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Procedia CIRP 00 (2019) 000–000

www.elsevier.com/locate/procedia

11th CIRP Conference on Industrial Product-Service Systems, IPS^2 2019, 29-31 May 2019, Zhuhai & Hong Kong, China

Simulation-based approach to apply uncertainty evaluation framework, for PSS economic models

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Abstract

PSS offerings are characterized by the presence of uncertainties due to the lack of information, in the design stage of the offer, about future events that the decision makers will face. These uncertainties must be anticipated to validate the profitability of PSS projects. In this paper, an approach to assess uncertainty is presented, then applied to a study case. This approach is an integration of the classical uncertainty management framework together with the quantitative uncertainty assessment framework. In the first part of this article, a literature review on uncertainty identification and assessment in the PSS context is presented. Then, an uncertainty assessment approach is proposed, with the methods and tools to implement it. Finally, the authors describe the results of the application to an industrial case study.

Peer-review under responsibility of the scientific committee of the 11th CIRP Conference on Industrial Product-Service Systems.

Keywords: Uncertainty; PSS economic models; PSS simulation; PSS value chains

1. Introduction

In the recent years, the Product-Service-System (PSS) business model has become an important key customer-centered strategy used by manufacturing companies to address challenges emerging from growing competition in costs and innovation. The presence of uncertainties in the bidding stage makes this business model different from the traditional sale of physical products. These uncertainties may affect the economic performance and delivery of the PSS offer in a negative way. Some companies that have adopted this business model have registered poor financial results. This phenomenon is known as the servitization paradox. The presence of uncertainties induced by the required process to shift from an exclusively manufacturing company to a PSS provider has been pointed out as one of the causes of this phenomenon [1].

Stakeholders that take part in the design of a PSS contract have to ensure the financial viability of their participation in the potential PSS value networks. However, the literature does not present a standard framework to deal with uncertainty when establishing the multi-actor economic model of such PSS contracts. There is still a lack of consensus on how to assess the uncertainties that arise in the design stage of PSS solutions. This assessment aims at identifying potential risks and opportunities, as well as establishing how to share these risks among the actors of the value network. The need to include uncertainties in the cost estimation of PSS contracts has already been emphasized [2]: this is crucial for the pricing contract process and decisive before launching the offering on the market. However, uncertainty assessment in revenue estimation for the actors involved in a PSS value network must be addressed following a rigorous and formalized path. Some uncertain factors that are not related to service delivery, such as demand volatility or the financial acceptability for the

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final client to enter into the PSS contract, have not been largely considered in this context.
This work presents a proposition of an exclusively quantitative uncertainty assessment approach aimed to identify the most important uncertain economic performance drivers for a PSS design process. Two methodological supports for uncertainty assessment are associated: sensitivity analysis and Monte Carlo simulation. Additionally, to cope with the multi-actor perspectives of PSS design, a PSS simulator for a real industrial context is used to measure economic performances according to various actor's points of view. This approach was applied to a case study in the meat transformation industry.

The first part of this paper (section, 2) presents a literature review on uncertainty identification and assessment in the PSS context. Then section 3 explains the uncertainty assessment approach proposed, together with the methods and tools used at each step. Finally, section 4 presents the industrial case study and the results of the application of the framework proposed. The framework described in this work is expected to assist companies in identifying economic uncertain factors that affect the variability of the foreseen revenues, when launching new PSS offers.

2. State of the Art

To address uncertainty management for economic models in the context of uncertainty in the PSS value networks, two complementary parts of a state of the art have been developed: section 2.1 reviews the potential sources of uncertainty arising in the implementation of a PSS offer, when section 2.2. analyses the key uncertainty assessment approaches already available to estimate the variability of PSS cost and revenue models.

2.1 *Sources of uncertainty in the PSS context*

Several researchers have analyzed, listed and classified the sources of incertitude affecting the definition of PSS business models or their pricing. Erkoyuncu presents a list of the types of uncertainties related to service delivery that may occur during the bidding stage of usage-oriented contracts in the defense sector [3,4]. Kumar et al. emphasize a set of types of uncertainty that may exist in the different stages of PSS life cycles [5]. Kreye et al. propose a framework aimed to help PSS providers in finding the main types of uncertainty that impact on the bidding strategy and the pricing of the PSS offering [6]. Hernandez et al. present a conceptual framework that details five types of uncertainty considering PSS development as a form of radical innovation [7]. Table 1 shows a summary of the uncertainty sources, found in previous research works.

Despite the recent efforts to characterize and classify the sources of uncertainty inherent to PSS offerings, in the literature there is no accepted standard typology of uncertainties that could be applied to any PSS value network regardless of its industrial context. This generic categorization would useful to ease the mathematical modelling of the interactions between the different sources of uncertainty and the assessment of their economic impacts. Furthermore, the literature does not present a general description of the types of incertitude sorted according to the actor of the value network where the uncertainty arises and the actor affected by this specific type of uncertainty. Such typology would help better understanding the impacts of uncertainty for each stakeholder.

Table 1. Key sources of uncertainty in the literature.

Source of uncertainty	Article					
	[4]	[5]	[6]	[7]	[8]	[9]
Market	*	X	X	*	*	*
Company	*	X	*	*	*	*
External environment		X	*	X		*
Product functioning	*	X	*	*		
Product function		X	X	*		
Service	*	X		*		
PSS integration	*	X		*		
Supplier coordination	*	X		*	X	X
Communication	*	X		*	*	*
Remanufacturing		X		*		
Client	*		X	*		

X= explicit, * = implicit

2.2 Uncertainty assessment in the PSS context

The most common approach used to assess uncertainty of a model includes to simultaneously or separately execute uncertainty analysis (also known as uncertainty propagation) and sensitivity analysis [10]. These two processes have been applied in numerous fields to quantify uncertainty. The goal of executing an uncertainty analysis is to obtain an uncertainty representation of the results of a model, from the estimates of incertitude on the input parameters. Sensitivity analyses are performed to determine the most influential uncertain input parameters that affect the outputs of the model.

In PSS context, uncertainty analysis has been mostly used to determine the costs of a PSS offer, especially those related to service delivery. The focus on service delivery cost aims at ensuring the financial viability of PSS contracts. This uncertainty propagation focusing on cost analysis has been applied to some PSS concrete cases [3,11-14]. Another approach to assess uncertainty known as NUSAP was proposed in 1990 [15]. This approach combines quantitative and qualitative dimensions of uncertainty through a diagnostic diagram. Two examples of its application in the PSS context are found in Erkoyuncu [3] and Durugbo et al. [16]. Durugbo and Wang present a framework using fuzzy extent analysis aimed to select the most important sources of network uncertainty and then to assign resources to mitigate those sources of uncertainty [8]. Wang and Durugbo define a set of uncertainty metrics to be evaluated through a framework applying fuzzy-based techniques [9].

These advances provide an interesting starting point to cope with PSS uncertainty management, however a guide for selecting the most appropriate methods to quantify and analyze uncertainty still needs to be developed, not only from the point of view of the Original Equipment Manufacturer but also to cope with uncertainty affecting each actor involved in the PSS contract delivery. Furthermore, computer tools that quantitatively evaluate impacts of uncertainty on the gains for the companies interested in creating PSS value networks remain scarce in the literature. Finally, uncertainty assessment approaches in the PSS context should assist the stakeholders in translating the uncertainty estimations into the definition of actions to handle and minimize risks and to identify business opportunities. Most uncertainty analysis approaches in the PSS context handle specific types of incertitude mostly focusing on cost of service delivery and market conditions. However, the quantitative assessment of other types of uncertainty in PSS context remains to be further explored**.**

3. Uncertainty Evaluation Framework for PSS economic models

An uncertainty evaluation framework to assess PSS economic models is proposed in this article. This framework intends to go one step forward to solve some of the challenges identified. This contribution offers the following advances:

- To remain open to any type of uncertainty sources affecting PSS economic models;
- To make possible a very contextualized and realistic evaluation of economic impacts of uncertainty, well-adapted to industrial decision-making;
- To provide a multi-actor perspective.

This framework is an integration of the steps of the classical uncertainty management process described in [17] and the phases of the quantitative uncertainty assessment methodological framework presented in [10]. The classical uncertainty management framework includes six phases: uncertainty identification, uncertainty assessment, uncertainty analysis, uncertainty reduction and uncertainty control. Complementary, De Rocquigny and al. present five steps for the quantitative uncertainty assessment framework: specification of a measure of uncertainty and quantities of interest related to this measure, uncertainty modelling, uncertainty propagation, sensitivity analysis and feedback process.

Additionally, in order to implement uncertainty assessment with a contextualized and realistic evaluation of economic impacts, we will integrate in the framework a simulator of PSS economic models dedicated to industrial decision-making (see section 3.1). By using this simulator, the final goal is both to identify the most important economic performance drivers represented by uncertain parameters and to analyze uncertainty impacts for various actors of the PSS offer.

3.1 Simulator for PSS economic models

In order to implement and experiment the proposed framework, the authors used an economic simulation platform called PS3A and previously developed by the research team. This platform, developed as a PSS design support tool, aims to offer a quantitative simulation of the economic performance of real industrial PSS value networks. The result of these simulations support decision-makers in comparing and evaluating different alternative PSS models, from the point of view of every actor involved in the PSS offer [18].

The simulation platform offers various advantages to contribute to the uncertainty assessment framework:

- The platform can be precisely tailored for each industrial case study, making possible to consider all contextual economic factors. The results presented later in this paper are generated by a tailored version of the platform for the case study introduced in section 4.
- Because it is based on a detailed economic model, the simulator delivers industrially accurate and reliable economic evaluation outcomes, offering good opportunities for operational risk assessment.
- It provides economic evaluation according to the point of view of the various actors of the PSS value chain, making possible to address the multi-actor perspective.

Until now, this simulator was only using deterministic parameters to compute cost and revenue previsions for each stakeholder. In spite of the uncertain nature of several parameters, the outcomes of the simulations do not consider uncertainty. The purpose of the current paper is to integrate this economic simulator within the uncertainty assessment framework proposed. Consequently, the approach associates the benefits from both (i) the accurate economic evaluation and (ii) the consistent uncertainty estimations. This integration increases the overall added value of the framework by implementing a real ability to provide useful industrial outcomes, which could be later used by decision-makers for risk management.

3.2 Uncertainty management framework for PSS models

Uncertainty is considered in this work as ‘‘the difference in the amount of information that is required to perform a task and the amount of information already possessed by the firm’’ [19]. The approach applied below integrates two methodological frameworks found in the literature: the usual ‘uncertainty management framework’ and the ‘quantitative uncertainty assessment framework’ (Fig. 1). Additionally, the frameworks involve the utilization of the economic simulator at different stages to increase technical operationality.

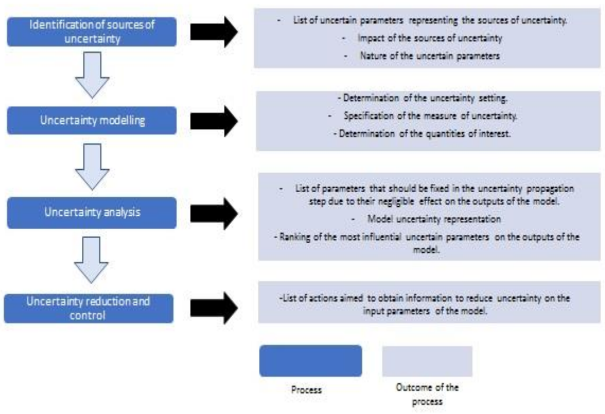

Fig. 1. Framework workflow.

3.2.1 Identification of sources of uncertainty

In this stage, the sources of uncertainty affecting the output of the model are defined and classified. Then, the potential impacts of the various types of uncertainty factors identified are stated and linked to parameters of the economic model. The nature of these uncertainty factors is then studied: an uncertainty factor can have an epistemic or aleatory nature, or a combination of both. A factor has an epistemic nature if the decision maker assumes that its value will not change in the future. If the defined value for the factor can only be used partially in the future, then the factors is characterized by both an epistemic and aleatory nature. Otherwise, the uncertainty factor gets an aleatory nature [20]. This classification is aimed to identify preliminary uncertainty reduction strategies for the epistemic factors.

3.2.2 Uncertainty modelling

The goal of this stage is to specify the uncertainty model expected to be used for assessment. First, the variable(s) of the interest of the model is (are) identified. These are the variables for which the impact of uncertainty will be quantified. Second, it is necessary to define an uncertainty setting. This setting is the mathematical representation of the uncertain space that contains the inputs and outputs of the model. Then, a measure of uncertainty is estimated, e.g. the probability distribution function of the uncertain input factor and a quantity for the output variable of interest is defined. This quantity is "a scalar quantity that summarizes mathematically the degree of uncertainty in the variable of interest", [10] e.g. a confidence interval. The definition of these values leads to the choice of an acceptable value of the quantity of interest that will enable the decision maker to make a decision regarding the objective of the uncertainty study after the execution of the uncertainty propagation step.

3.2.3 Uncertainty propagation and analysis

The aim of uncertainty quantification is to calculate the variability of the variable of interest. To do so, several methods can be used, such as Monte Carlo simulation and Taylor approximation. This propagation step is often supported with the execution of a sensitivity analysis. The sensitivity analysis method enables to determine the relation between the inputs of the model and the uncertainty in the model output. Some of the sensitivity analysis methods often used are variance analysis of Monte Carlo simulations, screening methods and graphical methods.

3.2.4 Uncertainty reduction & control

The results of the uncertainty analysis phase should be used to consider uncertainty mitigation strategies. Based on the identification of the most important uncertainty factors, the decision-maker may think of actions aimed at reducing the uncertainty of some factors, refining the model or reducing the negative influence of the source of uncertainty on the outcomes of the model. Furthermore this step covers the implementation of processes or tools aimed to supervise uncertainties on a regular basis. Based on the sources of uncertainty identified as the most important in the PSS offering, the decision maker may tailor control practices.

4. Case study

The quantitative uncertainty evaluation approach previously described was applied to an industrial case study in the design stage of a PSS offer. This work only presents the results of the first three phases of the framework presented above.

4.1 Industrial PSS case Study

The case study consists of a robotic cleaning solution for the meat transformation industry. The PSS offer is composed of an autonomous cleaning robot, together with services deployed during its PSS lifecycle. This PSS value network involves three stakeholders: a small-sized manufacturing company that designs and assembles special machines including robots as customized solutions, a small-sized manufacturing company that provides batteries for the robot and a medium-sized company from the meat transformation industry as the client of the offer. A fourth stakeholder is considered in some configuration scenarios, a service provider that assumes the role of the PSS solution provider.

This PSS offer is in the design stage, for this reason it is crucial for the project profitability to rely on an economic feasibility study that considers the uncertainties inherent to the nature of the PSS offer. This consideration of the uncertainties supports the decision-making process for all the value network actors through the quantitative identification of the most important economic performance drivers of the PSS economic model described in [21]. This leads to estimate economical risks when launching this PSS project for the various stakeholders. The proposed approach was tested on a use-oriented PSS scenario.

4.2 Analysis of uncertainty sources

The results of a literature review on the categories and types of uncertainty in the PSS context were used as reference to determine the sources of uncertainty related to the case study. During a brainstorming session held by the research team, 29 parameters of the economic model were listed and linked to one of the seven sources of uncertainty identified for the case study (market, client, service, product usage, supply, product functioning and remanufacturing). The uncertainty nature of those parameters was also determined. Most of the input parameters of the economic model had both an epistemic and an aleatory nature. The research team shortlisted to eight the number of uncertain factors pertinent for mathematical modelling, by considering their degree of uncertainty and their importance in the model.

4.3 Uncertainty modelling

The lack of historic data concerning the parameters of the economic model due to the novelty of the PSS offer leads to choose a deterministic uncertainty setting. The measures of uncertainty that best fit this uncertainty setting are the intervals on the values of the inputs of the economic assessment model [10]. The research team proceeded to define interval boundaries for the uncertain factors of the model based on their knowledge of the industrial case. The set quantity of interest for the uncertainty study was the expected value of the cumulative profit of each stakeholder in a ten-year simulation.

4.4 Uncertainty propagation and analysis: selection of key parameters for systematic simulation

A One-at-a Time (OAT) sensitivity analysis was performed by using the PS3A simulator. The simulator generated the values of the quantity of interest for each scenario assessed. Then, tornado diagrams were used to represent graphically the sensitivity measures for several scenarios with different values of yearly number of contracts. Owing to the fact that these diagrams neglect the interaction effects between uncertainty factors, a scenario decomposition was then applied. Seven scenarios with different sets of varied parameters were executed on the PS3A simulator. The resulting values of the variable of interest were used to calculate the finite change sensitivity indices [22]. These indices represent the interaction effect of the simultaneous variation of two or more parameters. The research team analyzed the outcomes of the OAT method and the scenario decomposition to establish the parameters that should be fixed in the uncertainty analysis. Three factors were set to be fixed in the next step: the number of available robots to perform the cleaning tasks, service delivery frequency and the amortization period of the robot. As for the factor “type of contract” it was decided to perform the uncertainty analysis on a result-oriented PSS contract for this work.

4.5 Results of Monte Carlo Simulation

The uncertain factors were assumed to follow a uniform distribution between the interval boundaries previously defined to generate the sampling values. The sampling technique used to generate the values for the scenarios was a simple random sample. Then, the economic assessment model was run 1000 times on the simulator in order to obtain an estimate of the variability of the output of the model (accumulated profits in euros in ten years). See Table 2.

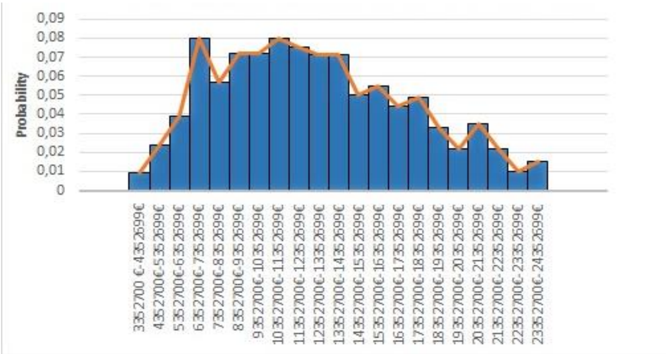

Fig. 2. Variability of the profits for the OEM.

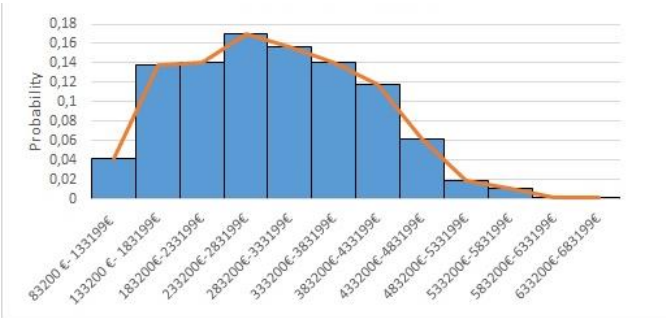

Fig. 3. Variability of the profits for battery provider

Next, the values of the uncertain factors obtained from the simulation sampling (average number of ongoing contracts per year, contract duration, lease amount and robot lifetime) and the values of the variable of interest generated by the simulator were plotted by using scatterplots. This visual inspection gives a first insight into the importance of each of parameter on the variability of the output of the model. It was proceeded to spot any patterns in the graphs that indicate the presence of high sensitivity.

Then, a statistical analysis of the input/output dataset generated by Monte Carlo simulation was carried out to rank the most influential uncertain factors of the economic assessment model. This statistical analysis was performed by calculating Pearson correlation coefficients between each uncertain input factor varied in the simulation and the cumulative revenue obtained from the simulator for each stakeholder. The uncertain factor having the highest correlation value for the battery provider and the robot manufacturer was the average number of ongoing contracts per year. This finding was supported by the previous visual inspection of the scatterplots. The revenue for the client was not considered due to the fact that a method to quantify the gains of using this robotic solution (productivity increase, accident risk reduction) has not been created yet. The convergence of the performed ranking sensitivity analysis was assessed by re-computing the correlation coefficients by using sub-samples containing 100 simulations from the original sample [23].

Table 2. Results of the Monte Carlo simulation.

	Original Equipment Manufacturer	Battery provider
Number of trials	1000	1000
Mean of the variable of interest	12 857 622,62 €	292 922,24 €
Standard deviation	5 055 448 €	102 725,38 €
Coefficient of variation	39,3%	35%

4.6 Interpretation of the results

The results of the simulation trials carried out on the PS3A platform gave an insight into the effect of the variation of some parameters on the expected profit for the stakeholders of the PSS offer. The number of yearly contracts proved to have a large impact on the profits. However, this parameter heavily relies on market conditions. Uncertainty reduction of this factor would require a solid market research. Besides, a larger number of contracts implies an increase in marketing costs. The increasing variation of the lease amount and contract length showed to have a positive effect on the profits. The reduction of these uncertain parameters relies on information related to the client, such as his acceptance to engage in the PSS contract and the cost-benefit ratio of implementing the PSS offer. Robot lifetime demonstrated to have a negligible effect on the profits.

The simulation showed that the probability of obtaining an average profit per year between 1000000 € and 1500000 € for the OEM is about 34%. The probability for the battery provider to obtain profits between 230000 € and 380000 € is about 46%. This information is aimed to support the feasibility study of the launching of the robotic cleaning solution. These profit values can be achieved with an average of 36 ongoing contracts per year, an average contract length of four years and an average amount lease of 72000 €. Since the most important factor affecting the profits is the number of contracts, efforts should focus on ensuring that the marketing department would obtain a certain number of contracts. This may imply a cost increase in this department that should be further examined.

5. Conclusion

Prior work has not addressed uncertainty management in revenue stream estimation for each actor of a PSS value network. The present paper presents a quantitative uncertainty assessment approach aimed to identify the economic performance drivers having the most impact on the revenues of the PSS value network actors. The presented approach was applied on a case study by using a tailored version of an existing PSS economic simulation platform. The final goal of this work is to integrate uncertainty assessment in the outcomes of the economic evaluation generated by this simulator. The approach was applied on a use-oriented PSS contract. Thus, further work requires to include product-oriented and result-oriented PSS contracts in the presented uncertainty assessment approach. The results showed that the number of contracts is the most impacting uncertain parameter of the model on the revenues generated by each actor involved in the PSS offering. Therefore, the client and the market are the most important sources of uncertainty for the case of study. The identification of these sources of uncertainty can lead the decision-makers to propose uncertainty mitigation actions dealing with the uncertainties that arise from these sources.

References

[1] Li, J. H., Lin, L., Chen, D. P., & Ma, L. Y. (2015). An empirical study of servitization paradox in China. *The Journal of High Technology Management Research*, *26*(1), 66-76.

[2] Datta, P. P., & Roy, R. (2010). Cost modelling techniques for availability type service support contracts: a literature review and empirical study. *Journal of Manufacturing Science and Technology*, *3*(2), 142-157

[3] Erkoyuncu, J. A. (2011). Cost uncertainty management and modelling for industrial product-service systems.

[4] Erkoyuncu, J. A., Durugbo, C., & Roy, R. (2013). Identifying uncertainties for industrial service delivery: a systems approach. *International Journal of Production Research*, *51*(21), 6295-6315.

[5] Kumar, A. A., Trinh, G. C., & Sakao, T. (2013). How is uncertainty perceived and managed in design by pss providers?-relation to pss types provided. In *The Philosopher's Stone for Sustainability* (pp. 91–96). Springer.

[6] Kreye, M. E., Newnes, L. B., & Goh, Y. M. (2014). Uncertainty in competitive bidding–a framework for product–service systems. *Production Planning & Control*, *25*(6), 462–477.

[7] Hernández, T. R., Kreye, D. M., & Pigosso, D. C. A. (2018). Typology of Uncertainties in the Development Process of Product-Service Systems. In *25th Annual EurOMA Conference*.

[8] Durugbo, C., & Wang, X. (2014). Network-oriented Uncertainty Evaluation of Industrial Product-service Collaborative Readiness. *Procedia CIRP*, *16*, 229-234

[9] Wang, X., & Durugbo, C. (2013). Analysing network uncertainty for industrial product-service delivery: A hybrid fuzzy approach. *Expert Systems with Applications*, *40*(11), 4621-4636

[10] De Rocquigny, E., Devictor, N., & Tarantola, S. (2008). *Uncertainty in industrial practice: a guide to quantitative uncertainty management*. John Wiley & Sons

[11] Lanza, G., & Rühl, J. (2009). Simulation of service costs throughout the life cycle of production facilities. CIRP Journal of Manufacturing Science and Technology, 1(4), 247–253.

[12] Estrada, A., Romero, D., Pinto, R., Pezzotta, G., Lagorio, A., & Rondini, A. (2017). A Cost-Engineering Method for Product-Service Systems Based on Stochastic Process Modelling: Bergamo's Bike-Sharing PSS. *Procedia CIRP*, *64*, 417–422.

[13] Kimita, K., Tateyama, T., & Shimomura, Y. (2012). Process simulation method for product-service systems design. *Procedia CIRP*, *3*, 489–494.

[14] Alfian, G., Rhee, J., & Yoon, B. (2014). A simulation tool for prioritizing product-service system (PSS) models in a carsharing service. *Computers & Industrial Engineering*, *70*, 59–73.

[15] Funtowicz, S. O., & Ravetz, J. R. (1990). *Uncertainty and quality in science for policy* (Vol. 15). Springer Science & Business Media.

[16] Durugbo, C., Erkoyuncu, J. A., Tiwari, A., Alcock, J. R., Roy, R., & Shehab, E. (2010). Data uncertainty assessment and information flow analysis for product-service systems in a library case study. *International Journal of Services Operations and Informatics*, *5*(4), 330–350.

[17] Erkoyuncu, J. A., Roy, R., Shehab, E., & Cheruvu, K. (2011). Understanding service uncertainties in industrial product–service system cost estimation. *The International Journal of Advanced Manufacturing Technology*, *52*(9–12), 1223–1238.

[18] Andriankaja, H., Boucher, X., & Medini, K. (2018). A method to design integrated product-service systems based on the extended functional analysis approach. *CIRP Journal of Manufacturing Science and Technology*, *21*, 120–139.

[19] Galbraith, J. R. (1977). *Organization design*. Addison Wesley Publishing Company.

[20] Moret, S., Gironès, V. C., Bierlaire, M., & Maréchal, F. (2017). Characterization of input uncertainties in strategic energy planning models. *Applied energy*, *202*, 597-617

[21] Medini, K., Boucher, X., Peillon, S., & Vaillant, H. (2018, August). Economic Assessment of PSS Value Networks–An Algorithmic Approach. In *IFIP International Conference on Advances in Production Management Systems* (pp. 141-149). Springer, Cham.

[22] Borgonovo, E., & Plischke, E. (2016). Sensitivity analysis: a review of recent advances. *European Journal of Operational Research*, *248*(3), 869-887.

[23] Pianosi, F., Beven, K., Freer, J., Hall, J. W., Rougier, J., Stephenson, D. B., & Wagener, T. (2016). Sensitivity analysis of environmental models: A systematic review with practical workflow. *Environmental Modelling & Software*, *79*, 214-232