Product-Service System Development with Discrete Event Simulation

Modeling Dynamic Behavior in Product-Service Systems

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***Abstract*—An ongoing trend in product development is to extend traditional products with appropriate services. This concept of Product-Service Systems (PSS) rises attractive opportunities for customers and companies. Based on literature an introduction into PSS development is given. PSS modeling and the dynamic behavior of PSS are discussed. Three suitable modeling methods are identified: Agent-Based Modeling (ABM), System Dynamics (SD) and Discrete Event (DE) Simulation. In this paper the well-known DE approach is transferred from its traditional applications to PSS development. Characteristics of DE simulation and its benefits and limitations in context of PSS are presented. A major advantage is the forecast and evaluation of different scenarios. This contribution identifies possible application areas to support PSS development with DE simulation in context of both development process and PSS type. Three examples show the applicability of the DE approach in a wide range, one from literature and two academic ones. The results are discussed and an outlook to future modeling methodology is given.**

***Keywords*—Product-Service System; Discrete Event Simulation; modeling; dynamic**

I. Introduction

Product-Service Systems (PSS) expand the traditional functionality of a product by additional services. Customers do not mandatorily possess the product, they pay for functionality. The focus is on the usage of the product. PSS rises attractive opportunities for the stakeholders. For instance, customers can profit from added value at cheaper prices and companies can benefit from long-term customer relations. Additionally PSS can lower the environmental impact because of long-term product lifecycles [1].

In this conceptual modification, PSS business models offer further challenges compared to traditional product development. To ensure success of these business models, new methods are required. Challenges occur due to the dynamic influences on PSS [2]. An approach to handle this dynamic-caused challenge are dynamic modeling methods.

This paper discusses the applicability of Discrete Event (DE) Simulation to support PSS development. The focus is on the analysis of the suitability of DE modeling for different PSS types to enable a wide field of possible applications.

The concept of PSS is introduced as well as its dynamic influences. Furthermore DE simulation is identified as possible modeling approach (section 2). Section 3 identifies possible application areas of DE simulation to support PSS development. In section 4 small cases verify these assumptions. Benefits and limitations of the approach are pointed out in section 5, followed by a conclusion and suggestions for ongoing work in section 6.

II. Background information

A. *Product-Service-Systems*

Reference [3] gives a first formal definition of PSS, which is widely used in literature [1]. A PSS is a marketable set of products and services capable of jointly satisfying user's needs.

A PSS basically consist of:

- Tangible products manufactured to be sold.
- A mostly commercial service, adding economic value in form of an activity, done by human beings or automated systems.
- A system as collection of elements and their relations

Three major categories classify PSS depending on the service level of the system (Fig. 1). Product-oriented PSS are customer owned products, which are extended with additional services during the product lifecycle. The focus is on recycling potentials and well-functioning and long-lasting products. Use-oriented PSS are usually not owned by consumers, but companies offer the availability in order to maximize the utilization of the product. Result-oriented PSS sell capabilities instead of traditional products. Consequently, customers pay for results, without owning the product [1, 4].

In literature there are already methodologies to design PSS, but typically these are adoptions of methodologies developed for traditional products or services. However, evaluations of the proposed methodologies are limited [1, 5-10].

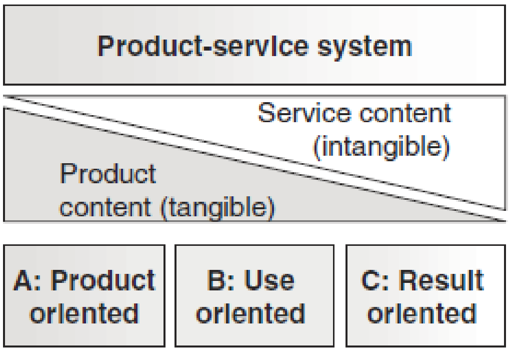

Fig. 1. Product-Services System types by [4]

B. *Dynamic in PSS and its modeling*

Literature mentions a couple of challenges, PSS development has to handle. References [2] and [9] point out the need for new development methodologies due to dynamic business relations and the resulting uncertainty. Additionally, [11] support the thesis of dynamic in business environment as reason for uncertainty. Uncertainty and thus high complexity are major challenges in PSS development [12]. Therefore, this contribution focuses on dynamic behavior of PSS and its modeling.

To come up to future changes, adaptability in strategic planning is a main aspect in context of dynamic behavior of PSS [13]. Reference [14] points out the enhanced influence of dynamics in PSS development in contrast to traditional product development and [15] address the dynamic along the PSS life cycle. Fully verified modeling and simulation methods to analyze the dynamic behavior of PSS are still missing. Three suitable modeling methods are identified: Agent-Based Modeling (ABM), System Dynamics (SD) and Discrete Event Simulation.

References [2] and [16] underline the importance of dynamic simulation for PSS development. They introduce a business model for PSS, based on system SD. SD is a common method to analyze the dynamics of a system. Therefore the system's entities are represented by stocks connected with flows [17, 18]. Reference [10] supports companies in changing from traditional product offering to PSS with SD. Reference [19] uses SD to analyze service performance and maintenance contracts.

A second approach for dynamic modeling of a PSS is ABM. In contrast to SD, ABM uses a bottom up modeling approach, in which a system is modeled as collection of autonomous decision-making entities called agents. Consequently, the system's behavior is affected by the behavior of individuals (agents) and their interaction, which is determined in a set of rules [20, 21, 22]. Reference [23] supports the development of an E-bike sharing system (PSS) with ABM.

A third method to model dynamic behavior of PSS is DE modeling. This paper transfers DE from its traditional applications to PSS development and shows the applicability over a wide range of PSS types. ABM was already discussed in a previous publication [23] and SD was presented in [13, 16]. Reference [24] present the application of DE in a car and ride sharing PSS.

C. *Discrete Event Simulation*

SD and DE are traditional approaches, whereas ABM is a relatively new approach. SD is usually used at very high abstraction levels, whereas ABM could be used across all levels. DE simulation deals with low or middle abstraction levels. Nevertheless ABM could not completely replace the traditional methods. For many of the potential applications it would be less efficient, harder to develop or doesn't match the nature of the considered system [20]. The choice of the modeling method depends on the system [25].

Already in the early 70s [26] deals with the approach of DE simulation to model complex systems. This traditional and well developed approach can describe a system's behavior as it evolves over time, thus its dynamic behavior [27]. DE models contain state variables, which could change, if events occur, at discrete points in time [28]. A holistic definition is given by [25] as they describe DE simulation models as networks of queues and activities, in which individual entities pass through series of activities. These entities are defined as distinct individuals, possessing characteristics, determining what happens to the individuals. The activity durations are sampled for each individual from probability distributions. Reference [20] proposes DE modeling may be considered as definition of a global entity processing algorithm, typically with stochastic elements.

DE models consist of several major parts, e.g. individual entities, discrete events and stochastic behavior [29]. Reference [20] specifies these entities as passive objects. Another, already mentioned, important part of the model is time.

There is a very wide range of application areas for DE, for example in the healthcare sector [30, 31]. Reference [32] classifies discrete systems:

- Queueing Systems (e.g. bank teller)
- Computer Systems (e.g. multiple tasks served by CPU)
- Communication Systems (e.g. message transfer via multiple servers)
- Manufacturing Systems (e.g. workpiece has to pass multiple manufacturing steps with several machines)
- Traffic Systems (Vehicles in traffic, with traffic lights and physical space on the street)

DE methodology is advisable if a complex dynamic system can be represented by a sequence of discrete events over time with passive entities flowing through it. Entities can be connected to resources, so they can pass an event just if the required resource is available (e.g. assembly line). As shown DE modeling typically covers technical as well as service applications. Consequently, it is highly interesting in context of PSS modeling. For DE simulation various free and commercial software is available. They have powerful graphical and animation facilities to clarify behavior or results.

III. DISCRETE EVENT SIMULATION SUPPORTING PSS DEVELOPMENT

A. Benefits of DE in context of PSS

The goal of this contribution is to discuss the applicability of DE methodology in context of PSS development. The DE modeling approach fits quite well to the challenges in modeling dynamic PSS behavior.

As obtained from literature major challenges in PSS development are to deal with complexity, dynamic behavior and uncertainty caused by changing environmental conditions of the system. In context of modeling a healthcare systems with DE, [25] address variability, uncertainty and complexity as major characteristics of the system. They also point out the ability to compare scenarios, for example with different staffing levels or the use of timescales. Consequently, the capabilities of DE methodology match the challenges in PSS development.

DE modeling has several benefits in context of PSS modeling:

- Transparency and comprehensibility
- Simulate uncertainty
- Connection of entities and resources
- Use of time schedules

Due to the sequence of events DE models are basically look like flowcharts. Reference [33] presents an exemplary flow chart logic, which is the basis of modeling a manufacturing system with DE methodology. DE simulation can integrate stochastic behavior, so a certain degree of uncertainty is realizable. This is a core aspect in PSS development. For example, uncertainty can be integrated in the duration of an event, the creation of entities or the decision which path entities to choose. Especially the connection of resources and entities is highly interesting for a PSS context. Here, sufficient resources must be available so that entities can pass an event. The number of available resources can be adjusted and the simulation of various scenarios is possible. Many model objects in the model can be connected to a time schedule, which offers the opportunity to reproduce realistic and numerous scenarios. The creation of entities, but also the availability of resources, can be restricted by time tables.

DE simulation can support PSS in combining and varying these factors (e.g. uncertainty, resources and time tables) to compare numerous possible scenarios. In the early development process, the planning phase, the simulation can evaluate many scenarios under varying boundary conditions. On the one hand optimal configurations can be defined and on the other hand opportunities and risks can be identified. In this early stage changes in future operation can be prepared and bottle necks identified. This reduces the risk of a wrong configuration and currently not predictable influences can be anticipated.

B. Limitations of DE in context of PSS

Besides the wide field of possible applications of DE simulation in context of PSS, there are also limitations. In contrast to ABM, DE simulation uses individual entities with only passive behavior. For instance peoples' behavior in sharing systems cannot be modeled with realistic individual behavior. Furthermore, there is no real randomness, only a forced uncertainty based on stochastic probabilities. Consequently, uncertainty is defined by the modeler in a certain range. Systems without a flowchart characteristic are hard to represent in DE logic.

C. Possible areas of application

A reference model of an integrated PSS lifecycle is presented in a very simplified form in Fig. 2 [15]. They address all phases of the PSS life cycle. In context of this publication the focus is on the planning and development phase.

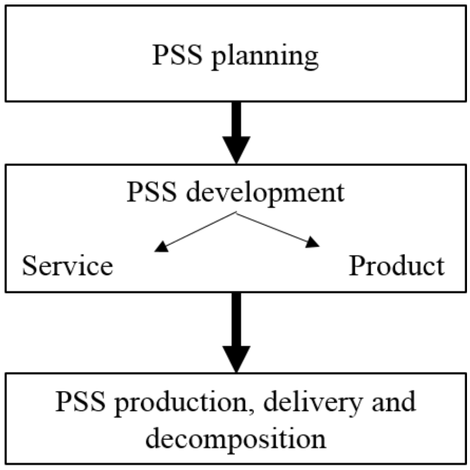

Fig. 2. Simplified Reference Model of integrated PSS lifecycle [15]

During the planning phase the evaluation of ideas is a first possible application area. Here, ideas can be evaluated by simulations to estimate their opportunities.

During the development phase, DE simulation can support both, service and product. For example, different scenarios can be evaluated and necessary resources or reachable customers quantified. The simulation can compare products with different characteristic properties included in the entire PSS framework. The best fitting type of product for each application is selected.

In contrast to the lifecycle classification, the application areas of DE simulation for PSS are distinguishable between the previously introduced three PSS types (Fig. 1):

- Result oriented
- Use oriented
- Product oriented.

In result oriented PSS, DE simulation can be used to model the entire process from both, customer's and provider's view. The result is the central aspect. Customers often do not care about how things work; they focus on time and costs. Providers can obtain those basic facts from simulation and give customers required information (e.g. cycle time depending on the configuration).

Typical use oriented PSS are leasing or sharing. Here, DE modeling can simulate flows of customers using products. Depending on the number of customer, the necessary amount of resources (products) can be evaluated. Even time aspects like distances or disturbances can be taken into account. For instance rush hours or other peak times can be considered in time schedules.

Furthermore DE simulation can model product related services in product oriented PSS. Exemplarily services, caused by either frequently required support or services caused by failures, can be considered. Resources, concerning these services, can be planned based on this analysis.

IV. Examples

It would be desirable to find a modeling method, which can support all three basic PSS types. From a theoretical point of view the DE methodology seems to be able to cover this wide range, at least partially. An example for each PSS type underlines this contribution. Two academic cases and one from literature are presented.

A. Result Oriented PSS – Laundry System

An academic example of a laundry service represents a result oriented PSS. The company offers devices, in this case washing machines or dryers, and simultaneously provides the necessary workforce. The customer pays per garment or service unit. Fig. 3 shows, in a simplified form, the DE model of processing laundry. The process, which has the significant style of a flowchart, is connected to time tables and resource pools. They manage the availability of resources (connections are marked with lines). Each event (washing, drying…) has a definable randomness in time delay to include uncertainty into the model. The process path of each item is based on a stochastic behavior.

Based on this model, alternative scenarios can be evaluated. These scenarios differ in time tables of working hours, assumed uncertainty in delay, machine capacity, number of resources (machines and workers) and amount of laundry. Fig. 4 shows an exemplary evaluation process with three different specified criteria. Each number represents one configuration alternative. This evaluation based on simulation results supports the resource planning under various boundary conditions and enables the possibility to identify weak spots in the process. For example, if there are not enough washing machines provided, the laundry cannot be processed. Consequently, this bottle neck causes a jam in the front part of the model.

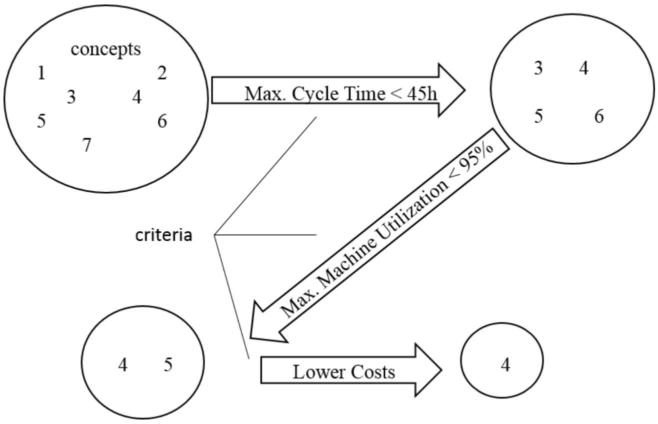

Fig. 4. Exemplary concept selection based on simulation results

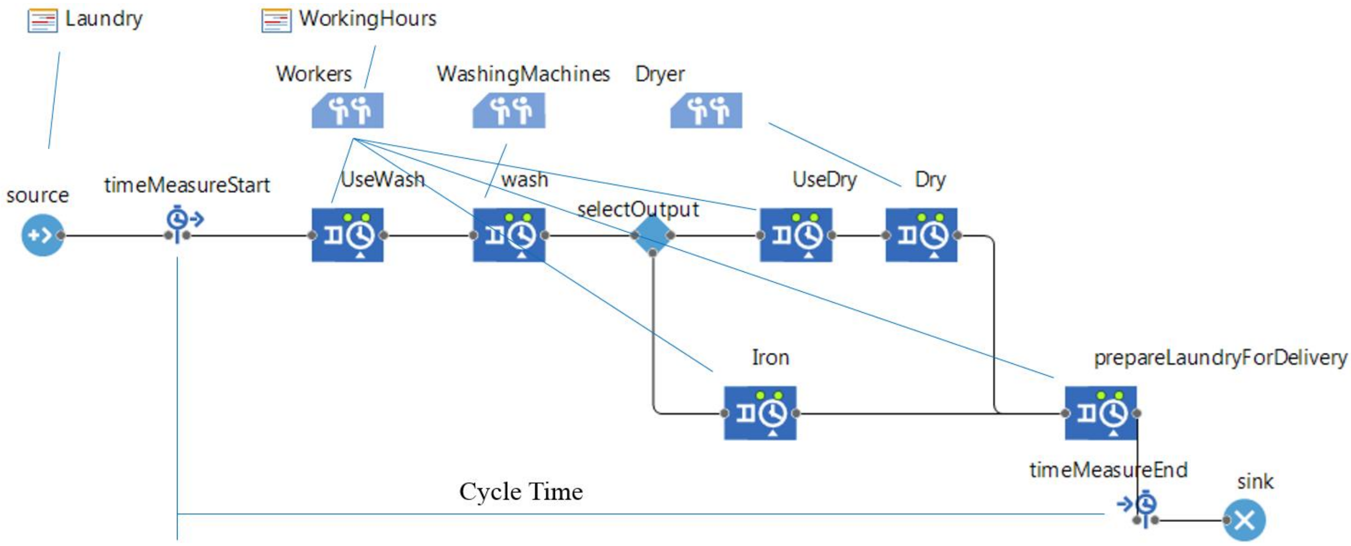

Fig. 3. DE model of a laundry service

B. Service Oriented PSS – Car and Ride Sharing System

The aspiring sector of car sharing systems is a typical example for a service oriented PSS. An example from literature [24] gives insights into the structure of such a system and presents the analysis performed with DE simulation. The focus is on reducing environmental impacts to a car and ride sharing system.

This model experiments with different system parameters, like the amount or type of cars. Additionally, changing environment factors are considered (e.g. daytime, flow of passengers, etc.). A close to reality DE model is designed to evaluate different scenarios. Therefore a realistic environment (map) and vehicle descriptions are used. Assessment criteria are costs, energy consumption and transport capacity. This simulation enables a reasonable selection of potential system configurations under varying boundary conditions.

The example shows how DE simulation can support PSS development, but it is not mentioned why they choose DE as modeling methodology, nor do they describe the structure of the model.

C. Product Oriented – Market System

The academic example of an electronic market represents product oriented PSS. Products are sold including a delivery service and service guarantee. The focus is on the product itself, but later repair services have already taken into account to plan resources reasonably. Different scenarios are possible, because of varying boundary conditions. Another factor is the uncertainty of future conditions. Uncertainty is included in the model in form of stochastic distributions, for example in the number of sold products, failure rate of products and service effort. Resources, like service workers or vehicles, can be adjusted to match these requirements.

Fig. 5 shows a simplified model of the electronic market PSS. Here the characteristic flowchart structure of the DE model is again recognizable. Starting point of the model is the customer, who buys a product. These products must be delivered and assembled by service workers. In case of a failure, the service workers fulfill the service effort. Two different activities (delivery/assembly and service) need the same resource pool (worker). An extended model could have additional features like vehicle, product resources or different types of products and workers.

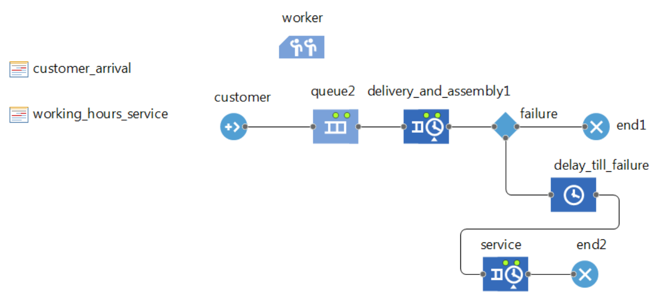

Fig. 5. DE event model of product oriented PSS

In this model uncertainty is included in the number of sold products, the failure rate of products, the time for delivery and assembly and the required time for repair services. Due to these uncertainty factors a reliable resource planning is complex. How DE simulation lead to a more reasoned planning is shown in a brief evaluation (Fig. 6). The number of workers is discussed depending on two uncertainty factors, the amount of products and the failure rate of the products. In this case the simulation obtains no optimal number of workers, but it indicates reasonable configurations. Therefore at least some boundary conditions or a value range should be defined. Here DE simulation is not a decision tool, but it can support decisions.

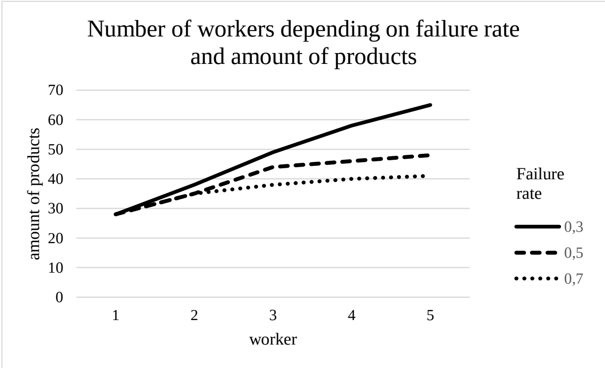

Fig. 6. Evaluation of uncertain influence factors on PSS resource planning

V. Discussion of the Presented Models

DE simulation can support development of all PSS types. The simulation identifies bottle necks and allocates resources in the result oriented laundry. For the service oriented car and ride sharing system a reasonable vehicle planning is achieved. The product oriented market system is supported in planning of worker resources.

Although the three academic examples are more or less close to reality, they do not use exact values. They are idealized cases for the application of DE methodology, which is reasonable under certain boundary conditions. But for oodeling methods, like ABM or SD may be more suitable. Consequently, this paper does not proclaim a general applicability, it only shows potential applications.

VI. Conclusion and Outlook

This paper discusses the applicability of DE methodology to support PSS development and thus handle its dynamic behavior. Based on literature the concept of PSS is introduced and its dynamic characteristic is pointed out. Dynamic modeling can support the development of such systems. One promising modeling approach is DE simulation. Its benefits and limitations are discussed. Possible application areas along the PSS development process are identified and the usefulness for three different PSS types is shown in small cases. Limitations of DE modeling are considered.

After ABM's and DE's applicability to support PSS development is demonstrated, a promising approach is the combination of both methods. This approach could cover a wider range of applications in PSS development. Reference [34] indicates those possibilities.

A suggestion for future work is to generate PSS concept alternatives automatically. By using decision methodologies concepts can be assessed and selected. Optimal solutions for different criteria under varying boundary conditions are identified and consequently, simulation becomes a decision tool in context of PSS configuration.

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