEE (Preference Ranking Organization METHod for Enrichment Evaluations) [21][25][26]. For some recent developments, it is possible to cite the Superiority and Inferiority Ranking (SIR) method, Stepwise Weight Assessment Ratio Analysis (SWARA), multi-attribute evaluation using Imprecise Weight Estimates (IMP), among others [16][27] [28].

2.3 Issues on Flexibility on System's Development

The complexity of market requirements and the different configuration of systems not always accompany each other, since deep changes in system's structure need to consider a significant number of factors and usually take time to be implemented [29]. According to [30] the possibility to the reconfiguration of a system is essential to maintain it agile and flexible in the industrial scenario, but there is still little consensus on which architectures are the most effective in general.

In the scenario of Smart Product-Service Systems, few models formalise development methods for application, as pointed out by [6]. According to the same author, Smart PSSs are in a verge of a challenge regarding adaptable systems, attributing it to the different contexts that a system is a part of. Furthermore, the author also comments about the implementation challenges related to sustainable applications of Smart PSSs, which received a lesser focus on research. According to [31], main issues on the flexibilization of the design of Smart PSSs can be related to the intense synergy that is demanded on the development of a complex system, in comparison to other kinds of system.

In another aspect, the development of the Smart Product component of Smart PSSs still deals with traditional manufacturing techniques that are not in synergy with the dynamic requirements in the development scenario. Currently, to improve that, the choice of advanced manufacturing technologies is made, based on operational criteria such as productivity and performance, which can offer a competitive advantage and more flexible [23][32].

Advanced manufacturing systems are systems that use mechanical, electronic and computational subsystems to operate and control production, encompassing a large set of machines that execute, monitor and connect the production processes [20]. According to [20], the adoption of advanced manufacturing technologies is a key condition for maintaining the company's competitiveness in the long term. Nevertheless, many advanced manufacturing implementation projects fail to be more significant in small and medium-sized companies, as the managers of these companies are the ones who most want to implement these technologies, but they do so from instinct or information from similar companies. Yet, authors in [33] and [34] states in his research that small and medium-sized companies do not wish to implement, or do not understand how these technologies could assist them in improving customer satisfaction and market results. The author also states that these companies have limited financial and human resources, preventing these companies from implementing complex technological systems.

Over the past two decades, there have been reports of improvements in flexibility, quality and productivity in industries caused by advanced manufacturing technologies. As shown in [5][12][13][32], advanced manufacturing technologies can effectively assist the length of manufacturing objectives and simultaneously consider competitive objectives and manufacturing decision areas, being considered resources mobilized for the construction of competencies.

3 Analysis of Results

At first glance, through the identification and representation of current issues on the flexibilization of Smart Product-Service Systems and reconfigurable manufacturing processes, it can be implied that a systemic approach would be necessary to cope with all those issues at once, but modularity in the system design is of great importance.

In addition, the mapping of the current issues revealed the limitations of an ontology-driven interoperable system when it is used in a highly mutable environment, and how the sharing of ambiguous information in such an environment can reduce the

competitiveness of an enterprise as it will difficult the decision-making process, raising costs and diminishing the quality of the product. Figure 2 show the proposed schema for the main issues found on the literature review.

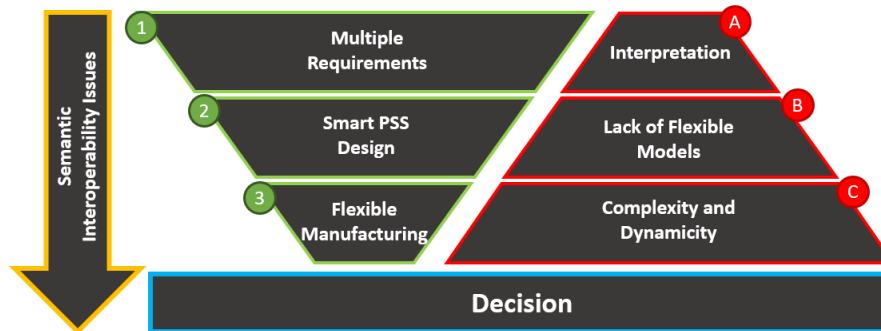


Fig. 2. Representation of Current Issues

The high dynamism of decision-making environment happens due to the numerous product and service requirements and their heterogeneous sources (Detail 1). These numerous and heterogeneous sources can cause information inconsistencies which can lead to wrong decisions (Detail A). The interpretation of these requirements is also subjective to the requirement analysis team which can cause non-optimal decisions to be made.

In the Smart PSS Design layer (Detail 2), the main issues identified were the lack of truly flexible PSS and manufacturing models that can solve the reconfiguration issue. There is also a lack of integrative methods between flexible manufacturing systems and services and Industry 4.0 technologies (Detail B). The industry 4.0 technology solutions identified, however, have their implementation too complex and not cost efficient.

In the last layer (Detail 3), it was identified as flexible manufacturing issues. These issues relate to the high complexity of flexible manufacturing systems and the numerous variables one must control to reconfigure the manufacturing process without losing product quality and increase process time and cost (Detail C).

All these layers of issues hinder the capacity of the real-time reconfiguration of a smart PSS and its manufacturing system. This makes it possible to note that the issues might have a significant impact on the success and longevity of the Smart PSS during its lifecycle. The concepts can be used integrated with ontology-based interoperability models to create a flexible decision-making environment that can aid in the reconfiguration of an advanced manufacturing system allowing for a more agile process and ensuring the product's quality.

The schema shows that semantic interoperability might have a significant impact on decision-making and consequently in themes of study, due to the necessity of keeping the semantical aspect of the requirements throughout the whole process of development.

4 Conclusion

This paper presented research that leads to the development of a model which shows some of the critical issues that hinder the development of flexible manufacturing on Smart PSSs. Results of the discussion showed that in an Industry 4.0 scenario, flexibilization demands that requirements from various sources must be considered and processed, as well as standardized for sharing across different phases of the system's development, without losing its content and context.

The research has identified that flexibilization of manufacturing in the context of Smart PSSs might have misinterpretation of information, heavily based on the heterogeneity of information and different sources of requirements.

In conclusion, the field and its associated domains have interesting exploration opportunities for the development of methods, approaches, and models to increase flexibilization while reducing semantic issues and improving the Smart PSSs by reducing development time and costs and improving the system quality dynamically.

The authors believe that key scientific topics to be explored in further works are:

- i. A state-of-the-art literature review on the domains approached in this research, in order to refine the gap of study and provide more precise directions of improvement; and
- ii. A model, approach, and/or architecture to handle the found issues in the application of flexible manufacturing in Smart PSSs.

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