Application of System Dynamics for Modeling Product-Service Systems

Hugo d'Albert*, Srinivasan Venkataraman, Mayada Omer

(Institute of Product Development, Technical University Munich, Germany)

Abstract: Product-service systems (PSS) are a new trend of business models. They combine advantages of traditional products with added services. According to this trend, companies can create innovative and complex structure to meet stakeholders' requirements. In comparison to traditional product or service development, the engineering of integrated systems offers some important advantages for the stakeholders, such as, for example added value for the customers or higher profits for the companies.

This paper examines the applicability of system dynamics technique for modeling of complex product-service systems. An exemplary case study considers an e-bike sharing system and analyzes the cyclic changes within the systems and discusses the system dynamics applications to support PSS design.

Keyword: PSS, system dynamics, dynamic modeling, e-bike sharing

1. Introduction

In this paper an e-bike sharing system as a case study is shown. An e-bike sharing system is one kind of product-service system (PSS) and is examined in the context of SFB 768 (one of Collaborative Research Centers in Germany). This e-bike sharing system includes both product and service components and helps to realize individual mobility needs offering added value to stakeholders. PSS are seen as a new selling approach in which both physical products and immaterial services are gathered to fulfill customer's needs (Goedkoop et al., 1999).

Due to structural complexity and dynamic interactions between system components, designers of product-service systems face uncertainties in planning and development. The system changes require quick adaptation and allow only short planning and adaptation period. The complexity connected with these dynamic changes increases possibilities of errors. Using modeling techniques in the designing of product-service systems should help to eliminate such errors and allow developing of robust dynamic structures. System dynamics is a method of examining dynamic systems. It allows viewing the system as a closed structure with individual's behavior.

The application of system dynamics can be regarded as a means for anticipating this behavior and uncertainties related with it.

*Corresponding Author: dalbert@pe.mw.tum.de

The aim of this paper is to examine an approach that uses system dynamics techniques to make PSS designing process more reliable.

This paper will begin with an overview of PSS and system dynamics modeling. Then, a link will be established between PSS and system dynamics approach by using an example to demonstrate the applicability of system dynamics modeling for the planning of various time changeable stocks within an e-bike sharing system.

The focus of this paper is twofold. On one hand, it describes an e-bike sharing concept as a PSS, and on the other hand, examines system dynamics for support of developing such systems.

2. Methodology

This paper discusses the abilities of system dynamics modeling to support PSS development. At first the characteristics of PSS and system dynamics will be presented in accordance with literature (Section 3). Next, the system dynamics model that describes a particular use case within PSS will be introduced (Section 4). In Section 5 the further topics of system dynamics modeling to support PSS development will be discussed.

3. Background Information

In this section, two subsections are included. First, the PSS will be defined and explained. Next, the system dynamics as a modeling technique will be described.

3.1 Product-service systems (PSS)

Faced with saturation of their core products markets, companies in search of growth are increasingly turning to services (Sawhney et al., 2004). They see the service provision as a new factor to increase the company's profits.

In contrary to the traditional philosophy of manufacturers with the focus on manufacture and sale of products, the PSS-approach suggests shifting towards the offer of a (specific) function (e.g. transport from point A to point B) to the customer by the provision of a whole range of product and service combination (Kuntzky et al., 2012). More traditionally oriented manufacturing companies implement this new philosophy and create a new business model which consists of tangible products and intangible services. Because products in combination with services could provide higher profits, the enterprises develop PSS instead of only selling of physical products or only providing service solutions.

A PSS integrates product and service components, whereby the product components may consist of a combination of elements from mechanical, electrical, electronic and software engineering (Schenkl et al., 2013). The designers of PSS try to create a marketable set of products and services capable of jointly fulfilling a user's need (Goedkoop et al. 1999). Tukker (Tukker, 2004) discerns three main types of PSS:

- Product-oriented service: The provider not only sells a product, but also offers services that are needed during the use phase of the product.
- Use-oriented service: The product is owned by the provider and only leased by customers. It might be shared by a number of users. The provider is responsible for maintenance, repair, and control. The user pays for the use of the product.
- Result-oriented service: The provider agrees with the client to deliver a result. The provider in principle has all the freedom in terms of how the result is delivered.

PSS design should focus on integrating business models, products and services together throughout the lifecycle stages, creating innovative value addition for the system (Vasantha et al., 2012).

This paper focuses on a hypothetical e-bike sharing company that offers use-oriented service.

3.2 System dynamics modeling

System dynamics is a computer-aided approach for analyzing complex physical, biological, social or industrial systems created in the mid-1950s by Professor Jay Forrester of the Massachusetts Institute of Technology (Forrester, 1961).

In system dynamics approach, the real-world processes are represented as a chain of stocks and flows, and information that influences the quantity of these flows. System dynamics suggests a very high abstraction level, and is positioned as a strategic modeling methodology (Borshchev, 2013). System dynamics is grounded in the theory of nonlinear dynamics and feedback control developed in mathematics, physics, and engineering (Sterman, 2000).

The system dynamics models do not consider single events and entities but the system behavior as a whole with policies that describe general conditions. The system is modeled as a closed structure with its own behavior over time. This behavior results from interacting feedback loops and delay structures that are based on mathematical equations. It helps to identify causalities, accumulations, and the flows within regarded system. Thus, qualitative exploration of these causalities is possible.

Applications of system dynamics have been made to corporate policy, behavior of diabetes as a medical system, growth and stagnation of urban areas, and to world forces representing the interactions of population, pollution, industrialization, natural resources, and food (Forrester, 1971).

The main goal of system dynamics is to understand, through the use of qualitative and quantitative models, how the system behavior is produced, and use this understanding to predict the consequences over time of policy changes on the system (Santos et al., 2002).

4. E-Bike sharing system as a PSS

To verify the applicability of system dynamics modeling on PSS development it has been applied to a case study involving an innovative e-bike sharing system as a product-service system which based on PSSycle.

The PSSycle was developed within the Collaborative Research Project 768 (Managing cycles in innovation processes – Integrated development of product-service systems based on technical products). The PSSycle is an e-bike that combines the elements of a standard bike with the supported electric motor. This e-bike is embedded in the social environment and enhanced with services. It can be reserved and hired via online. Users can also unlock and pay via an integrated customer terminal. It is a prototype of an innovative e-bike sharing system.

After defining requirements and functions, the PSS has been constructed as demonstrator and shown at Hannover Fairs International in 2013. To support the development of complete e-bike sharing system with a provider which manages a stock of e-bikes, modeling techniques will be examined.

The system dynamics modeling is used as an approach to analyze nonlinear relations within a hypothetical e-bike sharing system. The case study refers to innovative e-bike sharing, a product-service system which integrated PSSycle.

4.1 The case study

It is assumed that successful business model must fulfill the customers' requirements. One of these requirements is availability of products and services. A key issue of e-bike sharing company is to optimize its service processes with the aim to provide the customers the same level of availability over time. The case study examines one aspect of the e-bike sharing system: the stock of available e-bikes.

In this case study availability means the number of e-bikes that are available for the potential customers. The activities connected with this case study like observing the number of e-bikes in stock and periodical ordering of new e-bikes were examined.

As a simulation tool to test the applicability of system dynamics modeling for PSS development, AnyLogic is used. AnyLogic is a Java-based multimethod simulation platform that supports three modeling approaches: discrete event simulation, agent-based modeling, system dynamics, and any combination of these approaches within a single model. (Borshchev & Filippov, 2004).

AnyLogic uses for the system dynamics two different items: stocks and flows. The static structure model is built depending on a case study. To support the examined policy a number of parameters and variables might be defined.

In this case study, the model consists of two stocks and three flows [figure 1].

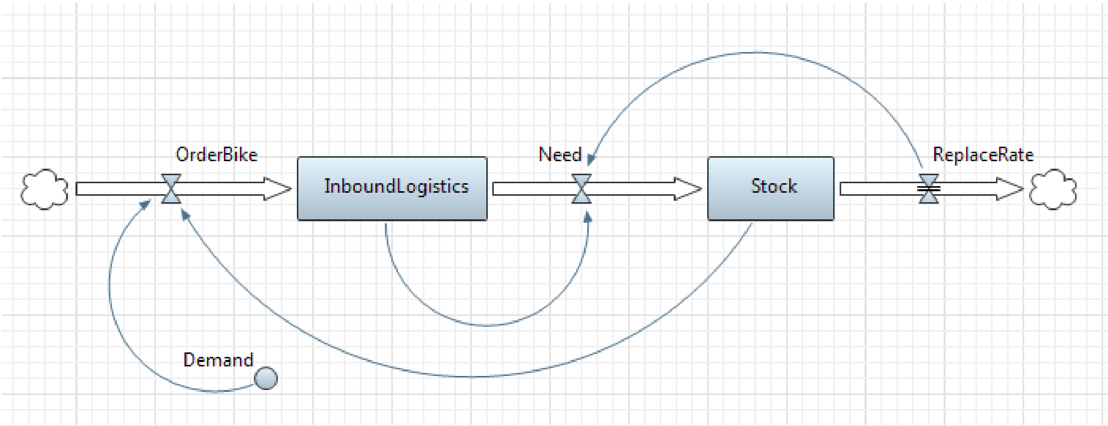

Figure 1 Static structure of case study in AnyLogic

The simulation starts with a defined stock of e-bikes. The stock contains all the e-bikes that can be used by customers.

Owing to damages and wear-out, the number of e-bikes must be replaced periodically. Replacement rate and demand are derived from the policy. According to the policy, the number of e-bikes that are available should be the same over time. To have the same number of e-bikes in the stock is necessary to order a specified number of new e-bikes.

There are two input parameters: replacement rate and demand. In each simulation replacement rate is varied from 1 to 6 in steps of 1. Demand has the value of 5 in each all simulations. The simulation is carried out for the following initial numbers of e-bikes in stock: 250, 100, 75, 50, and 25. At the beginning of the simulation, the number of e-bikes in the stock decreases but reaches the initial value again after a certain period. The intensity of these changes depends on the replacement rate and order rate. The time to reach the initial value in the stock and the number of orders are gathered and analyzed.

For development of e-bike sharing systems, it is important to analyze the changes in e-bike stock. The number of available e-bikes should be on the same level over time. Increasing numbers of e-bike can lead to overcapacity. On one hand, the e-bikes that are not hired cause financial loss for e-bike sharing company. On the other hand, if the number of the e-bikes decreases, then the customers' satisfaction and acceptance for the service decreases as well. If a customer wants to hire an e-bike but if it is not available at that moment, then the customer will look for an alternative service. Thus, the e-bike sharing company loses its customers and the resulting profit.

Replacement rate depends on a number of external factors such as intensity of use, maintenance periods, quality of e-bikes, vandalism etc. In this case study, replacement rate is varied from 1 to 6. It means that during a period, the number of e-bikes in the stock decreases by 1, 2, 3, 4, 5 or 6. The number of e-bikes is replaced by ordering new e-bikes.

The order is processed when the number of e-bike in the stock is less than the initial number in the same stock. Each order filled up the stock with 5 e-bikes (this value is assumed as a parameter).

4.2 Discussion of results

The results of the simulation show that the initial number of e-bikes in stock is not relevant for the frequency of ordering and time that is needed to fill the stock. The time to fill the stock is directly proportional to the replacement rate [figure 2]. If replacement rate is more than 4, it is not possible to fulfill the stock till the initial value under condition of this experiment. If the replacement rate is the same as demand (in this case study 5), the number of e-bikes in the stock reaches a constant value (always less than initial value in the stock) after a certain period [figure 3]. This period and the value in the stock depend on the initial number of e-bikes in the stock.
If the replacement rate is higher as demand (in this case study 6), the number of e-bikes in the stock falls to zero.

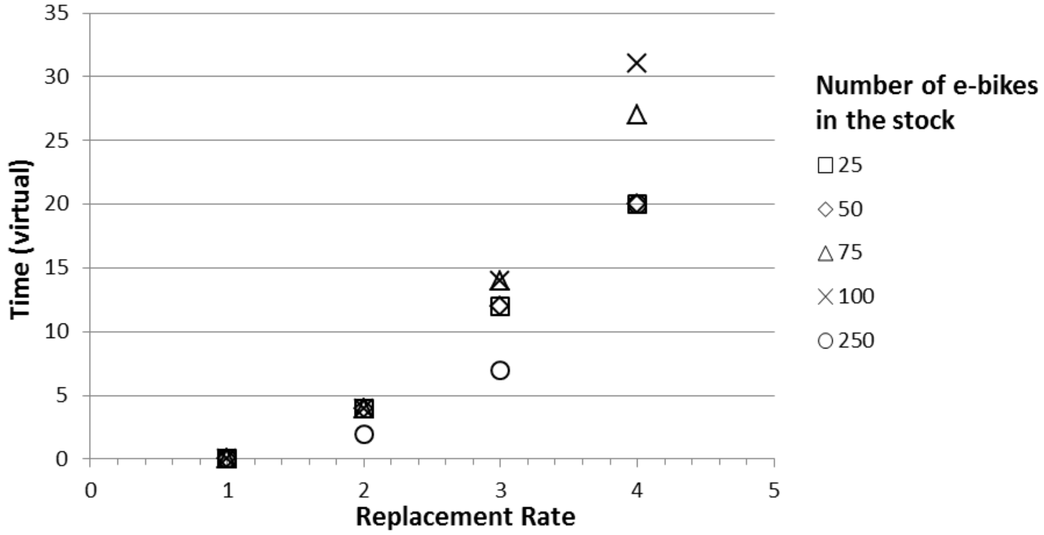

Figure 2 Time to reach the initial number of e-bikes in the stock

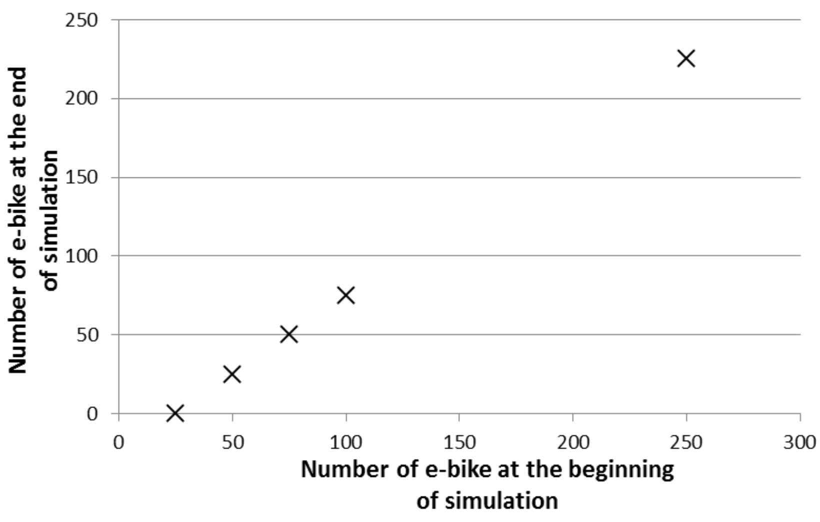

Figure 3 The number of e-bikes in the stock at the end of simulation (replacement rate is 5)

The number of orders is also directly proportional to replacement rate. The initial number of e-bikes in the stock has no influence on the number of orders [figure 4].

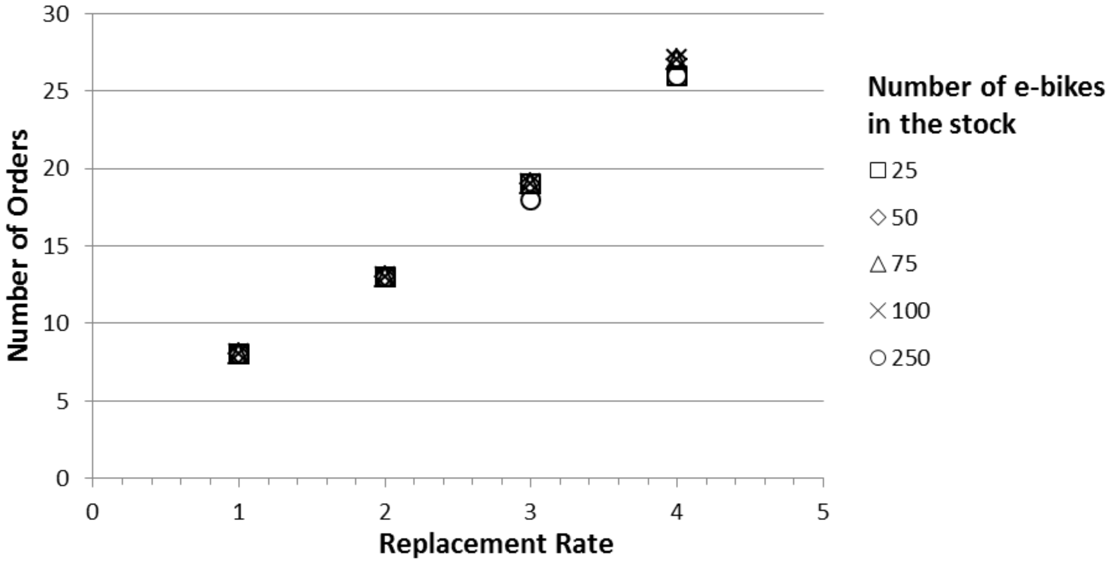

Figure 4 The number of orders to reach the same level in the stock

The model can be used for estimating an initial number of e-bikes in the stock depending on replacing rate. It can help to compute the appropriate ordering rate depending on the number of e-bikes that will be delivered per order. The successful business models should take into account the costs associated with ordering rate. The simulation helps to develop an e-bike sharing system on the basis of confirmed data. Enabling the determination of further estimation regarding supply is also possible. Thus, the model could serve as a basis for computing of costs that will be caused and must be taken into account in PSS development.

5. Conclusion and further work

This paper deals with PSS and discussed system dynamics modeling as an approach to support the development of PSS. PSS in real-world is sophisticated and combines many elements and functions. To support the development of PSS, function-dependent elements should be identified and their behavior must be simulated using system dynamics techniques.

A discussed case study of an e-bike sharing system shows a system dynamics model to predict the changes of an e-bike stock and calculate the order rate over time to fulfill customers' demand. The case study shows the applicability of system dynamics modeling for PSS development.

The presented model describes a simple case study to examine the potential of system dynamics in PSS-approach. A PSS might have very complex structure that includes not only the product and service but also sustainable relations with the system environment. System dynamics modeling can be used for design and development of such structures. Instead of modeling one complex real-world structure, a number of case studies including the sets of rules could be modeled. E-bike distribution, maintenance, customers' development, utilization of an e-bike sharing systems could be taken into account as examples for other case studies. Thus, several aspects of PSS and its interactions with the environment could be considered and analyzed.

Further work should also analyze other case studies and simulate real-world situations. The simulation results must be validated in comparison to the real data.

This will allow verifying system dynamics modeling as a simulation approach for PSS development in a broad spectrum and help identify the limitations.

Acknowledgment

The authors thank the German Research Foundation for supporting this project as part of the Collaborative Research Centre 768 – Managing cycles in innovation processes – Integrated development of product-service systems based on technical products.

References:

Borshchev A. (2013). The Big Book of Simulation Modeling, AnyLogic North America.

Borshchev A. and Filippov A. (2004). From System Dynamics and Discrete Event to Practical Agent Based Modeling: Reasons, Techniques, Tools, The 22nd International Conference of the System Dynamics Society, July 25–29, Oxford, England.

Forrester J. W. (1961). Industrial Dynamics, MIT Press, Cambrige Mass.

Forrester J. W. (1971). Counterintuitive behavior of social systems, Technological Forecasting and Social Change, vol. 3, pp. 1–22.

Goedkoop M. J., van Halen C. J. G., te Riele H. R. M. and Rommens P. J. M. (1999). Product Service systems, Ecological and Economic Basics, Ministry of Housing, Spatial Planning and the Environment, Communications Directorate.

Kuntzky K., Wittke S. and Herrmann C. (2012). Car and Ride Sharing Concept as a Product Service System – Simulation as a Tool to Reduce Environmental Impacts, Proceedings of the 4th CIRP International Conference on Industrial Product-Service Systems, Tokyo, Japan, November 8th – 9th.

Santos S. P., Belton V. and Howick, S. (2002). Adding value to performance measurement by using system dynamics and multicriteria analysis. International Journal of Operations & Production Management, 22, 11, 1246 – 1272.

Sawhney M., Balasubramanian S. and Krishnan V. (2004) Creating Growth with Services, MIT Sloan Management Review: 34-43.

Schenkl S. A., Behncke F. G., Hepperle C., Langer S. and Lindemann U. (2013) Managing Cycles of Innovation Processes of Product-Service Systems, 2013 IEEE International Conference on Systems, Man, and Cybernetics.

Sterman J. D. (2000). Business Dynamics: Systems Thinking and Modeling for a Complex World, McGraw-Hill.

Tukker A. (2004). Eight types of product-service system: Eight ways to sustainability? Experiences from suspronet, Business Strategy and the Environment, vol. 13, no. 4, 2004, pp. 246-260.

Vasantha G., Roy R., Lelah A. and Brissaud D. (2012). A review of product-service systems design methodologies. Journal of Engineering Design, Taylor & Francis: STM, Behavioural Science and Public Health Titles, 23 (9), pp. 635-659.