Product-service systems scenarios simulation based on G-DEVS/HLA: Generalized discrete event specification/high level architecture

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Abstract
In the past decade, personal customers expected manufacturing companies to provide them with a physical product with, nonetheless, some basic additional services. Currently, customers expect a more comprehensive solution, integrating both a physical product and non-physical services, which explains why companies have started to propose Product-Service Systems (PSS). The underlying objective of profitability can be attained if the system is designed, based on system use, to avoid waste, and if services are developed jointly with products. Although all the requisite conditions are well-known, the optimal way to satisfy them is not formalized or even guided by any clear methodology. This paper proposes to create PSS models to be simulated in different service scenarios based on G-DEVS / HLA. The simulation results provide pointers to help decision maker choose between several PSS design scenarios to be manufactured. A case study from the toy industry is used to illustrate the proposed methodology.

Keywords: Functional economy; Product-Service System; Service Simulation; Servitization; G-DEVS; HLA Federation.

1 INTRODUCTION

The traditional economy, based on the sale of tangible goods, is challenged by the growing interest of customers in product-use rather than exchange value. Manufacturing companies now propose Product-Service Systems to their customers [1]. This trend corresponds to new customer expectations expressed in terms of results: an attachment to product performances rather than to technical conformities. It can also indicate a preference for breakdown prevention rather than breakdown repair and an evolution from quality/price ratio to quality/cost-of-use ratio.
With national differentiation-inducing factors or international competitiveness-inducing factors the addition, or even the replacement, of a product being sold as a service represents for industrial companies a new source of turnover and a customer loyalty lever. Certainly, at the present time, the income generated by the sale of services and PSS sales is higher than that generated by product sales [2]. Nevertheless, the evolution towards new activities implies managerial and organizational developments that are beyond the reach of most SMEs or even some big industrial companies.
In addition to the product sector, the service sector is also challenged. Service providers must permanently adapt their offers to fluctuations and continually innovate to meet customer requirements. Thus, many different services are proposed, regardless of service design and development, which often lead to a certain number of service management difficulties [3]. The introduction of new service activities is, for instance, not guided by any clear methodology. The definition and practical implementation of services can often penalize the companies, especially because finding defects only at late stage can prove very expensive. Service design and manufacturing are nowadays considered a really vital issue. A methodology to systematize those activities and simulate sustainable development: i.e. the economic, ecological and social viability of the solution for both provider and customer, is required. The aim of this article is to contribute to PSS modelling and simulation by using discrete event models and distributed simulation techniques prior to development. Such modelling and simulation is carried out in order to validate the desired properties and to anticipate potential problems within the system. The simulation results give pointers to help decision maker choose between several PSS design scenarios to be developed. A case study from the toy industry illustrates the proposed methodology. In order to propose a simplified model of client behaviour, we have chosen first to study children's toy interest behaviour that has been abstracted from psychological literature and then give one of the first PSS simulations incorporating customer-usage feedback, even that is, for the moment, in a simplified version.

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The article is organized as follows. First, we review the PSS literature to present the PSS concepts and requirements. Second, we present a PSS business model which companies can use to create value. Next, a PSS G-DEVS/HLA (Generalized Discrete Event Specification/High-Level Architecture) based modelling and simulation framework is detailed. Scenarios based on this approach are subsequently tested on a case study from the toy industry before presenting our conclusions.

2 PSS VARIANTS AND CONCEPTS

The practice for industrial companies to associate products and services in the same offer is not new. Eiglier and Langeard (1975) had already introduced the idea of "extended products": i.e. products integrating services such as payment facilities, after-sales service, etc. [4]. Equally called complementary, secondary, additional or combined service in the literature [5], [6], [7], [8], [9], the different coupling possibilities have evolved and the PSS concept has started to emerge on the market [10], [11]. The currently accepted definition describes PSS as "Product(s) and service(s) combined in a system to deliver required user functionality in a way that reduces the impact on the environment" [12] in [3]. There are several variants of PSS: i.e. product-oriented services, use-oriented services and result-oriented services [13] according to the nature of the object being sold to the customer: i.e. respectively, a product, service (product use) or result (result target). Variants are also linked to the sustainability potential of the system [14].
The first aim of PSS is to satisfy users' functional needs and foster customer loyalty through an eco-friendly, individual and personalized offer, as customers are becoming more and more sensitive to environmental issues and to the sustainable aspect of the performance (economic, environmental and societal). The second aim is to enable providers to differentiate themselves from competitors and to respond to the incentive of reducing the environmental impact of their production.
System optimization leads to challenging the traditional economy to satisfy all stakeholders, and thus combines a sustainable solution offer which can be integrated in the functional economy in which business transactions must:

- Focus on the use of a capital good and not on its sale, and
- Exert positive effects on sustainable development by reducing consumption of material and/or energy [15].

Despite government incentives promoting the functional economy [16], and the interest of a product and service co-design to exploit their synergies, in practice industrial developments are product-centric. Services are subsequently developed according to the options proposed. The resulting product-service system is pushed at the customer who is often unable to grasp its fair value and/or appreciate its use. Innovation aimed at increasing customer satisfaction does not find an echo, and company return on investment is negligible. In addition, each system is unique and consequently does not benefit from the experience of previous systems and, moreover consumes new resources each time. To achieve its goal of sustainability, functional economics requires simultaneous consideration of industrial and service activity. Changes intended to combine these two activities are mandatory, as well as breaking with the traditional economy pattern, which is based on selling a product whose obsolescence is planned.

The strategic role played by services has over the years become a key element for companies to distinguish themselves from their competitors. Services are to be considered as mandatory for their contribution to enhancing incomes and profits, since the sale of services is more profitable than that of products; the latter is punctual whereas the former is generally recurrent and more long lasting. In addition, services can also increase profit margins as they favour the development of customer loyalty and differentiation. Consequently, the competitive set depends less on the price: service is combined in a more complex process and its life cycle is in a less mature phase than that of products. This is a real problem for industrial companies, which encounter difficulties in successfully exploiting the financial potential of the associated service offers.

This disability to create value should incite industrial companies to rethink their business model. This leads on to each company learning from its on-ongoing learning experience. Companies go through or have already gone through several stages, from a product manufacturing centric model to an intermediary additional services salesman-centric model and then to a service centric model. This evolution imposes major organizational challenges: the possession of an efficient network and of a specific structure in profit centres dedicated to the service activity. This last point raises the question of the business model associated with the service activity.

3 PSS Business model

The concept of a business model, extensively used in the business area since the development of companies on the Internet, has just began to be precisely defined in management literature. All the various definitions agree on the following constituent elements: the offer and implemented resources architecture, the value proposition for the customer, the position of the company in value creation, and the income model. The pillars of a business model able to handle PSS need to integrate:

- the value proposition which is offered on the market: the product / service combination. The value must be defined, calculated and optimized to obtain a competitive advantage
- management of the customer interface: the market segmentation concerned by the value proposition, as well as communication and distribution channels [17]
- management infrastructure: the competences, resources and activities for business model development
- financial aspects: instruments and mechanisms for the business model control

This view of the pillars of a PSS business model is aligned with the Muller-Stewens and Lechner business model proposition. The authors define a PSS Business Model composed of five sub-models [18] in [3]. However, although the objectives of each sub-model are described, the design and development phase of the PSS life cycle are given less attention. The next sub-section presents a general overview of a PSS life cycle-oriented business model.

3.1 Global overview of the business model

The proposed business model is based on a project process and follows the different phases of a project life cycle. The particularity of the project is to provide customers with a high value solution. As such, the design and development of the PSS are the main concerns. The project process is divided into four main phases (Figure 1). The article does not specifically focus on the PSS use phase as it is considered as orthogonal to project development. Feedback on customer-product uses are obtained during the definition and closing phases. During each phase, operational and support activities are carried out. Operational activities are activities that enable the PSS to evolve from the status of "idea" to that of a system “delivered” and “evaluated” " by customers. These activities ensure that the functional requirements of the PSS fully satisfy customer needs, the influence of the business environment and company profitability. The support activities ensure business process control and profit management during the whole PSS life cycle. The main aspects of those support activities are indicated in Figure 1.

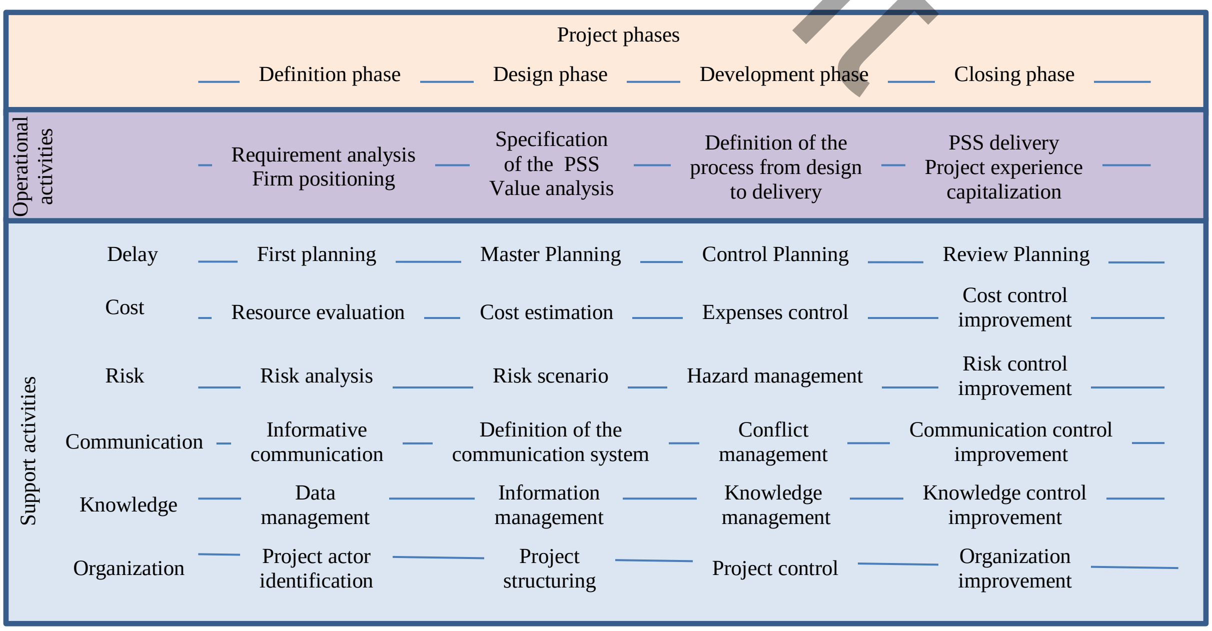

Figure 1: Business model of a PSS based on a project life cycle

3.2 Business model step by step

The first common step is a definition phase. This consists in a strategic diagnosis based, on the one hand on customer needs analysis and customer-product use analysis and, on the other hand, on the study of the macro- and micro-environment of the company, the potential of its resources and its ability to mobilize them. The former analysis gives feedback to the company on customer expectations and determines innovation paths. The latter analysis provides feedback on customers' real use of a product: the functions really used and customers' behaviour. The results of the two analyses compared to the study of the company's environment and the potential of its resources give a concrete idea of the motivations and barriers concerning an innovation path and an idea of the company's potential development. The result of the diagnoses, expressed in terms of strengths, weaknesses, opportunities and threats, is represented in a SWOT matrix chart. There are as many charts as there are innovation paths, allowing a strategist to choose out of several possibilities, those that are less risky, beneficial and respect a specific set of constraints [19]. The result of this first phase provides a short-list of PSS ideas.

The second step is a design phase that discusses the specifications of each PSS idea regarding its value for both the customer and the company. Based on a functional analysis and value engineering approach, value results are shown in a matrix aimed at analysing the soundness of a particular PSS offer design. The design and delivery costs, as well as the mercantile strategy of the company, are taken into account [20]. There are as many charts as there are PSS ideas. Simulation models and principles, discussed below, allow the high value solution among the PSS ideas to be chosen.

The third step corresponds to the development phase, whose objective is to define the process, resources and competence needed to set up the business model. Other simulation models could be used here to formalize the sequence by defining workflows [21]. These simulation models are, however, outside the scope of this paper.

The fourth step, i.e. the closing phase, corresponds to PSS evaluation and experience for future reuse. The simulation can be seen as initial feedback on the PSS idea. The discussion below does not concern this particular phase.

4 PSS Modelling and Simulation

Modelling and simulation (M&S) is extensively employed in industry for modelling the product lifecycle, including manufacturing, logistics and transportation. These techniques enable the existing production and supply chain systems to be studied, understood and improved. The formalization is mainly focused on the process (i.e. the workflow) needed to create or improve [21]. Scenarios are then played to check and validate the reliability of the economic hypotheses. Even if industry has mastered some cases by using these techniques for more than 60 years, until now the recent product and service coupling has still rarely been tackled by M&S projects. The main reason announced is the intangible (immaterial, not quantifiable) aspects of services. Also, the simulation loop of the product lifecycle is not closed, and clients are not often considered in models, due to their complex and non-deterministic behaviour.

4.1 Existing PSS Modelling techniques

Service Modelling is a recent domain, which has not yet adopted a unique common standard for developing frameworks to manage services processes. There is a lack of one specific modelling language for PSS [22]. The specification of Service Modelling can involve different process, application and actor components, which are essential to the service execution, but heterogeneous. The specification standards are numerous; Becker reports more than 15 main reference models [22]. To start working on modelling services, certain authors (e.g. [23]) have chosen to imitate the administrative or production workflow process sequence description and transpose it to service. Other authors have chosen to use the graphical definition of a Service-Oriented Modelling Framework (SOMF), presented in [34], [24]. Their reasons include the coverage of the domain and the user-friendly design. What is important, however, is to check for correctness or to evaluate the scenario on the service models. Concretely, this particular field lacks sufficient validation methods. Simulation can provide predictive information on the accuracy of these models.

The W3C also propose an XML representation of Service Modelling Language (SML) [25] that is accepted as a standard in the Service Modeling community. The XML Service Modelling process model structure correctness can be certified by referring to a Service Modelling Document Type Definition (DTD). However, this XML representation is not really convenient for the XML specification of a PSS Model. The description is more Computer Science Service Modelling oriented than industrial PSS oriented. For instance, the Service participants (human and machine users) are not taken into account.

4.2 Existing PSS Simulation frameworks

The literature reports several existing projects that are aimed at modelling and simulating PSS. In particular, the study of the dynamic behaviour of the PSS was driven by the goal to provide information to the designers on how to handle the system and to verify desired properties [26]. In [27], a state-of-the art of Discrete-Event System modelling of PSS is given. An approach that studies PSS scenarios with accidental events is recalled in [28]. Two other approaches are studied; they focus on the PSS lifecycle in order to follow indicators during design and production [29], [30]. In [23], the behaviour is studied via the implementation of agents. The different types of research identify the variables to be followed during simulation including the price, process costs lifetime, sales frequency, lifetime, etc. In what follows, focus is placed on the simulation of the product price and also its use, in order to compute its impact on the environment.

4.3 PSS G-DEVS/HLA Modelling & Distributed Simulation

The simulation requires interoperating and synchronizing with heterogeneous and distributed components/actors, with each implementing a subset of the PSS. In addition, actual complex industrial service processes are composed of heterogeneous and distributed resources (material, immaterial and human in the loop). To address these requirements of interoperability, the authors introduce a **compliant** Service Modelling Environment G-DEVS/HLA able to interoperate simulation components, human–computer interactions or tactile sensors. The section present a PSS Modelling Environment based on PSS Modelling Specification language and on Distributed G-DEVS Simulation.

4.3.1 DEVS and G-DEVS

In the early 70s, B.P. Zeigler defined a formal behavioural specification of real systems**.** This description, based on state, transition and discrete events, is entitled Discrete Event System Specification (DEVS) [31]. DEVS is defined as an abstract universal formalism remaining independent from implementation. An atomic DEVS is a block model with input and output ports to exchange discrete events. The behaviour of the model is described by states linked by transitions. The transition is fired by receiving discrete events, which causes the current state to change to the following one. In addition to major discrete event modelling techniques, DEVS allows the possibility of the autonomous evolution of the model through the state time life; associated with the life extinction of the current state, an internal state transition function is then triggered. The real world input, output signals and states are abstracted by piecewise constant values in which thresholds are considered as discrete events. The concept of coupled models, introduced later, provides a means to build new coupled models made by reusing and connecting stored models. The DEVS simulator is explicitly specified in the formalism and allows unambiguous simulator development to be obtained.

The Generalized Discrete Event Specification (G-DEVS) formalism, introduced by Giambiasi in 90s [21], is chosen for its formal properties to describe systems with discrete event models, and for its capacity of complex event simulation. This formalism emerged with the drawback that most classical discrete event abstraction models (e.g. DEVS) face: the approximate observed input–output signals as piecewise constant trajectories. G-DEVS defines abstractions of signals with piecewise polynomial trajectories. Thus, G-DEVS defines the coefficient-event as a list of values representing the polynomial coefficients that approximate the input–output trajectory. G-DEVS is a general specification language that clearly separates modelling and simulation processes. More specifically, G-DEVS privileges the use of two concepts: multi-value events, which are useful to carry complex information of a product or a service along the process, and timed states to represent the dynamic of the system.

4.3.2 Distributed Simulation with the High Level Architecture Standard

The PSS is a complex system. It does not appear realistic to try to completely tackle it by just using one model. The idea is to combine deterministic models (e.g. G-DEVS) and stochastic models (e.g. Excel and JAVA Gaussian random functions). Distributed simulation has functioned for many years to establish interoperability between heterogeneous simulation components. The authors propose to address the interoperability of the components by conforming to the distributed simulation standard High Level Architecture (HLA). HLA is a software architecture specification that defines a common technical interoperability language to create a global simulation composed of distributed simulations (or other software components). In HLA, every participating simulation is called federate. A federate interacts with other federates within an HLA federation, which is in fact a group of distributed federates. The HLA set of definitions brought about the creation of Standard 1.3 in 1996, which then evolved into HLA 1516 in 2000 [32] and HLA 1516, which evolved in 2010 [33]. Finally, the authors define a distributed PSS Modelling Environment that interfaces components (implementation of subsets) of the PSS Models and other actors in HLA compliant Federation.

4.3.3 PSS Modelling & Simulation Framework

The authors point out in §4.1 and 4.2 that several languages for modelling services and PSS coexist. Most languages are driven by the final step that consists in obtaining a software-oriented architecture solution. The authors stress that the approach presented in this paper aims at being independent of any specific computerized platform. **The authors have used the SOMF in a previous work [34] to represent a high-level description of PSS Models. However, they found it necessary to extend this formalism using the notion of resource. The resource is a key issue to represent accurately a service because most services are supported by resources which need to be available to allow the service delivery. The conclusion would be possible if the resource entity is considered as part of the model and simulation, and represents the abstracted behaviour of this final link in the service chain. If that is not possible by using distributed simulation interoperability, then humans, external machines or software should be involved in the simulation loop thanks to human machine interfaces. More exactly, the service process model is composed of sequences of sub-service components that build step by step in-progress services by calling resources and controller components that route in-progress service information between sub-services. This model, which can be considered as a Workflow (e.g. Figure 2), was edited and saved within the XML format. Upstream of the work presented in this article, the XML based method, and which was first introduced in [45], to transform the XML Service specifications to G-DEVS simulation models has been reused. This conceptual model was completed by temporal consideration and transformed to a formal G-DEVS model in order to simulate its behavioural patterns. For that purpose, the model state, information exchanged (event) and operational duration of sub-services have been made explicit and added. Each Service Modelling basic component of the PSS model has been transformed into a G-DEVS atomic model and then connected to form the G-DEVS coupled model of the complete system. This G-DEVS model takes advantage of formal properties and can be simulated. In this article, the focus is placed on the obtained simulation model to study the connection of the service components and, in particular, client resource behaviour.**

5 CASE STUDY: THE TOY INDUSTRY AS FIELD OF EXPERIMENTATION

The toy industry is currently one of the most dynamic business sectors in Europe. Despite its economic expansion for more than a decade, perpetual questioning and on-going challenges have to be met to reach economic, social and environmental incentives. The focal point of the case study used in this article deal with traditional toys. These are convenience goods with short life (interest) duration, as the needs of children evolve according to their growth, and to toy fads. The market is generally divided into six classes from 0 to 3 years old (0 to 3 mo., 3 to 6 mo., 6 to 9 mo., 9 to 12 mo., 1 to 2 yr. and 2 to 3 yr.), and in four classes from 3 yr. to 10 yr. old (differentiation between boys and girls and break at 6 yr. old. In what follows, the authors focus on the 0 to 12 mo. period.

5.1 Overview of the toy industry

The toy industry is made up of 2,000 manufacturers and employs approximately 100,000 persons in the EU [35]. In 2009, EU members exported some 953.2 millions euros of traditional toys and imported 5780 millions euros (the main importer country is China). Revenues generated by the sale of toys in the UE constitute some 14,485 million euros, which ensure EU world leadership in this domain [36]. Despite the recent crisis, no drop in customer spending has been observed in that sector since psychologists insist that toys are necessary tools allowing children to have cultural exchanges, socialization, training, and social consistency. The toy industry continuously innovates *(some companies renew 30 % of their collection every year[2]).* Toys for young children are leaders, and represent 23% of market share. In 2009, in the EU, the family budget was about 163 euros per child in the EU and, in France, 247 euros per child.

5.2 Challenges of the toy industry

Despite the growth of the sector, the toy industry is frequently challenged for several reasons. First, the child population in Europe is shrinking. Second, parents expect to be provided with a solution that can help them promote their children's development. Third, parents are pre-occupied by the safety of their children, and toys

[2] http://entrepreneur.lesechos.fr/entreprise/success-story/actualites/ecoiffier-joue-avec-les-petits-prix-113760.php

coming from Asia are sometimes recalled because of their bad design [37]. Furthermore, the legislative environment is uncertain and some UE organizations call on the authorities to define clear and consistent regulations. Fourth, the market evolves rapidly and is highly unpredictable. Fifth, regarding the problem of global warming and increased pollution, environmental protection is gradually becoming a priority in the toy industry as in many others. Thus, toy manufacturers are involved in a sustainable development approach combining eco-design and fair trade [38]. As one can confirm, toy industry challenges satisfy the concepts of PSS. Consequently, the sector undoubtedly constitutes a favourable field for experimentation.

5.3 Experimentation

In this study, the authors model a product-oriented service approach and a use-oriented service PSS. They propose a G-DEVS coupled model of both market circuit scenarios. This model has been formalized according to the data found in the CRIOC [39], TIU [38] and INSEE reports [40], concerning regular household consumption, including that of toys. A macro and greatly simplified behavioural model of child play has been set by means of psychological data given in [41] to simulate the use of toys. This client behaviour helps to validate strategy by closing the loop of partners. We propose to describe the Service Models using a formal approach, and to validate by simulation some properties like toy costs and their impact on the environment. The two scenarios are presented below.

5.3.1 Presentation of the scenarios

Scenario 1 is a function-/product-oriented scenario. The focus is placed on toys sold in a conventional way. Even though the product sale is the core concept, some services, such as repairs, warranty, etc. can be associated with the sale. In that classic scenario, the customer owns the toy. Some years after the end of its first use, the toy could be given to another user (new owner) and then recycled until the toy's end of life. But experience shows that most toys are thrown away in uncontrolled dumpsites or garbage dumps, thereby preventing circular economy because of time damage or accessory losses. The G-DEVS Model corresponding to that scenario is explained in the following subsection.

Scenario 2 is a use-/availability-oriented scenario. In this scenario, only the "use" of the toy is sold to a user. Thus, the toy stays in the provider's ownership. This scenario already exists in the toy industry market [42]. The purchasing procedure can be described as follows: the customer rents a set of toys (regardless of their unit selling price) via the Internet, for a specific duration and associated rate. At the end of the period, the customer can extend the renting, purchase one or all of the toys (with a discount) or send them back. In this latter case, once the provider has recuperated the toys, that provider has to test and clean them before being authorized to send them to another client. The provider is responsible for the return delivery of the toys. The G-DEVS Model corresponding to this scenario is explained in the following subsection.

Before simulation, it is interesting to present the *a priori* arguments defending both scenarios. Arguments in favour of the renting scenario are, for the customers: (i) the use duration of a toy (3mo. before the child is 1yr., 1yr. up to 3yr.), (ii) the cost of some toys which does not have to be considered, (iii) the disinterest for a toy after only a few weeks and, (iv) the known fact that only a few toys suffice for a child to find what he is looking for [43]. Against toy renting is, first, the seasonality and the difficulty of renting a toy for Christmas (54% of turnover) or for a birthday (20% of turnover). Thus, the toy rental market only represents 26 % of the total potential market. Second, the renting duration or rate may cancel the benefits of renting as regards the purchase price. Third, the prevention of some contagious diseases can prevent parents from renting toys for children, *a fortiori* when they are young and have not yet developed sufficient immunity. The decision for clients is whether to "rent or buy". For the provider, the main advantages concern: brand image enhancement, the ownership of the toy at its end of life, making circular economy possible, and offering a potential new source of revenue. The provider, however, remains responsible for children's safety. Consequently, the test and cleaning activities are of great importance and the associated cost is significant.

5.3.2 G-DEVS Models

In this part, we detail the G-DEVS coupled models for the toy selling/renting systems obtained by transforming from the PSS conceptual model. The general workflow model, proposed in Figure 2 describes the PSS chain from production of the product to client use where each block is a G-DEVS model. The colour distinguishes workflow steps. The white block production step generates goods according to annual sale forecasting. The green blocks represent service steps, and the blue blocks represent client behaviour. In the present contribution, two concurrent models can be distinguished, one for Scenario 1 and the other for Scenario 2.

In the upper part of Figure 2, the G-DEVS coupled model presents the main steps of the product-oriented PSS. This starts from traditional product manufacturing (**produce** block) that is defined by capacity based on seasonal demand forecast. This then goes the sale block that takes into account seasonality demand plans. The next phase is the baby's use of the toy. This duration (according to psychological studies) has been modelled as an atomic G-DEVS model (described in Figure 3). In case the product is broken during the warranty period, it is repaired or replaced. At the end of the rental period, the toy is disposed of. This block is a memory of toy duration.

In the lower part of Figure 2, the second G-DEVS coupled model describes a use-oriented PSS in which the toy is rented instead of being sold. This model also starts from a production phase that has been differentiated from the previous PSS on the basis that it is supposed to integrate more environmental care in the choice of the recycled raw materials; concretely, it can affect the cost of the toy and its time of manufacture. The second sub-model is the rental model which takes into account demands from clients, subject to seasonality. Once the rental agreement assignment has been signed, the toy is then prepared and sent to the client. The use model of the toy is the same as in the first scenario. In case the product is destroyed or damaged by the child, three possibilities are envisaged: product recycling, donation or renting to another client.

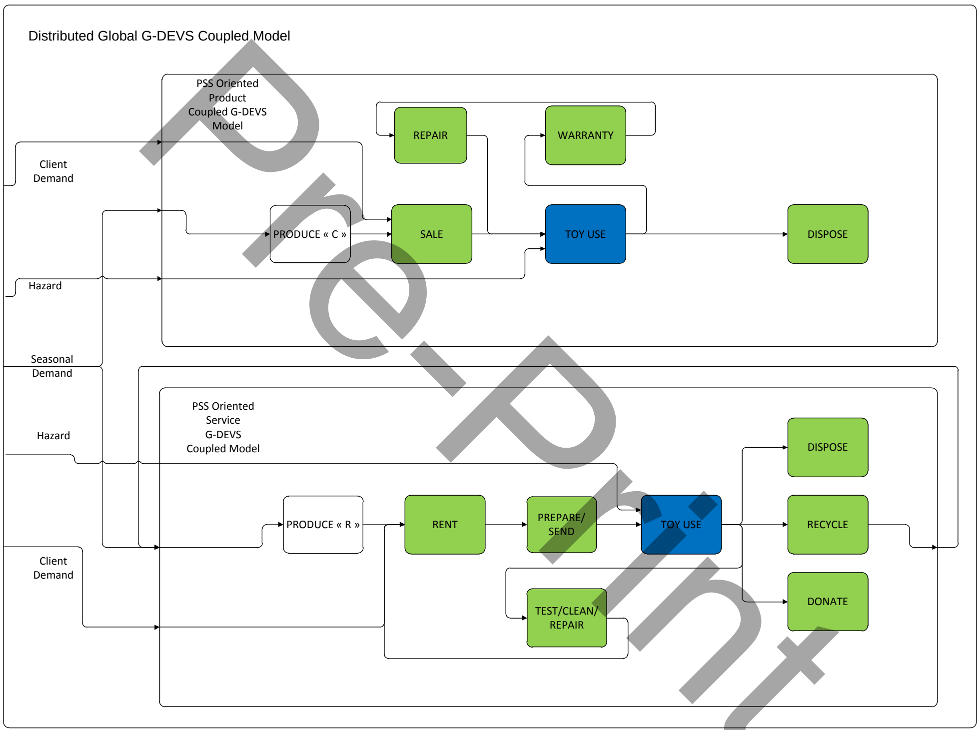

Figure 2: G-DEVS Coupled model with product-oriented PSS and use-oriented PSS

The G-DEVS child agent (Figure 3, "toy use" block) describes an extremely simplified behavioural model of the baby's play time durations. The same model is used in both coupled models (Sale/Rental). According to psychological child play studies of [41], [43], [44], the more the child grows, the longer the "play episode" duration. Small babies have more episodes but of shorter duration (e.g. During a 30 min period of study a 12 mo. child plays 42.04 episodes of 38.20 sec., whereas an 18 mo. child plays 34.76 episodes of 46.53 sec.). **The model has been built on the base of those studies. It incorporates toys and casual events such as broken toys and parameters to compute child interest duration. Then, the toy interest duration is stochastically computed by changing the state "playtime" to "pause" several times. The model has been instantiated by 60 different child agent model replications, each one tuning the profile of the child with different playtime characteristics (with stereotyped profile of 0 to 3, 3 to 6 and 6 to 9 mo.).**

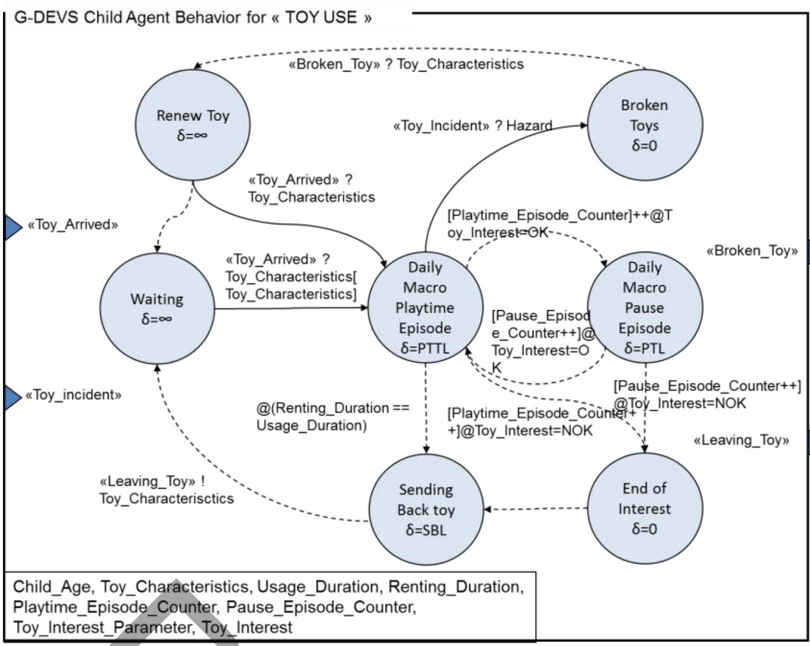

Figure 3 G-DEVS Child Agent Behavior for « TOY USE »

Going back to the general model of Figure 2, two situations can occur during use: if the toy is broken during the warranty period, it is either repaired or replaced. In case that happens when the warranty has expired, the toy is disposed of. The “after use” of the toys is described in the right hand part of Figure 2. We added a JAVA stochastic random function to compute randomly, in particular play time, pause time and end-of-interest to the simulation tool used (LSIS_DME [45]).

5.3.3 Other components

The seasonal toy market selling tendency has been implemented in an Excel file to transpose the results from the previously mentioned reports to G-DEVS events planned as inputs of the PSS G-DEVS models. This random event generator has been based on Excel stochastic function (based on [46]) to generate a file that contains events to feed the broken toy incidents. This file is charged in a scheduler for the G-DEVS models. In a similar way, a JAVA random function computes dynamically the length and number of play episodes of the baby with a considered toy inside the G-DEVS toy use model. It allows computing the toy interest duration before the toy is considered as old-fashioned for a child agent.

5.3.4 Distributed Architecture

This section presents the architecture of the implemented test case (Figure 4). The interoperability between heterogeneous components (Excel, JAVA code, LSIS_DME G-DEVS models, etc.) has been solved by the HLA standard. The HLA Run Time Infrastructure components from poRTIco has been selected for its open source development; it takes in charge the distributed execution and orchestrates the message exchange between the components. This architecture is based on previous works to handle message passing according to synchronization considerations [21], [47].

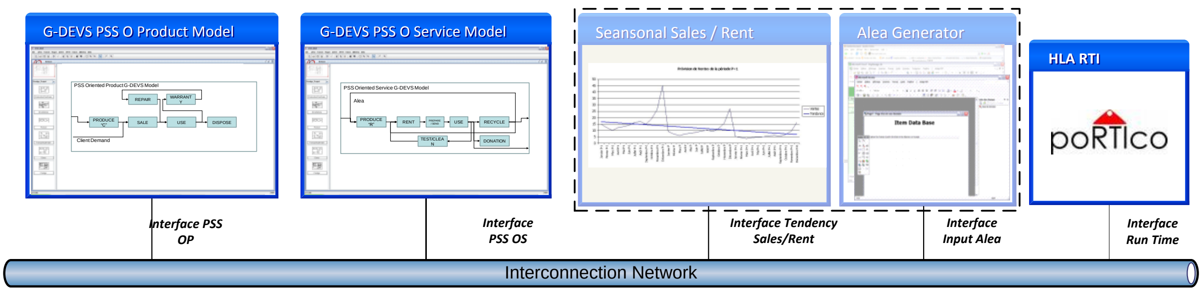

Figure 4 Representation of the distributed Architecture

5.3.5 Simulation Scenarios and results

The inputs of the simulator are, in particular, the sales demand of the client during the different seasons in the year. Figure 5 presents a distribution of 85 % sales versus 15 % renting. Three significant zones can be identified. The first period is March, with a small demand peak corresponding to Spring events and holidays. The second peak occurs during the Summer time. Finally, the most notable peak is the pre-Christmas period, with 60 % of annual sales being made during this period. That period has been replicated for more than 60 different child profiles introduced previously. The authors propose to follow up child play time with the toys over a period of one year, and also to indicate the cost of the solution during simulation in order to have a PSS evaluation. The simulation has been run based on several mixed sale/rental scenarios to provide the results explained below. The authors have balanced sales/rental ratios, starting with 15 % renting upto 50 % renting. In the test case, one simulation replica covers a one year period for 60 children. Several replicas have been launched. During the year the child ‘s behaviour evolves; the age of the child is assigned randomly at the beginning between 0 to 12 mo.

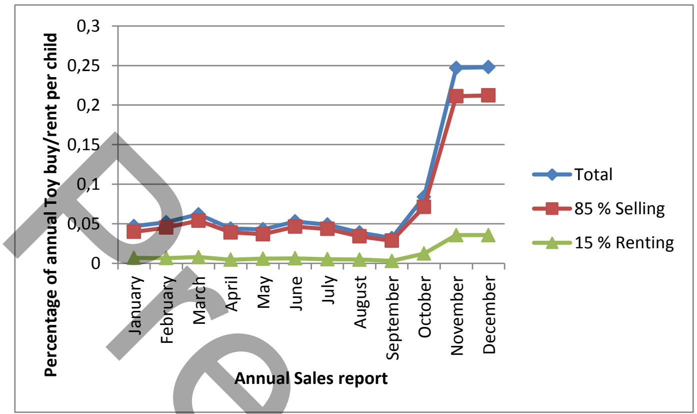

Figure 5: Example of Percentage of annual Toy purchases/rental per child

The different scenarios allow sales to be compared to rents on the basis of different criteria including, firstly, the price (selling vs. renting, according to the different formulas proposed) and, secondly, the impact on the environment by use duration in months for a set of 5 toys. The study starts from the postulate that parents spend some 247 € annually per child [33]. It proposes four toy renting formulas with decreasing prices depending on renting duration dedicated to parents of 0-12 month’s child (Figure 6 Horizontal dimension). The first formula consists in buying 5 toys for 35 €. The second one considers renting the same 5 toys for one month for 13 €. The third formula concerns renting the 5 toys for two months for 23 €. The last one covers renting the five toys for 3 months for 30 €. The study then distinguishes three scenarios (Figure 6 curve scenario). In the first scenario, the client plans to rent 15 % of the toys he plans to buy during a period of one year; the remaining 85 % is purchased by the client. In the second scenario, 25 % is rented. In the last scenario, 50 % is rented by the client. We integrate stochastic events for the use duration of the toys, which influences the computation of their price. The simulation results are shown in Figure 6.

The left hand side of Figure 6 shows distributed simulation client cost results. The scenarios are compared in terms of the total price to be paid by a client for one year of baby toy needs. The postulate is in case the client buys the toys at approximately three-month intervals. Due to young children’s frequent new needs, the simulated G-DEVS child agent will ask to renew toys based on the number and duration of playtime episodes.

- In the 0% scenario, the annual amount spent by parents has been fixed at 150 € (based on an average value for toy spending during baby’s first year). In simulation, this price fluctuates a little due to stochastic events and use behaviour
- The scenario that proposes renting 15 % and 25 % of the toys used shows that the three-month renting formula is less expensive than buying the toys
- The 50 % formula is much more expensive than buying the toys compared with the three-month renting formula

The simulation confirms that the rental price has been adapted to offer clients the possibility of renting at low prices.

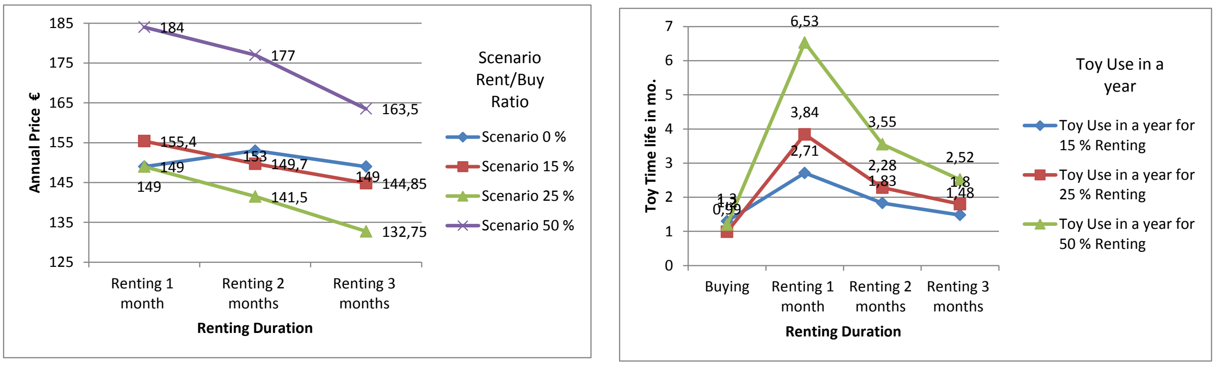

Figure 6 Comparison of scenarios as regards price and environmental impact

On the right hand of Figure 6, the average use of toys in terms of the different formulas is shown. The environmental impact of renting recyclable toys versus the production of disposable toys can easily be deduced. The simulation results clearly confirm that even when stochastic incidents and interest duration are taken into account as input to the G-DEVS model, the one-month renting solution offers the longest toy use duration by far compared with all the others scenarios. The three-month renting is just a little better than purchasing. This fact is because the turnover of the child's usage has been based on an average three-month period [43]. These results must be set against a toy's lifetime. When a toy is produced with a one year warranty, it can be concluded that it will be able to resist for approximately one third of that duration when used in active (intensive) plays. In the scenario of a one-month rental, the toys are actively used for 6.53 months by different children and in consequence, it is not certain that all toys can resist for that length of time.

The best mix for clients is to rent 25% of toys. For producers and sellers, the best formulas are either for rental periods of two- or three-months. They earn 2.5 to 3 periods of rent, and the environment is preserved in the same proportion. We have to bear in mind that all that works when the toys are adapted and resistant to several periods of child use.

6 CONCLUSION

The article demonstrates that profitability and significant margins can be obtained provided that PSS design and development consider simultaneously the design of products and services, the client specific usage of the PSS, and of its impact on the environment. A new business model is necessary to support a company PSS activity throughout the PSS life cycle. A special attention should be paid to the design phase to ensure that the offered system satisfies customer needs. The authors have presented a new perspective of a Service Modelling & Distributed Simulation Environment based on G-DEVS / HLA to support design validation. The simulation has shown that some stereotyped client behaviour can be integrated into the simulation loop to obtain a more realistic study of the client/supplier relation in the comparison of traditional sales versus PSS market. The play time behaviour of children of under one year has been modelled in order to deduce buying or renting potential habits of their parents. This model can close the simulation loop to have a more realistic evaluation of the optimal solution. Therefore, different innovative PSS scenarios can be simulated and tested regarding specific criteria, allowing a decision maker to decide on new developments by choosing the best win/win strategy. Future research will include the testing of other scenarios and the integration of other choice criteria and the inclusion of more complex client habits. The limited literature concerning the combination of service Modelling, Distributed Simulation and the next generation market suggests that there is ample room left for new perspectives.

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