A Software-Driven Approach to Model, Simulate and Optimize Service-Oriented Value Creation

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Abstract. Service-oriented value creation requires coordinated decisions across partners, resources, activities, and value appropriation. To support these decisions, we develop a model-driven, software-supported approach for configuring service value networks. At its core is a metamodel derived from analytic metatheory based on literature and expert workshops. The metamodel is implemented in a modeling software tool that integrates relevant service-oriented, value creation elements and their relationships into one single data model. The approach supports comparison of partner constellations, alignment of supply and demand, and evaluation of implications across the network. It enables firms to represent their value network, assess properties, simulate value distribution and optimize feasible configurations. The metamodel and the software tool have been evaluated in mobility, construction and additive manufacturing domain. Early results indicate that it is particularly effective in the systematic identification and analysis of interdependent action areas, the design of feasible business models, and the development of implementation strategies and funding opportunities in collaboration with relevant stakeholders.

Keywords: Value Creation Network, Modeling Software, Metamodel

1 Introduction

Over the last decades, industrial value creation has shifted from product-dominated, intra-firm approaches toward service-oriented, network-centric configurations, driven by the proliferation of digital technologies, globalization, and the rising salience of intangible assets (e.g., knowledge, data and skills). Accordingly, new forms of value creation have emerged in which services, rather than products, become the nucleus of value. As a result, value creation is gradually transitioning from closed organizational structures toward complex business ecosystems and networks, where competitors, complementors, customers, and suppliers co-evolve with each other and with their environment [1–3]. Consequently, manufacturing organizations must integrate digital services into their portfolios to enhance resilience and flexibility, improve customer proximity, leverage economies of scale and maintain technological competitiveness [4]. This shift is evident in the mobility sector, for example, where digitally orchestrated, usage-based on-demand mobility services rely on collaboration among various stakeholders (e.g., transport associations, app and service providers, and fleet operators) [5, 6]. Hence, incumbent organizations are required to strategically rethink their value creation design, transitioning from linear, product-centric models to agile, service-oriented value creation networks[7].

When conceptualizing service-oriented value creation networks, issues familiar from bilateral-relationships become more complex [8]. Therefore, the successful configuration requires addressing fundamental questions of coordinated decision-making across several dimensions: “Which partners are most appropriate?”, “how should resources and tasks be allocated?”, “how can quality be assured?”, “what roles and responsibilities need to be defined?”, “how should returns be distributed?” and, “how can value appropriation be designed to balance fairness and incentives?”. This results in complex and non-linear decision-making processes that are difficult to manage adequately using conventional methods and tools (e.g., Value Chain Analysis, Stakeholder Mapping, Business Model Canvas).

We pose the following research question: How can the complex decision-making processes in the configuration of service-oriented value creation networks be supported?

Within this paper, a model-driven and software-supported approach is developed to address this issue and answer the research question.

2 Conceptual Background

The following section reviews core concepts of value and value creation, focusing on service-oriented value creation networks.

Value and value creation are fundamental concepts in economics and management, yet their interpretation varies significantly across disciplines. From an industrial perspective, value is created for the customer by the organization, embedded in goods or services, and realized at the point of exchange (value-in-exchange) [9]. In this context, value creation is commonly framed as the monetary outcome of sequential activities and quantified as the net difference between the value of total output (e.g., sales) and the value of the preliminary input (e.g., raw materials). However, this linear, primarily monetary perspective fails to capture the complex, nonlinear dynamics of value creation driven by contemporary environmental changes (e.g. globalization and digitalization). As a result, scholarship has increasingly adopted configurational perspectives that model nonlinearities and interdependencies within value creation networks.

Bassetti and Romano describe a shift from value chains to value networks, defining the latter as “a cluster of actors that collaborate to deliver the highest value to the end consumer and where each actor is responsible for the success or failure of the network.” [10, p.6]. Benger characterizes value networks as decentralized, polycentric constellations of legally autonomous actors, connected by active and latent relationships and shared information platforms. These actors are economically motivated to achieve sustainable added value through collaborative engagement [11]. Collaboration within value networks appears both vertically along supply chains or across markets, and horizontally among direct competitors. This dynamic, the coexistence of competition and cooperation, is called "coopetition" and allows organizations to align network-level objectives with firm-specific goals [12–14].

Contemporary service and management research broadens the concept of value creation beyond a goods-dominant, exchange-centric logic toward a service-dominant (S-D) logic. This logic provides a framework for societal value definition and creation, resource expansion, sustainability, and public policy [15]. Under S-D logic, organizations do not create value per se but offer value propositions. Value emerges in use through customer co-creation (value-in-use). Service value creation thus involves allocation mechanisms, core activities, and firm-customer interactions. The effectiveness of these interactions varies, potentially resulting in value co-creation or, under certain conditions, co-destruction. Thus managing this complexity requires configuring service-oriented value creation networks through orchestrated resources, defined roles, interaction patterns, and governance structures to align value-relevant processes and interactions across organizational boundaries [16–21] .

3 State of the Art

Since 2004, S-D logic, introduced by Vargo and Lusch [17], has evolved into a network-oriented framework that analyzes value creation through patterns of resource integration among collaborating actors rather than through discrete outputs [22]. Its foundational premises are codified in five axioms:

"*1. Service is the fundamental basis of exchange. 2. Value is cocreated by multiple actors, including the beneficiary. 3. All social and economic actors are resource integrators.* 4. *Value is always uniquely and phenomenologically determined by the beneficiary. 5. Value cocreation is coordinated through actor-generated institutions and institutional arrangements.*" [23, p.18].

Service, the core concept, is the intangible, interaction-intensive application of specialized operant resources (knowledge and skills) to operand resources (physical resources), through which parties create value for others and themselves [15, 24]. The key is a resource reorientation that distinguishes operand resources, which are acted upon, from operant resources, which act on other resources and produce effects. As operant resources drive competitive advantage, analysis shifts from output attributes to the capabilities that actors deploy and combine across network ties [17, 22]. On this basis, value is understood as emergent in use, realized in context, and is therefore inherently dynamic [25]. Therefore, for decision support, analysis should focus on interactions, role and actor configurations as well as resource combinations. The firm's contribution should be framed as a value proposition that invites participation rather than unilateral delivery [22]. Pfeiffer et. al. operationalize this perspective by mapping roles, value propositions and resource integration across firm boundaries, and by showing that digital technology can function as an enabling operand resource and as an initiating operant resource within the same arrangement [25]. Complementary work on coopetition strengthens this network notion by demonstrating that value creation and value appropriation unfold in value networks formed by both positive and negative interdependencies. These tensions and harmonies shift where and how value is created and captured across relationships [14].

However, consistent guidelines and a widely accepted framework for research within and using S-D logic remain limited, and analyzing value and value creation networks is methodologically demanding and requires the integration of system- and subsystem-level as well as structural and process analyses [8, 21, 26].

Given this complexity, modeling helps to reduce complexity and promotes comprehension and innovation in socio-technical systems [27]. Software automates the preparation, analysis, and optimization of complex models, while metamodels define the key elements, structures, relationships, and constraints for building domain-specific models and for aligning a software tool's support with the decision problem [28].

In practice, an extensive repertoire of modeling approaches exists. OMEGA [29] and GEMINI [30] support business model and value creation modeling and analysis. Service Blueprint [31] separates frontstage customer interactions from backstage support processes. The Supply Chain Operations Reference (SCOR) model [32] provides reference processes and metrics. Business Process Modeling and Notation (BPMN) [33] formalizes standardized workflow logic. These methods offer structure but capture process and resource dynamics only to a limited extent.

Ontology-based approaches add a semantic layer for typed resources, constraints and compositions rules. The OBELIX service ontology [34], for example, supports knowledge-based configuration of service bundles and models services from value, offering, and process viewpoints. It also captures resource types but focuses on conceptual modeling rather than executable process/resource dynamics. The UFO-based Ontology of the Value Proposition [35] clarifies the distinction between value proposition and offering but leaves network dynamics unaddressed.

The Service-oriented Business Model (SoBM) Framework [25] operationalizes a service-centric, network-oriented perspective. e3value [36] addresses value allocation in multi-actor constellations and supports profitability assessment. Service Value Network (SVN) [37] enables market-based service composition from standardized modules and provides a formal model for analysis. All of these models provide economic insight but remain only partially linked to process and resource dynamics.

In digital contexts, numerous formal, partly machine-readable and machine-evaluable service-description languages exist, including Linked-USDL [38], SPARQL [39], OWL-S [40], SAWSDL, WSMO [41, 42], and BSMM [43]. OWL-S structures service descriptions for automation. Linked-USDL provides linked data vocabulary for technical, economic and legal aspects and BSMM offers a UML-profiled business service metamodel. These approaches ensure precise semantics and technical interoperability, yet they couple value appropriation with resource dynamics only weakly.

Recent research and practice show that current approaches do not meet the specific needs of service-oriented value creation networks. They offer a solid theoretical foundation, but each approach focuses on only particular perspective of service value creation. Consequently, they either overlook the multidimensional nature and interdependencies of decision-making or fail to link the different perspectives across the network. They are therefore inadequate for capturing, managing and mitigating the complexity described in Section 1.

We argue that value is created primarily in *use* – the integration and application of resources in a specific context – rather than in *exchange*, where value is embedded in firm outputs and reflected in price. Service systems interact through reciprocal service-exchange relationships that improve the adaptability and survivability of all systems engaged in exchange by enabling the integration of mutually beneficial resources. Accordingly, we develop a formal metamodel for service-oriented value creation and a supporting software tool [44]. This allows companies to systematically model, analyze, evaluate and optimize their value creation networks.

4 Approach

Our approach follows a model-driven and software-supported approach to mitigate the complexity of decision making in service-oriented value networks. Thus, at the core of our approach, we need to establish a metamodel, which is then integrated into a modeling software with further algorithms to depict, analyze and optimize value creation networks. To develop the metamodel, we follow established ontology engineering practices, based on the steps of Fernández et al. [45]: Acquiring and documenting knowledge, conceptualization, formalization, integration and implementation.

Acquiring and documenting knowledge: The knowledge content of our metamodel is developed via analytic metatheory development (see [46, 47]). We start with a literature review and expert knowledge to identify key concepts of service-oriented value networks among previous works. Thereby, we build up an unstructured body of knowledge based on previous scientific findings and knowledge, without own research.

Subsequently, the gathered knowledge is further structured, and a precise terminology is established (conceptualization). The precise terminology encompasses the identification of model elements for our metamodel as well as modeling mathematical relationships that connect them. Each identified meta- model element and relationship is categorized into one of three classes, with each class representing a distinct level of strength regarding the validity of the element or relationship (see also [44]):

- Axioms: Axioms represent essential and immutable findings in the gathered knowledge regarding value creation and value creation networks. As a result, they establish the foundational elements and relationships in the topology of the metamodel. Furthermore, they define constraints that must be satisfied in all models derived from the metamodel.
- Normative propositions: Normative propositions outline basic assumptions of service-oriented value creation that are commonly shared among many relevant theories. They maintain their validity unless a paradigm shift in theory occurs. Consequently, these propositions are mainly defined as relationships within the metamodel. However, they do not establish core elements or dependencies and may be subject to modification in future versions of the metamodel.
- Assumptions: Assumptions are relationships between elements that are generally regarded as true. However, for specific service-oriented value

networks, their existence or specification may vary or may not apply at all. Therefore, these assumptions are not seen as hard constraints on the models derived from the metamodel, but rather as a hint towards the decision makers.

The definition of the precise terminology and subsequent metamodel for service-oriented value networks followed an iterative and a simultaneous deductive and inductive process to conceptualize the necessary body of knowledge. Firstly, the theoretical literature review in the field of service-oriented value networks (see section 2 and 3) provided a deductive way to identify model elements and relationships from theory. Core elements for the metamodel were formally defined by experts by analyzing the different theories in dedicated workshops (formalization). Examples for such core elements of the metamodel are resources, activities, and actors (see section 5). Subsequently, expressed relationships between the elements were identified. Finally, the experts filled the missing gaps within the metamodel from their knowledge and/or via assumptions (inductive approach). These assumptions were then again checked against a more focused literature research and further theories. The process was then started a new for a different aspect or perspective on service-oriented value networks. In total, more than 15 workshops with about 120 hours in total were conducted, including four to eight experts in the field of service-oriented value creation networks.

The metamodel was then transferred into a software tool (integration and implementation). Within the software, users can model their current, planned or assumed service-oriented value network based on their knowledge, using our metamodel. Based on the relationships between the model elements from within the metamodel, the service-oriented value network can be viewed from different perspectives, it can be analyzed regarding specific properties (e.g., temporal stability), it can be simulated (e.g., with respect to value distribution) or it can be optimized (e.g., regarding service quality). The software was developed using the Eclipse Modeling Framework (EMF [48]), with the metamodel defined in XCore [49]. The software is available as an open-source release under https://gitlab.cc-asp.fraunhofer.de/sow/metamodel.

5 Metamodel and Modeling Software

The metamodel, together with its modeling environment, distinguishes itself by integrating heterogeneous perspectives on service-oriented value creation into a unified, formally specified data model. Multiple viewpoint representations can be derived from this common schema, while simultaneously, cross-view integrity constraints ensure that the model automatically maintains global consistency. Decisions, including explicit design choices and implicit assumptions, are propagated across all perspectives, rendering their implications across the system transparent and preserving coherence throughout the model. In doing so, the approach supports systematic analysis, traceable trade-offs, and consistent decision-making in the configuration and governance of service-oriented value networks.

To achieve this, the metamodel comprises the following core elements and relationships (see Fig.1), which are assigned to different perspectives on the service-oriented value network (see Fig. 2-4):

5.1 Metamodel Elements

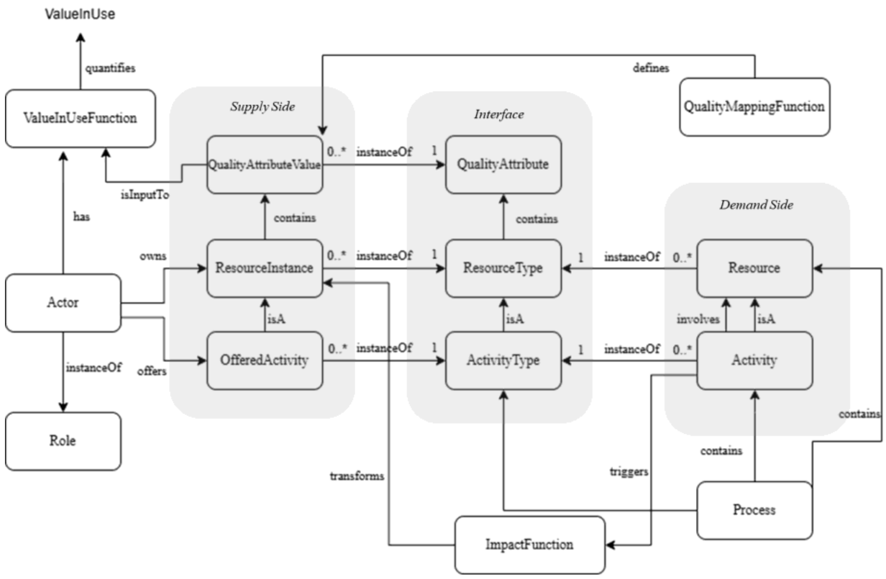

Fig. 1. Metamodel of Service-oriented Value Creation Networks - own diagram

Building on BPMN principles, a process represents the value creation flow and consists of activities and resources (see Fig. 2). Activities define the steps to be executed in the process and are named with verbs. Resources represent the inputs (tangible or intangible) required at each step and are deployed, modified or consumed during value creation. Branching and synchronization of the flow are modeled using AND/OR gateways (see Fig. 2).

In the proposed model, activities are treated as resources and therefore follow the same type-instance logic as resources. Each resource is assigned to exactly one resource type. This functional classification enables an unambiguous, type-based mapping between process demands (demand side) and actor offerings (supply side). Each resource type is defined by the subset of quality attributes relevant to the value creation process. Resource instances and offered activities constitute the supply side. They are specified by values of the corresponding quality attributes that describe their operational state in the given context.

Quality-mapping function computes the value of a specific quality attribute by deriving it from other quality attribute values, thereby making the relationship between target and inputs explicit. Overall, quality attributes delineate what matters for value creation, and their values enable execution and deployment options to be compared, selected, and evaluated.

An actor represents any person, firm, organization, or technical system within or around the network. Roles are optional classifications that restrict which kinds of activities an actor is authorized to perform and which resources it is authorized to provide or use. Actors can contribute to value creation by supplying two kinds of offerings: offered activities and resource instances.

An offered activity is an actor's commitment to perform an activity of a given type within the process. A resource instance is an actor-owned unit of a resource type that may be deployed, modified, consumed or reassigned during process. Assignments between process objects and offerings are therefore permitted only if the types match (type compatibility) and, where specified, role constraints are satisfied.

Execution effects are captured by impact functions (see Fig. 6), which specify how an activity creates, removes, reassigns or updates resources and their quality attribute values.

The actor-specific value-in-use function (see Fig. 7) measures perceived utility. It captures the benefit an actor derives from the service when acting as a beneficiary and from participation in the network when acting as a participant, based on the quality attribute values. Because the same configuration may be perceived differently, value-in-use can vary across actors and is re-evaluated whenever impact functions update the quality attribute values of resource instances.

5.2 Software Tool

The software realizes the metamodel elements within multiple complementary perspectives.

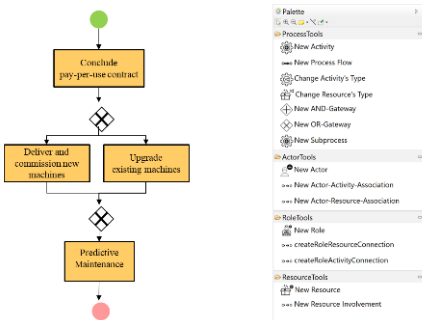

Fig. 2. Process perspective

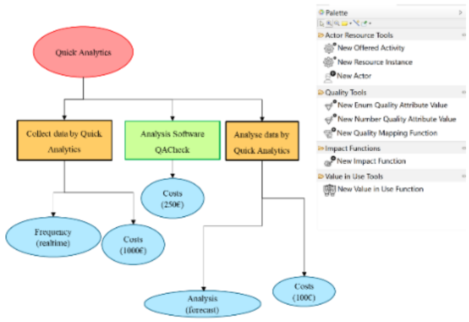

Fig. 3. Actor perspective

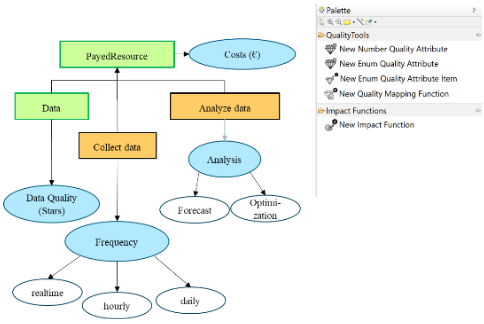

Fig. 4. Quality perspective

Consistent with established tools, the software provides a process perspective (see Fig. 2). This perspective specifies the required actions and the resources demanded by the process (demand side). It also determines the allocation of actors who can or should execute the respective activities or provide the required resources. Additionally, it defines roles that authorize activity execution and the provision or use of resources. These role specifications function as compatibility and authorization constraints for subsequent assignments and execution.

The actor perspective (see Fig. 3) instantiates the supply side by providing an inventory of the actors' capabilities, listing explicit activities, resources and the quality levels at which they can be performed or supplied.

A service-oriented value network is fully specified by (1) a defined process, (2) the necessary resources, and (3) the assignment of the actors to activities and resources. The service quality at network level is determined by the quality attribute values of the concrete resource and activities deployed in the process. As such, the software also incorporates a quality perspective (see Fig. 4). It specifies the relevant quality attributes, including their scales (numeric or categorical), as target or threshold levels used for evaluation.

The software represents the demand side through the process and quality perspectives, and the supply side through the actor perspective with its capability inventory. This provides a common basis for demand-supply alignment, network gap detection and configuration analysis. Integrated simulation and optimization algorithms quantify the effects of assignments and substitutions automatically, enabling results to be presented on a comparable basis.

6 Evaluation and Results

We validated the software tool by modeling and analyzing a hypothetical use case of a medium-sized spinning-machine manufacturing company considering a pay-per-use business model. We used the software tool to create a model that enables a better understanding of whether such a business model is feasible for the company and which partners need to be involved. This subscription-based approach shifts the paradigm from selling machines to delivering a value proposition based on productivity optimization and therefore maximizing machine uptime by implementing predictive maintenance. This raises several challenges, including the need to integrate new actors into the network when existing structures cannot effectively execute required resources or fail to meet the quality standards necessary to prevent machine downtime. Moreover, reconfiguring the actor network is viable only if each actor realizes greater individual value than under the previous configuration of the traditional business model. Consequently, this results in a need to find a combination of elements that enable a subscription-based business model.

The overall approach is to compare different constellations of actors performing newly defined activities or resources and to identify the scenario in which the value created for the customer and each actor is balanced at an optimal level. To this end, the model can be used to identify individual factors that contribute to value creation by simulating various epochs, allowing the modeler to iteratively adapt assumptions.

Our modelling approach uses the metamodel's elements and integrated logic to analyze how value creation is structured at each step of the process. We defined

- a value-in-use function to calculate the value for all actors,
- processes and subprocesses by making use of the activity elements,
- resources and their allocation needed to create value,
- actors that could perform activities or provide resources
- quality attributes values characterizing options, how to perform activities
- impact functions that determine how resources and subsequent activities change when an activity is performed,
- a simulation script to calculate the values created in each step and for each actor.

The value-in-use function was determined by less frequent production stops for the customer, as well as high spinning quality and low use of resources. Other actors valued high margins, data availability and customer retention.

This value creation process was mapped to a process containing four activities including an "or" decision (see Fig. 5). From "conclude pay-per-use contract", then either "upgrade machines or "deliver and commission new machines" then "predictive maintenance". The activity predictive maintenance was divided into a subprocess from collecting and analyzing data to schedule and perform maintenance.

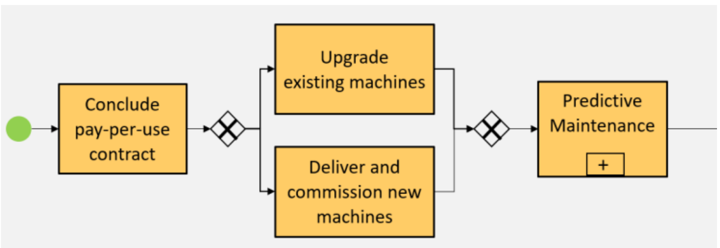

Fig. 5. Process of a pay-per-use business model

In the next step the resources "data" and "report" were defined and associated with the activities "collect data" and "analyze data". To specify the resources and activities, quality attributes like "data quality" measured in "stars" [0,1,2,3,4,5] and "frequency" with values [realtime, hourly, daily] (see Fig. 4) allocated to the activity collect data, were defined. Actor roles like “spinning mill”, “technical service provider” and “data analysis company were defined, while the role “spinning mill” was divided into two subroles “standard” and “premium customer”. Each role then had specific actors like “Happy Yarns”, “Müller Garne” or “Quick Analytics”. For the specific actor “Quick Analytics” we defined what activities it can perform and what resources it had. In our example “Quick Analytics” could perform the activities “collect data” with the quality value “realtime” for frequency and at costs for 1000€. Lastly the functions and the simulation were scripted as described in Figures 6-8.

```
IF
Actor „DeeperInsights“ performs Activity „Analyze data“
THEN
Set Attribute „Analysis“ to „forecast“.
Set Attribute „Costs [€]“ + 500.
Set Attribute „Time required“ to „high“.
.
IF
Actor „QuickAnalytics“ performs Activity „Analyze data“
THEN
Set Attribute „Time required“ to „low“.
.
```

Fig. 6. Impact function

```
IF
Attribute „Analysis“ of Activity „Analyze data“ == „forecast“.
Attribute „Time required“ of Activity „Analyze data“ == „low“.
Attribute „Costs“ of Activity „Analyze data“ < 350.
THEN
Set ValueInUse to 100.
```

Fig. 7. Value-In-Use function

```
Run simulation of Process „Predictive Maintenance“ for 2 epochs.

Actor „QuickAnalytics“ performs Activity „Collect data“.
Actor „QuickAnalytics“ performs Activity „Analyze data“.
Actor „QuickAnalytics“ provides Resource „Analysis Software“ through
ResourceInstance „QACheck“.
Actor „Up & Running“ performs Activity „Schedule Maintenance“.
Actor „ Up & Running“ provides Resource „ Staff Planning Tool“ through
ResourceInstance „Plan.AI“.
.
```

Fig. 8. Simulation script

By performing the simulation, it became apparent which actors and activities contributed the most to the value creation process. This enabled us to analyze the starting question.

In a further step, it was possible to optimize the allocation of actors and resources to obtain optimal value creation.

Additionally, the model was not only able to analyze the hypothetical use case but was also useful to replicate the previous use cases configuration optimization approach in three real use cases from mobility, construction and additive manufacturing. First, in the mobility use case the model and software helped to identify additional stakeholders that profit from a mobility on-demand service and are willing to pay additionally for it. Second, in the construction use case simulation and optimization were used to come up with optimal configurations of partners involved in a construction project, with regards to time and money saving, considering dynamic changes of the system. Third, by modelling the prosthetics ecosystem, new business models based on 3D printing technologies could be identified, that could be performed with already existing actors. In total, all use cases were defined by a complex set of questions, where the model worked as a single source of truth, and therefore was useful for discussing various perspectives regarding the system.

7 Discussion and Conclusion

The proposed metamodel and tool proved feasible and useful across one hypothetical and three industry cases as reviewed in section 6. In all studies, the approach supported the end-to-end task: modeling the value creation flow as a BPMN-oriented process, representing demand through process elements (activities and resources), and supply through actors which offer activities and provide resources, deriving attributes via quality-mapping functions, propagating execution effects with impact functions, and evaluating outcomes with the actor-specific value-in-use. This combination enabled systematic comparison of alternative partner constellations and made trade-offs explicit, for example between cost, lead time, and reliability, and how these trade-offs determine value-in-use for customers, participating providers, and relevant environment actors.

The evidence, while encouraging, remains limited in scope. There are limitations that qualify the findings.

1. Modeling currently entails substantial manual effort and expert knowledge, including the selection of process-relevant attributes, the definition of quality-mapping and impact functions, the specification of actor preferences for value-in-use and the specification of role constraints. Results depend on input quality and may be sensitive to incomplete or biased input variables.

2. External validity is constrained by the small number of cases and limited sector coverage. Many organizations operate portfolios of interwoven services. Considering that, scalability and runtime behavior on very large networks have not yet been stress-tested.

Despite these limitations, the approach demonstrates practical utility. It offers a single, consistent representation that links process logic on the demand side to actor offerings on the supply side under clear assignment rules (type compatibility and roles). It renders the consequences of assignments transparent, supports what-if analysis, and helps identify missing partners, weak quality links, and promising substitutions. The explicit linkage from quality attributes and values through impact functions to value-in-use provides a clear explanatory pathway from operational assumptions to perceived value.

Future work focuses on three directions: First, we evaluate applicability to portfolios of interwoven services. Second, we reduce manual effort and expert dependence by improving the workflow and the GUI. Third, we explore AI support for the modeling process, for example assisting with attribute selection, the specification of functions as well as type- and role-consistent assignments.

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