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Product-Service Systems across Life Cycle

Systematic eco-innovation in PSS: state of the art and directions

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Abstract

Studies on PSS are emerging as a growing body of literature driven by the desire to reach economic aspects and sustainable resource management. Although recent studies have highlighted environmental benefits of PSS, insights about how companies can systematically obtain eco-innovations in PSS design, using only TRIZ or TRIZ combined with other methodologies, are still limited. In this sense, aiming to identify the state of the art eco-innovation practices with TRIZ in PSS, a literature review was conducted. Findings were accumulated in order to present the current research framework in this research field. Trends and research opportunities also were identified.

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Keywords: PSS, Eco-innovation, TRIZ, Product-Service Systems, Systematic innovation.

1. Introduction

Enterprises need to invest in systematic eco-innovation if they plan to win or at least survive. In addition, the innovation can no longer be seen as the product of occasional inspiration [1]. In this sense, the main objective of this research was to identify the state of the art of systematic eco-innovations when TRIZ is adopted in Product-Service Systems (PSS) design. The main concepts of approaches discussed in our research are the following. Eco-innovation is considered as "a new product or process that adds value to the business and the customer, significantly decreasing the environmental impact" [2, 3].

TRIZ is a Russian acronym of *Teoriya Resheniya Izobretatelskikh Zadatch* (TRIZ), which means Theory of Inventive Problem Solving in English. TRIZ was firstly developed by Genrich Altshuller, beginning in 1946, and has been improved and modified up to the present. Based on the scientific and systematic analysis of more than 2 million patents, Altshuller found innovation patterns that resolve contradiction problems [4]. The most recent PSS concept states that PSS are a specific type of value proposition that a business (network) offers to (or co-produces with) its clients and one definition of PSS is 'a mix of tangible products and intangible services designed and combined so that they are jointly capable of fulfilling final customer needs' [5].

We identified several previous studies about use of TRIZ in product or then in service context, but only few researches investigating TRIZ in PSS and more recent adding the eco-innovation perspective [6, 7, 8, 9, 10, 11, 12]. For example, Pezzotta et al. [8] proposed a TRIZ-based approach for Product-Service Engineering. Chen and Huang [10] present an eco-innovative design methodology to support PSS designers using functional analysis and the substance-field model of TRIZ. A TRIZ based innovative design method for eco-leasing PSS is discussed in Chen and Jiao [12]. Moreover, systematic innovation methods into sustainable design can reduce the innovation risk [4]. Thus, to comprehend this scenario is one of the motivations of this study.

Furthermore, the fast growth of researches about PSS contributes to problems associated with accumulating and systematizing of research findings [13]. Therefore, also it is necessary to understand the current landscape of research of systematic eco-innovation in PSS. Other reason to investigate the use of TRIZ in PSS is corroborated by Navas [1] that

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affirm which the incremental eco-innovation is not always sufficient to prevent environmental impact of economic activities and more radical eco-innovation initiatives are required.

In this sense, aiming to identify the state of the art eco-innovation practices in TRIZ + PSS and drive new scientific efforts, a systematic literature review was conducted following the criteria and steps by Dresch et al. [15]. To explore this topic, were analyzed the main follow constructs: the context of application eco-innovation and the type of eco-innovation more frequency in TRIZ+PSS, what are the contributions and gaps of TRIZ application in PSS context and general research gaps. Section 2 discusses mains concepts and examples of eco-innovation with TRIZ in PSS. In section 3 is detailed the method and steps of research. Section 4 shows the results and discussion. Section 5 points conclusions and research opportunities.

2. Eco-innovation in TRIZ-PSS context

This section detail the mains concepts and classifications of themes discussed in this study. Kemp and Foxton [16] proposed the following classification for eco-innovations: (i) environmental technologies: pollution control technologies including waste water treatment technologies, cleaning technologies that treat pollution released into the environment; cleaner process technologies: new manufacturing processes that are less polluting and/or more resource efficient than relevant alternatives; (ii) organisational innovation for the environment: the introduction of organisational methods and management systems for dealing with environmental issues in production and products; (iii) product and service innovation: offering environmental benefits: new or environmentally improved products and environmentally beneficial services; (iv) green system innovations: alternative systems of production and consumption that are more environmentally benign than existing systems; biological agriculture and a renewables-based energy system are examples.

PSS is a system of products, services, supporting networks and infrastructure that is designed to be competitive, to satisfy customer needs and to have a lower environmental impact than traditional business models [29]. A PSS can have three main categories: (i) a product-oriented PSS, in which the business model is still largely associated with the sale of products to consumers with some additional services (e.g. maintenance contracts, financing schemes, and the supply of consumables); (ii) a use-oriented PSS, in which products remain a main part but are owned by service providers and made available to users in different forms (e.g. product leasing or sharing); (iii) a result-oriented PSS, in which customers and service providers agree on the desired outcome (e.g. companies that offer to deliver a specified “pleasant climate” in offices rather than gas or cooling equipment or companies that promise farmers a maximum harvest loss rather than selling pesticides) without a specific product involved [13].

In literature, are available eco-innovations resulting of use of TRIZ in PSS and some studies identified are highlighted. For example, after collected and analyzed 103 PSS cases and divided in eight categories to develop a model to identify consumers’ use habits, design tables were developed and used as tool for eco-innovation in PSS [17]. An eco-innovative design methodology to support designers in developing PSS by using functional analysis and the substance-field model of TRIZ was proposed [10]. Some studies have tried to apply TRIZ in PSS design focusing on the Inventive Principles of TRIZ directly for PSS eco-innovation without using the Contradiction Matrix, while the principles are either identified through innovation rules or reinterpreted and transformed to PSS concept generation [18]. To obtain systematic eco-innovation, tools TRIZ were applied to low-carbon PSS [12] and eco-innovative PSS [9, 10], for instance. Also was identified in our study the adoption of TRIZ for systematically generate eco-innovation in new green services [19, 20, 21] and still the propositions of new approaches aiming the integration of TRIZ in steps of PSS design [6, 7, 22, 23, 24, 25, 26]. In sum, aiming to comprehend and advance in this research field and its particularities, is necessary a systematic review of previous studies, as next section.

3. Method

A systematic review of the literature able to understand the state of the art about the research theme and to identify the information [27, 28, 15]. In this sense, were adopted the following steps [15]: 1. Definition of issue and conceptual framework: what is the state of the art eco-innovation through the use of TRIZ in PSS? 2. Choose the work team: formed by authors. 3. Search strategy: a) search terms: all possible combinations (eco-innovation, sustainable innovation, environmental innovation, green innovation, clean innovation and ecology innovation + TRIZ, Theory of Inventive Problem Solving + PSS, product service, product-service system) were surveyed in the title, abstract and keywords (e.g. eco-innovation + TRIZ + product-service system); b) search period: in all available years on data base. c) data bases: Scopus (formed by several data bases like Inderscience, Emerald, Elsevier, Taylor & Francis, Web of Science, i.e) and B-on (formed by 18 data bases like Ebsco bases, IEEE, ISI Proceedings, Sage, Springer and Wiley, i.e).

Our search covered the mains scientific data bases totaling more than 30.000 peer-reviewed journals; d) inclusion and exclusion criteria: inclusion (scientific papers peer-reviewed, case study or theoretical on “eco-innovation in TRIZ+PSS” or combined with other methodologies) and exclusion (high quantitative or statistical bias and with low methodical rigor). e) search, eligibility and coding: in the first search cycle, the title/abstract of approximately 450 articles were verified. Were pre-selected 85 papers to analyze. After a detailed analytical reading, 20 articles were selected. After this, was made a second search cycle on the references of papers most frequently cited or adhering to our research objective. In some cases was necessary request the papers directly to authors. After finalize the exhaustive strategy [15] of search and excluding the duplicate and without access, we obtained a total of 25 studies. After presents the mains metadata results, the synthesis based on configurative and aggregative analyses [15] is discussed in the follow sections.

4. Results

4.1 Metadata

In this section the mains metadata resulting of systematic review are showed. Fig. 1 shows exemplifies the total of published articles (status in 9/jan./2016) and matching keywords searched title, abstract and keywords in Scopus. In the same search it can check the growing trend (Fig. 2.) of publications and that these areas can be considered recent, since most articles are concentrated in the last 10 years. The first published paper found in product service system is of 1983 and analyses the technological developments in computer and information processing in PSS [30]. The first papers found in TRIZ were in 1997 on option-generating [31] and engineering products [32] and on eco-innovation [33] in 2000.

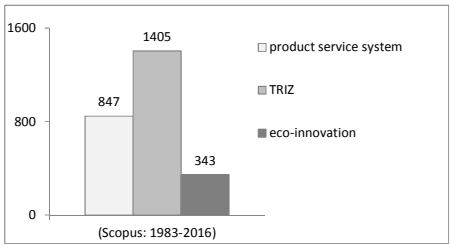

Fig.1. Exemplifying search results of topics.

Considering the selected studies, the period of publications are distributed as follow ratio: papers published in 2000 (4%), 2001 (4%), 2002 (4%), 2004 (8%), 2005 (12%), 2009 (8%), 2010 (8%), 2011 (24%), 2012 (16%), 2013 (4%) and 2014 (8%). 60% of studies were published after 2010.

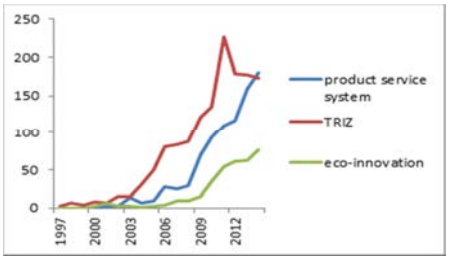

Fig.2. Trends on the topic.

This aspect can reveal that investigation on eco-innovation applying TRIZ in PSS is a recent research topic. The landscape (Fig. 2.) also may contribute to this finding. Considering the countries of origin of researches, the distribution is as follow: Czech Republic (4%), Australia (8%), China (8%), Germany (12%), Italy (20%), Singapore (4%), South Korea (8%), Taiwan (24%) and UK (12%). The largest proportion of research on this topic is carried out by researches groups from Asia (44%) and Europe (48%).

4.2 Tools for systematic eco-innovation in PSS

The distribution of tools used to generate eco-innovation with TRIZ in PSS design seemingly no showed surprise (Table 1). 80% of studies prioritize use TRIZ applying the combination of the various solutions and tools of TRIZ scope. The Laws of Technical Systems Evolution, Evolution Trends and Ideality are used to predict the most likely improvements that can be made to a given PSS [34]. Several combined tools TRIZ (e.g Patterns of evolution, Smart Little People, Morphological Box and S-Curve analysis are applied in [21]. Quality Function Deployment (QFD) is employed to priorize the customer requirements analysis and to more systematically define the contradictory problems and TRIZ helps eliminating the contradiction on customer requirements [7]. New tools also are proposed for achieve a systematic innovation process. A new tool called 'Evolution Potential' was suggested [35].

Table 1. Set of tools apply for eco-innovation

Tools	Ratio
Only TRIZ tools	80%
TRIZ + Six Sigma	4%
TRIZ + QFD	8%
TRIZ+ QFD +LCA+AHP+ managerial tools	4%
TRIZ + QFD+AHP+ Fuzzy Logic+ Pugh Chart	4%

The original TRIZ principles were re-examined and reinterpreted to suit the characteristics of PSS innovation and a new template is suggested [10]. QFD is used to identify problems, TRIZ tools and quantitative decision-making tools (e.g. Analytic Hierarchy Process (AHP) and Fuzzy Logic) are used to choose innovative ideas [36]. Considering this landscape, in order to advance on environmental impact of PSS systems, emerges the opportunity to integrate tools with environmental proposal available in the literature, and already tested with TRIZ in other contexts. Such as [37] QFDE (QFD for Environment), Life Cycle Assessment (LCA) [26], Biomimetic [9, 38] and eco-design [39, 40].

4.3 Context of case studies

Still, the literature presents different contexts in relation to type and size of company investigated and business perspective. The discussion is made as follow.

The case studies discussed in papers were carefully analyzed. It was possible to classify the type of enterprises which TRIZ, isolate or combined with other methodologies, was applied to PSS design in four categories: manufacturing (28%), services (32%), case study not performed (12%) and theoretical discussion of cases (28%). In manufacturing, prevailed discrete manufacturing consumer goods: SME in sector of machining [41], gas turbine [20], large copy printer machine manufacturer [23, 43], electromechanical SME [44], [45] heavy industry company that developed a hydro turbine axle. Some examples of cases in services are: leisure resort in Singapore Sentosa Island and a university [46], launderette, telecommunications and car sharing services [47, 19], energy market in EU [21], European project SUPPORT [35], Chinese data service system company [36] and office automation furniture [11].

Theoretical discussions of generic situations or product also were conducted. The need of "travelling freely and safely

with snowing road conditions" [6]. The transition of traditional paper books to e-book [10]. The physical life of personal computer [12], a laptop [24] and a notebook renting station [17]. Public cases of 96 companies in Fortune Global 500 [4, 7]. Lastly, some models with TRIZ to PSS design have been developed but not tested [48, 25].

Not all case studies had sufficient information about the business perspective. Was possible to identify the type of business relationships in as B2C [41, 47, 19, 22, 36] and as B2B [42, 23, 7, 24, 45]. Considering of three main PSS categories, the cases are distributed as follows: product-oriented PSS (28%), use-oriented PSS (24%), result-oriented PSS (20%), sample of enterprises with all three PSS types (8%), and non-identify due lack of information or when the paper realize a theorical proposition (20%).

The diversity of context (segment, product type, type of company) where the case studies were conducted, show that there is not an oriented trend research in a given context. This allows point relevant aspects. First, there is the pressing need of further research involving a larger number of case studies. For example, since 103 PSS cases collected and divided into eight categories, [17] developed a model and the effectiveness model was verified on one case study of self-service notebook renting station. In this direction, proposing rigorous research to understand certain types of companies, size or segment, are relevant opportunities for improvement this research field.

4.4 Eco-innovations categories

Is possible affirm that all new methods integrating TRIZ into PSS applied in a real enterprise aimed eco-innovations, can be classified the organizational innovation for the environment [16] to context of this company. In our systematic review, various artifacts oriented in eco-innovations were identified. An eco-innovative design model for eco-leasing PSS using TRIZ [11]. A method aims an early integration of resource and environmental requirements into the innovation process [22]. A model to low-carbon PSS using TRIZ also is presented [12].

Aiming to comprehend the state-of-art of eco-innovations generated applying TRIZ in PSS, were analyzed the category (Table 2) of resulting eco-innovations implemented or suggested in the case studies of studies. For example, the innovative resulting idea in Cheng and Huang [10] was use a new technology – a solar battery instead of a traditional battery, in order to reduce pollution in transitions of books to e-books.

Table 2. Nature of resulting eco-innovations

Eco-innovation categories	References
Environmental technologies	[41]
Organisational innovation for the environment	[35], [44]
Product and service innovation	[20], [47], [19], [4], [46], [17], [6], [21], [8], [25], [36], [12], [34], [7] [45], [42], [23], [11], [7], [24]
Green system innovations	[10]

After analyze scenarios of washing service delivery, three solutions were generate: one, the washing machines are deployed in the customer's place and operated by this customer only; second solution is clean clothes supply service and the third one is mobile Laundromat [36]. The categories of eco-innovations [16] are synthetized (Table 2).

A case study on data service system design is discussed and the solution suggest is consider establishing virtual datacenters for more business customers based on cloud data services [34]. A low-carbon eco-innovative PSS of a personal computer is proposed by changing from "recycling parts", "provide parts" and "replace broken parts" to "contract recycled parts" and "provide new & good parts" [12]. In a heavy industry company that developed a hydro turbine axle for a large hydroelectric plant, the new ideas generate were: implement completely or partially changes on object, prior to locate the object on the most convenient place, so as to put into use immediately the principle of change the characteristics [45]. Moreover, organizational innovations like an innovation toolbox (implementation of tools like House of Quality and several TRIZ tools), an open innovation module based on PSS and an expert module to suggest innovation projects based [44]. From the nature of eco-innovations resulting, we conclude that the use of TRIZ alone or in combination with other methodologies can, in a systematic perspective, generate innovations in product, services and also others types [16]. In addition, as new research efforts to be realized in TRIZ into PSS, it must be assessed whether there is or not the need of new scientific concepts to this field, as specific typology to eco-innovation or eco-innovation classification.

4.5 Classification of artifact researches

Was performed the classification of literature review (Table 3) for research outputs [43]: (i) Constructs or concepts: form the vocabulary of the domain. They constitute the conceptualization used to describe problems within the domain and to specify their solutions. They form the specialized language and shared knowledge of the discipline or sub-discipline; (ii) Model: is a set of propositions or statements among constructs expressing relationships. Is the representation of how the things are; (iii) Method: is a set of steps used to perform the task; (iv) Instantiation: is the realization of an artifact in its environment. Instantiations operationalize constructs, models and methods.

Table 3. Classification of research framework

Framework	References
Constructs	[44]
Model	[41], [47], [19], [20], [42],[23], [11] [21], [35], [8], [25], [12], [45], [6], [34]
Method	[17], [4], [7], [24], [10], [46], [36]
Instantiation	[34], [36], [12], [7], [24]

Only one research is focused on constructs definition. Fulea and Brad [44] show an ontology-based approach for supporting creativity in PSS design with TRIZ and other approaches. Constructs are extremely important in both natural and design science. They define the terms used when describing and thinking about tasks [43]. In order to advance in this topic, we suggest more researches on construct or even

on typology to define concepts in eco-innovation in TRIZ + PSS applications. The most researches can be classified as models. In design activities, models represent situations as problem and solution statements and certain inaccuracies and abstractions are expected [43, 15].

Natural scientists often use the term model as a synonym for theory, or propose models as weak or incipient theories, in that they propose that phenomena be understood in terms of certain concepts and relationships among them [43]. In our point of view, models are relevant and necessary steps in order to advance in systematic eco-innovations with TRIZ into PSS through of pragmatic methods. Method is set of steps or guideline to perform the task. In this sense, representations of tasks and results are intrinsic to methods [43]. Kim and Park [4] propose a concept generation method based in TRIZ for service-supporting product development from the service-centric point of view with. Kim and Yoon [7] show a method to creating PSS concepts by resolving contradictions between product and service components using TRIZ. A two-phase integrated PSS design and valuation method using TRIZ and others tools also is suggested [24]. In this method, inventive principles are applied to generate new PSS ideas to identify the ideal final result for PSS innovation based on trend of evolution. Chen and Huang [10] apply functional analysis and Substance-field of TRIZ to generate eco-innovation in PSS. Problem solving process of TRIZ is applied together with Contradiction Matrix and Innovative Principles to obtain innovative PSS [36].

Instantiations demonstrate the feasibility and effectiveness of the models and methods they contain [43]. In this sense, some studies, around 16% of all, detailing clearly instantiations for deployment of environmental innovation applying TRIZ to PSS. Following phases and sub-phases, a theorical analysis of 96 PSS cases among Fortune Global 500 companies was performed [7]. A method composed of four macro phases and six intermediary methods is validated by analyzing a case PSS of laptop [24]. To operationalize the method, among other instantiations, it is suggested a reinterpretation and expansion of TRIZ 40 inventive principles to PSS innovation [36]. The PSS case study of a virtual washing machine for a customer is performed generating scenarios of washing service delivery. Yang and Xing [34] improved a previous method [36] adding QFD to identify problems, other TRIZ tools and decision-making tools such as AHP and Fuzzy. Based on results, in our point of view, to expand the adoption of TRIZ in PSS context promoting systematic eco-innovation artifacts is crucial that the artifacts have clear and detailed instantiations. This also helps to mitigate one of the main criticisms about TRIZ, related with its complexity of execution [23, 46]. And also helps in sustainable PSS design, that requires the analysis of complex relationships among different social actors involved [19, 42, 6]. Therefore, detailed instantiations, especially within new pragmatic methods, are an important avenue for leverage systematic eco-innovations with TRIZ in PSS.

5. Conclusions and research directions

Although recent studies have highlighted several potential benefits of PSS design, insights about how enterprises and practitioners could adopt TRIZ in this context are still very limited. Then, aiming to identify the state in this research field a systematic literature review with configurative and aggregative analyses was performed [15]. The results and synthesis were organized in constructs: tools and methodologies perspective, context of case studies (type of enterprise, B2B or B2C, segment, type of PSS, i.e), classification of artifacts and eco-innovations categories. Based on our findings, we suggest, as continuity, the follow research opportunities to advance in this topic:

First. Researches oriented to develop construct or even on typology to define concepts on the subject**.** The target is to avoid problems associated with accumulating and systematizing in new researches [13].

Second. The proposition of new TRIZ+PSS methods is a relevant and necessary step in order to advance in effective systematic eco-innovations and reduce the environmental impact in PSS design.

Third. To expand the adoption of radical eco-innovations [1] with TRIZ in PSS design is need that artifacts have clear and detailed instantiations. Detailed instantiations, especially within new well organized methods, are recommended.

Fourth. To reduce environmental impact in PSS design, researches to assess other methodologies like [37] QFDE, LCA [26], Biomimetic [38, 9] and eco-design [39, 40] are indicated.

Fifth. Based on results of systematic review and considering the pulverized context of studies, without a dominant orientation of researches, there is the pressing need of new researches involving a larger number of case studies aiming the generalization of findings.

Sixth. More deep researches aiming to understand contingencies (types of companies, size, segment, i.e.) also are recommended.

Our study has some limitations that could be considered. These limitations also can generate future researches. Even if, Scopus and B-on data bases covers the mains collections and more than 30.000 peer-reviewed journals, others sources such as the private on universities or grey literature are not considered. Our study can also be complemented with other categories of analysis on the literature. Although there are limitations, this study identified some insights that could be analyzed in future researches and might contribute to expand the PSS theory on eco-innovation.

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