System Dynamics modeling for Product-Service Systems A case study in the agri-machine industry

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Abstract. The increasing role of services in the strategic plans and the economics of industrial companies poses new relevant organizational and management challenges. Shifting from a transactional to a lifelong relational approach with the customer requires major consideration of those processes which are carried out through the service network. Empirical decisions for tackling such new market opportunities could turn out to be counterproductive if taken on the fly, affecting negatively the overall performance of a service network. This paper exploits the potential of continuous simulation as a support for handling decision making processes in a Product-Service System context. A System Dynamics model has been developed and, within this paper, has been specifically applied to quantitatively assess how the introduction of preventive maintenance contracts can influence the overall service performance of a manufacturer of farm machinery.

Keywords: Product-Service System, Service Performance, Maintenance, System Dynamics

1 Introduction

Companies operating in the western mature markets have progressively realized the importance of complementing industrial goods with the provision of value added services. This has been pushing companies into providing services jointly devised with the products and into searching for new tools to design the product-service bundle. A term, namely Product-Service System (PSS*)*, has been recently coined in literature for identifying a solution which consists of tangible products and intangible services, designed, combined and delivered so that they are jointly capable of fulfilling specific customer's needs [3]. Supplying spare parts, offering technical support, conducting repairs, installing upgrades, reconditioning equipment, carrying out inspections and day-to-day maintenance are some consolidated and traditional examples of services bundled with products. Their supply, which normally comes during the middle and end of life of a product, can be a more stable source of revenues, since services are more resistant to the economic cycles that drive investments and equipment purchases [9, 13], and also a bountiful way of generating profits for companies [4]. According to [1], profits from services are generally higher than those obtained with the product sales, and they may generate at least three times the turnover of the original purchase during a given product life cycle.

However, despite the obvious appeal, most industrial organizations do not detain the right competences and managerial levers to effectively provide these services. Even if they heavily invest in extending their service business and in increasing their service offerings, they experience the so-called "service-paradox", that is, they incur in higher costs, and at the end they do not get the expected returns [7]. In order to gain the envisioned benefits, it is necessary to develop new capabilities, organizational structures, processes, metrics and incentive mechanisms not only at a company's scale, but necessarily involving all the downstream service network. This could turn out to be a major managerial challenge for a company [8, 2].

Concerning this research domain, the authors have already provided in previous publications some contributions which have been addressed to: (i) design the main service processes that a company manages when provides its PSS and identify the relation between the product characteristics and the most suitable typologies of assistance support to carry out at the tactical and operational levels; (ii) boost and control the results of companies operating in a PSS context through the definition of a specific and multi-level Performance Measurement System (PMS); (iii) qualitatively explore the causal relations which lie within the defined PMS in order to understand the non-linear relations among all those processes that are involved when providing a PSS.

Based on the results achieved in these former contributions, this paper provides a further insight: it deals with the development of a System Dynamics model which has been created to quantitatively explore the abovementioned causal and non-linear relations and the impact that introducing a new policy may exert on the improvement of the service performance. More in detail, to show the potentiality of the developed model, a specific application is proposed for a company operating in the agri-machine industry: analyses will get into understanding the effect of making use of preventive maintenance contracts, during the warranty and post warranty periods.

The paper is organized as follows: §2 gives some insights about the methodology adopted to carry out the simulations and the developed model; §3 shortly describes the case study used to perform the analyses and explains the policy introduced and tested within the dynamic model, while §4 discusses the results achieved through the simulations. Finally, §5 draws some conclusions and insights on future developments.

2 System Dynamics modeling

Traditionally, formal modeling of systems has been carried out via mathematical models which attempt to find analytical solutions enabling the prediction of the system behavior from a set of parameters and initial conditions. For many systems, however, simple closed form analytic solutions are not applicable and thus computer simulation models are necessary. Simulation generates a sample of representative scenarios for a model in which a complete enumeration of all possible states would be

prohibitive or impossible [5]. Modeling multifaceted, interactive and dynamic structures, like those involved in the PSSs provision, requires a powerful tool or method which helps to understand complexity, to design better operating product-service polices and to guide changes. System Dynamics (SD) modeling as well as Discrete Event Simulation (DES) can be both used to model corporate business decisions. For the purpose of this research, it has been decided to apply a SD approach as it is the most suitable method to enhance learning in compound systems [11]. Moreover, it is suited to problems associated with continuous processes where behavior changes in a non-linear fashion and where extensive feedback occurs. The main goal of SD is to understand, through the use of quantitative models, how the system behavior is produced and to predict the consequences over time of policy changes on the system performance [10]. DES models, in contrast, more often represent particular processes, not entire systems, and they are better at providing a detailed analysis of systems involving linear processes and modeling discrete changes in system behavior [12].
Given the aforesaid potential of SD, a model has been developed to: i) understand and represent, through the study of the causal relations between the service metrics, the non-linear relations among all those processes that are involved when providing a PSS; ii) quantitatively evaluate how introducing new policies for handling PSSs significantly affects the company's performance; iii) attribute the appropriate organizational changes to the processes thanks to the answers (feedbacks) given by the simulation study with regard to the changes adduced to the service performance. From a technical point of view, the introduction of a policy requires a proper change of some exogenous parameters which trigger off the SD model and whose value is usually provided by the user's model. The model has been applied to two specific types of services: maintenance and spare parts provision. Figure 1 shows, in a macro detail, the elements and the logic adopted to build the SD model.

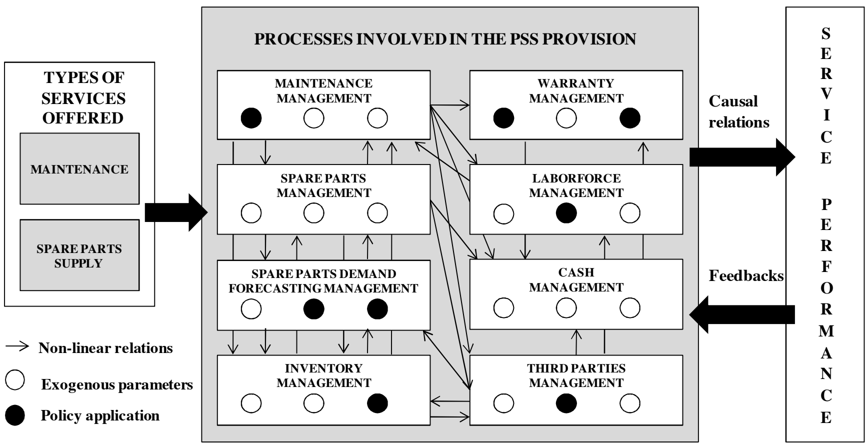

Fig. 1. Logic beneath the SD model building

The developed SD model has a general structure and it can be used by any company which ventures in the provision of new services (at this stage of application, limited to maintenance and spare parts provision) and needs to test the impact that the application of a new policy can determine on its service performance. In order to show the potential of the model, this paper proposes a specific application for an agribusiness firm.

3 The case study

The case study refers to a company which manufactures and assembles farm machinery with a considerable presence both in Europe and in the rest of the world. Beside the production and sale of trailers, which however constitute a considerable share of its profits, its main market regards the production, selling and repairing of round balers. They are used to compress grass and maize feed for cows, industrial waste and garbage. Sales of round balers count around 50% of the turnover; around 240 balers are manufactured a year and almost 50% of them are exported.

A key issue for the company is to improve and optimize its service processes in order to increase the profits coming from this business and retain its customers to secure itself with future sales. Service activities consist in providing spare parts and maintenance to the customers. A round baler standing idle might cause losses for the customer: the harvest season has to be completely exploited and a quick repair has to be assured by the company or one of its authorized technical assistance center. For this reason, the company has recently approached a new strategy to keep down the number of maintenance interventions, especially during the harvest season: since these corrective repair services are completely unplanned and difficult to handle, it is moving towards the additional provision of a preventive support to be performed with more regularity.

According to [6], maintenance can be defined as a series of actions either to (i) prevent the deterioration process leading to the failure of a system or (ii) restore the system to its operational state through corrective actions after a failure. The former is called Preventive Maintenance (PM) and the latter Corrective Maintenance (CM). CM actions are unscheduled activities intended to restore a system from a failed state to a working state. This involves either repair or replacement of failed components. In contrast, PM actions are scheduled actions carried out to either reduce the likelihood of a failure or prolong the life of a component. Normally, the regularly scheduled downtime provided by the application of PM activities could imply higher direct costs to the manufacturer than operating the equipment until repair is absolutely necessary. However, it is important to compare not only direct costs but the long-term benefits and savings deriving from opportunity or indirect costs associated with PM (e.g. decrease of the system downtime, better spare parts inventory management, improved system reliability, etc.). Moreover, from the manufacturer's perspective, the role of PM assumes more relevance during the warranty period: in general, a customer pays for having a PM contract, thus the costs of repairing item failures through CM can be reduced for the manufacturer. However, for a myopic buyer, who does not consider the impact that investments in PM during the warranty and the post warranty periods have on the total life cycle maintenance cost of a product, there is no incentive to invest any effort into PM, especially during the warranty period when the buyer can claim any repairs on the product. For this reason, it is worthwhile for the manufacturer to promote a PM policy only if the expected extra costs are more than balanced by an overall positive return. Regarding the case study, due to the recent introduction of PM contracts, the management of the company needed to better assess the main pros and cons related to their adoption. The simulation, based on a SD model, tries to provide some valuable answers.

4 Modeling and results

In order to assess how the introduction of PM contracts impacts on the company's service performance, the analyses have been conducted assuming three different scenarios:

- Scenario A – PM contracts are not applied, either under or out of warranty;
- Scenario B – PM contracts are purchased by the customers just during the warranty period;
- Scenario C – PM contracts are purchased throughout the whole life cycle of the product, both under and out of the warranty periods.

The analyses have been performed considering the manufacturer's perspective (in terms of revenues and costs) and considering a life cycle temporal horizon. The model has been initialized considering the current company's installed base; the simulation time has been set on a monthly base and simulations have been run for 30 years, in order to analyze the entire life cycle of a round baler, which normally accounts for 15-20 years.

The model has been based on the following assumptions: (i) whenever a failure happens, it is due to a component malfunctioning and it occurs on all the installed base of machines on the market; (ii) just one type of component is considered (i.e. the rotor cutter); (iii) the part failure rate has been estimated constant and occurring after a certain number of bales produced; (iv) the customer purchases a PM contract paying a quota which includes the price of the PM intervention and of the part replaced, both during and out of the warranty periods; (v) PM actions are time-cyclical, being carried out at predetermined time intervals; (vi) both PM and CM interventions are performed assuming that the restored component works as good as new.

In order to run the SD model, different exogenous parameters have been introduced, and in particular: (i) the demand and the disposal rate of round balers sold, (ii) the warranty time (set to 1 year), (iii) the cycle time of a PM intervention, (iv) the part failure rate, (v) the prices and costs of respectively a PM intervention and a CM intervention, (vi) the unitary cost of personnel, (vii) the unitary cost of spare parts backlog and inventory. Their values have been provided by the company.

The following graphs report the main results achieved through the simulation. The crucial outcome is that the company gets benefits from the introduction of PM contracts. In particular, the higher the use of PM is, the higher the company's service performance is. Limiting the PM just to the warranty period is less convenient than extending it to the entire life cycle of the round balers. Even though following this strategy makes the company incur in higher operational costs (due to the necessity of performing both CM and PM interventions and, consequently, due to the presence of more personnel who accomplishes these interventions), this is more than balanced by the profit made along the product life cycle (Figure 2 and 3).

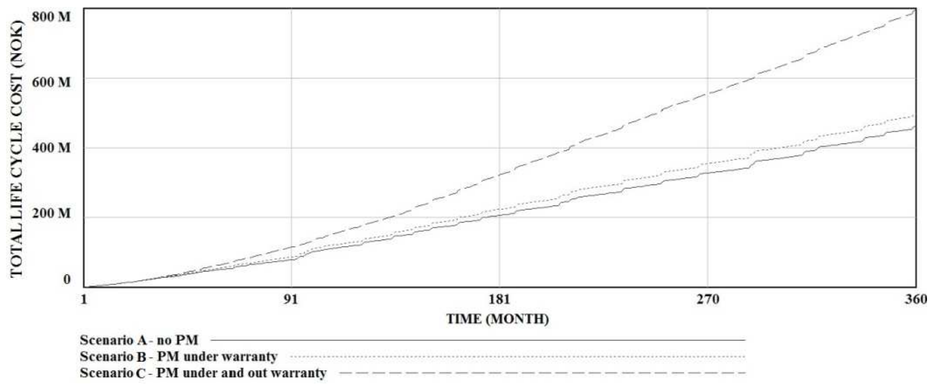

Fig. 2. Total life cycle cost for the three simulated scenarios

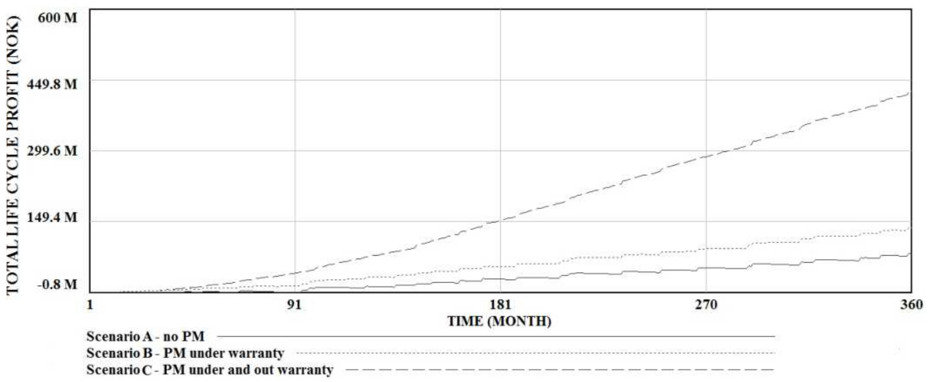

Fig. 3. Total life cycle profit for the three simulated scenarios

Another interesting result regards the reduction of the spare parts backlog. This is due to the fact that PM interventions are regularly scheduled and this reduces the uncertainty in forecasting the desired level of spare parts necessary. Figure 4 shows the trend of the spare parts backlog costs accumulated during the product life cycle for each simulated scenario.

Finally, it is interesting the trend that the costs for the inactivity of the personnel accumulate during the product life cycle. As already mentioned, PM interventions are regularly planned compared to those of CM, thus the working time of the personnel can also be planned and better exploited. Figure 5 shows how the costs of the inactive personnel decreases when the incidence of the PM increases.

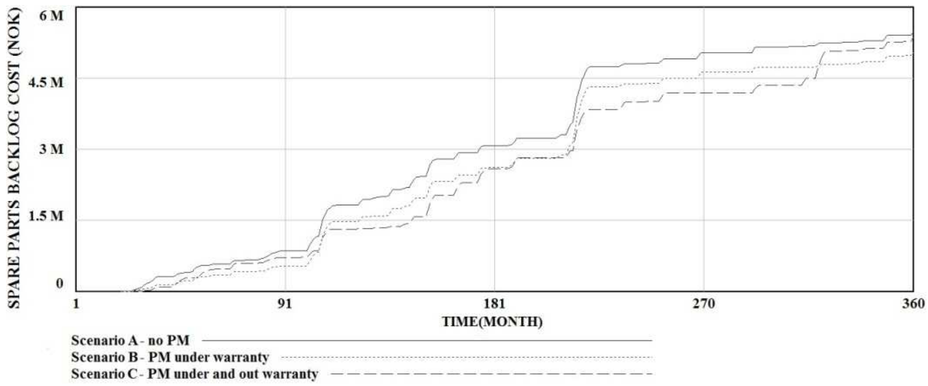

Fig. 4. Spare parts backlog cost in the product life cycle for the three simulated scenarios

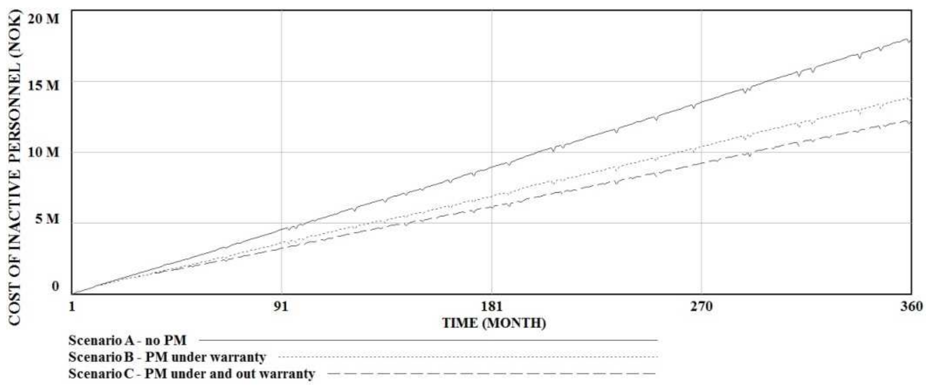

Fig. 5. Cost of inactive personnel in the product life cycle for the three simulated scenarios

5 Conclusions and further developments

This paper aims at contributing to the research in the field of PSS, which is a still a quite relatively new topic and not yet consolidated, and it proposes a SD model to answer to the need of adopting new tools to design the product-service bundle. More in detail, a general SD model has been developed to quantitatively simulate how the provision of PSS can affect the service performance of a company. Within this paper, this model has been applied to a specific case study in order to show some of its potentialities. For this reason, different scenarios have been examined to evaluate how the introduction of PM contracts may affect the total service performance of the studied company. For this particular case, given the initial assumptions made for the analysis and the exogenous data provided by the manufacturer and used for the simulations, it comes out that introducing PM contracts is advantageous to the company. It turns out that the higher the application of PM is, the higher the expected results are: even though the company incurs in higher operational costs, this is more than balanced by the improvement of several results, such as the increase of the

overall service profit, the reduction of the inactive personnel costs and the reduction of the spare parts backlog costs. Further analyses can be conducted on this case study in order to define which is the best maintenance strategy to adopt, the optimal number of preventive cycles to carry out during the warranty period, the benefit of extending the warranty period, etc.
Regarding the developed general SD model, future work may be addressed to further test its potentialities through its application to other companies which operate in the service business and have to deal with the provision of PSSs.

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6 References

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