Association for Information Systems
AIS Electronic Library (AISeL)

Research Papers ECIS 2018 Proceedings

11-28-2018

Towards Design Elements to Represent Business Models for Cyber Physical Systems

Nicola Terrenghi
HEC Lausanne, nicola.terrenghi@unil.ch

Johannes Schwarz
HEC Lausanne, johannes.schwarz@unil.ch

Christine Legner
HEC Lausanne, christine.legner@unil.ch

Follow this and additional works at: https://aisel.aisnet.org/ecis2018_rp

Recommended Citation

Terrenghi, Nicola; Schwarz, Johannes; and Legner, Christine, "Towards Design Elements to Represent Business Models for Cyber Physical Systems" (2018). *Research Papers*. 181.
https://aisel.aisnet.org/ecis2018_rp/181

This material is brought to you by the ECIS 2018 Proceedings at AIS Electronic Library (AISeL). It has been accepted for inclusion in Research Papers by an authorized administrator of AIS Electronic Library (AISeL). For more information, please contact elibrary@aisnet.org.

TOWARDS DESIGN ELEMENTS TO REPRESENT BUSINESS MODELS FOR CYBER-PHYSICAL SYSTEMS

Research paper

Terrenghi, Nicola, University of Lausanne, Faculty of Business and Economics (HEC), Lausanne, Switzerland, nicola.terrenghi@unil.ch

Schwarz, Johannes, University of Lausanne, Faculty of Business and Economics (HEC), Lausanne, Switzerland, johannes.schwarz@unil.ch

Legner, Christine, University of Lausanne, Faculty of Business and Economics (HEC), Lausanne, Switzerland, christine.legner@unil.ch

Abstract

Cyber-physical systems turn products into connected devices that enable interaction among individuals, organizations, and other objects. They find application in areas such as healthcare and automotive, enabling new value propositions created by multiple players for a shared customer. Despite the perceived business potential, practitioners in primarily physical industries struggle to analyze and design value creation mechanisms for cyber-physical systems. The prevailing business model conceptualizations follow a mono-organizational logic and are unable to express hybrid and interactive value creation. To close this gap, we apply a design science research approach to develop and evaluate a taxonomy of design elements to represent business models for cyber-physical systems. Through an analysis of 21 use cases of value creation mechanisms in the automotive industry, we identify the design elements adopted in practice; we then validate the identified design elements via 13 interviews and a workshop with our target users, obtaining a final taxonomy comprising 23 design elements. We improve the expressive power of business model conceptualizations by identifying specific roles, control points, and value exchanges in a network of players, representing hybrid and interactive value creation.

Keywords: cyber-physical systems, design science, business model, automotive industry

1 Introduction

The continuous miniaturization of computer and communication hardware and more effective power management have turned the vision of ubiquitous computing into a reality (Yoo, 2010). Products become part of cyber-physical systems (CPS), in which physical and computation processes are integrated (Lee, 2008). CPS find application in areas such as medical devices, traffic control, and advanced automotive systems (Shi et al., 2011). They enable new value propositions (Oks et al., 2017), drive *servitization* of primarily physical industries (Herterich et al., 2015) and are expected to have strong environmental impacts (Rajkumar et al., 2010). CPS are experiencing strong momentum in practice, thanks to initiatives such as *Industry 4.0* (Bunse et al., 2014) and *Industrial Internet* (Evan and Annunziata, 2012). These initiatives stimulate CPS adoption in the industrial sector. For example, in the automotive industry, CPS use cases include predictive vehicle maintenance to prevent expensive repairs, networked parking service to avoid time wastage and traffic congestion, and a connected navigation service, which aggregates location data from every driver and suggests the shortest or most scenic route in real time (McKinsey&Co., 2016).

Despite CPS's potential, managers perceive the conflation of digital components and analog products as "extremely challenging" (Piccinini et al., 2015), not only for technical reasons but also because managers struggle to identify suitable applications and business models for CPS (Oks et al., 2017). CPS require close collaboration between multiple players in a network in which products, services, and data are exchanged to create value for customers and for the involved stakeholders (Mikusz, 2014). In this context, identifying viable and sustainable business logics is a complex task. Current business model representations don't fully support practitioners in designing new value creation mechanisms for CPS. Specifically, most of the prevailing business model approaches follow a mono-organizational logic. In doing so, they are not able to capture the full potential of technologies with mainly multiplayer game and value co-creation characteristics (Iivari et al., 2016; Oks et al., 2017).

We fill this research gap with a design science approach. Specifically, by looking at current representations from industry, we derive a taxonomy of specific design elements, in the form of entities, relationships, and their attributes, to support innovation managers, product managers, and scholars in designing and analyzing business models for CPS. We contribute to the research into business models and CPS, suggesting answers to the following research questions: *What are the key design elements to represent business models for cyber-physical systems?* (RQ1), *How do these design elements support target users in representing business models for cyber-physical systems?* (RQ2).

The remainder of this paper is structured as follows: In the next section, we discuss the literature on the concepts of CPS and business model representations, with a focus on hybrid and interactive value creation. We then describe each phase of our design science approach to develop the final artifact. Specifically, we describe the taxonomy we have developed by identifying and classifying the design elements from the analysis of empirical data. We then propose a visualization of the identified design elements, structured as entities, relationships, and attributes, by extending an existing notation. In the results section, we present and describe the design elements identified in existing representations and classified in a bottom-up approach. We continue by presenting the outcomes of the evaluation phase, composed of two primary steps: validation of the artifact's *completeness* and *consistency* via semi structured interviews with 13 target users, and evaluation of the *utility*, identified in a workshop with a target user. In the discussion, we explore the relationships between the design elements we identified and those in other existing business model representations.

2 Theoretical Background

2.1 Cyber-physical Systems

As predicted by Moore (1965), we are experiencing the proliferation of low-cost sensors and increasing technical capabilities, which are pushing the diffusion of CPS in society and, in particular, in sectors where large-scale and affordable computation technologies open up new problem-solving opportunities

(Rajkumar et al., 2010). "Cyber-physical systems are integrations of computation with physical processes. Embedded computers and networks monitor and control the physical processes, usually with feedback loops where physical processes affect computations and vice versa" (Lee, 2008). They result in linked systems that operate flexibly, cooperatively (system-system), and interactively (system-human) (Mikusz, 2014). Areas where CPS applications are found include automotive systems, traffic control, smart grids, process control, and medical systems (Shi et al., 2011).

Oks et al. (2017) classify the literature on CPS along three dimensions: technical, human, and organizational. The *technical* literature describes how sensors, actuators, communication protocols, interfaces, and other technical components are combined and enable CPS (Lee, 2008). The *human* domain builds on the assumption CPS's economic success significantly depends on user acceptance. The global distribution of mobile devices, people's familiarity with such technologies and 'passive' human-machine interaction (e.g. activity trackers) raise expectations of high adoption rates in both private and professional contexts (Kim et al., 2014). Research in the *organizational* domain addresses the challenges for companies in identifying suitable applications and business models for CPS. While the technical and human dimensions propose extended research in computer science and human-computer interaction domains, the organizational dimension is argued to be still immature (Oks et al., 2017).

Oks et al. (2017) distinguish two key value creation mechanisms in CPS at the organizational level: *hybrid value creation*, intended as innovation strategy of generating additional value by innovatively combining products, data, and services, and *interactive value creation*, an innovation strategy based on new forms of open and personalized collaboration between partners.

2.2 Hybrid Value Creation in Cyber-physical Systems

Hybrid value creation can be defined as "the process of generating additional value by innovatively combining *products* (tangible component) and *services* (intangible component)" (Velamuri et al., 2011). Owing to technological innovation, particularly the spread of phenomena such as smart products and the Internet of Things, hybrid value creation is often explicitly or implicitly characterized by a third component: *data* (e.g. Oks et al., 2017). In this sense, firms increasingly shift their focus from offering standalone products or services towards integrated combinations of products and services as solutions that address specific customer needs (Velamuri et al., 2011). This strategy challenges traditional business logics for offering products, spare parts, and support services (Windahl and Lakemond, 2006).

Scholars argue that organizations can typically gain value from hybrid value creation in three ways (e.g. Oliva and Kallenberg, 2003; Velamuri et al., 2011): First, particularly for primarily physical industries, hybrid value creation offers economic value, with higher returns owing to shrinking margins for manufactured goods (Windahl and Lakemond, 2006). Second, strategic value, since firms can gain a competitive advantage that is hard to imitate. Third, environmental value, since the same economic function can be served with a reduction in the quantity of materials required to do so. Thus, it is generally argued that offering hybrid solutions provides more value to customers than the sum of value of each product or service separately (Mikusz, 2014).

Hybrid value creation typically relates to the business model concept to express new value creation and value capture mechanisms (Hui, 2014). This perspective is in line with the understanding of the business model as "a focusing device that mediates between technology development and economic value creation" (Chesbrough and Rosenbloom, 2002). The introduction of new technologies such as radiofrequency identification (RFID), Bluetooth, and smart computing has enabled many new application and business propositions in traditional industrial sectors (Iivari et al., 2016). Specifically, hybrid value creation is demanding new service concepts and business models, since companies need to "fundamentally rethink their orthodoxies about value creation and value capture" (Hui, 2014). However, the literature shows that researchers and practitioners have not yet sufficiently studied how digitization and the hybrid value creation affect business models (Turber and Smiela, 2014).

2.3 Interactive Value Creation in Cyber-physical Systems

Interactive value creation can be generally conceptualized as a natural ecosystem in which firms cannot thrive alone (Moore, 1996), but depend on one another for their effectiveness and survival (Iansiti and Levien, 2004). Building on this perspective, Zott and Amit (2013) state that the ecosystem concept is closely related to the business model because "it recognizes the need to go beyond focal firm's boundaries and adopt a more systemic perspective that emphasizes interdependencies and complementarities between a firm and third parties in order to properly understand how value is created". They conceptualize a business model as a "system comprised of activities that are performed by the firm and by its partners" (Amit and Zott, 2014).

In CPS, partnerships are key to finding the components (products, services, and data) to combine in a solution that addresses specific customer needs. This is not necessarily restricted to manufacturers and customers, but is open to organizations operating in various industries, including services (Mikusz, 2014). For instance, the integration of competences from telecommunication suppliers and software developers, which are essential to construct and operate cross-industry product innovation, has resulted in new forms of cooperation, competition, and solutions (Acatech, 2011; Mikusz, 2014). This characteristic extends previous conceptualizations, which have limited interaction to collaboration between manufacturers and their customers in order to achieve a more user-oriented approach to value creation, ultimately leading to products and services with higher benefits for customers (Reichwald and Piller, 2009)

In their multiple-case analysis, Windahl and Lakemond (2006) identified six key factors for developing integrated solutions: the strength of the relationships between the actors; a firm's position in the network as either integrator or supplier; a firm's network horizon, intended as its boundaries and the players' view of the network extension; a solution's impact on existing internal activities, which have important consequences for the internal coordination of the development of integrated solutions; a solution's impacts on customers' core processes, which affect their interest in an integrated solution; and external determinants, intended as driving factors that affect customer needs.

Interactive value creation as core perspective in business model representations is taken by scholars who provide business model ontologies (e.g. Gordijn, 2002; AI-Debei and Avison, 2010) or frameworks (El Sawy and Pereira, 2013; Turber et al., 2014). However, none propose a means to specifically represent business models for CPS. In other words, interaction in value creation is a phenomenon that is still under-represented in the dominant business model logic (Iivari et al., 2016). From an academic perspective, we still lack solid contribution on the identification of suitable business model representations that can drive value (co-) creation for actors in CPS networks (Oks et al., 2017). For instance, in the analysis of the business model state of research, Wirtz et al. (2015) found evidence that the analysis of the interactions and relationships between different business model actors covers only 5% of the literature.

3 Research Methodology

To address this research gap, we seek to develop a taxonomy of design elements to represent business models for CPS. Our research scope are organizations in primarily physical industries, which need to find novel ways to create and capture value for CPS. Specifically, we address innovation managers and product managers, helping them to design and analyze business models for CPS.

We base our methodology on the design science research (DSR) approach, adopting the six phases proposed in Peffers et al.'s (2007) process model (Table 1). DSR has gained wide acceptance in the information systems domain (Hevner et al., 2004), and "has a critical role to play in addressing major organizational and societal issues" (Prat et al., 2015). The problem we identified is motivated by both research and practice. Our research contributes to the theory type V., design, and action according (Gregor, 2006) by providing a design element taxonomy for practitioners and academics who need to represent value creation mechanisms for CPS.

To develop the artifact, we proceeded with an in-depth study of the automotive industry, which is recognized as an exemplary case to describe "the potential and significance of cyber-physical systems" (Acatech, 2011) and is particularly relevant in the recent exploration of IT-enabled business models (e.g. Hanelt et al., 2015; Hildebrandt et al., 2015). This industry has a physical component at its core, the vehicle, complemented with an increasing number of sensors that enable innovative, hybrid value creation mechanisms. For instance, connectivity has enabled carsharing services (e.g. Car2Go), and large investments are made in self-driving vehicles (e.g. Waymo).

To get evidence of the identified problem and explore CPS's specific challenges in this industry, we conducted two preliminary interviews with a partner from a top-tier consultancy firm with 10 years' global experience in the digitalization of the automotive sector. We focused on his experience in several projects on connected and self-driving cars, with customers playing different roles in this ecosystem (e.g. original equipment manufacturers (OEMs), insurers, data analysts, legal regulators, startups, etc.).

Problem identification and motivation	Business models in the context of CPS involve complex interdependencies between several actors, which are not addressed by existing business model representations. This is a challenge for decision-makers in the design of viable value creation mechanisms.
Objectives of a solution	Support innovation managers, product managers, and scholars in designing and analyzing viable and sustainable business models for CPS.
Design and development	*Activity*: Taxonomy development (empirical to conceptual): • Identification of meta-characteristics from literature. • Analysis of design elements from 21 value creation models of connected vehicles in the automotive industry. *Outcome*: 30 design elements (entities, relationships, and attributes) related to hybrid or interactive value creation as meta-characteristics.
Demonstration	*Activity:* Visualization of the identified design elements and extension of the *e3-value ontology* notation. *Outcome*: Visualization of the identified design elements.
Evaluation	*Activity*: 13 semistructured interviews with target users. *Outcome*: Validation of the taxonomy concerning its completeness and consistency. Final taxonomy of 23 design elements.
	Activity: One-day workshop with a target user in the logistics industry. *Outcome*: Evaluation of the identified design elements' utility.
Communication	Academic conference and journal contributions. Software-based reference model.

Table 1. Research based on Peffers et al.'s (2007) Process Model.

3.1 Design and Development

Taxonomies allow for the combination of theoretical knowledge and empirical findings, making them particularly suitable for our purposes (Remane et al., 2016). They are used in various domains to classify objects of interest into mutually exclusive and collectively exhaustive categories, via classificatory schemes (Hanelt et al., 2015). To develop our taxonomy, we followed Nickerson et al.'s (2013) guidelines. This method is based on three key development criteria: first, meta-characteristics must be defined as the basis for the choice and classification of all the dimensions in the taxonomy; second, ending conditions, as reaching theoretical saturation in the taxonomy, are chosen; third, the iterative development is set; this can include inductive (empirical to conceptual) and deductive (conceptual to empirical) iterations.

To identify and refine the design elements to represent business models for CPS, we seek to develop a design element taxonomy. To this purpose, we analyzed a set of 21 value creation models. Such models describe and represent specific use cases of connected vehicles, for instance, usage-based tolling and taxation, driving style suggestions, advanced tracking and theft protection, etc. As shown in the anonymized example in Figure 1, the information provided in each use case included a value creation flow with the key actors (e.g. OEM) and the value exchanged among them (e.g. usage data), their expected benefits (e.g. lower insurance premiums) and the key control points in the network (e.g. analytics capabilities). These use cases are secondary data built on 60 semistructured interviews and two round-tables (15 participants each) with chief technology officers (CTOs) and heads of innovation from the automotive industry.

Building on the reviewed literature, we defined hybrid and interactive value creation as meta-characteristics to classify the collected dimensions (i.e. design elements). Having access to a use cases set based on 60 interviews and two round-tables, we considered the coverage of the 21 use cases as ending conditions for our taxonomy. Finally, given the scarcity of articles on design elements relating to hybrid and interactive value creation, we conducted only empirical to conceptual iterations.

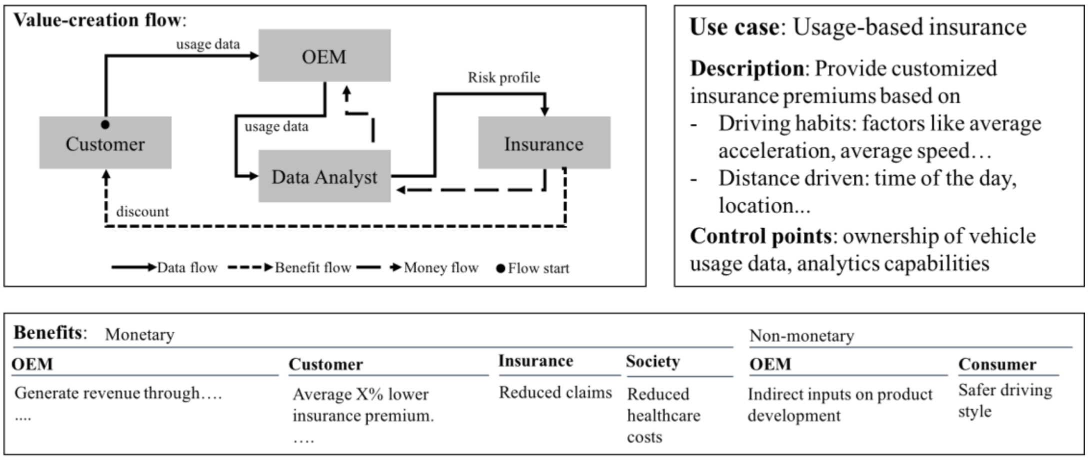

Figure 1. Anonymized example of a connected vehicle use case.

The analysis of each use case was conducted by two authors in sequence. Initially, all actors, flows, control points, and benefits were listed; this led to 51 elements. However, the use cases included elements that were industry-specific. For this reason, to reach higher generalizability, we merged similar elements. For instance, we included the role *insurance* was included in the more generic role *service provider*. This activity was conducted by two authors; in case of disagreement, a third author helped to reach consensus. We then counted every element's recurrence. To include only elements that are potentially relevant for CPS, we considered only elements that were present in at least three of the 21 use cases – for instance, we did not include the actor *parking provider* (counted only once). In a final step, since the initial result of the taxonomy was a list of uncategorized elements, we classification of each of them, by adopting an entity-relationship-type model, as in Gordijn et al. (2005). Our model is characterized by entities with specific attributes and their related instances. Every entity is in relationship with another, as part of a network. For instance, the entity *driver* has the attribute *role*, which has the instance *customer*, which is in relationship with another actor via *data*. The design and development phase led to an initial taxonomy of 30 design elements to be evaluated.

3.2 Demonstration and Evaluation

To evaluate the taxonomy of design elements with our target users, we needed to visualize the identified design elements and specifically the de facto interdependencies among actors. Thus, in the demonstration phase, we defined a means of visualization based on the notation of the *e3-value ontology* by Gordijn and Akkermans (2001). This conceptual model is explicitly based on a notation that represents relationships (value exchange) between entities (actors) and provided a visual representation of the design elements, which facilitated the following evaluation with target users. Design elements that were not represented in the e3-value ontology (e.g. control points) were designed by the authors and were later validated in the semistructured interviews. However, such notation is not this study's core artifact, but the means to evaluate the identified design elements.

To "observe and measure how well the artefact supports a solution to the problem" (Peffers et al., 2007), the evaluation took two phases, each targeted to specific criteria suggested in Prat et al.'s (2015) classification. First, via 13 semistructured interviews with target users, we assessed the collected design elements' *completeness* and *consistency*; second, in a full-day workshop with a target user, we evaluated the artifact's *utility*.

3.2.1 Completeness and Consistency

This phase of the evaluation consisted of 13 semistructured interviews with target users in the automotive industry. We interviewed three automotive consultants, three product managers in three car manufacturers, six innovation managers in a software company, and a digital business model manager in an insurance company. All the interviewees were already familiar with the concepts of hybrid and interactive value creation and use them in their business activities. Every interview was about one hour long, via video-call, conducted by two persons (one took extensive notes) and was structured as follows: after introducing the interviewee to CPS and to the study motivations, we showed and explained the representation of the use case *usage-based insurance*, visualized through the e3-value ontology notation. In a later step, we showed the full design elements taxonomy to the interviewee, who assessed its completeness (i.e. the inclusion of all the necessary entities, relationships, and attributes) and consistency (i.e. uniformity, standardization, and freedom from contradiction among design elements). The interviewees could take one of the following decisions on each element: *confirm* (the design element is relevant and consistent), *adapt* (the design element is relevant but needs improvement to be consistent), *add* (an essential design element is missing), or *delete* (a design element is not relevant). We included the design elements confirmed by at least three interviewees (i.e. about 23% of them) in the final taxonomy. We merged those labelled as *adapt* more often than *confirm* with other elements or rephrased them, depending on the insights from the interviewees. This evaluation phase led to a consolidated taxonomy of 23 design elements, which we consider to be complete and consistent for our target users.

3.2.2 Utility

While the interviews were essential to consolidate the identified design elements, they were not the ideal means to evaluate their de facto utility (the ratio between the value of the documentation and the time/complexity effort). Thus, we conducted a workshop with an innovation manager and his team from a truck manufacturer, which would allow us to observe and evaluate the use of the suggested artifact by target users. Five persons from the company's digital unit attended the full-day workshop, which was has two main sessions. Giving specific guidelines, we first asked them to brainstorm and generate potential use cases for their physical product by describing how this could interact with other objects and which customers need they address. We then supported the team in creating a business model scenario, by means of our design elements, on one of the generated use cases. At the end of the two sessions, we involved the team in an open discussion on two primary factors: their perceived value in using the business model representation for their use case and the potential complementarity of this representation with different ones (e.g. the *Business Model Canvas*). We did this by asking the attendees to spend five minutes thinking and providing insights on the two factors, individually; this was necessary to avoid the dominance of any one participant. We then invited each participant to share their insights, while one author took extensive notes. We then collected and consolidated the insights, identifying similarities and differences.

4 Results

4.1 Taxonomy of Design Elements to Represent Business Models for CPS

In Figure 2, we present the final (post-evaluation) taxonomy to represent business models for CPS, which we derived from analyzing and categorizing design elements from 21 value creation models of connected vehicles in the automotive industry. Our artifact is characterized by actors and their value exchanges, which correspond in order to the meta-characteristics of hybrid and interactive value creation. An actor is a "an independent economic (and often legal) entity" (Gordijn and Akkermans, 2001). Interacting with other actors in a network, an actor increases its utility. Actors exchange value in monetary and/or non-monetary forms.

In CPS, interactive value creation is intended as the forms of open and personalized collaboration between value creation partners (i.e. actors). Such value is co-created to be offered to the same customers (Storbacka et al., 2015), which is also considered a value creator (Vargo and Lusch, 2008). Every actor in a network has one or more roles. A role describes an actor's contributions or functions in a business model. In this sense, actors co-create and co-capture value (Iivari et al., 2016).

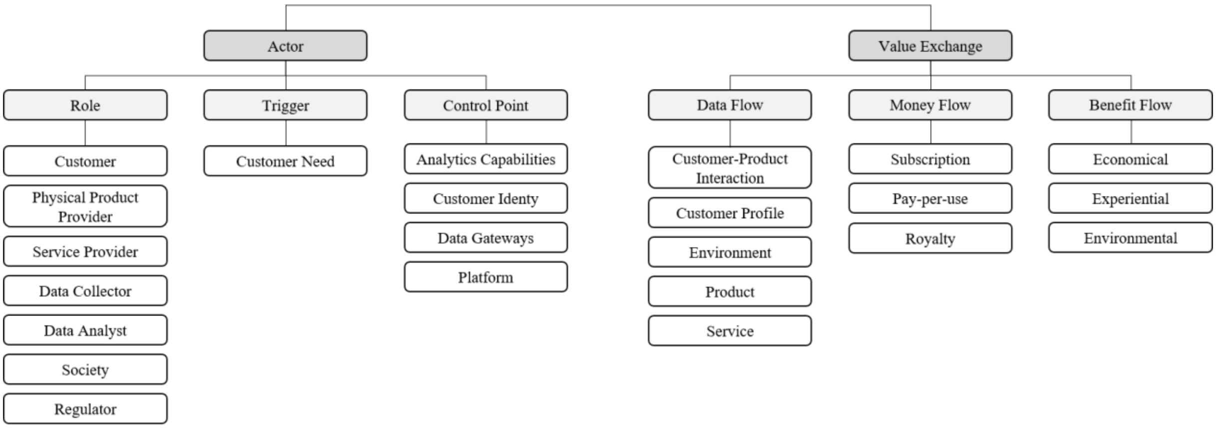

Figure 2. Design elements taxonomy to represent business models for cyber-physical systems.

The *value exchange* dimension builds on the concept of hybrid value creation, intended as "the process of generating additional value by innovatively combining *products* (tangible component) and *services* (intangible component)" (Velamuri et al., 2011). Analyzing the 21 empirical use cases, there is evidence that this added value, or solution, takes the shape of a service, enabled by the processing of data that are collected through a product. In this sense, the tangible component works as an *operand resource* (or transmitter) of services (Vargo and Lusch, 2008).

We will now show the recurrence of every design element in the 21 use cases, their evaluation in the 13 semistructured interviewees, the final decisions concerning inclusion/exclusion, and their notation.

4.1.1 Design Elements to Represent Interactive Value Creation: Actor Attributes

Customer: Having a specific need, it triggers value flow in a network. It is also the final recipient of benefits, which works as a solution to a stated problem. The customer exchanges data or money in return of a benefit. For instance, a driver that needs to travel to a certain destination sends this location to another actor and receives the fastest route. However, the customer is not always the end-user or, in this case, the driver. For instance, a connected vehicle can collect data on road conditions; this information is relevant for another potential customer: the road maintenance provider.

Physical product provider: Provides the main physical object that collects inputs from the user and the environment and sends data to one or more actors. For instance, a car manufacturer is the provider of the connected vehicle, which includes sensors that provide a variety of data.

Data collector: The actor who aggregates the data received from the physical object. For instance, a car manufacturer directly collects driving behavior datasets, such as location, time of the day, acceleration, etc.

Service provider: Leveraging a connected physical object, this actor offers a specific service to the customer or to another actor. For instance, having access to real-time vehicle location and performance, road assistance and emergency services can seek to provide rapid support. In-car applications are also considered service providers that are offered to drivers via the operating system.

Society: A community such as a city or a country that benefits from a use case of a connected physical product. For instance, an insurance premium based on monitored driving behaviors can help to reduce car accidents and can therefore lower investments in healthcare.

Regulator: Working as a supervisor of the economy, a regulator can benefit from use cases that increase transparency and safety. For instance, a municipality or government can leverage traffic data to identify a pollution footprint and to prioritize interventions.

Data analyst: Receiving data from one or more data collectors, a data analyst processes data to retrieve information that is valuable to other actors. For instance, integrating traffic flow data, a data analyst can provide the authorities with valuable information to spot or even prevent congestion.

Design element	Recurrence in 21 use	13 interviews				Included in taxonomy	Notation based on the e3-value ontology (Gordijn and Akkermans, 2001)
		Confirm	Adapt	Add	Delete		
Role							
Customer	21	13				Yes	Actor Name (Role)
Physical product provider	21	13				Yes	
Data collector	16	9	4			Yes	
Service provider	14	13				Yes	
Society	11	11			2	Yes	
Regulator	11	10			3	Yes	
Data analyst	8	13				Yes	
Authorities	4		5		8	No	Included in service provider
Advertisers	4		8		5	No	Included in service provider
Physical product				2		No	Not minimum 'add' achieved
Trigger							
Customer need	21	13				Yes	Customer Need
Control point							
Analytics capabilities	10	10	1		2	Yes	Control Point
Customer identity	9	13				Yes	
Data gateways	7	12	1			Yes	
Platform	5	12			1	Yes	
In-product sensors	7	2	1		10	No	Not considered as power enhancement

Table 2. Attributes of the actors.

The value exchange among actors needs a starting point in the representation of the flow. In this sense, each business model focuses on a specific *customer need*, which triggers the value creation mechanism. The customer need should be defined at the outset, to allow proper scoping of each use case. For instance, an advanced emergency call service is a use case that should be designed and represented around drivers' need for timely intervention in the case of an accident. All the other actors and value exchanges are built on this need.

Control points are the "positions of greatest value and/or power" (Pagani, 2013). In other words, they are factors that increase the power of an actor compared to the others in the network.

Analytics capabilities: An actor owns the critical technological capabilities or algorithms (usually patented) to analyze a dataset. For instance, a data analyst that developed and patented an algorithm to create driver profiles from driving behaviors could gain this control point type.

Customer identity: An actor that has access to a customer's details (name, address, etc.). For instance, an insurer that has access to a driver's details could directly communicate with them, offering new insurance packages built on top of an existing one.

Data gateways: An actor that has direct and exclusive access to a dataset from the physical product. For instance, if a car manufacturer is the only actor to collect location data, it could sell it to local parking providers to optimize available parking spaces.

Platform: In-product development and execution environments that support the running of applications. For instance, a car manufacturer that develops an operating system in-house becomes the only platform where application developers and providers can reach the customer.

4.1.2 Design Elements to Represent Hybrid Value Creation: Actors' Value Exchanges

Actors exchange various value types among one another: data, money, and benefits. A data flow is potentially valuable information generated by or collected from one actor and handed to other actors, usually in exchange of money or benefits.

Design element	Recurrence in 21 use	13 interviews				Included in taxonomy	Notation based on the e3-value ontology (Gordijn and Akkermans, 2001)
		Confirm	Adapt	Add	Delete		
Data flow							
Customer-product interaction	18	10	3			Yes	Data Flow [name]
Customer profile	18	11	2			Yes	
Environment	9	8	2		3	Yes	
Product	6	12	1			Yes	
Service				6		Yes	
Geo-location	14	2	8		3	No	Included in customer-product interaction
Money flow							
Subscription	11	13				Yes	Money Flow [name]
Pay-per-use	8	13				Yes	
Royalty	5	10	2		1	Yes	
Freemium model	5	4	6		3	No	Included in subscription fee
Personalized pricing	4	2	8		2	No	Included in dynamic pay-per-use
Benefit flow							
Economic	15	12	1			Yes	Benefit Flow [name]
Experiential	11	9	3		1	Yes	
Environmental	10	10	1		2	Yes	
Efficiency	5	6	6		1	No	Included in economical

Table 3. Types of value exchanged among actors.

Customer-product interaction: Data related to the interaction between the customer and a physical product; for instance, the driver's behavior when using the product, such as acceleration, speed, etc.

Customer profile: Data related to the individual or legal entity; for instance, driver age, status, and employment information.

Environment: Data related to the external environment gathered by the sensors in a physical product. For instance, a car can provide data about road conditions, which are relevant for maintenance providers.

Product: Data related to a physical product's status, performance and condition; for instance, tracking tire conditions to promptly arrange replacement.

Service: Processed data that serve as valuable information for an actor; for instance, usage-based tolling as a service offered to the driver that automatically pays road tolls and provides access to restricted areas, based on the de facto road usage and driving style.

Actors can exchange monetary value with one another. In case of CPS, the analyzed use cases show that this takes three main generic types:

Subscription: Based on consecutive, regular payments between two actors. For instance, a driver subscribes to a theft protection service that enables vehicle location and movement tracking. Such protection could be personalized, depending on the specific driver profile.

Pay-per-use: A monetary transaction between two actors takes place for each data exchange. For instance, a parking provider suggests a parking spot for every driver, possibly proposing a dynamic price that depends on zone, duration, etc.

Royalty: A percentage of an actor's revenue is shared with other actors. For instance, a car manufacturer and the actor who owns the operating system retain a percentage of the revenues generated by an application developer.

Finally, the analyzed data suggest that actors can exchange three generic benefit types.

Economic: An actor benefits from higher revenues, cost reduction, or other financially related benefits. For instance, a driver who makes their driving style safer can benefit from a lower insurance premium.

Experiential: An actor benefits from the enhancement of their experience, such as time savings, entertainment, a sense of safety, or transparency. For instance, a transparent and full monitoring and scoring of a vehicle's conditions over time can be beneficial to a buyer of a second-hand car.

Environmental: An actor benefits from a more sustainable environment or community. For instance, an optimized traffic flow can help to reduce CO2 emissions and therefore air quality for the community.

4.2 Illustrative Use case

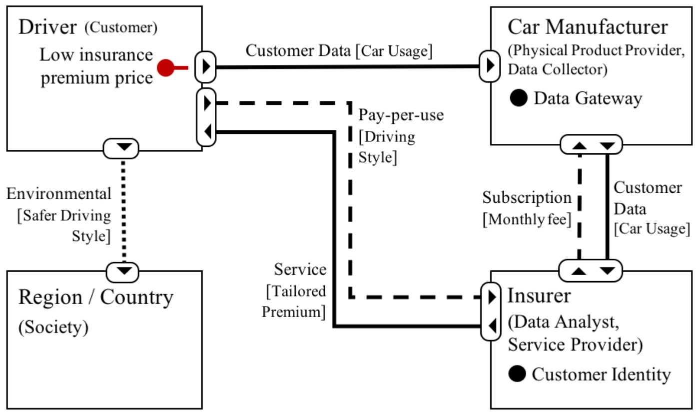

Figure 3. Representation of a business model scenario for CPS by means of the design elements visualized through the e3-value ontology.

The flow starts with the collection of car usage data by the car manufacturer, which has the roles of physical product provider (car) and data collector. This data is exchanged with the insurer, which has the capabilities to analyze the acquired data and to derive specific driver profiles. Such profiling can enable a service, shaped as tailored premium, to a driver. This may mean a significant cost reduction and, in a *pay-how-you-drive* system, is a strong incentive to drive carefully, increasing safety. Safer driving behavior is also valuable to other actors: society can expect fewer accidents and therefore lower investments in healthcare. In this use case, two control points, data gateway and customer profile, are equally distributed among two actors, suggesting equilibrium in the network.

4.3 Utility

To assess the artifact's utility for our product and innovation managers, we conducted a full-day workshop with a team of five in a project relating to new connected trucks. For reasons of confidentiality, we cannot describe or visualize the use case represented by the team. However, the participants provided three main insights concerning the utility of the design elements adopted to represent the business model for their use case.

Design elements as guidelines to identify and agree on the key actors and their interrelationships. Having a taxonomy of predefined design elements helps a user to identify the critical actors to involve in the business model, as well as secondary ones that were not initially considered relevant (e.g. society, regulator). Further, the attendees argued that testing different value exchange scenarios helped them to reach a shared understanding of the business model under analysis. In this sense, the representation served as common ground for teams designing business models for CPS.

Control points to identify and prevent disequilibrium in the network. Being labels of favorable positions in the network, the control points are considered a key element to identify every actor's extent of power in a network. This is important information for the users, who – in the business model design – try to prevent excessive dominance by other actors, mostly concerning data, patents, and operating systems. The participants also noted that these elements help to identify actors in a network that are not only partners, but also potential competitors.

Value exchanges as an end-to-end value flow. A participant stated that the representation of the value exchange triggered by a customer need and continued through the actor network was a "journey of value generated along the flow with the objective of filling a need". In this sense, the design elements enabled a comprehensive description of the business logic through the overall value exchange in the network. Further, a participant noted that this type of representation complements the *Business Model Canvas*, which focuses only on one organization.

5 Discussion

Our design elements taxonomy contributes to the research into the organizational dimension of CPS (Oks et al., 2017), which addresses companies' challenges in identifying suitable and viable business applications of CPS. Building on empirical insights from 21 value creation models, we derived an artifact that supports practitioners and scholars in developing business model representations and in-creasing their understandings of hybrid and interactive value creation in CPS. In this sense, the suggested taxonomy acts as a "focusing device that mediates between technology development and economic value creation" (Chesbrough and Rosenbloom, 2002).

Concerning interactive value creation on CPS, we have contributed to the research by suggesting specific actor types and refining their roles. In the existing literature, business model representations propose various roles. Pagani (2013) distinguishes five roles: consumer, service provider, tier 1 enabler, tier 2 enabler, and auxiliary enabler. Her research describes value networks in relation to digital business strategies. It is evident from the roles that this analysis considers no physical component that is key to CPS. While the representation proposed by Turber et al. (2014), which centers around to the *Internet of Things*, is likely the closest to the CPS field, the authors focus on suggesting a framework in which the entities in the network are classified as collaborators. In our design elements taxonomy, we suggest seven roles that best represent business models for CPS. Customer need is an element that can be deducted only in a few existing representations. For instance, Gordijn and Akkermans (2001) propose *stimulus* as the trigger of their representation, but this can be related to any actor, not necessarily to the customer. However, business model representations typically describe the value to the customer explicitly, but omit the customer need they are addressing (e.g. Osterwalder 2004). The notion of control point is unusual in the business model domain. The value network described by Pagani (2013) suggests a classification of critical positions of the actors in the network, using *control point* to describe the advantage in value creation or capture. Although this classification helps to identify actors that serve as gateways in the network, we argue that it doesn't explain the asset that makes an actor more powerful than another (e.g. analytics capabilities).

Considering the existing literature on hybrid value creation, we significantly contribute to the extension of the value types exchanged in a network. Several business model representations don't classify the value types exchanged among actors (e.g. Kundisch and John, 2012; Pagani, 2013). While this gives scholars and practitioners more freedom when designing and representing business models, describing business models for CPS without a reference is likely extremely challenging. Focusing on the *Internet of Things*, Turber et al. (2014) classify value as monetary and non-monetary. We extend this classification by suggesting three value flow types in CPS. In our view, the concept of money flow is already largely analyzed in the business model domain, because revenue models are at the core. However, we know that, in CPS, the revenue models are mainly based on subscription, pay-per-use, and royalty models. We additionally identify data flows, which are not covered in prior research.

Although our representation builds on CPS, we found no strong evidence of a key role of the physical object as actor in the representation. According to actor-network theory (Law, 1992; Latour, 1996), objects should be described as actors, proposing that value is exchanged as object-object and object-organization. However, we argue that a collaborative network of organizations and individuals has the ultimate goal of describing the value generated for them, while the object is the means to generate and exchange such value (Vargo et al., 2004).

6 Conclusion

This study provides a design elements taxonomy to represent business models in CPS. Adopting the DSR methodology, we developed an artifact that extends the research into hybrid and interactive value creation, addressing a specific organizational issue: creating and capturing value from CPS. Our empirical analysis suggests that CPS requires innovative business logics for specific use cases, in which value is generated and exchanged by multiple actors interacting and potentially competing with one another. We have shown that a specific set of design elements should be considered when representing such business logics.

We argue that an in-depth analysis of the automotive industry was necessary to get a detailed understanding of the CPS phenomenon and collect a first set of design elements to be validated with the target users. We should also consider that connected objects expand an industry's boundaries. For instance, connected cars could become relevant for local retailers; similarly, interactions between a connected car and home devices could create CPS applications that go beyond a specific industry. However, relying on a single source of secondary data to develop our taxonomy can be a limitation. The evaluation phase of our study provided relevant insights on the artifact's utility for our target user, but evaluation in a single workshop is a limitation. As opportunity for future research, researchers should analyze use cases from a diversity of contexts, where connected objects enable collaboration and competition between actors that typically belong to different markets. Thus, this study should evolve with the analysis of other areas of application of CPS; for instance, smart homes and healthcare. The focus on other industries could help us to validate and extend the taxonomy, to identify further elements and to adapt existing ones.

The evaluation phase of our methodology provided relevant insights on the artifact's utility for our target user. However, a single workshop is a limitation. To fully support practitioners and scholars in the design and analysis of business models for CPS, the research must go beyond a design elements taxonomy, developing it into a conceptual model and related methods to represent hybrid and interactive value creation mechanisms.

References

Acatech (2011). *Cyber-Physical Systems - Driving Force For Innovation In Mobility, Health, Energy And Production*. Acatech Position Paper. National Academy of Science and Engineering.

AI-Debei, M. M. and Avison, D. (2010). "Developing A Unified Framework Of The Business Model Concept.", *European Journal of Information Systems* 19 (3), 359–376.

Amit, R., & Zott, C. (2014). "Business Model Design: A Dynamic Capability Perspective". *J. Manage*.

Bunse, B., Kagermann, H. and Wahlster, W. (2014). *Industrie 4.0, Smart Manufacturing for the Future*. Report. Germany Trade and Invest.

Chesbrough, H. and Rosenbloom, R. S. (2002). "The Role Of The Business Model In Capturing Value From Innovation : Evidence From Xerox Corporation's Technology Spin-Off Companies", *Industrial and Corporate Change* 11(3), pp. 529–555.

Evan C., P. and Annunziata, M. (2012). *Industrial Internet: Pushing the boundries of Minds and Machines*. URL: https://www.ge.com/docs/chapters/Industrial_Internet.pdf (visited on 18/09/2017).

Gordijn, J. (2002). "Value Based Requirements Engineering: Exploring In- Novative E-Commerce Idea", PhD Thesis. Vrije Universiteit.

Gordijn, J. and Akkermans, H. (2001). "Designing And Evaluating E-Business Models", *IEEE Intelligent Systems and Their Applications*, 16(4), 11–17.

Gordijn, J., Osterwalder, A. and Pigneur, Y. (2005). "Comparing two Business Model Ontologies for Designing e-Business Models and Value Constellations." In: *18th Bled eConference*. Bled, Slovenia.

Gregor, S. (2006). "The Nature of Theory in Information Systems", *MIS Quarterly* 30(3), 611–642.

Hanelt, A., Piccinini, E., Gregory, R. W., Hildebrandt, B., Kolbe, L. M. (2015). "Digital Transformation of Primarily Physical Industries – Exploring the Impact of Digital Trends on Business Models of Automobile Manufacturers." In: *12th International Conference on Wirtschaftsinformatik*. Osnabrück, Germany, p 1313.

Hanelt, A., Hildebrandt, B. and Polier, J. (2015). "Uncovering the Role of Is in Business Model Innovation – a Taxonomy-Driven Aproach To Structure the Field." In: *23rd European Conference on Information Systems*. Muenster, Germany.

Herterich, M. M., Holler, M., Uebernickel, F. and Brenner, W. (2015). "Understanding the Business Value: Towards a Taxonomy of Industrial Use Scenarios enabled by Cyber-Physical Systems in the Equipment Manufacturing Industry." In: *International Conference on Information Resources Management*. p. 323.

Hevner, A. R., March, S. T., Park, J., Ram, S. (2004). "Design Science In Information Systems Research." *MIS Quarterly* 28(1), 75–105.

Hildebrandt, B., Hanelt, A., Firk, S., Kolbe, L., M. (2015). "Entering the Digital Era – The Impact of Digital Technology – related M & As on Business Model Innovations of Automobile OEMs." In: *36th International Conference on Information Systems*. Ft. Worth, Texas.

Hui, G. (2014). *How the Internet of Things Changes Business Models*, *HBR*. URL: https://hbr.org/2014/07/how-the-internet-of-things-changes-business-models (visited on: 07/09/ 2017).

Iansiti, M. and Levien, R. (2004). "Strategy as Ecology." *Harvard Business Review*.

Iivari, M. M., Ahokangas, P., Komi, M., Tihinen, M., Valtanen, K. (2016). "Toward Ecosystemic Business Models in the Context of Industrial Internet." *Journal of Business Models*, 4(2), 42-59.

Kim, B., Kang, M. and Jo, H. (2014). "Determinants of Postadoption Behaviors of Mobile Communications Applications: A Dual-Model Perspective." *International Journal of Human–Computer Interaction* 30(7), 547–559.

Kundisch, D. and John, T. (2012). "Business Model Representation Incorporating Real Options: An Extension Of E3-Value" In: *Proceedings of the Annual Hawaii International Conference on System*

Sciences. Hawaii, USA, pp. 4456–4465.

Latour, B. (1996). "On Actor-Network Theory: A Few Clarifications." *Soziale Welt*, 47(4), 369–381.

Law, J. (1992). "Notes on the Theory of the Actor-Network: Ordering, Strategy, and Heterogeneity" *Systems Practice*, 5(4), 379-393.

Lee, E. A. (2008). "Cyber Physical Systems: Design Challenge." In: *11th IEEE Int. Symp. on Object and Component-Oriented Real-Time Distributed Computing*. Orlando, USA, pp. 363-369.

McKinsey&Co. (2016). *Monetizing Car Data*.

Mikusz, M. (2014). "Towards An Understanding Of Cyber-Physical Systems As Industrial Software-Product-Service Systems.", In: *Product Services Systems and Value Creation. Proceedings of the 6th CIRP Conference on Industrial Product-Service Systems*, pp. 385–389.

Moore, G. E. (1965). "Cramming More Components onto Integrated Circuits." *Proceedings of the IEEE*, 86(1), 82–85.

Moore, J. F. (1996). "The Death of Competition: Leadership and Strategy in the Age of Business Ecosystems." *Leadership*, p. 297.

Nickerson, R. C., Varshney, U. and Muntermann, J. (2013). "A Method For Taxonomy Development And Its Application In Information Systems." *European Journal of Information Systems* 22(3), 336–359.

Oks, S. J., Fritzsche, A. and Möslein, K. M. (2017). "An Application Map for Industrial Cyber-Physical Systems." *Industrial Internet of Things, Springer Series in Wireless Technology* 62(2), 21–45.

Oliva, R. and Kallenberg, R. (2003). "Managing The Transition From Products To Services.", *International Journal of Service Industry Management* 14(2), 160–172.

Osterwalder, A. (2004). "The Business Model Ontology - A Proposition in a Design Science Approach.", PhD Thesis, University of Lausanne, Switzerland.

Pagani, M. (2013). "Digital Business Strategy and Value Creation: Framing the Dynamic Cycle of Control Points." *MIS Quarterly*, 37(2), 617–632.

Peffers, K., Tuunanen, T., Rothenberger, M., Chatterjee, S. (2007). "A Design Science Research Methodology for Information Systems Research." *Journal of Management Information Systems*, 24(3), 45–78.

Piccinini, E., Hanelt, A., Gregory, R. W., Kolbe, L. M. (2015). "Transforming Industrial Business : The Impact of Digital Transformation on Automotive Organizations." In: *36th International Conference on Information Systems*, Ft. Worth, Texas.

Prat, N., Comyn-Wattiau, I. and Akoka, J. (2015). "A Taxonomy of Evaluation Methods for Information Systems Artifacts." *Journal of Management Information Systems*, 32(3), 229–267.

Rajkumar, R., Lee, I., Sha, L., Stankovic, J. (2010). "Cyber-physical systems: The Next Computing Revolution." In: *47th Design Automation Conference (DAC)*, Anaheim, California pp. 731–736.

Reichwald, R. and Piller, F. (2009). *Interaktive Wertschöpfung: 2. Auflage, Interaktive Wertschöpfung*. Wiesbaden: Gabler.

Remane, G., Hanelt, R., Nickerson, R., C., Tesch, J., F., Kolbe, L., M. (2016). "A Taxonomy of Carsharing Business Models" In: *37th International Conference on Information Systems*, Dublin, Ireland.

El Sawy, O., and Pereira, F. (2013). *Business Modelling in the Dynamic Digital Space - An Ecosystem Approach.* Heidelberg: Springer Briefs Series in Digital Spaces

Shi, J. Wan, H., Hui Suo, H., Y. (2011). "A Survey Of Cyber-Physical Systems." In: *International Conference on Wireless Communications and Signal Processing, WCSP 2011*. Nanjing, China.

Storbacka, K., Pennie, F., Nenonen, S., Payne, A. (2015). "Designing Business Models for Value Co-Creation." *Review of Marketing Research*, *Special Issue – Toward a Better Understanding of the Role of Value in Markets and Marketing*, 9, 51–78.

Turber, S., Brocke, J., Gassman, O., Fleisch, E., (2014). "Designing Business Models in the Era of Internet." In: *DESRIST*, pp. 17–31.

Turber, S. and Smiela, C. (2014). "A Business Model Type for the Internet of Things." In: *22nd European Conference on Information Systems*, Tel Aviv, Israel.

Vargo, S. L. and Lusch, R., F. (2004). "A New Dominant Logic for Marketing." *Journal of Marketing*, 68(1), 1–17.

Vargo, S. L. and Lusch, R. F. (2008). "Service-dominant Logic: Continuing the Evolution." *Journal of the Academy of Marketing Science*, 36(1), 1–10.

Velamuri, V. K., Neyer, A., Moeslin, K. (2011). "Hybrid Value Creation: A Systematic Review Of An Evolving Research Area." *J Betriebswirtsch*, 61(1) 3–35.

Windahl, C. and Lakemond, N. (2006). "Developing Integrated Solutions: The Importance Of Relationships Within The Network." *Industrial Marketing Management*, 35(7), 806-818.

Wirtz, B. W., Pistoia, A., Ullrich, S., Goettel, V. (2015). "Business Models: Origin, Development and Future Research Perspectives." *Long Range Planning*, 49(0), 1-19.

Yoo, Y. (2010). "Computing in Everyday Life: A Call for Research on Experiential Computing." *MIS Quarterly*, 34(2), 213–231.

Zott, C. and Amit, R. (2013). "The Business Model: A Theoretically Anchored Robust Construct for Strategic Analysis." *Strategic Organization*, 11(4), 403–411.