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Simulation of Product-Service-Systems Piloting with Agent-Based Models (outlined revision).

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Abstract

Product-service systems (PSS) can improve sustainability in terms of responsibility of providers and intensified customer-provider relationships. Therefore, a PSS approach has been applied on the distribution of solar home systems in rural areas of emerging countries to improve quality and increase confidence in this technology. However, many innovative projects fail at the piloting stage because of insufficient validation before implementation. Validation methods for PSS like an integrated gap model (e.g. identification of gaps between deliverables and customers expectations) or interdisciplinary design reviews show its limits on the interdependences between product and service development. A new approach to test PSS involves agent-based simulation models and is presented within this paper. Among system dynamics and discrete event simulation, an agent-based simulation is able to work with less quantitative data and a more detailed view on individual entities than the alternative approaches. Thus, it is possible to create more realistic simulation models to validate especially resource planning of a PSS. Agent-based simulation is used within the MEVIS (Micro Energy Supply Information System) project to model a network of solar home systems which are controlled by remote monitoring in order to improve service processes, e. g. maintenance and repair operations. The pilot test should be carried out efficiently by the preceding virtual validation in the form of a simulation, which is built in NetLogo, a tool that enables modeling of a multi-agent environment. Within this environment, communicating technical artifacts as well as different groups of actors are mapped as agents. As a result, diagrams of relevant parameters like the overall repair costs or the estimated customer's satisfaction are displayed and the resource planning is visually supported. This helps to push a PSS into a new market, where you have to deal with existing resources that must be used efficiently. The contributions in this paper provide the conception and an exemplary presentation of the simulation run.

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Keywords: product-service system; piloting; validation; agent-based simulation; solar home system

1. Introduction

Distribution of decentralized energy supply for households and small businesses, in particular of solar home systems, is conducted more sustainable by application of methods for development of product-service systems (PSS) [1]. According to the applied methodology, planning of the pilot stage begins, when all artifacts of the system domains were fully developed and their integration into the overall system is complete. This is the final iteration step of ensuring the entire system, in which final parameters for a successful implementation are to be determined [2]. In preparation of the pilot stage the system components are transferred into a simulation model to test its behavior virtually. The goal is to map properties of the system in the context of examined parameters as realistic as possible. Thus, errors in the configuration, which lead to unplanned costs in the implementation, can be uncovered with relatively little effort.

1.1. Application of PSS development methods on solar home systems

In many developing countries, solar home systems have been established as a successful option for electrification of households in rural areas without access to electrical infrastructure. To make these systems affordable to local people, there has been taken advantage of a widespread network of microfinance institutions. This enables people with low incomes to divide high acquisition costs with a micro loan into small fractions for a longer period. Bad transport infrastructure and a lack of trained technical staff make it difficult to expand the distribution of renewable electric energy in rural areas of emerging coun-

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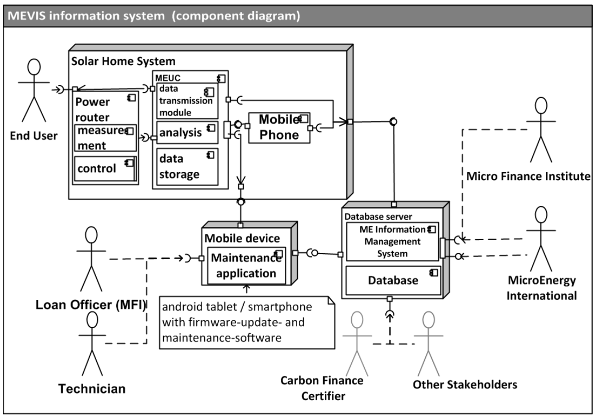

Fig. 1. Information system for solar home system's service support.

tries. Bad planning, faulty installations and unclear warranty cases are reducing confidence into this technology on the customers side as well as on the providers side [3]. The project MEVIS (that means Micro Energy Supply Information System) is conducted by the Fraunhofer IPK with partners from industry to improve quality of planning, installation and maintenance for a wider distribution of this solution. For this issue new approaches from the common department of Fraunhofer IPK and Technische Universität Berlin on developing product-service systems have been applied. This helps focusing on basic customer demands as well as the whole product life cycle [4]. Additionally, methods were given to check out if all aspects of the service network are taken into account. With PSS development methods, you are able to consider the whole product life cycle and ensure high quality of service activities in every stage [5]. To meet the specific conditions of the target regions, a remote monitoring system was implemented, as shown in figure 1. This system aims to centralize control of product life cycle processes. Faulty components or improper use are detected early and are known to the technician in preparation of maintenance. This makes service processes much more efficient and reduces demands on knowledge of the technician with respect to fault analysis. Although this technology still depends on existing infrastructure, it can help to offer a quality service, even under difficult conditions[6] [1].

1.2. Approach on validating the piloting stage

The developed system of technical artifacts, information system and services should be thoroughly tested before its launch to prevent it from failing. It should be tested, if the intended use of resources as well as the design of the system for planned compliance with its requirements is sufficient [7]. In the area of services a pilot phase is often initiated in which the proposed system is tested with all its components in an idealized environment. Such a practical implementation of processes to investigate the interaction of the components is very important because here also problems occur in areas that may have not been examined in virtual tests[8]. A pilot study is, however, very time and resource intensive, therefore it requires a very thorough planning in order to ensure beforehand that the pilot brings maximum success.

When developing the pilot project for final verification of the product-service system, the concept was tailored to characteristics that are to be examined. It is not necessary to implement all parts of the overall solution, which reduces the extent of concepts. In return, additional parameters and processes for test executions have to be defined. To successfully implement this concept in the pilot stage, results of the approach are evaluated by a simulation. The simulation method of agent-based models is used to represent interaction of actors with artifacts. All actors and artifacts are represented by specific virtual objects, the agents. These move along defined paths or are at fixed locations and interact automatically, according to the implemented features. Desired parameters are measured at running the simulation to assess the system's suitability to its use case. These are displayed in diagrams to allow rapid evaluation of the simulated solution.

2. Simulation methods for PSS

Simulation of PSS is typically applied by the simulation methods of discrete-event simulation, agent-based simulation and system dynamics [9], which are explained in the following. After an introduction and evaluation the agent-based simulation is chosen as the suitable method.

Discrete-event simulation (DES) is generally a computer evaluation of a dynamic system model with discrete events in which operations of the system are performed by a chronological sequence of events. This simulation method is particularly suitable for manufacturing systems, transportation systems and service systems, such as in hospitals, which are coined by queues and events that alter the state variables of a system[10]. For evaluation of PSS, DES is used as a method for decision finding and comparison of traditional business models to a PSS-model, e.g. to analyze a capacity management for scenarios and strategies in a production system[11]. Most frequent criticisms consider simple and highly specialized models that are controlled by a central system and do not permit decentralized decisions [12].

Models for **system dynamics (SD)** basically consist of three elements:
- Stocks, which represent accumulations of equal object within one system
- Flows, which connect the stocks and are transporting contents from one stock to another
- Decision functions, which operate as filters and control the flow rates between stocks

Modelling is done by differential equations that form cause-effect relationships. These are implemented as control loops and process highly aggregated values, which are equal to another in one stock. Target of this method is to recognize patterns in complex structures and their changes over time. Critics on SD have been the simplified models and assumptions that decrease usability of the results. Additional weaknesses were identified by Phumbua [12], which are subjective weighting and scaling of values, decentralized decision finding and stochastic influences of services, stakeholder interactions and lifecycle of objects.

Agent-based simulation (ABS) is focusing on examination of systems from the perspective of individual, interacting components that could evolve over decentralized adaptive mechanisms in a changing environment. It ranges from modeling of customers and financial markets on industrial supply chains and health systems and ecosystems. Those allow an understanding of system behavior that results from complex interactions. Three typical elements can be found in each ABS model. The main element is the *agent* that represents an active, discrete object and is equipped with individual characteristics and behaviors. Agents exchange information flows with their *environment* and other agents. These are connected by *relations* and interaction methods. In principle, agents have only local information, which supports the decentralized stochastic nature of the ABS model. Lagemann [13] described the strategic positioning of a robust (stable and flexible) capacity planning. By state diagrams, the two types of agents machines and technicians were mapped during the PSS-use, so that uncertainty and time factors of capacity planning could be evaluated in customer service in the simulation software AnyLogic.

One advantage of ABS is explicit modelling of environment and spatial relationships, so that a very realistic image of interacting agents and their environment is generated. Since the systems and agents behavior is controlled via rule sets, dynamic relationships can deform and change as well as adaptation and learning processes are simply modeled. It is also the appropriate simulation technique that allows to implement decentralized models. There are concerns that varying output is always dependent on the model accuracy and completeness of entries, so that the results from qualitative insights to quantitative values for decision-making and implementation support can vary. In addition, the presentation of all individual capabilities in large systems can be time consuming and require extensive computing resources.

Comparison and result: As a part of the MEVIS project, resource planning of technicians is to be treated in a network of a product-oriented PSS, which requires decentralized decision-making and coordination. It is located separately in a rural area of emerging and developing countries where specific circumstances, such as immature infrastructure prevail. Therefore, the agent-based approach is appropriate to represent the decentralized nature and the spatial relationships.

3. Development of simulation model

According to the framework of MEVIS, special distribution models such as micro financing are necessary in order to offer advanced technical products in developing and emerging countries. However, responsible providers often reject the idea because of difficult resource planning, which costs they could not cover. In detail, four main reasons cause their reluctance:

At first, maintenance and repair operations of a complex technical product, such as solar home systems, require well educated technicians who are rare and cause high costs in rural areas due to bad infrastructure and long travel distances. So, how can a simulation model optimize the logistical planning of technicians who are located at different stations and offer different levels of education?

Secondly, regular maintenance and repair operations on the systems are needed in order to offer the promised performance of the solar home system. If the performance suffers and does not meet the customers expectations, the customer is unwilling to pay. Therefore, how can a simulation model assist in designing a valuable technical service for customers?

Thirdly, service personnel require adequate information about the systems size suitable to the energy demand of new customers and what competence is needed to repair faulty systems. So, how can a simulation model make experience and usage profiles available and deal with the distribution of responsibility between different stakeholders in cases of faulty components?

At last, warranty cases are difficult to detect due to missing monitoring of the systems usage. As long as the provider cannot differentiate without doubt between a quality issues or an overload of the system by the customer, the system needs to be replaced free of charge in order to avoid image loss. Therefore, how can a decision support be granted by a simulation model? An agent-based model built in the simulation software NetLogo is capable of addressing those questions. For developing an agent-based simulation, the generic developing process of Deckert [14] was followed. The process involves five linear steps as shown in figure 2.

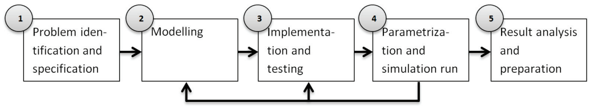

Fig. 2. Simulation development process [14].

3.1. *Define use cases for service on solar home systems*

As the main problems were identified above, specification of the model can be completed now. The target groups that benefit the most from the simulation model and its results include micro finance institutions and system providers. The specification involves four different use case diagrams which are derived from each of the mentioned issues and were shown in figure 3.

For **logistical planning**, known error cases have been added to the simulation model. In regard to those errors, the provider can develop a priority list of customers to determine in which order the customer should be served. Possible priority options include waiting time of the customer, distance to customer and severity of an error or error set. Certain restrictions such as the current location and skill level of the technician are considered. The provider is able to simulate the overall costs and durations to serve the customers in the chosen order.

The **technical service** includes mainly the regular maintenance activities. That procedure is important for customers to prolong the lifetime of the system and keep the system in optimal working conditions. The provider simulates the regular maintenance schedule of the technicians. This simulation contains data from minor issues which were removed by the customer and the regular visits of technicians to optimize the maintenance schedule. When the results are satisfactory, the order of the maintenance tasks and distribution to the technicians can be transmitted into the individual maintenance schedule.

To simulate **responsibility distribution**, data is extracted from studies and fault reports of existing systems. The imported data contains information about what fault occurred and who could correct this error. After receiving a sufficient amount of such data, distributions for specific error cases are created and the simulation can choose the appropriate person. Each person,

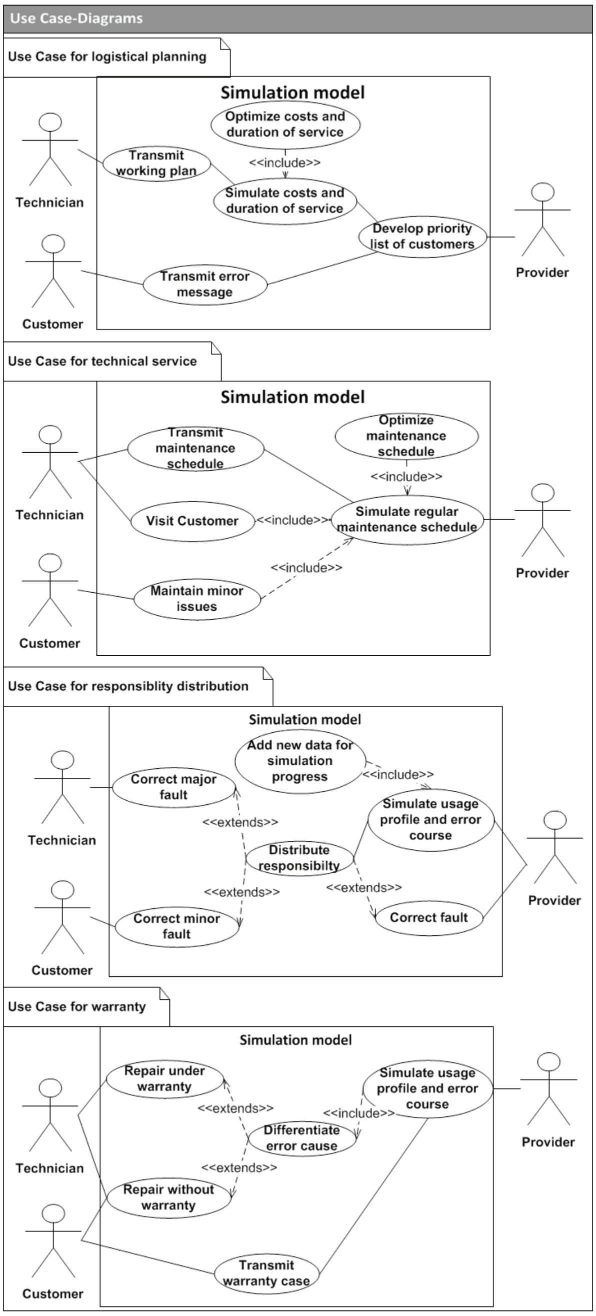

Fig. 3. Implemented use cases in simulation model.

such as technician, customer and provider owns specific cost and time variables which assist in making the best choice in specific error cases.

The use case for **warranty** works similarly as the responsibility distribution. According to detected errors of a system, the provider is able to see if the reason is a quality issue or misuse of the system. For example, if the data base reports significant higher voltages of attached load, the provider knows that the customer connected too many devices and if this behavior results in an error case. Individual customers or distribution among customers with and without warranty can be implemented in the simulation model and show a forecast of how many warranty cases on average, the provider needs to expect. With the aid of the simulation model, warranty costs can be calculated more realistically. It helps to develop improvement actions in case of warranty such as changing the producer of certain components which demonstrate a high failure probability.

3.2. Modelling of PSS to prepare simulation

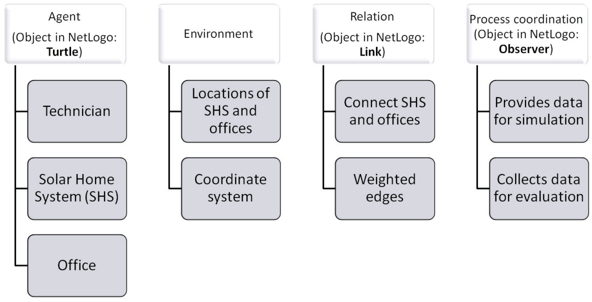

Fig. 4. Object types in NetLogo.

The modelling is based on the available objects in agent-based simulation and on needed parameters or attributes to simulate the use cases. These basic objects of an ABS in the simulation software *NetLogo* are shown in figure 4. The simulation works with three breeds of agents, which are indicated as *turtles* in the *NetLogo* environment. Turtles are mobile agents, which have the ability to move along the simulation environment. Solar home systems and offices are modelled by the agent type *turtle* instead of the static agent type *patch*, because the agent type *link* can only connect *turtles*. *Links* own a weight variable, which represents the distance between two agents. The office breed owns a location within the network and represents start and destination place for technicians . Each office has a run time variable which saves the ID of technicians. The technicians own an identity and a skill level. During the simulation run, its location changes as they move along the links within the network. The technician saves the number of repairs, its costs due to the skill level and the fulfilment time for each task. The last turtle breed represents the solar home systems or customers which are one in order to simplify the simulation. Those turtles own a size, location and growth rate of dissatisfaction. While simulating, the age, error probability depending on the age, type of error, priority index depending on the time passed by and an individual dissatisfaction index which increases due to the chosen growth rate with simulation time until it was visited by a technician. This turtle type transmits the individual error rate, caused costs and number of interactions with technicians. The last part of the simulation model includes the observer. This agent coordinates the other agents from the background. It represents the data base in MEVIS where all evaluation data is collected and prepared for further analysis and diagram output. Primarily, it is responsible for the costs which are calculated by multiplying the skill level required to repair the error and repair time, the revenues which are the result of adding a factor on top of the costs and the dissatisfaction index which represents the sum of individual dissatisfaction indices of all customers with errors. Besides the agents, the environment in which the agents interact needs to be considered. The network is built in two ways. At first, text files can be imported, which contain the attributes for the turtles like an individual id, x-coordinate, y-coordinate and the shape format, as well as the id of the turtle on the one end of the link, the id of the turtle on the other end and the weight of the link. The other option to create a network is based on buttons and input boxes where the required data is entered. Buttons are implemented for manipulating the original network by adding new elements, removing redundant elements or creating new connections but can also be used to build the network from scratch.

4. Implementation of simulation model

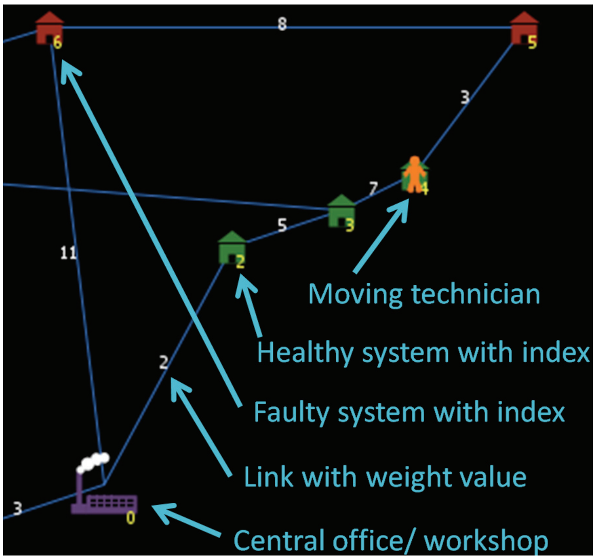

Fig. 5. Simulation model build in NetLogo.

On figure 5, you can see a segment of the simulation model, which conducts a simulation run with two offices and two technicians within a network of ten SHS. The green houses are SHS without error, the red ones have specific errors. Two simulation runs with identical settings are described here to show basically, how an optimization with NetLogo is conducted. One simulation was conducted with one technician of skill level 3 and one with two technicians of skill level 2 and 3. The technician walks along the shortest way to the closest faulty house and repairs it which means that the house's color returns to green.

Table 1. Assumed time for repair operations.

Error	Repair time	Priority	Severity of error
Whole system	8 hours	5	3
Solar panel	5 hours	3	2
Battery	2 hours	4	0
Controller	2 hours	2	2
Connections/ Load	1 hour	1	1

Repair time, priority and severity of faults (see table 1) are taken from the developed service plans of the MEVIS project and are based on the complexity of the related subsystems. The priority represents the consequence of errors for customers (none 0 serious 5). Severity of error represents skill levels required for repair. Costs are calculated by multiplying severity and repair time. Revenue is calculated by multiplying the costs with a revenue factor, which is set to 1.1 in this example. In the following the calculation basis for simulation evaluation is described. Dissatisfaction of one customer grows with waiting time before served (0-1 per cent). Growing rate per customer is 0.1 every 24 ticks (1 day) when errors have occurred. Dissatisfaction index represents the sum of dissatisfaction for all customers.

Table 2. 2013 wage list for India to calculate costs (US$) [15].

Job description	Skill level	Gross monthly wage	Gross daily wage
Loan officer	0	134	6.24
Technician	1	139	6.48
Technician	2	156	7.24
Technician	3	170	7.91

According to Pasvantis [15], the gross monthly wage of a loan officer and a technician is displayed in table 2 in US$ in the average exchange rate of 2013. The technicians are divided further in three skill levels. It is assumed that technicians with skill level 1 receive wage orientated on the lower end of the span and the ones with skill level 3 on the higher end. This study also provides data of working and free time in table 3. Thus, monthly working time equals 21,5 days which is assumed to evaluate the daily wage for the different people.

Table 3. Average working time in India (2013 and 2014) [15].

Working and free time	Span in 2013	2014
Working time	48 hours per week	313 days
Vacation and sickness days	42-45	43
Holidays (regional)	Max. 24	12

4.1. Preparation and evaluation of results

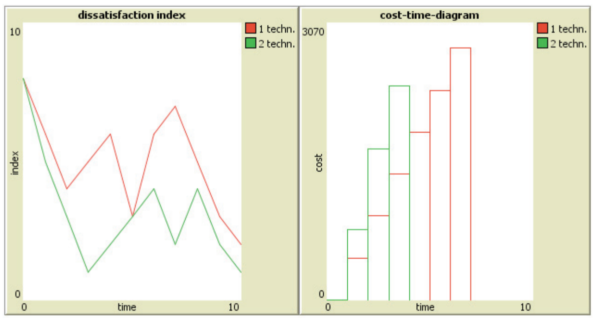

Fig. 6. (left) Dissatisfaction Index; (right) Cost-Time-Diagram.

For both simulation runs, the dissatisfaction index of customers and the costs of technicians are calculated as shown in figure 6. The dissatisfaction index shows that two technicians achieve a higher satisfaction because the customers can be served faster. Regarding the costs, two technicians are more expensive in the beginning but comparing the total costs after serving all ten clients, one technician is more expensive and needs more time to serve all clients than two. This is due to the fact that if employing one technician only, the best skill level of 3 is required in order to fulfill all possible tasks. This technician is paid the same wage each day regardless of the severity of the error. If two technicians work, one of them may own a lower skill level than the other which causes less costs and this lower skilled technician takes care of the less serious error cases.

The simulation in NetLogo is capable of optimizing the logistical planning of resources within the piloting of a product-service system. The dissatisfaction index is lower due to different parameter settings which can be applied on the number of technicians. It combines the amount of costs and revenues in order to evaluate the resulting benefits which can be achieved by offering a regular technical service and optimize its planning with a sufficient number of technicians. However, two simulation runs with two are types of technicians are not representative for a sufficient resource planning, but show the optimization potential of this simulation environment. The applied assumptions are based on the knowledge from field studies in particular developed countries and could be different in other regions and countries.

5. Conclusion

As part of the development cycle for a product-service system in which solar home systems are offered, planning the pilot phase was evaluated by simulation. Various simulation methods were introduced and agent-based simulation was chosen as appropriate. Subsequently the components of PSS with their properties, as well as the environment and the relationships between the components and actors were modeled and assigned to the objects of the agent-based models. After selecting the appropriate simulation tool NetLogo, the simulation model has been implemented. Thus, an overview was carried out that assessed the use of human resources with the help of cost and customer satisfaction. The simulation results are highly dependent on the detail level of the underlying data for the properties of the actors, products and networks. Furthermore, the data for error cases was extracted from different studies and different countries in order to achieve a sufficient amount of data with the simplifying assumption that no major difference between those countries exists. So, further studies should concentrate on generating or finding more accurate data about the particular region, where the PSS should be implemented. Further use cases with different parameters are planned in order to increase the validity of the implemented model.

It would also be a feasible approach, to accompany the pilot stage by the simulation, which obtains a higher quality of expressiveness through the provision of real-time data. Thus, running processes can be optimized during operation. With the increasing use of cyber-physical systems in PSS, specific real-time usage data can be utilized in the coordination of service processes. Existing resources can be used more efficiently by simulating the PSS during operation based on this data.

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