Transdisciplinary Engineering: A Paradigm Shift
C. Chen et al. (Eds.)

doi:10.3233/978-1-61499-779-5-214

Requirements Engineering in the New Product Development Process: Bibliometric and Systemic Analysis

Jaqueline Sebastiany IAKSCH[1], Milton BORSATO, Juliana SCHMIDT, and Arturo VAINE
Federal University of Technology, Paraná, Brazil

Abstract. In the recent decades, the challenges related to global competition, the reduction of product lifecycle, the increase of technological changes and the level of customer demand have been intensified. In this scenario, the New Product Development Process (NPD) is noticed as a critical factor to maintain the competitiveness in organizations. The New Product Development Process (NDP) is noticed as a critical factor to maintain the competitiveness in organizations. The Requirements Engineering (RE) approach plays a vital role within the New Product Development Process (NDP) lifecycle, once the product performance and its acceptability on the market depend on how RE is integrated into the product development. In this way, this article aims to identify the proposed solutions and trends regarding Requirements Engineering, through a literature review based on studies produced in the last five years. Hence, the existing gaps in the literature about this theme will be presented and analyzed. In order to achieve these objectives, the present study was based on ProKnow-C process (Knowledge Development Process - Constructivist). In the first step, the bibliographic portfolio was obtained, represented by 38 articles aligned with the research theme. Moreover, the bibliometric analysis was performed to identify the relevance of journals and congresses about the topic of research, the authors that stand out in the research area, the year of publication of the articles, as well as the keywords found in the portfolio. Thereafter, a systemic analysis was accomplished in order to analyze the content of the articles from the bibliographic portfolio and to identify the main research problems, objectives and proposed resources. Finally, the main research opportunities were recognized and presented.
Keywords. Requirements Engineering (RE), Requirements, New Product Development, Bibliometric Analysis, Systemic Analysis

Introduction

The costumers' needs conversion and other factors into well-defined requirements is called clarification. This transformation of customer needs into specifications can be ambiguous, therefore the requirements must be specified and documented, describing all the parameters, constraints and product properties. Requirements specification allows the developer to create a product design and it forms the basis of the relationship between developer company and customer. In addition to that, this specification can be reviewed at any time during the NPD [1].

Thus, source [2] defines RE as the process by which the requirements of the products or systems are defined, by discovering the needs of stakeholders, understanding the context in which requirements are proposed, modeling, negotiating, validating, recording and managing these requirements.

[1] Corresponding Author, Mail: jaqsiaksch@gmail.com

The use of requirements that are not well defined and structured may cause an increase in product development time or even non-acceptance by customers, generating extra costs and delay in placing the product on the market [3]. In this way, this article aims to identify the proposed solutions and trends regarding RE, through a literature review based on studies made in the last five years. Hence, the existing gaps in the literature about this theme will be presented and analyzed. In order to achieve these objectives the present study, based on *ProKnow-C* process, is represented by 38 articles aligned with the research theme.

Section 2 presents the methodological aspects of the research, followed by the presentation of the sequence of activities to realize the selection of the bibliographic portfolio in section 3, as well as the bibliometric analysis and the systemic analysis in sections 4 and 5, respectively. Section 6 presents the final considerations.

1. Methodological aspects

This section aims to provide a methodological support for this study, presenting the steps used to select the articles that compose the bibliographic portfolio and that will be used in the bibliometric analysis, thus enabling understand how the objectives are achieved.

It was chosen to adopt *Knowledge Development Process-Constructivist* (*Proknow-C*) as a methodological procedure in this research. This instrument was developed to assist researchers in the recognition of relevant content, since there is an extensive availability of information at the present time [4]. *ProKnow-C* consists of the following steps: selection of the bibliographic portfolio, followed by bibliometric analysis, systemic analysis of the portfolio and, finally, definition of the research question and objective respectively [5][6]. In the first step, definition of the bibliographic portfolio, the research axes and the keywords are defined, as well as the databases, and then the searches are carried out. After this search, the bibliometric analysis stage begins, which defines the authors, articles, journals and the most relevant keywords to the subject of research. The third step, systemic analysis, consists of the articles' interpretation of the bibliographic portfolio.

In this paper, we will cover only the first three steps of *ProKnow-C*, since we intend to present the state of the art and the research opportunities based on the systemic analysis step. To achieve this result, the *EndNote* and *Microsoft Excel* softwares were employed. *EndNote* supports bibliography management, while the data tabulation was performed in *Excel*.

2. Bibliographic portfolio selection

In this section the steps for selecting the bibliographic portfolio are presented, which aimed to gather publications with relevant content and scientific recognition that are aligned with the research theme.

A. Preliminar article database selection

This phase is composed by the following activities:

1) Definition of research axes and keywords:

The axes were defined as: *(i)* Requirements Engineering; *(ii)* New Product Development Process. These axes were defined according to the purpose of the study, i.e. to identify RE trends in NPD.

Afterwards, keywords were defined for each search axis. The choice of these words was based on the previous reading of some articles aligned to the research. Because the searches were more comprehensive when done in English, keywords were defined only in English. In addition, in some words the "*" operator was used to allow their variations to be found.

Thus, searches were carried out with the following combination: (*"requirement* engineering" OR "requirement* identification" OR "requirement* management" OR "requirement* analysis" OR "requirement* standardization" OR "requirement* specification" OR "requirement* validation" OR "formaliz* requirement*" OR "requirement* model*") AND ("NPD" OR "new product development" OR "product development" OR "product development process" OR "product requirement*").*

2) Selection of database:

The databases were defined according to their alignment relative to the research area, as well as their availability in the CAPES (Coordination of Improvement of Higher Education Personnel) periodicals portal. Thus, the bases chosen were: ProQuest, Engineering Village (COMPENDEX), Scopus, Web of Science, Wiley, Emerald, Springer, Science Direct, EBSCO e IEEE.

3) Definition of limiting search filters:

Only papers from congresses and journals published in the last five years (2011 to 2016) were considered.

4) Test keyword adherence:

The keywords adherence was accomplished by reading the titles of the papers. Three articles that were aligned to the research theme were selected and were verified that the keywords were aligned with those defined previously. In this way, the search continued using the keywords presented above.

5) Criation of the preliminar article database:

Searches, according to the above definitions, were done between October 24 and 29 2016 and resulted in 844 references.

B. Filtering Articles

As an initial activity in this step of filtering the base of papers, all duplicate references were removed, which accounted for about 7% of the preliminar articles base, resulting in 787 articles. Were also detected, despite the pre-selection performed directly in the bases, the presence of 3 references from previous years to those considered in this study, as well as the presence of other types of references and documents from other areas that were not of interest (medicine, biology, etc.), leaving 619 references.

Thereafter, the individual analysis of each article was started. First, each of the 619 titles in the portfolio was read, analyzing which were or were not aligned with the objectives and axes of the research. The papers that were not aligned were excluded, leaving 99 papers for the following analyzes.

Through Google Scholar [7], the citations number for each article were verified on October 30, 2016. The references were tabulated, sorted in descending order in

number of citations, identifying which articles were the most cited. The criteria for selecting articles for the next stage of the analysis was that it should be cited at least once. With this, 61 articles were chosen.

Then, with the 61 articles with the highest scientific recognition, the paper went to the stage of reading and evaluating its abstracts to select the papers that in fact were aligned with the research. Thus, 38 publications remained.

3. Bibliometric analysis of bibliographic portfolio

Bibliometric analysis allows evaluating and interpreting the bibliographic portfolio [10]. In this way, it is possible to identify the relevance of journals and congresses about the topic of research, the authors that stand out most in the research area, the year of articles publication, as well as analyze the keywords found in the portfolio.

During the analysis of publications, it can be seen that most of the publications were written by different authors. With the exception of authors A. Knauss, D. Damian, D. Hauksdottir, E. Knauss, NH Mortensen, PE Nielsen, R. Feldt, S. Choie T. Gorschek who have two articles in the bibliographic portfolio, the other 118 authors wrote only one article each. When analyzing the year of article publication, it can be observed that the year of 2014 had the most publications on the subject.

Continuing the analysis, keywords found in the portfolio articles were verified. The similar terms were clustered together, resulting in 82 words. It is possible to realize that 67 words appeared only once in articles. The words *engineering requirements* and *product development* appeared 10 and 5 times respectively. Therefore, the words defined at the beginning of this research were in line with the results found. It can be verified that the journal Requirements Engineering is the most representative in the portfolio, followed respectively by Computers in Industry and Research in Engineering Design.

4. Systemic analysis

The systemic analysis stage focused on analyze the articles content on the bibliographic portfolio according to established criteria. In this study, to conduct systemic analysis, each of the selected articles was read aiming to identify the following aspects: *(i)* objective, *(ii)* methodology, *(iii)* main results, *(iv)* future recommendations, *(v)* research opportunities pointed out by the authors and *(vi)* research opportunities identified from critical analysis. To organize this information extracted in this stage, an Excel spreadsheet was prepared and data were tabulated to facilitate the overall analysis after the readings. The solutions proposed by each study and the research opportunities were identified and presented below.

A. Key research issues presented

***Customer requirements**:* The difficulty of incorporating customer needs into product development is exposed [8][9], as this incorporation is one of the critical factors for the success of all products on the market. For [8] one of the problems is the

lack of integration between product development tools, customer needs and engineering requirements in the development of product families. The imprecision and uncertainty in customer requirements (CR) is addressed [10], which also highlighted the need of CRs prioritization. Another problem presented is the need for customer requirements to be better integrated into the product lifecycle management [11].

Specification, formalization, categorization and prioritization of requirements: The absence of specification, formalization, categorization, and prioritization of requirements are extensively discussed in studies of [1][12]. Thus, increase time and costs of product development with the lack of clear and unambiguous requirements [2] and some associated problems such as the lack of a structured workflow for the creation and specification of requirements [1][19] are presented. In study [18] the difficulty in identifying the criteria, methods and techniques used in the practice by the companies for the prioritization of requirements is perceived. The lack of a requirements model also leads to difficulties in product development cooperation, as presented by source [17], beyond currently requirements categorization models being used only in defining the product or system boundaries in development [16]. In turn, the difficulty generated by the lack of standardization for structuring requirements can be observed in the work of [17], [12], [13]. According to source [20], problems with requirements specification are probably the main reason for project failure, late delivery and unsatisfactory product performance.

Knowledge transfer: The efficient and effective knowledge transfer during the engineering requirements process is crucial to the success of product development. However, this transfer is a challenge since the requirements are often not tangible and the knowledge about them is, most of the time, unspoken [21]. In this sense, the main difficulties in the product development have been the lack of knowledge of the whole life cycle by developers, the lack of clarity in the request of the clients and the poor communication [22]. All projects require some information exchange inside and outside organizations, especially in the early stages of the product life cycle. However, often the loss of information fidelity for issues related to the lack of formalization of this exchange occurs [23].

The objectives and resources used to address and solve these problems as follows.

B. Proposed objectives and resources

Improving requirements reliability: Source [10] develops an improved Kano model that takes into account both the discontinuity problem and uncertainty of customer requirements, proposing a new tool for decision support in product development. Also, in this sense, Source [16] propose a model capable of categorizing requirements that influence design, such as constraints and non-functional requirements, to assertively establish the correct requirements, determining the minimum necessary requirements to meet the needs of stakeholders.

Methodological processes to drive requirements: Many of the objectives and development methods presented are focused on software development. Source [1] considers that the creation of methods in companies or in specific projects is fundamental to have a process to follow in the implementation of the idea or the product. In this way, a method is created for the evaluation of engineering requirements in technology companies information [3].

Requirements modeling: Source [21] presents a requirements modeling method to conduct the formal expression of the requirement, proposing a framework model and its optimization algorithm. Using this model, the problem of semantic consistency between client and designer is solved. Source [22] applied the SysML language to show the importance of modeling requirements in the development of complex products in order to mitigate cooperation difficulties in product development, providing transparency, communicability and coherence.

Requirements reuse: With regard to the requirements reuse search, source [24] propose a new structure for specifying requirements, so that they can be reused. For this, they identify the structural characteristics necessary for the reuse of the requirements, suggesting a structure that fulfills these criteria.

Identifying knowledge stream: In order to overcome the challenges linked with knowledge transfer practices without a requirements engineering process, source [25] collect several data, in interviews and in the literature, combine an extensive theoretical review and empirical analysis findings to develop the means to overcome the challenges and propose suggestions to improve the process of knowledge transfer to RE process.

Evaluating PDP activities related to requirements: In qualitative analysis, the work [24] aims to describe and analyze the role of requirements manager of new product development projects through interviews and document analysis. In the same way, Source [25] aims to analyze the effects of cultural aspects in improving RS processes and to understand the interaction between technical and cultural perspectives. It is noteworthy that most of these modifications are related to the incomplete capture of requirements at the early stage of product development.

C. Research Opportunities:

Through the problems and solutions presented, some research opportunities could be identified:

- ***Requirements standardization and formalization:*** the representation and communication of stakeholder requirements in a format that requirements engineers can easily incorporate into their formalized requirements documents is one of the identified gaps. In addition, another gap concerns the transformation of stakeholder requirements into tangible project requirements that can be easily implemented by development teams [9].
- ***Knowledge management:*** although there are several studies indicating the best technique or method for the management of requirements, is necessary to focus on improving the knowledge and understanding of all those involved in the requirements management process [18]. In this way, managing the interaction of stakeholders across boundaries and between teams, as well as managing the domain and technical knowledge during requirements deployment at all organizational levels, are some of the challenges identified [23].
- ***Optimization of interaction between stakeholders:*** there is also an research opportunity in the development of methods and support tools to optimize the engineering requirements, in order to make possible a real interaction of stakeholders in the NPD, connecting the process to the right people early to establish requirements [25].

- ***Requirements reuse:*** requirements reuse has been recognized as a capable source of increasing the efficiency and quality of product development processes [20]. It is recommended a practical application with requirements reuse approaches that combine different levels of fit and results, on how different implementations affect the process performance result [26].
- ***Conducting studies in other areas of application:*** analyzing the application of all studies, it is clear that the topic of requirements engineering is still closely linked to its area of origin (systems / software engineering). It is suggested to deepen the knowledge on the subject, as well as to study the research opportunities presented above in other areas of engineering development.

5. Conclusion

This article presents a structured review of the literature on the topic of requirements engineering, which plays a vital role within the product development process life cycle, identifying the state of the art and research opportunities on the subject, through the ProKnow-C.

In the systemic analysis, the reading of all papers was conducted in order to identify the main research problems addressed, the proposed objectives and resources, and future research opportunities. The research opportunities encountered were: *(i)* standardization and formalization of requirements; *(ii)* knowledge management; *(iii)* optimization of stakeholder interaction; and *(iv)* reuse of requirements.

During the course of this work some difficulties were encountered. The first one was related to the searches in the databases, since each base has a unique way to carry out the research. In addition, exporting references was also a difficulty, as some bases required it to be done manually, exporting one by one. Also, the methodological procedure adopted in this study requires that the researcher record each step performed, which makes the process laborious.

It is recommended in the future to carry out all the steps again, including the analysis of the references of the papers that constitute the bibliographic portfolio which, in favor of brevity, has been adapted in this study. Besides that, ensuring the analysis not only of the most recent articles but also of the articles that give rise to the concepts on the subject.

References

[1] T. Reichel, G. Rünger, D. Steger and H. Xu, It support for the creation and validation of requirements specifications - With a case study for energy efficiency, *ICED 11 - 18th International Conference on Engineering Design - Impacting Society Through Engineering Design*, 2011, pp. 238-247.

[2] D. Hauksdóttir, N. H. Mortensen and P. E. Nielsen, Identified adjustability dimensions when generating a product specific requirements specification by requirements reuse, *Computers in Industry*, Vol. 65, 2014, pp. 952-966.

[3] S. Wiesner, M. Peruzzini, J. Baalsrud Hauge and K.-D. Thoben, Requirements Engineering, in: J. Stjepandic et al. (eds.) *Concurrent Engineering in the 21st Century: Foundations, Developments and Challenges*, Springer International Publishing Switzerland, 2015, pp. 103-132.

[4] J. Eduardo Tasca, L. Ensslin, S. Rolim Ensslin and M.B. Martins Alves, An approach for selecting a theoretical framework for the evaluation of training programs, *Journal of European Industrial Training*, Vol. 34, 2010, pp. 631-655.
[5] L. Ensslin, S.R. Ensslin and W.B. Vianna, O Design Na Pesquisa Quali-Quantitativa Em Engenharia De Produção–Questões A Considerar, *Revista Gestão Industrial*, Vol. 3, 2007, pp. 172-185.
[6] L. Ensslin, S.R. Ensslin, R.T.d.O. Lacerda and J.E. Tasca, ProKnow-C, knowledge development process-constructivist, *Processo técnico com patente de registro pendente junto ao INPI*, Vol.10, 2010, p. 2015.
[7] Google Scholar [Online].
[8] T. Simpson, A. Bobuk, L. Slingerland, S. Brennan, D. Logan and K. Reichard, From user requirements to commonality specifications: an integrated approach to product family design, Research in Engineering Design, Vol. 23, 2012, pp. 141-153.
[9] P. C. Anitha and B. Prabhu, Integrating requirements engineering and user experience design in Product life cycle Management, *1st International Workshop on Usability and Accessibility Focused Requirements Engineering, UsARE 2012*, Zurich, IEEE, 2012, pp. 12-17.
[10] M. Wu and L. Wang, A continuous fuzzy Kano's model for customer requirements analysis in product development, *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture*, Vol. 226, 2012, pp. 535-546.
[11] J. Papinniemi, L. Hannola and M. Maletz, Challenges in integrating requirements management with PLM, *21st International Conference on Production Research: Innovation in Product and Production, ICPR 2011*, Stuttgart, 2011, pp. 1-6.
[12] W. Brace and K. Ekman, CORAMOD: A checklist-oriented model-based requirements analysis approach, *Requirements Engineering*, Vol. 19, 2014, pp. 1-26.
[13] F. Christophe, F. Mokammel, E. Coatanéa, A. Nguyen, M. Bakhouya and A. Bernard, A methodology supporting syntactic, lexical and semantic clarification of requirements in systems engineering, *International Journal of Product Development*, Vol. 19, 2014, pp. 173-190.
[14] E. Marcelino-Jesus, J. Sarraipa, C. Agostinho and R. Jardim-Goncalves, A requirements engineering methodology for technological innovations assessment, J. Cha et al. (eds.) *Moving Integrated Product Development to Service Clouds in the Global Economy - Proceedings of the 21st ISPE Inc. International Conference on Concurrent Engineering, CE 2014*, IOS Press, Amsterdam, pp. 577-586.
[15] S.N. Pedersen, M.E. Christensen and T.J. Howard, Robust design requirements specification: a quantitative method for requirements development using quality loss functions, *Journal of Engineering Design*, Vol. 27, 2016, pp. 544-567.
[16] A. Salado and R. Nilchiani, A Categorization Model of Requirements Based on Max-Neef's Model of Human Needs, *Systems Engineering*, Vol. 17, 2014, pp. 348-360.
[17] C. Stechert and H.J. Franke, Requirements models for collaborative product development, *Competitive Design - Proceedings of the 19th CIRP Design Conference*, 2014, pp. 24-31.
[18] R. B. Svensson, T. Gorschek, B. Regnell, R. Torkar, A. Shahrokni, R. Feldt, et al., Prioritization of quality requirements: State of practice in eleven companies, *Proceedings of the 2011 IEEE 19th International Requirements Engineering Conference, RE 2011*, 2011, pp. 69-78.
[19] W. Wei, A. Liu, S.C.Y. Lu and T. Wuest, Product requirement modeling and optimization method based on product configuration design, *Procedia CIRP*, 2015, pp. 1-5.
[20] D. Hauksdottir, N.H. Mortensen and P.E. Nielsen, Identification of a reusable requirements structure for embedded products in a dynamic market environment, *Computers in Industry*, Vol. 64, 2013, pp. 351-362.
[21] A. Distanont, H. Haapasalo and M. Vaananen, Organising knowledge transfer in requirements engineering over organisational interfaces, *International Journal of Innovation and Learning*, Vol. 15, 2014, pp. 41-64.
[22] R. Dias, A.S. Cabral, B. López and M.C.N. Belderrain, The use of cognitive maps for requirements elicitation in product development, *Journal of Aerospace Technology and Management*, Vol. 8, 2016, pp. 178-192.
[23] E. Knauss, D. Damian, A. Knauss and A. Borici, Openness and requirements: Opportunities and tradeoffs in software ecosystems, *Proceedings of the 2014 IEEE 22nd International Requirements Engineering Conference, RE 2014*, 2014, pp. 213-222.
[24] J. Fernandes, E. Henriques, A. Silva and M. Moss, Requirements change in complex technical systems: an empirical study of root causes, *Research in Engineering Design*, Vol. 26, 2015, pp. 37-55.
[25] E. Knauss, A. Yussuf, K. Blincoe, D. Damian and A. Knauss, Continuous clarification and emergent requirements flows in open-commercial software ecosystems, *Requirements Engineering*, 2016, pp. 1-21.
[26] C.L. Pacheco, I.A. Garcia, J.A. Calvo-Manzano and M. Arcilla, A proposed model for reuse of software requirements in requirements catalog, *Journal of Software: Evolution and Process*, Vol. 27, 2015, pp. 1-21.