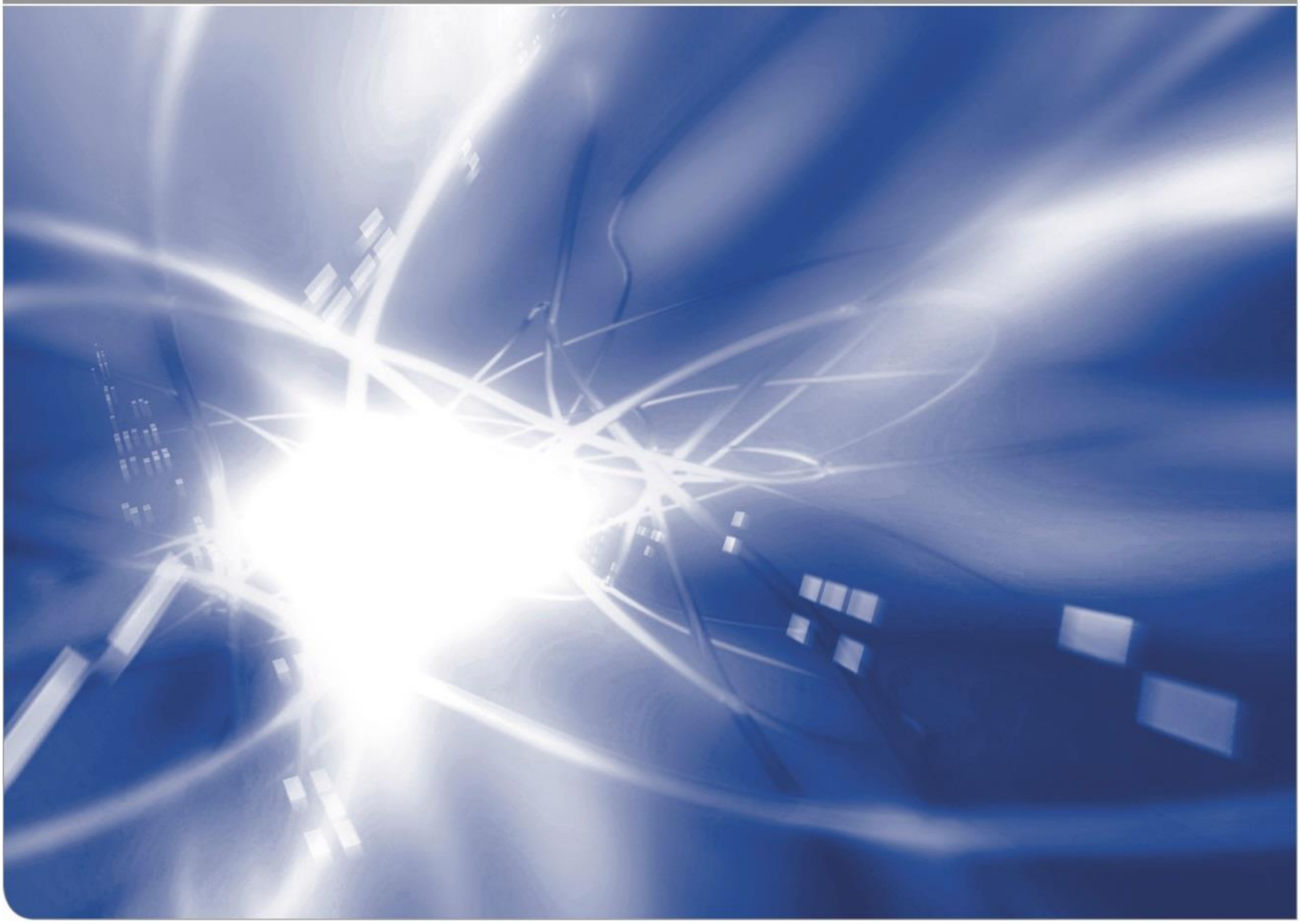
Karlsruhe Institute of Technology

Proceedings of the Second KSS Research Workshop

Karlsruhe | Germany | February 2016

Edited by Peter Hottum, Melanie Reuter-Oppermann, Margeret Hall, Maria Maleshkova, Patrick Jochem

KIT SCIENTIFIC WORKING PAPERS 69



Karlsruhe Service Research Institute (KSRI)

Kaiserstr. 89
D-76133 Karlsruhe, Germany
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Impressum

Karlsruher Institut für Technologie (KIT)
www.kit.edu

2017

ISSN: 2194-1629

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Preface

Since April 2008 KSRI fosters interdisciplinary research to support and advance progress in the service domain. As an industry-on-campus partnership between KIT, IBM and Bosch, KSRI brings together academia and industry thus serving as a European research hub on service science. In the past years, we have established a vivid speaker series and an enriching exchange with guest professors from leading global universities and practitioners with responsibilities for the services business of their respective companies. Our regular Service Summits and Summer Schools are a well-known place for collaboration and source of inspiration for our partners from the service science and service business communities.

With the Second Karlsruhe Service Summit Research Workshop KSRI provides a service innovation hub for researchers and practitioners in the fields of business engineering, economics, computer science, information systems, operations research, logistics and social sciences. With the help of reviewers, we selected valuable submissions and grouped them in the following four tracks.

1) Energy and Mobility Services: The energy sector continues to undergo substantial structural changes. Currently, the expanding usage of renewable energy sources (RES), the decentralization of energy supply and the market penetration of electric vehicles have a significant impact on the future development of services in energy and mobility. In the energy sector, for instance, the share of self-generated electricity in the overall electricity demand steadily increases. Consequently, utilities are transforming their business models from pure delivery of energy to tangible (energy) service providers. While services for the energy sector were traditionally considered technical affordances (e.g., ancillary services), the recent increase in “prosumption” shows that the need for a set of tangible, non-technical services in the energy retail market, taking consumer engagement into consideration, is no longer an issue of future services, but current reality. Moreover, the increasing volatility and uncertainty of power supply lead to a rising demand for flexibility, which cannot be provided by the conventional supply side alone.

2) Healthcare Services: Demographic changes cause higher patient demands alongside severe cost pressure and increasing quality requirements. Therefore, more efficient healthcare services and logistics are desirable. Even though underlying planning problems in the area of Operations Research resemble the ones from other service or manufacturing industries (e.g., scheduling of different tasks, processes or appointments) healthcare services are especially challenging, because patients need different care than, for example, parts of cars. In addition, particularly interdisciplinary approaches are necessary for research on and improvement of healthcare services. Since Information Systems have high potentials for improving efficiency, they also play an important role.

3) Participation & Crowd Services: Today, crowd-based and participatory approaches are playing an increasingly important role in tackling innovative endeavors. Thus, platforms in the areas of open innovation, crowdfunding, participatory budgeting, crowdsourcing

and idea markets are used by a broad set of organizations to facilitate innovation processes and enhance engagement. Governmental organizations involve citizens, companies their wider staff, others engage parties from outside of their organization in strategic, direction setting activities. The employed approaches contribute to the generation, conceptualization, evaluation, funding, implementation, and increased acceptance of related projects. However, there is a lack of interdisciplinary research for understanding cognitive and collaborative processes that underpin these platforms, design options for approaches and their appropriateness for different settings and goals.

4) Smart Services and Internet of Things: Market competitiveness as well as new technology developments raise the need for constantly reshaping and improving the organizational, controlling and manufacturing aspects of the lifecycle of products and services. Production industries are increasingly characterized by individualized customer needs shaping not only the final result but also the actual design, development, manufacturing and delivery process steps, as well as the associated business models. Furthermore, flexibility, customization and the need to be able to support real-time scenarios are crucial in order to be able to keep up to date with current developments. These requirements aim to be addressed by Industry 4.0 – a vision of tomorrow's manufacturing, where in intelligent factories, machines and products communicate with each other, cooperatively driving production. Key technological pillars for realizing Industry 4.0 are cyber-physical systems, the Internet of Things (IoT) and the Internet of Services, which together facilitate the vision of the Smart Factories.

In cooperation with the International Society of Service Innovation Professionals (ISSIP), we honoured outstanding research papers with the ISSIP Most Innovative Paper Award. Winner of the ISSIP Most Innovative Paper Award 2016 are Daniel Gartner and Rema Padman with their work on "Length of Stay Outlier Detection through Cluster Analysis: A Case Study in Pediatrics" (page 74).

Congratulations to the award winners as well as to the runner-ups Lars-Peter Lauven and Johannes Schmidt (Comparing flexibility options on the supply and demand side of the German electricity market – page 2), Stefan Zandera and Yingbing Huab (Utilizing Ontological Classification Systems and Reasoning for Cyber-Physical Systems – page 176) and Simon Kloker, Tobias Kranz, Tim Straub, and Christof Weinhardt (Shouldn't Collaboration be social? - Proposal of a social Real Time Delphi – page 140).

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Energy and Mobility Services

Comparing flexibility options on the supply and demand side of the German electricity market

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Abstract

In order to exploit flexibilities on energy markets in the most profitable way, providers or aggregators need suitable techno-economic models. In this paper, we illustrate the potential role of operation research on this field by investigating whether optimization models can help to understand, predict and improve the participation of actors offering flexibility options in the electricity markets. First investigations show that multiple ways to make use of flexibility potentials existist, which differ signficicantly in terms of revenue or saving potential and required effort. The implementation and operation of virtual power plants (VPPs) could therefore benefit from planning tools that help to speedily assess the most efficient choices from a portofolio of flexibility options.

1 Introduction

The increasing share of volatile electricity production in wind turbines and photovoltaic modules requires increasing flexibility both on the supply and demand side of the German electricity sector (Pecas Lopez et al., 2007). In principle, there are four different flexibility options on both the supply side (1-3) and the demand side (4) (BMWi, 2014; Connect, 2014; Siano, 2014):

1. Flexible conventional and renewable production;
2. Efficient and effective energy grids;
3. storage systems (e.g., pumped-storage);
4. Flexible demand from industry (e.g. shiftable industrial processes), commerce, households and electric vehicles (EVs).

On both sides, however, the unearthing of decentralized potentials is stalling most notably because of the substantial investment required for constructing infrastructure (e.g. smart meters, on the demand side or additional energy storages on the supply side), user acceptance problems, lack of incentives, and extensive regulatory requirements on energy markets (Geelen et al., 2013; Kim, 2011).

In particular, many business cases for demand side integration (DSI) – defined as the consumer's ability to alter his or her energy consumption pattern in response to time-dependent electricity prices or incentive payments (Strbac, 2008) – are hindered by extensive requirements concerning minimum order sizes on energy markets, security levels, contract or reaction time or market time frame (BMWi, 2014). Due to this reason, most energy end-users are aggregated by intermediaries or utilities to participate in DSI (Chiu et al., 2009). On the supply side, the latest renewal of the Renewable Energy Law (EEG, 2014) seeks to increase the number of biogas plants that react flexibly on changes in market prices. So far, however, the number of biogas plant operators that have taken advantage of the subsidies for such adaptations to their plants is relatively low (6.9% of the maximum eligible plant capacity of 1.35 GW have been realized until November 2015).

To overcome the regulatory hindrances, bundling and combined control of decentralized units in portfolios may help to overcome the above-mentioned difficulties and thus unearth the potential of flexibility options. Such portfolios are offered by service providers – known as curtailment service providers (CSPs), demand response providers (DRPs) or aggregators – whose business model is to manage and combine various demand-side and supply-side resources in the most profitable way. To illustrate the potential role of operations research in this field, we thus investigate whether optimization models can help to understand, predict and improve the participation of actors offering flexibility options in the electricity markets in this paper.

2 Flexibility options

Numerous flexibility options are available to guarantee the secure, cost-effective and environmentally friendly synchronization of electricity production and electricity consumption. Therefore, precedence can be given to selecting the most inexpensive option. In the following, two promising fields of applications on the energy supply and energy demand side are presented; commercial heavy duty electric transport vehicles operating in closed transport systems (ETVs) and biogas plants. Regarding the energy demand side, EVs seem to be good candidates for initial DSI applications, such as the vehicle-to-grid concept (Kempton and Tomić, 2005) or smart charging (Goebel, 2013), mainly because they remain idle for the greater part of the day and it is thus possible to utilize the corresponding load-shifting potential for DSI (see also: Gu et al., 2013). Due to the high requirements on most DSI energy markets (see Section 1), , commercial ETVs seem to be particularly suitable for a broad implementation of DSI; it is possible to pool the ETVs – each with a considerable battery storage capacity – on company grounds and act as a single entity on energy markets (Schmidt et al, 2014). The energetic potential of using ETVs as flexibility option is difficult to assess as, so far, only few ETV fleets are in use (e.g., in the port of Hamburg).Regarding the energy supply side, biogas plants are both a renewable energy source, abundantly available in Germany and capable of adapting electricity production flexibly. The flexibility potential of biogas plants in Germany is estimated to be very high, up to 20 GW positive and negative power (Krzikalla et al., 2013).

2.1 Flexible demand

In order to assess the potential of DSI for this application context, a research project (called BESIC) with a container terminal operator was initiated in 2012. Within the frame of the project, 10 of the terminal's 80 conventional diesel-powered automated guided vehicles (AGVs) have been substituted by battery-powered AGVs (B-AGVs). The main goal of the project is to assess how the charging flexibility of the B-AGV fleet can be optimally utilized for DSI (see also: Schmidt et al., 2015a). To apply DSI programs in practice, a simulation model was established which enables the fleet operator to forecast the state of charge of the batteries for approx. 40 hours. This is necessary because it must be ensured that the logistic processes of the terminal operator are not negatively affected by influencing the charging processes. So far, it was found that controlled charging based on variable prices for electricity seems to be the most promising option for the fleet operator, mostly because of significant cost-saving potentials identified and relatively simple feasibility (Schmidt et al., 2015b).

2.2 Flexible renewable production

In order to find a more market-based way that utilizes biogas plants' ability to react to fluctuating electricity production from other renewable energy sources, the most recent versions of the EEG in 2012 and 2014 encourage biogas plant operators to produce electricity when the spot market prices is highest. In Germany, the largest spot market volume is traded on the EPEX.

The two most visible instruments to achieve these aims are commonly referred to as market premium and flexibility premium. While the market premium is paid on top of EPEX revenues to encourage direct marketing of produced renewable electricity at the energy stock exchange, the flexibility premium is designed to give an incentive to biogas plant operators to compensate the fluctuating production from wind turbines and photovoltaic cells instead of contributing to basic load.

3 Materials and Methods

In the context of VPPs and DSI, two different kinds of optimization models can be applied. On the demand side, the cost of electricity purchases at the EEX can be minimized. On the supply side, notably for biogas plants, a maximization approach can be used to decide when to produce and sell electricity for the market. In this section, we illustrate both optimization approaches. While several models for either electricity demand or supply have been presented (e.g. Panžić 2013, Oskouei 2015), only few papers present combined approaches (e.g. Nosratabadi 2016). It must be noted that the applied optimization approaches are simplified as, for example, we do not consider grid costs, partial load, or the the potential problems of simultaneous ETV charging.

3.1 Cost minimization on the electricity demand side

Under current energy market conditions, the DSI programs *controlled charging based on variable electricity prices* can be realized by procuring the required power on the electricity spot market and shift the energy demand to the hours with the lowest prices. A precondition for the implementation of this DSI program is the availability of information regarding the energy demand and charging flexibility of the B-AGV for a certain period. The main goal of this DSI program is to optimize charging costs C_{TF} by shifting the charging times to fully charge a battery system to the M time slots in which the electricity spot market prices per time slot (i) are the lowest. For that, let I be the number of 15-minute time slots i in which a vehicle is connected to the grid, and thus a subset of the set T of 15-minute intervals t in the year as a whole. In the interest of constraining the charging processes to the hours with lowest prices for electricity procurement, we use the following function as a decision variable

$$x(i) = \begin{cases} 1\, for\ charging\ a\ battery\ in\ time\ slot\ \ i \\ 0\, for\ not\ charging\ a\ battery\ in\ time\ slot\ i. \end{cases} \tag{1}$$

Next, we calculate the hourly electricity demand $\mathrm{d_t}$ per time slot t of 15 minutes in which the battery is charged under consideration of the charging efficiency η and the charging power $W_{Charging}$ (in kW). Thus, we derive

$$d_t\big(x(i)\big) = \frac{W_{Charging}\,\frac{1}{4}h}{\eta}\,x(i). \tag{2}$$

The corresponding optimization problem for one time frame resolves to

$$\min_{x(i)} C_{TF} \sum_{i=1}^{I} p_{spot}(i) d_t x(i), \tag{3}$$

subject to

$$\sum_{i=1}^{I} x(i) = M \; \forall \; x(i) \in \{0,1\}; i \in \{1, \dots, I\}, \tag{4}$$

in which the first constraint states that each battery system must be fully charged at the end of each charging period as requested by the terminal operator.

Using driving profiles based on the simulation model developed, a cost-saving potential of up to 30% compared to the case of no DSI program application was calculated for the period of one year (annual charging costs uncontrolled charging: €129,164 / annual charging costs controlled charging €194,343).

3.2 Revenue maximization on the biogas-based electricity supply side

For the supply side, the optimization problem is framed by the regulations in the EEG of 2014. Whether biogas plants produce or use the time window in which operators can wait for higher electricity prices is therefore determined by a) the ratio of power generation capacity P_{inst} to biogas production capacity P_{biogas} and b) the remaining available biogas storage capacity at time m cap_m. Furthermore, we can assume that biogas plants will be operated to the full potential of their biogas production capacity over the year. Given that the plant produces at its full installed electrical capacity P_{inst} whenever it produces (which is not necessarily the case in reality), the biogas plant operator's revenue maximization problem can therefore be simplified to

$$max\left(\sum_{i}^{I}(p_i x_i P_{inst})\right), \tag{6}$$

s.t.

$$\frac{\sum_i^I x_i}{|I|} = \frac{P_{biogas}}{P_{inst}}, \tag{7}$$

$$|I|P_{biogas} - P_{inst}\sum_{i=0}^{I} x_i \leq cap_{max} - cap_{i=0} \tag{8}$$

4 Discussion and Conclusion

Existing enterprises like "Next Kraftwerke" offer services similar to those described in Section 2. Combined flexible supply and DSI has therefore proven to be possible already. The actual realization of such measures on a greater scale seems to be hindered by different factors on the supply versus the demand side. On the supply side, lack of monetary incentives is frequently cited as a reason for stagnation in the flexible power supply by biogas plants. On the demand side, regulatory hurdles make it difficult to motivate industrial electricity consumers to participate in demand side integration schemes. This is partly due to the fact that electricity consumers are usually primarily engaged in industries other than energy, and therefore face numerous constraints in their ability to reduce (or expand) their demand.

As shown in Section 3, the knowledge of day-ahead prices makes it possible to adapt flexible electricity consumption and electricity supply to market signals. As aggregators continuously control increasingly large numbers of supply and demand actors, constrained optimization may become a helpful means in the automatization of the operation of flexibility options. Furthermore, as actors in the electricity market already attempt to optimize their reaction to price signals, properly designed models can help to understand market participants' behavior. Identifying reasons for more or less enthusiastic behavior may help policy makers to improve regulations, and subsequently, market designs.

The overarching goal of developing a system of specific optimization models would therefore be to rank flexibility options and choose the best ones first in order to maximize the efficiency of responding to price signals. Aggregators, or any "virtual power plant" consisting of various supply-side and demand-side flexibility options, are thus enabled to determine an optimal reaction to price signals. It could therefore be attempted in the future to develop a comprehensive decision support system based on constrained optimization models that helps to choose the best flexibility option to react to market signals.

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Business Model Clustering: A network-based approach in the field of e-mobility services

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Abstract

Empirical insights about business models in the field of e-mobility services are of high importance to academia, industry and politics. As basic clustering algorithms do not deliver semantically valuable findings on business model structures based on obtained empiric data, this paper proposes a similarity measure-based network approach of clustering the latter. On the basis of graph, social network and similarity measure theory, an approach is designed which compares every business model instances of a data set with each other. The paper comes up with a matching score in order to determine whether two business models are connected contentwise within a cluster or not. The plotting of the resulting matching scores leads to a visually based determination of a meaningful matching score which bonds two business models together or not. The elaborations result in four e-mobility service clusters: Data-and-software-driven-, brokering-, transportation- and energy supply-based business models. Additionally, further findings on current opportunities in clustering business models and future solution proposals are described.

Keywords: Energy and Mobility Services, E-mobility, Business Models, Clustering

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1. Introduction

In the last decade, the importance of an exit from nuclear and fossil-fuel energy concepts as well as sustainable mobility has become obvious among science, industry and politics. One important aspect of this shift is *e-mobility*, holistically defined as "*a highly connective industry which focuses on serving mobility needs under the aspect of sustainability with a vehicle using a portable energy source and an electric drive that can vary in the degree of electrification.*"(Scheurenbrand et al., 2015, p. 25) Besides traditional research areas of e-mobility–like battery technology, ICT, manufacturing, etc.–innovative business models and complementary mobility services are important for the success and acceptance of electric vehicles (Stryja et al., 2015a; Hinz et al., 2015). A framework for capturing and describing business models for e-mobility services was presented in Stryja et al. (2015b) and continued in Kuehl et al. (2015). This framework (cf. figure 1) delivers a scientifically created and practically validated tool for registering the essences of business models. As a next step, we would like to identify clusters of empiric data from existing projects, who could submit their business model via the web platform `e-mobility-atlas.de`. These clusters may support interested parties to find "types" of typical e-mobility service business models and identify gaps as well. This may be of help to researchers, who struggle with e-mobility services because of their high heterogeneity. It also delivers results for practitioners to see in which combination existing concepts occur–and what might be missing. A first attempt to cluster business models on the basis of a k-Means clustering algorithm was presented in Kuehl et al. (2015). One outcome was that when applying commonly used clustering algorithms the outcomes are not semantically meaningful. This may have the following reasons: As (Beyer et al., 1999, p.217) concludes: "[A]s dimensionality increases, the distance to the nearest data point approaches the distance to the farthest data point"–so typically-used distance measures are not meaningful anymore. Additionally, most clustering algorithms will assign all observations to a cluster–even outliers. One way to eliminate these outliers is outlier detection (cf. Aggarwal and Yu (2001)), but it would remove actual observations from the (already small) data set which are no errors. Also, the high number of features (characteristics of business models) makes the clustering more complex. In order to face this challenge a feature reduction is possible, but it only improved the meaningfulness of the clusters fractionally (as shown in Kuehl et al. (2015)). To continue with our research, the paper at

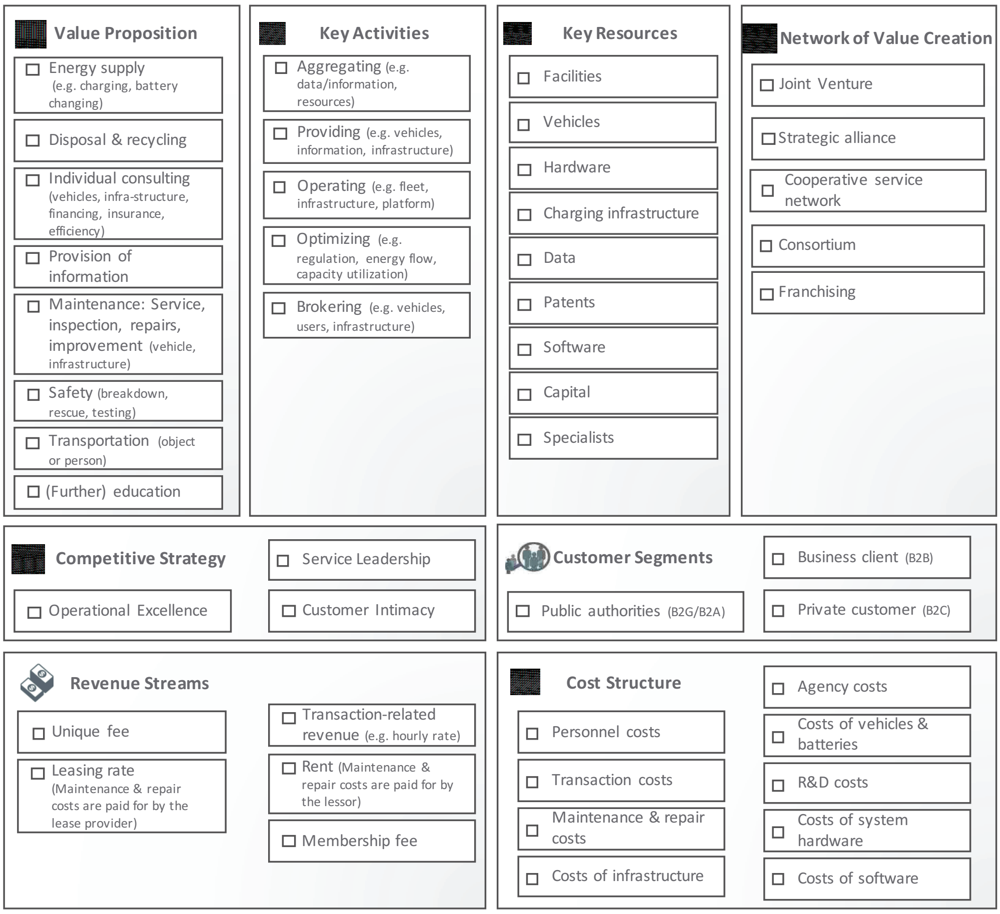

Figure 1: E-mobility specific service business model framework

hand aims at answering the following three research questions:

1. Which clusters are identified by applying a similarity network approach?
2. How do these results compare to a baseline of clusters from previous research?
3. What are relevant insights of e-mobility service business models for politics, academia and industry?

Its contribution is threefold: At first, we acquired a larger data set (n=40) of business model instances than in Kuehl et al. (2015). Secondly, we explain, apply and interpret a different approach of clustering and thirdly we are able to deliver new empiric insights of e-mobility service business models.

2. Methodology

As mentioned before, most commonly used algorithms for clustering have several restrictions in providing meaningful clusters for our problem. As meaningful and interpretable results are the key factor for our research, we need approaches which are customized to our specific needs. As a prerequisite we set the following definitions: The observations are called *Business Model Instances (BMIs)*, the attributes are called *characteristics*. Both dimensions are indexed as shown in figure 2. The indexing is based on the concept of

$$
\begin{array}{ll}
C = \{c_1; c_2; \dots c_j \dots; c_p\}, & \triangleright \text{ Business Model characteristics} \\
j \in J = \{1, \dots, p\} & \\
B = \{b_1; b_2; \dots b_i \dots; b_n\} & \triangleright \text{ Business Model Instances} \\
i \in I = \{1, \dots, n\} & \\
x_{ij} \in X : I \times J \to \{0; 1\} & \triangleright \text{ Occurrence (0 or 1)}
\end{array}
$$

Figure 2: Prerequisites

Boolean matrix entries which are used in this work to present a bipartite network, also called "two-mode network" (Salton et al., 1983, 1975; Opsahl, 2013). For instance, the survey participants of the first BMI can characterize it along the dimensions $(x_{11} \dots x_{1p})$. This means that $x_{11} \dots x_{1p}$ can either take values of 1 or 0. Thus, all of the n business models can be represented through a Boolean vector. This transformation helps to make the business models comparable.

This paper proposes an approach of clustering business models within a similarity measure-based node network. It combines two classic approaches which are often applied in literature: The concepts of *similarity measures* and the concept of *structuring relations within node networks.*

2.1. The concept of similarity measures

In order to compare the BMIs, this paper uses similarity measures (Choi et al., 2010). A binary similarity measure based on the Jaccard coefficient is used to say “how similar” the compared business models are (Choi et al., 2010; Cheetham and Hazel, 1969). If the business model instances Y and Z are compared, the similarity score between them is calculated as follows:

$$\text{Matching Score}(Y, Z) = \frac{\sum_{d \in D} \frac{|Y_d \cap Z_d|}{|Y_d \cup Z_d|}}{|D|}$$

The Jaccard value as a binary measure for similarity (Choi et al., 2010; Cheetham and Hazel, 1969) is calculated within each characterizing category of the vectors Y and Z of the business models and then normalized along the number of categories. This measure is called ”Matching Score” in this paper. D is the set of all high level categories of characteristics while d is one category within D. As shown in figure 1, d could examplarily be ”Key Activities”, and thus, the characteristics would be ”Aggregating”, ”Providing” etc.

In order to get an understanding of how each of the business models can be compared to the others and to find out the best-matches (the most similar business models) and the worst-matches (the most distinct business models), every business model vector has to be compared to all other business model vectors and the particular matching scores have to be calculated. If n is equal to the number of observed BMIs, this means that $\frac{n*(n-1)}{2}$ matching scores are calculated. We conduct this approach in order to find out how the similarity measures within the business model context behave and what a meaningful matching score which acts as a threshold should look like to speak of two business models being similar (Cha et al., 2005). In the following we speak of two BMIs being similar or related if their matching score is higher than or equal to the “meaningful matching score”. The meaningful matching score can be inferred by plotting the down-ranked matching scores within a figure and visually analyzing the curve. In this paper the meaningful matching score (=threshold) is set at the point bewteen disjunctive and non-disjunctive clusters. This matter-of-fact is explained in detail within the results section.

2.2. The concept of structuring relations within node networks

In order to apply distinct metrics to calculate valid business model clusters, this approach focuses on representing BMIs as nodes within a network. This approach originates from the research field of computer sciences to structure and view complex data sets and to retrieve new information out of it (Bondy and Murty, 1976; West et al., 2001). Nowadays, a vast modern research stream, called *social network analysis*, uses the network modeling approach to infer information about network structures like clusters and its participants (Scott, 2012; Hanneman et al., 2001). We try to apply the methods and tools of network analysis on our business model case: On the basis of the "meaningful matching score" which is illustrated within the results section, it can be inferred whether two nodes are connected or not: Only if two business models reach above the meaningful matching score, a non-directed relation is established between the particular nodes. One of the most-used metrics which can be derived from a network like this is the "degree" of a node which tells with how many other nodes the particular node is connected to (Bollobás, 1998). In the following we use the node degree to identify the most prominent nodes of the network and use them as the representatives of distinct clusters of the network (Scott, 2012; Kempe et al., 2003). This approach is based upon the so-called principle of "one-mode projection" which is highly prominent in Network Analysis literature (Zweig and Kaufmann, 2011). The tool to visualize the resulting business model networks which serves as the basis for the further analysis is called *NodeXL* and has been developed by scholars from the United States in cooperation with Microsoft Research (Smith et al., 2009).

2.3. The similarity network methodology at one sight

Summarizing the above explained methodology leads to the following structured order:

1. Indexing: Representing business models within a Boolean vector
2. Calculation of the matching score for every business model pair
3. Visual identification of the "meaningful matching score"
4. Representation of the business models within a node network according to the distinct matching scores
5. Calculation of the node degree in order to identify clusters and their particular representatives

3. Results

The methodology from the previous chapter is now applied on the data set. The data set consists of 40 invited e-mobility projects, which were chosen for

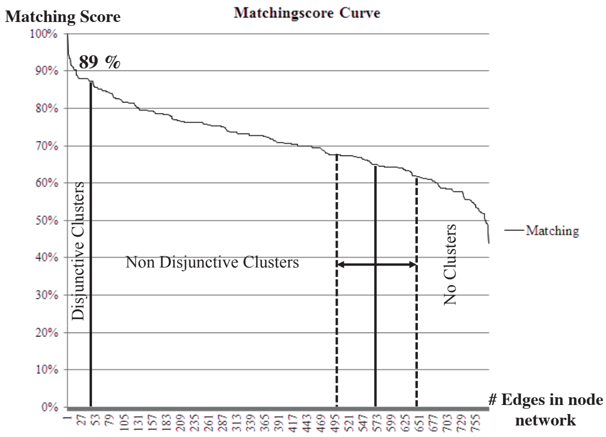

Figure 3: Matching score curve

their diversity and their service focus to submit their business model through an online tool (`e-mobility-atlas.de`).

3.1. The Matching Score Curve

As n equals 40, $\frac{40*(39)}{2} = 780$ comparisons are conducted, the particular matching scores are calculated and ordered decreasingly. Figure 3 shows the resulting matching score curve. The number of comparisons can be interpreted as the number of edges in a resulting node network consisting of BMIs. As figure 3 depicts, three areas of distinct cluster types can be derived from the analysis: A disjunctive clustering area, a non-disjunctive clustering area and an area of no clusters. The iterative visualization of the node network with a changing number of nodes according to the matching score shows that below a value of 89 percent in this data set no more disjunctive clusters can be found by performing the methodology proposed in section 2. Below a value of 89 percent all nodes of the network are connected to one big component (cf. figure 5).

Therefore, this part is called non-disjunctive clustering area. Identifying the lower boundary below no more clusters (disjunctive and non-disjunctive) can be found will be a future research focus, but is not of interest for this paper as the focus is put upon finding disjunctive clusters. Therefore, only business model pairs which reach above a "meaningful matching score" of 89 percent are considered.

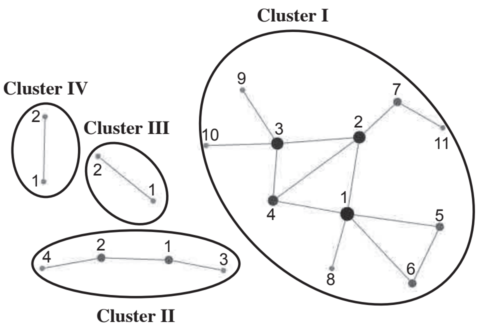

Figure 4: Disjunctive e-mobility clusters based on the chosen approach

3.2. Resulting Clusters

From the data set of 40 business models four disjunctive clusters of 19 BMIs can be found. Figure 4 illustrates the node network. The node size depends on the particular node degree. The higher the degree, the bigger the node. The nodes in each cluster are numbered and matched to the particular business model characteristics which are depicted in the appendix in table 1. The business model node with the highest node degree can be seen as a representative for the cluster. The four e-mobility business model clusters which are found in this paper can be named as following:

- Cluster I: Data-and-software-driven services
- Cluster II: Brokering vehicles or specialists
- Cluster III: Energy services
- Cluster IV: Transportation services

3.3. Non-Disjunctive Clusters

As elaborated above, we only analyze disjunctive clusters in this paper. Nonetheless, a short wrap-up of the non-disjunctive clustering problem shall be given. As figure 5 shows, below a value of 89 percent all nodes within the network are connected to one component and with a decreasing matching score the number of edges within the resulting business model networks is rapidly increasing. When the matching score reaches a value of 44 percent, all nodes are connected with each other. Due to reasons of visualization the

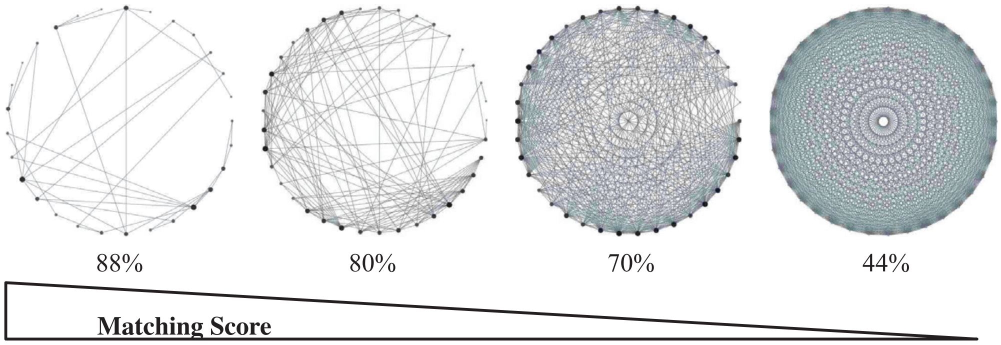

Figure 5: Business model networks in dependence of distinct matching scores

networks are depicted as circles. This makes it easier to see how the network changes with a decreasing matching score. This consequently means that the setting of the matching score requirement in the non-disjunctive clustering area has got huge impact on the clustering results. Thus, it could be of further scholarly interest to develop ways of appropriately setting the matching score and clustering in the non-disjunctive clustering area. This could lead to more clusters than only studying the disjunctive clustering area and consequently reveal further insights concerning business model research.

3.4. Comparison to baseline

As a baseline we use the clustering approach from Kuehl et al. (2015) with the larger data set (n=40) with a minimum number of desired BMIs per cluster of 4 ($k_{min} = 4$) and a minimum number of characteristics per cluster of 3 ($g = 3$). The approach results in two clusters, which are almost identical to the results from the smaller data set:

- Cluster I: In this cluster we identify four different BMIs and corresponding projects after five iterations, all of them therefore sharing at least five commonalities. Their value proposition is the *Provision of information*, the key resources are *Data* and *Software*, and the key activities are *Providing* and *Aggregating*.
- Cluster II: In this cluster we identify five different BMIs and corresponding projects after three iterations, all of them sharing at least

three commonalities. Their key activity is *Operating*, their value proposition is *Transportation* and their key resources are *Vehicles*.

The main structural difference between the two approaches is the following: The frequences-algorithm (Kuehl et al., 2015) faces the prerequisite of the characteristics being disjunctive while the similarity measure-based approach is working on the basis of disjunctive BMIs. The results shown in table 1 from the approach presented in this paper find two more clusters than the baseline and also assign almost twice as many BMIs over all clusters. Moreover, cluster 1 in the baseline is a proper subset of cluster I presented in this paper in table 1 and the second cluster in the baseline is a subset of cluster IV in this paper. So even though two elementary different approaches were chosen, both methods come to similar results, which shows that there is no contradiction, but that these results support each others hypothesis. The approach at hand in this paper is more detailed, so depending on the interest of the researcher, (s)he may choose between an easy approach with restrictive input parameters or a more complex approach with more sophisticated clusters.

4. Conclusion and Outlook

This paper proposes an approach for clustering business models within an e-mobility service context. Summarizing the steps which have been taken to achieve this goal, the following can be stated: On the basis of treating business models as Boolean vectors which describe the characteristics of distinct business model instances (BMIs) and make them comparable, a pairwise comparison grounded on network, graph and similarity measure theory is conducted. This approach leads to four clusters of e-mobility services: Data-and-software-driven services, brokering vehicles or specialists, energy services and transportation services. The fundamental insights which are gained during the taking of the methodological steps are that disjunctive and non disjunctive clustering areas exist within the network-based approach. These areas have to be treated in different ways whilst this paper concentrates on elaborating the former. Concerning a wider matter of interest, this work delivers politically and economically relevant insights into the structure of current efforts of deploying e-mobility within a socially accepted and profit gathering manner. It is indisputably clear that in the e-mobility projects which are analyzed in this paper the main focus is put upon leveraging data, software and specialists in order to transfer the idea of e-mobility to common sense. Additionally, services concerning the e-mobility-based transportation and energy supply are in focus of current national study efforts in a business model context. These clusters should be taken as a starting point for both, further studies in this field and for business people for entering the so-called "white spots" which are not displayed in the current e-mobility service spectrum.

As limiting aspects of this work several points have to be adressed. The first restrictive point is that the Jaccard coefficient, which is part of the matching score formula, overestimates the non-selected (=0 or false) characteristics within the business model vectors because there are more characteristics which are not "fulfilled" in the particular business models than characteristics being applied in the business model. This is the reason for 44 percent being the matching score which connects every node with each other (cf. figure 5). It could be of future scholarly use to adjust the existing and study other kinds of matching score calculations and compare the results to the findings in this paper. As this phenomenon occurs in each BMI vector comparison, the results of this approach are nonetheless valuable. Concerning alternative similarity measures, the similiarity measure presented by Sohn (2001) could be an interesting starting point for further research, for example. Furthermore, dealing with disjunctive networks and the setting of a lower boundary (below it no more clusters are found) should be in the focus of further research in this field in order to eliminate the above named inaccuracy and to broaden the spectrum of identifiable business model clusters. At the moment, the node degree is the only graph theoretical network measure which is in focus of the elaborations. In future works it could be enlarged by adding further measures like network centrality measures and distinct clustering coefficients for networks.

At the moment the data set which was retrieved by the project DELFIN consists of 40 projects dealing with e-mobility business models. This number of analyzable projects will be increased in near future and offer the opportunity to apply the above mentioned prospective proposals in order to substantiate the findings of this paper and to receive new results concerning the fields of business model clustering and e-mobility services.

Acknowledgements

This paper has been written in the context of the research project *DELFIN*. The project is funded by the German Federal Ministry of Education and Research (BMBF) under the promotion sign 01FE13002. We also thank the project management agency German Aerospace Center (PT-DLR) for the project support.

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Appendix

Cluster	BMI	Node Degree	Value Proposition	Key Activities	Key Resources
I	1	5	Provision of information	Aggregating	Data
	2	4	Provision of information	Aggregating, operating	Data, software
	3	4	Individual consulting, provision of information	Aggregating, providing, operating	Data, software
	4	3	Provision of information	Aggregating, providing	Data, software
	5	2	(Further) Education	Aggregating	Data, specialists
	6	2	(Further) Education, provision of information, safety	Aggregating	Data
	7	2	Provision of information	Operating	Software
	8	1	Provision of information	Brokering	Data
	9	1	Individual consulting, provision of information, transportation	Aggregating, providing, operating	Data, vehicles, charging infrastructure, software
	10	1	Individual consulting, provision of information	Aggregating, providing, operating, optimizing	Data, software
	11	1	Transportation	Operating	Software
II	1	2	Transportation	Brokering	Vehicles
	2	2	(Further) Education	Brokering	Specialists
	3	1	Transportation	Providing, brokering	Vehicles
	4	1	Safety	Brokering	Specialists
III	1	1	Energy supply, provision of information	Operating, brokering	Data, software
	2	1	Energy supply, provision of information	Operating, brokering	Supplying customers, software
IV	1	1	Transportation	Providing, Operating	Vehicles
	2	1	Transportation	Providing, Operating	Vehicles

Table 1: Overview of the resulting disjunctive business model clusters and their characteristics (BMI enumeration can be compared with figure 4)

Choice design as key to technology adoption
- A research agenda in the domain of electric cars -

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Abstract

Whether an innovation is adopted or rejected by a consumer depends not only on technological, economic or social factors but also on psychological attributes of the decision maker (Kleijnen et al., 2009). Furthermore, according to studies from the domain of behavioral economics, there is evidence that the design of the decision situation itself has a significant impact on the final decision as well (Thaler et al., 2013). The goal of the research proposed in this paper is to apply insights from innovation resistance theory and behavioral economics to the case of technology adoption, that is (1) to consider psychological aspects in the design of technology adoption settings and (2) to evaluate the effect such consciously designed choices have on real adoption decisions. As part of the study, several experiments will be conducted to test the influence of different choice designs on the perception and adoption of electric vehicles and to identify potential strategies for the design of decision settings that are supportive to their adoption.

Keywords: choice architecture, experimental studies, nudging, innovation resistance, sustainable technology

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Preprint submitted to Elsevier *January 27, 2016*

1. Motivation

Electric cars are important means to mitigate climate change problems, increasing global resource shortages and reduce pollution especially in urban areas (Jochem et al. (2015), Kley et al. (2011)). In 2010, the German government announced the target of reaching one million electric cars in 2020 in Germany (Abdelkafi et al., 2013). The establishment of electric cars is of particular interest for several interest groups. First, general public whose health and life quality could be enhanced by reduced noise and air pollution in growing urban areas. The European Union captured the goal of reduced air pollution in their climate targets for 2030 (Jochem et al., 2015). To meet the targets, Germany has to reduce GHG (green house gas) emissions of passenger cars by 60 % between 1990 and 2050 which can hardly be achieved without the use of electric cars (EC (European Commission) (2011), Jochem et al. (2015)). Besides social and environmental consequences, lagging behind at electric car diffusion could undermine Germany's position as one of the most influential automotive industry nations in the world and thus lead to losing industrial power (Handelsblatt, 2016). Due to contradicting interests of reaching short-term profit targets with traditional gasoline cars Germany's car manufacturers and suppliers are trapped in striving to maintain the status quo (Sorge, 2014) while in the meantime international car manufacturers and new players from the IT sector establish their global production facilities (Geiger, 2015). As a result, the global rise of electric cars may lead to dramatic shifts in industrial power structures and drives risk for national automakers and suppliers to face the threat of falling back because of missing innovative alternatives for their core businesses (Schipper, 2015). The more it is important to get consumers interested and demand the technology to provide an intrinsic motivation for automakers to invest in the technology of electric cars.

The remainder of the paper proceeds as follows: Section 2 provides related work from relevant domains. Section 3 introduces the research problem and the hypothesis of the study. Section 4 explains the underlying research questions and methodology. Section 5 completes the paper with a conclusion and discussion of the topic.

2. Related Work

The question of what determines the adoption of an innovation has a long history in research (Venkatesh et al., 2007). Also the adoption of electric cars in particular and considerations how it could be enhanced and predicted has been subject of many scientific and corporate research studies since the early 80s of the last century (e.g. Calfee (1985), Beggs et al. (1981)). Since then a lot of research has been done to understand which premises have to be fulfilled that individuals use or buy electric cars and how fast markets would develop as a consequence. The following section gives a short insight into the state of knowledge relevant for the planned research.

2.1. Adoption of electric cars

The majority of research on this topic bases its results on empirical findings made in surveys or interviews (Rezvani et al., 2015). Most of these studies focus on the identification of adoption factors and barriers in order to derive strategies how these requirements could be addressed best (e.g. Fazel (2013), Egbue and Long (2012), Lane and Potter (2007)). According to Rezvani et al. (2015) there are four groups of adoption factors identified in existing literature: (1) technical factors, (2) contextual factors, (3) cost factors and (4) individual and social factors. **Technical factors** are all issues concerning the vehicle like e.g. its driving range, emissions and environmental impacts, performance, safety but also its ease of use (e.g Moons and De Pelsmacker (2012), Lane and Potter (2007)).**Contextual factors** comprise all external (governmental, industrial) aspects whose availability is relevant for the willingness to purchase and use electric cars, that is e.g. the availability of (public) charging infrastructure, governmental incentives like tax reliefs or buyers premium (e.g. Egbue and Long (2012), Lane and Potter (2007)). In Germany, governmental incentives like a buyers premium are still hypothetical means and their actual effects thus remain unclear. Several studies try to analyze and predict the (long-term) effects of fiscal incentive mechanisms (e.g. Lieven (2015), Sierzchula et al. (2014), Shepherd et al. (2012)). Fiscal incentives are not planned to be part of this research as the study focus lies on the question of how the setting of the (experimental) adoption decision should be designed and what effect is caused hereby and not how governmental incentives itself should be designed to be most effective. That is why theory on this topic is not elaborated in further detail in this paper. In

Rezvani et al. (2015) purchase cost, running cost and (saving) fuel cost are considered as **cost factors** (based on e.g. Schuitema et al. (2013), Egbue and Long (2012), Lane and Potter (2007)). Aspects concerning the adopting person and societal influencers as a whole are considered in the fourth group as **individual and social factors**. Studies on these aspects are of particular interest for this study since they comprise valuable investigations on the personality of early electric car adopter or the role of emotions and psychological barriers for the adoption of electric cars (e.g. Steinhilber et al. (2013), Moons and De Pelsmacker (2012), Franke et al. (2012)). Furthermore, several of these works already use established adoption models like the Theory of planned behavior (TPB) (Fazel (2013), Moons and De Pelsmacker (2012), Egbue and Long (2012), Lane and Potter (2007)) or theoretical constructs from economic decision theory like the Rational choice theory (Lane and Potter, 2007) as theoretical foundation. Most promising studies for this research are (Franke et al., 2012) and (Moons and De Pelsmacker, 2012). In their study, Franke et al. (2012) focus on driving range as major psychological barrier for the acceptance of electric cars. Based on an empirical study they examine the individual perception of a comfortable driving range and its antecedents (e.g. personality traits, coping skills). In contrast, Moons and De Pelsmacker (2012) integrate emotions towards car driving and electric cars into the Theory of Planned Behavior (TPB). Theoretical contribution is the investigation of emotions in the usage intention decision process of new and more sustainable consumer products and differences in motivations to use these new products. Result is that emotions and attitude are the strongest predictors of usage intention, followed by subjective norm. Reflective emotions towards car driving and perceived behavioural control factors are also important antecedents.

2.2. Innovation resistance theory

As innovations, new technologies usually impose some form of change for the consumer (Kleijnen et al. (2009), Bagozzi and Lee (1999), Ram (1987), Sheth (1981)). However, *"the typical human tendency is to strive for consistency and status quo rather than to continuously search for, and embrace new behaviors"* (Sheth (1981), p.275). Because of this tendency, consumers usually seek for psychological equilibrium (Osgood and Tannenbaum, 1955) and anything which endangers the status quo is likely to evoke initial resistance (Ram and Sheth (1989), Rogers (1976)). The stronger the habit which is challenged by the innovation, the stronger the resistance of the consumer (Sheth, 1981). As such, resistance is a natural part of the adoption process: only when the initial resistance of the consumer has been overcome, adoption takes place (Sheth, 1981). However, according to Rogers (1976), traditional innovation and adoption research suffers from a so-called "pro-change bias", i.e. assumes customers to be always open to change and eager to instantly use innovations. The theory of innovation resistance strives to close this gap by studying antecedents and barriers to the adoption of innovations with the goal of being able to understand the psychological processes behind consumer resistance (Kleijnen et al. (2009), Bagozzi and Lee (1999)). So far, there is evidence to suggest that resistance is a product of internal processes and external innovation-related barriers. Internal processes comprise the individual inclination to resist changes, i.e. the attitude towards change in general (Heidenreich and Handrich (2014), Kleijnen et al. (2009)) and the inherent human tendency to maintain the status quo, i.e. to misperceive expected changes due to loss aversion (Kahneman and Tversky, 1979). Innovation-related barriers comprise functional concerns about usage, value and risk issues while psychological barriers reflect concerns regarding the image of the innovation and its compliance with existing traditions of the consumer (Ram and Sheth, 1989). An understanding of the decision making of technology adoption therefore requires an understanding of the resistance provoked by the technology.

2.3. Choice architecture

The theory of choice architecture states that the way a choice is presented to the decision maker already influences the decision he takes (Johnson et al., 2012). Initially introduced by Leonard (2008) the term "choice architecture", also labelled as "nudging", has gained increasing and controversial interest in science and public (Selinger and Whyte, 2011). The concept of libertarian paternalism understands humans as mostly irrational decision makers who often vote for options which are, rationally considered, not the best choice for them. To help them to make better decisions, choices are designed in a way that decision makers are more likely to vote for options they would also chose when deciding on a completely rational basis (Thaler et al. (2013), Goldstein et al. (2008)). Especially in the context of environmental consciousness and sustainable behavior, choice architecture has been established as promising tool to affect irrational decision making (Mont et al. (2014), Bothos et al. (2014)).

3. Research Problem

According to Steinhilber et al. (2013) the transition to low carbon transport requires a "new notion of mobility" (p.532) and thus challenges long established mobility routines and habits. This inevitably provokes consumer resistance. A widespread market success of electric cars is still absent although electric cars are in general honored by consumers (Bühler et al., 2014). Empirical studies identify three main concerns regarding the adoption of electric cars that explain the gap: these are (1) perceived limited range, (2) high costs and (3) limited charging infrastructure (Steinhilber et al. (2013),Egbue and Long (2012)). While high initial costs are still an actual problem for widespread electric car adoption, major barriers like perceived range anxiety and the associated fear of limited public charging infrastructure has been proven to be mainly a psychological concern (Franke et al., 2012). As a result, even in rental and carsharing settings where usage costs are almost equal compared to costs for using traditional gasoline cars consumers tend to back off from chosing electric cars in anticipation of perceived limitations in driving experience even if their desired driving range would be fully covered by the range of the car (Holzer, 2015). The resulting research problem can be formulated as followed:

> **Research Problem:**
> *The transition to electric cars leads to a significant change in mobility behaviour and thus provokes consumer resistance. One of the major barriers for electric car usage is their perception. Electric cars are perceived to fall short of consumer expectations in regard of range and convenience. Even in settings where costs correspond with gasoline cars it can be observed that customers back off from chosing electric cars due to range anxiety.*

A significant part of consumer resistance against electric cars is based on perceptual misconceptions. Electric cars are perceived as inferior choices in comparison to traditional gasoline and diesel drive cars. This perception changes with the usage of electric cars. As soon as consumers actually drive and experience electric cars, their perception of range anxiety changes significantly towards a positive attitude (Bühler et al., 2014). This leads to the conclusion that in specific settings electric car adoption could be enhanced by supporting consumers to overcome their so far irrationally biased perception of electric cars.The resulting hypothesis for the study can then be formulated as followed:

> **Working Hypothesis:**
> *Electric car adoption can be enhanced by supporting consumers to overcome their biased perception of electric cars . Due to the nature of human decision making and based on insights from choice architecture theory it is assumed that such support can be realized through a conscious design of the adoption setting. Supportive electric car choice design may thus have a positive impact on the selection of electric cars over conventional car alternatives which will in turn enhance adoption probability.*

The adoption of electric cars has not been studied from the perspective of behavioral theory and economics so far and therefore lacks a deeper understanding of and ways to address psychological factors in adoption decisions. This study aims to bridge this gap.

4. Research Approach

In order to understand and control influencing variables in electric car adoption decisions, experimental studies are chosen because of their explanatory strength: nonexperimental research techniques such as interviews, case studies or surveys are "limited to statements about description and correlation" while "experiments permit statements about causation" (Kantowitz et al. (2005), p.52). During the experiments, individual choice behavior will be observed, e.g. by the use of eye tracking. An important part in experimental decision studies is the measurement of emotion since human decisions are strongly influenced by emotions (Coricelli et al., 2007). To understand and shape consumer perception, it is necessary to also measure cognitive and emotional arousals during the experimental selection process. According to Myers (2004), emotions manifest in behavior but also in psychophysiological data collected by biosensor technology. In this research it is planned to use biosensor technology like electrocardiograms and electrodermal measurement in order to identify and understand unconscious and emotional factors such as anxiety, stress, effort or arousal in the adoption process. Based on this knowledge, choices can be designed in a way that e.g. negative emotions are better compensated and perceived biases towards the technology of electric cars can be alleviated.

5. Conclusion and Research Contribution

The research proposed in this paper aims to consider psychological aspects and insights from innovation resistance theory and behavioral economics in the design of technology adoption choices. This will be achieved by conducting experimental lab studies to test the influence of different choice designs on the perception and adoption of electric cars. The intended research contributes in several aspects to the body of knowledge. First, the study of experimental decision making allows a deeper and more realistic understanding of how technology adoption decisions are made by individuals. So far, theoretical contributions to this area are mainly built upon empirical studies which assess the intention or willingness to adopt a technology (in case of electric cars: e.g. Fazel (2013), Moons and De Pelsmacker (2012), Egbue and Long (2012)). Moons and De Pelsmacker (2012) themselves state the so-called "intention-behavior linkage" as main limitation of their work and emphasize that *"behavioural intentions do not evidently translate into objectively measured buying behaviour"* (p.220). Besides the intention shortcoming, one of the main weaknesses of existing technology adoption models such as TAM are the limited consideration of emotions (Bagozzi, 2007). The proposed research will address both issues by providing behavioral observations of actual adoption decisions and measurements of occurring emotions in this context and thus contributes to the theory of technology adoption in multiple areas of interest. The second contribution will be made by studying the role of emotions and resistance behaviour during the experience of applied choice architecture ("nudging") which has been considered little in existing studies on this topic so far (Bothos et al., 2014). Insights on this issue may offer valuable starting points for further studies in innovation resistance theory, adoption of electric car research and applied behavioral economics.

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Efficient use of Renewable Energy with Storage and E-Mobility Service

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Abstract

We consider a stochastic and dynamic decision problem of an innovative private household acting as a "prosumer" in the energy market. The household is equipped with a renewable energy source, with a stationary energy storage device and with an electric vehicle. Its goal is maximization of profits from both trading energy and offering a car sharing service to customers. We formulate the problem as a Markov Decision Process and propose two policies for solving the problem. The policies are evaluated in terms of their performance.

Keywords: Energy and Mobility Services, Energy Storage, Plug-In Electric Vehicles, Stochastic Optimization

1. Introduction

The recent technological progress in the areas of energy storage (Blonbou, 2013) and electric vehicles (Manzetti and Mariasiu, 2015) enables new ways of utilizing renewable energy. Hence, both companies and private households that generate renewable energy do face new opportunities of turning this energy into profits. To ensure high profits, operators of renewable energy generating units need to constantly make the right decisions about energy use. In many cases, however, making economically efficient decisions about the use of currently generated renewable energy is a major challenge. Algorithmic decision support is needed in order to address this challenge.

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In this work, we propose and compare two approaches to algorithmic decision support for an innovative private household with a source of renewable energy, battery storage and a plug-in electric vehicle. The household acts as a "prosumer", i.e., energy market access is granted and the generated energy may be used to satisfy the household's own demand. Moreover, the household provides a mobility service in terms of sharing its electric vehicle. If the vehicle is available at the charging station it may be rented by a customer for a per distance fee. As the households goal is to operate its energy system with maximum profit, and as each of generated amount of energy, load, energy market price and transportation demand is subject to stochastic variations over time, the system operator needs to repeatedly adapt its decisions about energy flows. At each point in time, decisions are made about how much energy to transfer between renewable source, storage device, vehicle battery and electricity grid while satisfying the household's energy demand.

Within the past few years an increasing discussion about innovative business models with electric vehicles can be observed (e.g. Budde Christensen et al., 2012). In this context electric vehicle sharing has been identified as one of the service-oriented new business models (see, e.g. Kley et al., 2011) that may involve sharing personal electric vehicles on a peer-to-peer basis (Lue et al., 2012). Weiller and Neely (2014) present a study of the various energy services that electric vehicles can provide and conclude that residential applications such as vehicle-to-home and smart home systems are realizable in the near future. Moreover, Geelen et al. (2013) stress the need for better service design that supports private households in their role as prosumers in a smart grid. Tan et al. (2016) review approaches to integration of electric vehicles into smart grids and propose the use of bidirectional vehicle to grid technology in order to optimize the efficiency of renewable energy sources. Concerning the combination of renewable energy and electric vehicle a number of studies illustrate that renewables could (Bellekom et al., 2012; Hennings et al., 2013) and should (Ajanovic and Haas, 2015) be the only source of energy for electric vehicles. For a recent review on electric vehicles interacting with renewable energy in smart grid we refer to Liu et al. (2015).

Our work connects the area of electric vehicle services with the area of energy storage optimization in the presence of renewable energy. We refer to Powell and Meisel (2015b) for a recent overview of optimization approaches to energy storage problems, and to Banos et al. (2011) for an overview of optimization in the presence of renewable energy.

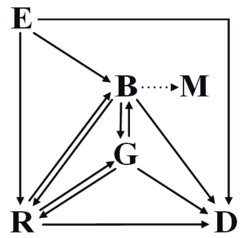


Figure 1: Solid line arrows represent energy flows in kWh between energy source (E), stationary storage (R), car battery (B), grid (G), household's demand (D) and customer demand (M).

2. Problem Formulation

We rely on the canonical modeling framework proposed by Powell and Meisel (2015a) for representing the decision maker's problem as a Markov Decision Process. New decisions about energy flows are made at discrete points in time $t \in \{0, ...T\}$ over a given time horizon of, e.g., one week.

2.1. State Variable and Decision Space

At time t the decision maker observes the energy system's current state

$$S_t = (D_t, M_t, P_t, E_t, R_t, B_t, A_t, f_t),$$

where D_t represents the household's current demand for energy, P_t is the current retail electricity price, E_t is the currently generated renewable energy, R_t is the current amount of energy in the stationary storage device, B_t is the current amount of energy in the electric vehicle's battery and M_t is the current customer demand for transportation in km. We assume that customers book the vehicle for a predefined number of time steps and that A_t always indicates the number of time steps remaining until the vehicle returns, i.e., $A_t = 0$ indicates that the vehicle is on-site. Moreover, we assume that we have access to forecasts of $D_{t'}$, $M_{t'}$, $P_{t'}$ and $E_{t'}$ for all $t' > t$, and that these forecasts are represented as four vectors $f_t = (f_t^D, f_t^M, f_t^P, f_t^E)$.

With capital letters in the superscripts denoting origins and destination of flows, as given in Figure 1, the decisions at time t may be represented as

$$x_t = (x_t^{ED}, x_t^{RD}, x_t^{BD}, x_t^{GD}, x_t^{ER}, x_t^{BR}, x_t^{GR}, x_t^{RG}, x_t^{BG}, x_t^{EB}, x_t^{RB}, x_t^{GB}, x_t^{m}),$$

where x_t^m is a binary variable indicating whether or not a customer takes the electric vehicle. Note that we assume that the decision maker always shares his car if possible, i.e., if the car is on-site and if the current battery charge level is sufficient. With these assumptions the set of feasible decisions at time t is defined by Equations 1–21:

$$x_t^{ED} + \eta_R^d x_t^{RD} + \eta_B^d x_t^{BD} + x_t^{GD} = D_t + E_t^- \quad (1)$$
$$\eta_R^c (x_t^{ER} + \eta_B^d x_t^{BR} + x_t^{GR}) \leq R^C - R_t \quad (2)$$
$$\eta_B^c (x_t^{EB} + \eta_R^d x_t^{RB} + x_t^{GB}) \leq B^C - B_t \quad (3)$$
$$x_t^{RD} + x_t^{RB} + x_t^{RG} \leq R_t \quad (4)$$
$$x_t^{BD} + x_t^{BR} + x_t^{BG} \leq B_t \quad (5)$$
$$x_t^{ED} + x_t^{ER} + x_t^{EB} \leq E_t^+ \quad (6)$$
$$x_t^{ER} + x_t^{GR} + \eta_B^d x_t^{BR} \leq \delta_R^c \quad (7)$$
$$x_t^{RD} + x_t^{RB} + x_t^{RG} \leq \delta_R^d \quad (8)$$
$$x_t^{EB} + x_t^{GB} + \eta_R^d x_t^{RB} \leq \delta_B^c \quad (9)$$
$$x_t^{BD} + x_t^{BR} + x_t^{BG} \leq \delta_B^d \quad (10)$$
$$A_t \leq K(1 - y_t) \quad (11)$$
$$1 - A_t \leq K y_t \quad (12)$$
$$M_t' - B_t \leq K(1 - z_t) \quad (13)$$
$$M_t' - B_t > -K z_t \quad (14)$$
$$x_t^m \leq z_t \quad (15)$$
$$x_t^m \leq y_t \quad (16)$$
$$M_t' > -K(1 - x_t^m) \quad (17)$$
$$y_t, z_t, x_t^m \in \{0, 1\} \quad (18)$$
$$x_t^{BD} + x_t^{BR} + x_t^{BG} + x_t^{EB} + x_t^{GB} + x_t^{RB} \leq K(1 - x_t^m) \quad (19)$$
$$x_t^{BD} + x_t^{BR} + x_t^{BG} + x_t^{EB} + x_t^{GB} + x_t^{RB} \leq K y_t \quad (20)$$
$$x_t^{ED}, x_t^{RD}, x_t^{BD}, x_t^{GD}, x_t^{ER}, x_t^{BR}, x_t^{GR}, x_t^{RG}, x_t^{BG}, x_t^{EB}, x_t^{RB}, x_t^{GB} \geq 0 \quad (21)$$

We consider the fact that a generating unit such as a wind turbine consumes energy during operations by letting $E_t^- = -1 \cdot \min(0, E_t)$ and $E_t^+ = \max(0, E_t)$. The (dis-)charge efficiencies of stationary storage and vehicle battery are denoted as η_R^d, η_R^c, η_B^d and η_B^c. Accordingly, we denote the storage device's (dis-)charge rates as δ. R^C and B^C are the storage capacities. M_t' denotes the transportation demand converted into kWh and K is a very large number.

2.2. State Transition and Objective Function

The transition from state S_t to successor state S_{t+1} is determined by both decisions x_t and uncontrolled exogenous influences W_{t+1}. We model these influences as changes $W_t = (\hat{D}_t, \hat{M}_t, \hat{P}_t, \hat{E}_t, \hat{f}_t)$ of D_t, M_t, P_t, E_t and f_t.

The profit at a point in time results as the sum of (a) money made by selling energy to the market, (b) money gained from car sharing, (c) opportunity costs of satisfying the household's demand from renewables, minus (d) the money spent on buying energy. The total profit at time t is defined as

$$C(S_t, x_t) = P_t(D_t + \eta_R^d x_t^{RG} + \eta_B^d x_t^{BG} - x_t^{GR} - x_t^{GB} - x_t^{GD}) + \alpha M_t x_t^m,$$

where α is the fee we charge the car sharing customers per km. The decision maker aims at finding an optimal policy, i.e., an optimal decision rule, $X_t^\pi(S_t)$, that given any system state S_t returns the best feasible decisions. His overall goal is the maximization of the expected sum of profits over the entire time horizon, which results into the objective function

$$\max_{\pi \in \Pi} \mathbb{E}^{\pi} \sum_{t=0...T} C(S_t, X_t^{\pi}(S_t)). \tag{22}$$

3. Policies

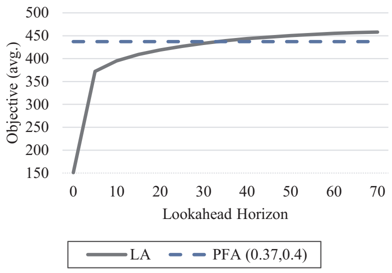
Due to the well-known curses of dimensionality (see, e.g., Powell, 2011) problem (22) typically turns out to be computationally intractable for real-world applications. As an optimal policy cannot be computed, we propose and compare the performances of two alternative policies.

Policy Function Approximation (PFA). PFAs are analytic functions that map states to decisions without solving an optimization problem. We propose a PFA, $X_t^{PFA}(S_t|\theta^L, \theta^U)$, with tunable parameters θ^L and θ^U. The PFA is in the spirit of the PFA proposed by Powell and Meisel (2015b) for an energy storage problem. For the sake of brevity, we do not provide a formal definition of the PFA, but describe its logic at each point in time t. As much of E_t as possible is used for satisfaction of the household's demand. Then, as much of the remaining energy as possible is transferred to the stationary storage. As much as possible of the still remaining energy is then transferred to the car battery. If part of the demand is still unsatisfied and if $P_t \leq \theta^L$, we buy energy at the market in order to satisfy the remaining demand. If $P_t > \theta^L$, we first rely on the stationary storage as much as possible, before we rely on the car battery as much as possible and buy any additional energy needed for demand satisfaction at the market. If $P_t > \theta^U$, as much energy from the two storages as possible is sold to the market, and if $P_t \leq \theta^L$, as much energy as possible is bought at the market and stored in the two batteries.

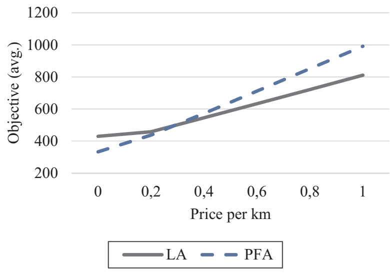
Lookahead (LA) Policy. We propose a deterministic LA policy $X_t^{LA}(S_t|\theta^H)$, with the lookahead horizon as the tunable parameter θ^H. The LA policy determines the decisions x_t by solving the optimization problem

$$\arg\max_{\tilde{x}_t} \sum_{t'=t}^{t+\theta^H} f_{tt}^P (f_{tt}^D + \eta_R^d \tilde{x}_{tt'}^{RG} + \eta_B^d \tilde{x}_{tt'}^{BG} - (\tilde{x}_{tt'}^{GR} + \tilde{x}_{tt'}^{GB} + \tilde{x}_{tt'}^{GD})) + \alpha \cdot f_{tt}^M \cdot \tilde{x}_{tt'}^m,$$

where the set of feasible decisions is defined along the lines of constraints 1–21 for each t' with $t \leq t' < t + min(T-t, \theta^H)$, and where the decision vectors for points in time $t \dots t + min(T-t, \theta^H)$ are represented by $\tilde{x}_t = (\tilde{x}_{tt}, \tilde{x}_{t,t+1}, ..., \tilde{x}_{t,t+min(T-t,\theta^H)})$. For notational convenience we define $f_{tt}^D = D_t$, $f_{tt}^M = M_t$, $f_{tt}^E = E_t$ and $f_{tt}^P = P_t$.



(a) Weekly profits with $\alpha = 0.2$.



(b) Weekly profits with $\theta^H = 70$.

Figure 2: Comparison of weekly profits.

4. Computational Results

In this section, we showcase one illustrative example of the policies' performances. The considered problem instance is derived from Problem 2 in Meisel and Powell (2016). We adopted the characteristics of all stochastic processes, but scaled them to the numbers that correspond to an average household in Germany. The capacity of the stationary storage is $R^C = 10$ kWh with $\delta_R = 3.3$ kW and $\eta_R = 0.9$. The simulated time horizon is one week and one time interval is set to 15 minutes. The electric vehicle has battery capacity $B^C = 85$ kWh with $\delta_B = 10$ kW, $\eta_B = 0.85$ and a consumption rate of 20 kWh per 100 km. The stochastic demand for transportation varies between 0 and 100 km. We estimate the quality of a policy by generating $n = 100$ sample paths for the exogenous processes and by approximating $\mathbb{E}^\pi \sum_{t=0...T} C(S_t, X_t^\pi(S_t))$ by sample average.

Figure 2a compares the performances of PFA (with manually tuned parameters) and LA policy (with different lookahead horizons) at a per km fee of $\alpha = 0.2$ €, which is about the average fee in German car sharing services. The figure allows for the conclusion that the LA policy should be preferred over the PFA provided that $\theta^H > 33$. However, Figure 2b shows that the advantage of the LA policy critically depends on α. As soon as $\alpha > 0.3$ the tuned PFA clearly outperforms the LA policy.

5. Conclusions

We present a model of a dynamic decision problem of an innovative household that acts as a “prosumer” in the energy market and that provides customers with a e-vehicle sharing service. For solving the problem we propose and compare a lookahead policy and a policy function approximation. Our computational results show that the preferred policy depends on the service fee.

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Towards Smart Distribution Grids: A Structured Market Engineering Review

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Abstract

The changes taking place in the energy sector, the transition towards smart grids and an increasing share of renewable energy sources (RES) generate the need for new market designs as well as new business models on the level of distribution grids. This work applies the market engineering framework to markets in smart distribution grids. First, a systematic overview of research approaches in the respective fields is given. Second, by viewing intermediaries as market engineers in their own one-sided market, existing industry projects from intermediaries are compared along the market engineering framework.

Keywords: Energy and Mobility Services, Market Engineering, Smart Grid

1. Introduction

New proposals for energy market designs on both national [4] and EU level [12] call for a better integration of the increasing share of RES as well as opening the market to more actors in order to utilize their flexibilities. In particular, distribution system operators (DSOs) and aggregators could leverage flexibility from consumers to further generate revenue from new business models. Moreover, flexibility products and services as well as other measures

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beneficial to the grid and security of supply are necessary. In the following, this work gives a structured overview and analysis of current research approaches and real-world industry projects in Germany regarding smarter distribution grids along the elements of the market engineering framework. Moreover, all components of the market engineering framework are analyzed and illustrated by examples.

2. Related Work

The market engineering framework [44] serves as a basis for the development of a layout for markets in distribution grids. Along the elements in the framework, this work will analyze current developments in research, politics and industry related to the design of future local markets. In the framework, every market is surrounded by an economic and legal environment. The good traded between parties in a market is called transaction object. According to the market engineering framework, the market structure itself consists of the microstructure, the IT-infrastructure and the business structure. The microstructure defines the market mechanism, i.e., pricing and allocation rules. All facilities required in order for markets to function on a technical level form the IT-infrastructure. The business structure encompasses the business and pricing model as well as possible trading fees in auctions [45, 5]. Perceiving new companies in the energy market as single markets themselves allows for analysis of new business models in the context of the market engineering framework. Finally, the market outcome (or performance) constitutes the result of a market by which different markets can be compared.

3. Smart Distribution Grids: A Market Engineering Overview

This section elaborates on current research agendas by reviewing publications and projects for (local) markets in smart grids along the elements of the market engineering framework. In the following, this work broadens the focus from the perspective of the market engineer to additionally incorporate the role of market intermediaries, or aggregators, which can also take the role of a market engineer, whose market environment depicts a one-sided market, sometimes with a fixed price strategy. In addition, engineering a business structure and designing appropriate transaction objects remains an important task.

3.1. Economic and Legal Environment

Both on European Union (EU) as well as on national level, efforts towards achieving ambitious energy targets, such as the EU 2030 targets [12] or the exit from nuclear power generation [3], are driving changes to the current legal and economic environment which governs energy markets. Recently, the EU started working on proposals for a new energy market design, which envisions a market design that should allow innovative companies to provide for the energy needs of consumers by using new technologies, products and services [12]. Opening the market to more actors, therefore allowing access to flexible demand and new energy service providers, e.g. aggregators, remains a priority. In late 2015, German policy established measures that target the development of an advanced electricity market – the *electricity market 2.0* [4]. The electricity market 2.0 draft tackles issues concerning the improvement of market mechanisms, fostering the market participants' flexibility, as well as the integration into the EU's internal energy market (IEM).

3.2. Market Outcome

Markets are designed to achieve a desired outcome, i.e., an allocation and pricing result [44]. Concerning the design of markets for distribution grids, market efficiency is crucial in order to ensure a continuous balance of supply and demand. Considering system stability, incentives of agents should be aligned with security of supply in mind to prevent market failure. The following suggestions for outcome objectives of secondary nature represent promising goals towards the success of local markets in smart grids. (i) Consumer privacy must be protected in light of the large amount of high-resolution data collected by smart meters. (ii) In order to integrate customers into such markets, intermediaries such as aggregators are required. These in turn will only operate given viable business models. Thus, a market outcome should also consider revenue streams not only for the market engineer but also for its participants. Focusing on aggregators, the main market outcome is to allocate and in turn provide balancing power to ensure grid stability by efficiently controlling small power plants or to manage a pool of consumer batteries efficiently.

3.3. Agent Behavior

Agent behavior results from the transaction object and market structure. Therefore, it is not the goal of the market engineer to influence this behaviour directly, but instead analyze and anticipate behavior and characteristics of agents [44, 45]. In context of the smart grid, agents are expected to offer their flexibility to a market or market intermediary [1]. Flexibility corresponds to deferring or reducing loads over time [43] and increasing production, for different types such as storable, shiftable, curtailable, base load and self-generation [21, 36]. In addition, other approaches to stimulate agent behavior might include: (i) Gamification, i.e., using game design elements such as rankings in non-game contexts [9] to support the consumers' value creation [25]. (ii) Hidden markets [40] can influence and mediate user behavior with the graphical user interface of a market. (iii) Following the sharing economy [2, 19], peer-to-peer (P2P) platforms present an opportunity to communicate and share different transactions objects with close neighbors or friends. When looking at real-world examples of intermediaries, for example the strategy of employing hidden markets can be observed. Most of the time, it is reasonable not to inform customers about details behind the intermediaries' business models. Existing companies putting this approach into practice are for example Next Kraftwerke, Caterva, LichtBlick and Beegy.

3.4. Market Structure

Focusing on distribution grids, strengthening the role of DSOs in markets and enabling the participation of flexible users and intermediaries, i.e., businesses that facilitate the participation of flexible users on (new) markets, represent the main challenges [3]. New transaction objects and market microstructures are emerging, while IT infrastructure considerations on privacy and security need to be addressed.

Microstructure. The market microstructure describes the mechanism under which resources are allocated and priced. It consists of a market's trading rules and systems, considers structural characteristics of markets and the form in which information is exchanged, i.e., the bidding language [44]. Different decentralized mechanisms which aim at reducing peak loads [37], using balancing markets [23], and incentivizing agents to reveal true preferences [30] have been proposed. When applying the microstructure element of the framework to intermediaries, the market mechanism corresponds to the general terms and conditions of the respective intermediary. They basically define the rules of the trade, such as the delivery of the product and the payment period. The customers do not submit bids to an auction but rather inquire (customized) offers. As can be seen in table A.1, some companies offer customized products and services with individual pricing, while others have a general fixed price product portfolio.

IT Infrastructure. IT infrastructure is deemed a fundamental and critical component in the smart grid as it is responsible for ensuring a reliable system operation. Firewalls and encryption mechanisms must ensure reliable system operation [33]. Authentication solutions [32, 28], extensions of current architectures [35] as well as complete system architectures [33] have been proposed. Moreover, smart meter data must be protected [15] and consumer anonymity must be ensured [10, 31, 27]. Standards can facilitate the information flow in a heterogeneous landscape of devices in the smart grid [17, 16]. Moreover, interfaces to the market are required to allow and encourage agent participation [40, 41]. For existing intermediaries/virtual power plants (VPPs) for example, the communication with the distributed power plants plays a crucial role and happens via DSL connection or mobile (GSM) communication. Besides, the communication between intermediary and customer often is done completely through web portals and mobile applications. The individual characteristics of each of the surveyed companies are summarized in table A.1 below.

Business Structure. Business structure concerns the charges for accessing the market, as well as fees for using the communication means and for executing orders [44]. Important revenue streams of current energy markets like the European Energy Exchange include fees for connectivity and trading.[1] By means of aggregators, or VPPs, consumption and production capacities could be pooled and sold accordingly [24, 18, 22]. Use cases include wind [34] or electric vehicle (EV) pooling [7, 26, 11]. Moreover, tariff and coordination models are explored [8, 29]. Current startups such as Next Kraftwerke aggregate several types of plants. From a market perspective their revenue stream

[1] `https://www.eex.com/blob/65974/e8b0e854878e50ae201afd097495c704/membership-options-technical-access-data.pdf`

through one time sales of hardware for connection to the pool corresponds to initial connectivity fees. The second major revenue stream, keeping a share of the revenues from flexibility marketing, corresponds to costs for trading.

Transaction Object. The good traded between parties in a market is called transaction object. In general, this can be a product or a service [6]. Early research suggests to differentiate products, i.e., tariffs, along temporal and spacial components [39]. Similarly, concepts for quality of service (QoS) level indicators for new tariffs [20] and electric mobility [14] are suggested. While electricity will remain a homogeneous good regarding its technical properties (voltage and frequency), a product differentiation along non-functional quality attributes of electricity services presents an emerging approach. In particular, temporal and curtailment flexibility as well as reliability requirements constitute promising characteristics to further raise efficiency not only on the local, but also on the global electricity market level [38, 42, 13]. Existing intermediaries in smart grids offer various types of transaction objects, like hardware products for the connection and integration into the swarm, intelligent management software and a wide range of different services.

Summary. As shown before, initial solutions from the industry exist already today. The findings are summarized in table A.1, structured according to the market engineering framework.

4. Conclusion and Outlook

This work highlights that local markets in distribution grids are a promising way to cope with the challenges posed by the transformation of the energy sector. Therefore, a survey of current research is conducted and subsequently structured according to the market engineering framework. By defining intermediaries in distribution grids as one-sided markets on their own, they can be included in the analysis.

Future research opportunities regarding market engineering in smart distribution grids include the application of the structured market engineering process [44], which allows achieving specific market design goals in a systematic and structured way. Besides, it would be valuable that the research approaches mentioned above are elaborated, refined and adjusted to a rapidly changing economic and political environment.

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Appendix A. Market Engineering Overview Table

Table A.1: Overview of prominent products and services from industry (● = Fulfilled, ○ = Not fulfilled or unknown)

	Next Kraftwerke	Beegy	LichtBlick SchwarmEnergie	Sonnenbatterie	Tesla	Caterva
Market outcome						
Ensure grid stability through efficient allocation	●	●	●	●	●	●
Generate revenues through flexibility marketing	●	●	●	○	○	●
Agent behavior						
Private households	●	●	●	●	●	●
Industry consumers	●	●	●	○	●	○
Solar generation installed	●	●	●	○	○	●
Wind generation installed	●	○	○	○	○	○
Microstructure						
Custom prices	●	●	●	○	○	○
(IT) infrastructure						
Internet access required	●	●	●	○	○	●
Mobile (GSM) access available	●	○	○	●	○	●
Provides mobile application	●	●	○	●	○	●
Business structure						
One-time sale	●	●	●	●	●	●
Subscription	○	●	●	○	○	●
Brokerage fee/ Shared revenue	●	●	○	○	○	●
Transaction object						
Physical product	●	●	●	●	●	●
Service	●	●	●	○	○	●

Own data from 2015/11.

Willingness to Pay for E-Mobility Services: A Case Study from Germany

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Abstract

We analyse the relevance of and willingness to pay for services connected to operation and charging of electric vehicles. Our survey data comprises fleet manager answers from 109 German organizations, mainly small and medium-sized enterprises. The results indicate that semi-public charging infrastructure at the organizations connected to services enabling the operation of an inter-organizational charging network are relevant to most of the fleet managers. In most of the organizations willingness to pay for connected charging services is available, but only sporadic usage of inter-organizational charging activities could be observed.

1 Introduction and literature review

Electric vehicles (EV) are an important technology to reduce greenhouse gas and local air emissions as well as the dependency on fossil fuels. Yet, their market diffusion is still at low levels (IAE 2015) due to several barriers linked with this new technology (Steinhilber et al. 2013), such as a limited mobility radius or a higher recharging necessity resulting in a so-called range anxiety (Tate et al. 2008). New business models or services could diminish these concerns by proposing alternative procedures, such as mobility guarantees in case of trips that are not performable with an EV or the provision of a larger charging network (Kley et al.

2011). While business models or services[1] in the automotive industry are the subject of many papers (see e.g. Tongus and Engvall (2014) for an evaluation of business models and technology development) only some works focus on business models for EV (see Wells (2013) for a review). There are qualitative studies on business models for EV available (e.g. Bohnsack et al. (2012), Piao et al. (2014), Cherubini et al. (2015)). Furthermore, frameworks for EV business models exist (Kley et al. (2011), Stryja et al. (2015), San Roman et al. (2012)). Beyond that specific case studies are evaluated as well (Christensen et al. (2012), Illing et al. (2014), Kosub (2010)). By contrast, this paper determines the current relevance and willingness to pay (WTP) for services provided to commercial EV users. A survey targeting this issue with 109 company car pool managers, who actually procured EV within the project Get eReady, which was scientifically accompanied and partly carried out by the authors of this paper between 2013 and 2015, was performed. Findings of this case study are described in the next section before a conclusion, limitations and a brief outlook are provided.

2 Case study: Project Get eReady

2.1 Sample description and background information

The data used in this study was gathered in an online survey during the e-mobility project Get eReady. The objective of the project was to determine critical success factors for EV in organizations. Therefore, a large-scale fleet trial including 109 organizations and 327 EV was set up in order to prove whether appropriate sales activities for product service systems consisting of EV, connected charging services, charging infrastructure (EVSE[2]), consulting activities and an adequate compensation of expenses lead to an accelerated market diffusion of EV. The industry partners within the project, i. e. Bosch Software Innovations GmbH responsible for software solutions concerning connected charging services tested

[1] According to Osterwalder & Pigneur (2010), Chesbrough & Rosenbloom (2002) as well as Stryja et al. (2015) the value proposition represented by the utility that a provider offers to its customers with products and services is in the center of a business model. In this paper, we focus on services that could offer a business model. In literature, these terms are often used equivalently.
[2] Electric Vehicle Supply Equipment, i.e. charging stations

in the project, Heldele GmbH responsible for EVSE and Athlon GmbH associated to the project for EV leasing purposes, pushed the sales activities for the product service systems offered. The scientific partners, i. e. Fraunhofer ISI and KIT, supported the sales activities by fleet consulting activities as well as the contractual project integration of the participating organizations (associated with a compensation of expenses granted and the commitment to acquire the number of EV contractually specified, to install and use project specific EVSE and the project specific connected charging services). Most of the EV were registered after their contractual integration (75 %). Due to long delivery periods, the time lag between these two events was three months on average. Almost all organizations installed the project specific EVSE after becoming part of the project (about 97 %). Preconditions for project participation were, that the organizations intended to participate at least with one EV, that the organizations were allocated in Baden-Württemberg and that they still applied for the program after intensive sales conversations leading to individual recommendations concerning individual constructual, security and telecommunication requirements. The organizations participated in the project between 7 and 27 months, 16 months on average. They received a monthly compensation of expenses for participating of up to 500 Euros net per full electric vehicle (BEV) or range extended electric vehicle (REEV) and 350 Euros net per plug-in hybrid electric vehicle (PHEV) for additional costs of project specific EVSE and for the still existent economic disadvantages of EV. Overall, the resulting compensation per EV ranged between 1,200 Euros and 13,200 Euros including 19 % VAT, 8,100 Euros on average. Fleet managers[3] of all 109 participating organizations were asked to fill out two surveys with a response rate of 100 % each, i.e. all organizations participating in the project answered both questionnaires.

According to the survey results, 75 % of the participating organizations were small and medium-sized companies with up to 250 employees. The allocation of EV within the Get eReady project represents the sectors of the participating

[3] In the project Get eReady fleet managers, i. e. persons responsible for the organizations' car pools mostly involved in purchase decisions for the EV, as well as fleet EV users not involved in the EV purchase decisions, participated in the surveys. However, this article only focuses on the answers of the fleet managers.

organizations reasonably well, e. g. 36 % of the participating organizations and 35 % of the EV are allocated in the manufacturing sector (C)[4]. Comparing the EV of the Get eReady project with new commercial EV registrations in Germany shows that the manufacturing sector (C) is overrepresented by 15 percentage points (pp), information and communication (J) is overrepresented by about 11 pp and public administration (O) is overrepresented by about 9 pp. On the other hand, wholesale and trade (G) is underrepresented by 20 pp. The sector of other service activities (S) is underrepresented by about 13 pp. Despite these discrepancies, results can be considered to be representative for the current commercial EV users in Germany.

The fleet managers and decision makers in the participating organizations are on average 45 years old (SD=12), are predominantly male (about 85 %) and are well educated. About half of them have completed academic studies and about 30 % have a degree at university entrance level or a master craftsman diploma. 50 % have a technical, about 40 % a commercial background. On average, the respondents have been employed for 16 years in their organizations (SD=12) and have an experience level with fleet management activities of 10 years on average (SD=10). Half of them dedicate more than 10 hours per month to fleet management activities, 25 % four hours or less and 25 % more than 20 hours.

2.2 Relevance of different services

In a workshop with the Get eReady partners in the year 2013, a set of different services potentially relevant for EV were identified in order to ask the fleet managers and decision makers of the participating organizations about the attractiveness and relevance of these services. Based on the fleet managers' answers, the project partners agreed to consider only the relevant services in the second survey with a focus on the WTP for these services (Table 1 in the appendix). This set of services was completed by three additional services not in focus so far, but according to the authors of this study potentially relevant. These are on the one hand two alternatives of a smart charging energy service that could potentially be pro-

[4] Sectors distinguished according to NACE, Rev. 2.

vided by a Smart Charging Service Provider (SCSP) (Ensslen et al., 2014)[5] and on the other hand, the relevance and WTP of inductive EV charging as a service, which is potentially increasing the comfort level of EV charging.

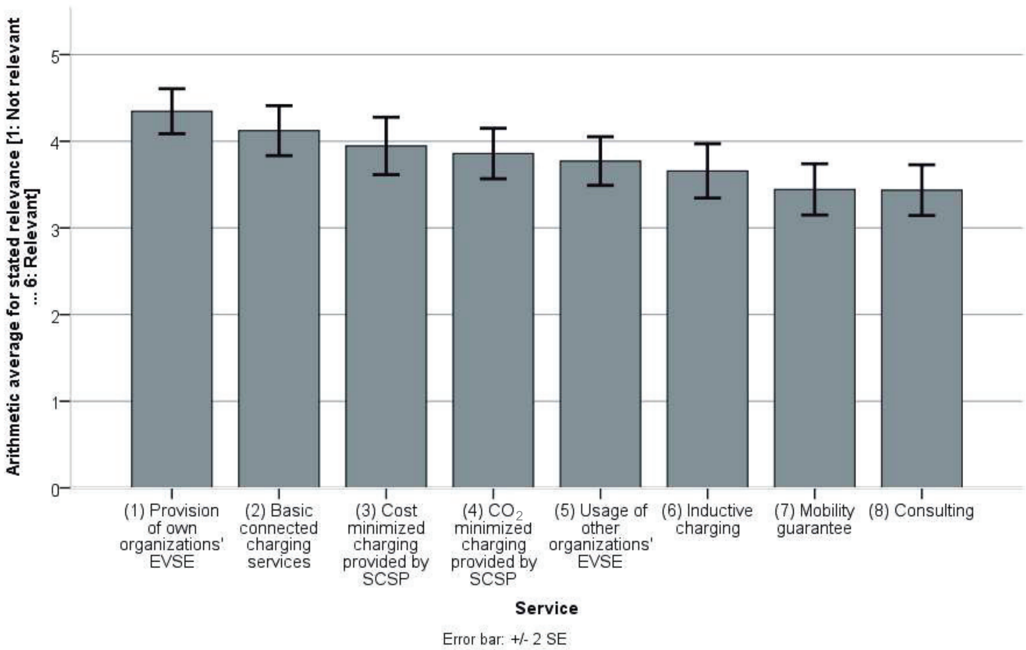

Figure 1: Relevance of e-mobility services in Get eReady[6]

Figure 1 shows the results concerning stated relevance for the services considered in the survey. The most important services are: (1) the possibility to provide the own EVSE to other organizations, (2) the basic connected charging services including a web-based map displaying charging points including information about their current availability and a reservation function as well as (3) a smart charging tariff provided by a SCSP incentivizing EV users to hand over control of the charging processes to the SCSP scheduling the charging events in a cost-minimizing manner in order to co-create value. These are also considered as comparably most relevant by the Get eReady fleet managers according to paired t-tests (cf. Table 2 in the appendix). (4) A smart charging tariff incentivizing EV users to hand over control for EV charging to a SCSP scheduling the charging

[5] This option of a new type of operator, the so-called SCSP, is contracting households and organizations and manages the charging of their EV. This operator considers the EV load shifting potentials and current price signals from electricity markets. Details about the value proposition of the SCSP are available in Ensslen et al. (2014).

[6] Scale: 1 Not relevant; 2 Predominantly not relevant; 3 Rather not relevant; 4 Rather relevant; 5 Predominantly relevant; 6 Relevant

events in a CO_2 minimizing manner and (5) the possibility to use EVSE of other organizations are somewhat less important, i.e. less important than (1). According to the respondents, (6) inductive charging, (7) mobility guarantees as well as (8) consulting activities for EV, infrastructure and car pools are least important amongst the services considered. Although some statistically significant differences between the services considered could be observed, most of them are on average considered to be rather relevant. In order to verify whether the differences observed in individuals' evaluations in the paired t-tests would also be valid if the samples were considered to be independent, additional pairwise comparisons with a one way analysis of variance were conducted ($F(7,815) = 4.763$, $p<.001$). Results of multiple comparison t-tests according to Bonferroni (cf. Table 2 in the appendix) show significant differences between services 1 and 2 and services 7 and 8 as well as between services 1 and 6. It should be remarked, that services 1 and 2 were actively tested within the project, services 6 and 7 were not. This could indicate that actually experiencing a service might contribute to an increased acceptance of a service.

2.3 WTP for different services

Two different types of services can be distinguished: E-mobility services actively tested during the Get eReady field trial (services 1, 2, 5, 8) and other e-mobility services not actively tested in the field trial (services 3, 4, 6, 7).

Table 3 in the appendix contains results for usage frequencies of the connected charging services tested within the project and Table 4 for WTP and corresponding cost assumptions. According to the results, the WTP per month and vehicle to get access to the Get eReady charging network (service fee) is higher for most of the participating organizations than the monthly costs. According to the results the participants charge the EV only scarcely at EVSE of other organizations. However, they frequently charge their EV at their own connected EVSE. The WTP for charging at own EVSE of most organizations seems as high as the current costs. Cost assumptions for all other connected charging services presented in Table 4 are higher than the WTP of most organizations.

As EV are frequently parked at the workplace for longer time periods, the control for charging EV incentivized by smart charging tariffs discussed in this study is handed over to the SCSP who is scheduling the charging events in a cost or CO_2 minimizing manner in order to co-create value.
WTP was measured with the Van Westendorp method (Reinecke et al. 2009) and is presented in Table 5 in the appendix. Using the Van Westendorp method is appropriate as this method supports to determine WTP for innovative services with unknown price conceptions as well as a so far missing competitive environment (Reinecke et al. 2009). All of these three criteria apply to the SCSP's value proposition. Furthermore, the Van Westendorp method is considered as a very efficient alternative to determine prices, that has been frequently disregarded (Reinecke et al. 2009). The method permits to determine the lower bound and the uppter bound of an acceptable price range. Furthermore, an optimal price point, which is maximizing the turnover, can be determined. Comparing the difference between the indifference price point and the optimal price point permits to derive estimates about the price sensitivities of the potential customers. Lower differences between the two price points implicate higher price sensitivities of the potential customers (Reinecke et al. 2009).
The SCSP's tariff consists of two price levels: (a) The price level for charging the EV as quickly as possible to guarantee a minimum amount of range, so that the EV could be used e.g. in cases of emergencies. (b) The price level for controlled EV charging of a SCSP who is scheduling the charging events in a cost or CO_2 minimizing manner.
The results concerning WTP for the two smart charging tariffs provided in Table 5 include complete and consistent answers from 57 fleet managers. The results indicate that the organizations' fleet managers are willing to pay somewhat less for the energy charged during the time they are handing over control of the charging process to the SCSP, if the SCSP minimizes costs (b_1), compared to a single price level state of the art reference tariff without controlled EV charging. However, the price levels for the two tariffs do not differ significantly (Table 6 in the appendix). On the other hand, they are willing to pay more compared to the reference tariff, if the charging events are scheduled by the SCSP in an environmental-

ly friendly, i.e. in a CO_2 minimizing manner (b_2). Paired t-tests show that two of the four price curves measured differ significantly (Table 6). Furthermore, respondents are also willing to pay a premium so their EV is directly charged up to an individual minimum range threshold after it was plugged in. Paired t-tests show that significant differences could be observed in three of the four price curves measured (Table 6).

3 Conclusion, limitations and outlook

We showed that the connected charging services offered and tested within the Get eReady project are relevant to fleet managers in most of the participating organizations. However, our results seem ambiguous here: On the one hand, fleet managers state that connected charging services are relevant to them, particularly the possibility to provide their own EVSE to other organizations. On the other hand, we observe only sporadic usage of inter-organizational charging activities. Hence, the connected charging services tested within this case study may be interpreted as an “insurance” for the EV users. Furthermore, not only the e-mobility services tested within Get eReady are relevant to fleet managers, but also smart energy services, i. e. controlled EV charging by a SCSP. For this reason, we recommend to expand the existing Get eReady product service system offering by smart energy services. This would strengthen the arguments for connected charging infrastructure solutions as these form the basis for additional smart charging activities. However, the results concerning WTP for smart charging tariffs provided by a SCSP can be scrutinized as fleet managers come from organizations varying in size and internationalization. Electricity costs per kWh might vary largely between the organizations.

Future work could focus on analyzing costs and benefits of service systems consisting of EV, EVSE and corresponding services in order to provide an answer to the question whether offering suitable service systems can be supportive to EV adoption. Furthermore, acceptance in organizations for controlled EV charging in fleets should be studied more profoundly.

Acknowledgements

The research was made possible as part of the project Get eReady funded by the German Federal Ministry for Economic Affairs and Energy (FKZ 16SBW020D).

Appendix

Table 1: Services considered within the Get eReady project

<table>
<tr><th>Services considered</th><th>Average scores for services considered in the first survey for fleet managers (n ~ 40)</th><th colspan="2">Services considered in the second survey for fleet managers</th></tr>
<tr><td>Fleet consulting – Item: “Trips which are outside the range of EV can be distributed amongst conventional vehicles”</td><td>5.3</td><td>x</td><td rowspan="7">Results cf. Figure 1</td></tr>
<tr><td>Sharing of own organizations’ EVSE over platform – Item: “My organization would offer EV charging possibilities on the premises to other organizations against payment.”</td><td>4.6</td><td>x</td></tr>
<tr><td>Usage of other organizations’ EVSE over platform – Item: “For my organization it would be attractive to have the possibility to use EV charging possibilities of other organizations against payment.”</td><td>4.3</td><td>x</td></tr>
<tr><td>Display of current EVSE availability – Item: “Frequently access to publicly accessible charging points is not possible because these are occupied by (conventional) vehicles.”</td><td>3.9</td><td>x</td></tr>
<tr><td>Web-based map displaying charging points – Item: “It is difficult to find out where publicly accessible charging points are allocated.”</td><td>3.7</td><td>x</td></tr>
<tr><td>A EVSE reservation function – Item: “Frequently publicly accessible charging points are occupied by other EV.”</td><td>3.5</td><td>x</td></tr>
<tr><td>Mobility guarantees (rental car option) – Item: “Trips that cannot by made with EV due to their range limitations could be substituted by free of charge rental cars.”</td><td>3.3</td><td>x</td></tr>
<tr><td>Using advertisement space on the EVSE for own advertisements – Item: “For our organization it would be attractive to place advertisements on our charging station.”</td><td>3.1</td><td colspan="2" rowspan="6">Representatives of the Get eReady project partners considered these services not to be relevant for further analyses during a workshop in the end of the year 2014.</td></tr>
<tr><td>Mobility guarantee (train travel option) – Item: “Trips that cannot by made with EV due to their range limitations could be substituted by free of charge train trips.”</td><td>2.5</td></tr>
<tr><td>Leasing of advertcement space on the own EVSE to other organizations – Item: “For our organization it would be interesting from a financial point of view to rent advertisement space on the charging point out.”</td><td>2.3</td></tr>
<tr><td>Sharing of the own organizations’ EV over a platform – Item: “For my organization it would be attractive to rent fleet vehicles of our organization to other organizations.”</td><td>2.0</td></tr>
<tr><td>Usage of EV from other organizations over a platform – Item: “For my organization it would be attractive to use fleet vehicles of other organizations against payment.”</td><td>2.0</td></tr>
<tr><td>Separate registration and billing of private and business trips – Item: “For us it is a problem that business and private trips can not be registered in a way that separate billing is possible.”</td><td>1.6</td></tr>
<tr><td>Billing of charging events</td><td colspan="3" rowspan="5">Representatives of of the Get eReady project partners considered these services not to be relevant for further analyses during a workshop in the end of the year 2013.</td></tr>
<tr><td>Roaming</td></tr>
<tr><td>Authorized repair shops</td></tr>
<tr><td>Breakdown- and maintenance service</td></tr>
<tr><td>EV specific add-on for fleet management systems</td></tr>
</table>

Annotation concerning the measurement scale for the items on the services considered:
1 Not applicable at all; 2 Predominantly not applicable; 3 Rather not applicable; 4 Rather applicable; 5 Predominantly applicable; 6 Completely appicable

Table 2: Paired samples t-test results and Post Hoc ANOVA results (in brackets) for different services

	Provision of own organizations' EVSE (1)	Basic connected charging services (2)	Cost optimal smart charging tariff provided by SCSP (3)	CO_2 optimized charging provided by SCSP (4)	Usage of charging infrastructure of other organizations (5)	Inductive charging (6)	Mobility guarantee (7)
Basic connected charging services (2)	n.s. (n.s.)						
Cost minimized charging provided by SCSP (3)	n.s. (n.s.)	n.s. (n.s.)					
CO_2 minimized charging provided by SCSP (4)	** (n.s.)	n.s. (n.s.)	n.s. (n.s.)				
Usage of charging infrastructure of other organizations (5)	*** (n.s.)	** (n.s.)	n.s. (n.s.)	n.s. (n.s.)			
Inductive charging (6)	** (*)	** (n.s.)	n.s. (n.s.)	n.s. (n.s.)	n.s. (n.s.)		
Mobility guarantee (7)	*** (***)	*** (*)	* (n.s.)	* (n.s.)	* (n.s.)	n.s. (n.s.)	
Consulting (8)	*** (***)	*** (*)	** (n.s.)	* (n.s.)	* (n.s.)	n.s. (n.s.)	n.s. (n.s.)

Annotation: *p<.05, **p<.01, ***p<.001, n.s.: not significant

Table 3: Usage frequency of connected charging services

Service	N		Number of charging hours / usages per month				Percentiles		
	Valid	Missing	Mean	Std. Deviation	Min	Max	25	50	75
Reservations	82	27	2.00	6.90	0	50	0	0	1
Charging at the own EVSE	81	28	64.47	90.51	0	600	15	32	80
Charging of others at the own organizations' EVSE within a regional charging network (Get eReady)	73	36	1.74	6.42	0	50	0	0	0
Charging of others at the own organizations' EVSE within a supra-regional charging network (Hubject)	74	35	1.24	6.16	0	50	0	0	0
Charging at other organizations' EVSE within a regional charging network (Get eReady)	76	33	3.45	10.41	0	60	0	0	1
Charging at other organizations' EVSE within a supra-regional charging network (Hubject)	78	31	4.42	18.38	0	120	0	0	0

Table 4: WTP for e-mobility services

Service	Pricing model (payment frequency and object)	Cost assumptions	N		WTP / Expected refund [in Euros]						
									Percentiles		
			Valid	Missing	Mean	SD	Min	Max	25	50	75
Activation fee	One time per organization	248.65	89	20	102.18	145.09	0	1000	10	50	135
EVSE maintenance	Monthly per EVSE	54.20	89	20	19.38	21.61	0	100	5	10	25
M2M	Monthly per EVSE	15.00	95	14	1.85	2.24	1	15	1	1	2
Service fee	Monthly per EV	2.45	87	22	8.52	13.6	0	100	2	5	10
Reservation	Pay per use	1.00	76	33	1.08	1.80	0	10	0	0.50	1
Charging at the own EVSE[7]	Pay per charging hour	0.95 (≤ 3.3 kW) 0.85 (> 3.3 kW)	58	51	0.93	1.25	0	5	0	0.5	2
Regional provision of EVSE (in Get eReady)[8]	Credit per charging hour	1.00 (≤ 3.3 kW) 3.10 (> 3.3 kW)	52	57	1.65	1.56	0	6	1	1	2.75
Supra-regional provision of EVSE (in Hubject)	Credit per charging hour	n. a.	55	54	1.82	1.95	0	10	0	1	3
Usage of EVSE of other organizations within a regional charging network (Get eReady)[9]	Pay per charging hour	1.95 (≤ 3.3 kW) 3.95 (> 3.3 kW)	57	52	2	1.74	0	6	1	2	3
Usage of EVSE of other organizations within a supra-regional charging network (Hubject)	Pay per charging hour	n. a.	57	52	1.82	1.71	0	6	0	2	3
Mobility guarantee (free usage of a rental car at 20 days per year)	Pay per EV per year	n. a.	86	23	98.6	190.45	0	1200	0	22.5	100
Consulting	One time payment per organization	1,000	86	23	70.88	121.17	0	500	0	0	100
Inductive charging	One time payment per EV	n. a.	84	25	309.89	686.77	0	5000	0	22.5	437.50

Table 5: WTP for smart charging tariffs of a SCSP (n=57)

	Optimal price point	Indifference price point	Point of marginal cheapness	Point of marginal expensiveness
Reference tariff with a single price level	2.65 €	3.55 €	1.30 €	5.00 €
First price level: Direct charing so the minum range threshold is reached as quickly as possible.	2.95 €	3.80 €	1.70 €	5.90 €
Second price level: SCSP controls the charging processes in cost minimizing manner.	2.60 €	3.15 €	1.40 €	4.95 €
Second price level: SCSP controls the charging processes in an environmentally friendly, CO_2 minimizing manner.	3.25 €	3.85 €	1.70 €	5.25 €

[7] Excluded outlier: 1 respondent with WTP of 85 Euros per charging hour
[8] Excluded outlier: 1 respondent expecting credit of 95 Euros per charging hour
[9] Excluded outlier: 1 respondent with WTP of 395 Euros per charging hour

Table 6: Differences between WTP for the two price level smart charging tariffs of a SCSP controlling charging events of EV and a state of the art single price level reference tariff without controlled charging

Pairwise comparisons	WTP compared	Paired differences				
		Mean	**SE**	**t**	**df**	**Sig. (2-tailed)**
Reference tariff **vs.** (a) First price level with direct charing so the minum range threshold is reached as quickly as possible	Too expensive	-0.59	0.26	-2.25	49	**0.029**
	Expensive	-0.50	0.22	-2.28	49	**0.027**
	Cheap	-0.28	0.13	-2.08	49	**0.042**
	Too cheap	-0.12	0.07	-1.65	49	0.106
Reference tariff **vs.** (b_1) Second price level with SCSP controlling the charging processes in cost minimizing manner	Too expensive	0.20	0.30	0.67	47	0.507
	Expensive	0.18	0.25	0.73	47	0.469
	Cheap	0.06	0.15	0.37	47	0.711
	Too cheap	0.07	0.07	1.05	47	0.300
Reference tariff **vs.** (b_2) Second price level with SCSP controlling the charging processes in CO_2 minimizing manner	Too expensive	-0.64	0.37	-1.72	48	0.091
	Expensive	-0.45	0.28	-1.61	48	0.114
	Cheap	-0.53	0.20	-2.68	48	**0.010**
	Too cheap	-0.32	0.15	-2.17	48	**0.035**

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Healthcare Services

Length of Stay Outlier Detection through Cluster Analysis: A Case Study in Pediatrics

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Abstract

The increasing availability of detailed inpatient data is enabling the development of data-driven approaches to provide novel insights for the management of Length of Stay (LOS), an important quality metric in hospitals. This study examines clustering of inpatients using clinical and demographic attributes to identify LOS outliers and investigates the opportunity to reduce their LOS by comparing their order sequences with similar non-outliers in the same cluster. Learning from retrospective data on 353 pediatric inpatients admitted for appendectomy, we develop a two-stage procedure that first identifies a typical cluster with LOS outliers. Our second stage analysis compares orders pairwise to determine candidates for switching to make LOS outliers similar to non-outliers. Results indicate that switching orders in homogeneous inpatient sub-populations within the limits of clinical guidelines may be a promising decision support strategy for LOS management.

Keywords: Machine Learning; Clustering; Health Care; Length of Stay

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1. Introduction

Length of Stay (LOS) is an important quality metric in hospitals that has been studied for decades Kim and Soeken (2005); Tu et al. (1995). However, the increasing digitization of healthcare with Electronic Health Records and other clinical information systems is enabling the collection and analysis of vast amounts of data using advanced data-driven methods that may be particularly valuable for LOS management Gartner (2015); Saria et al. (2010). When patients are treated in hospitals, information about each individual is necessary to perform optimal treatment and scheduling decisions, with the detailed data being documented in the current generation of information systems. Recent research has highlighted that resource allocation decisions can be improved by scheduling patient admissions, treatments and discharges at the right time Gartner and Kolisch (2014); Hosseinifard et al. (2014) while machine learning methods can improve resource allocation decisions and the accuracy of hospital-wide predictive analytics tasks Gartner et al. (2015a). Thus, using data-driven analytic methods to understand length of stay (LOS) variations and exploring opportunities for reducing LOS with a specific focus on LOS outliers is the goal of this study.

Using retrospective data on 353 inpatients treated for appendectomy at a major pediatric hospital, we first carry out a descriptive data analysis and test which (theoretical) probability distribution best fits our length of stay data. The results reveal that our data matches observations from the literature. In a first stage cluster analysis, we identify one potential outlier cluster while a descriptive analysis using box plot comparisons of this cluster vs. the union of patients assigned to all other clusters supports this hypothesis. In a second clustering stage, we analyse the patient sub-population who belongs to that outlier cluster and provide order prescription behaviour insights. More specifically, on a pairwise comparison, we describe which orders are likely to be selected in the outlier population vs. ones that are deselected in the non-outlier population and vice versa. Our findings reveal that four order items are not prescribed in the outlier population while in the non-outlier sub-population, these orders were prescribed. On the other hand, 51 orders were prescribed for the outlier patients which are not enabled in the non-outlier population. These novel data-driven insights can be offered as suggestions for clinicians to apply new evidence-based, clinical guideline-compliant opportunities for LOS reduction through healthcare analytics.

2. Related Work

Clustering algorithms and other machine learning approaches are discussed in Baesens et al. (2009); Jain (2010); Meisel and Mattfeld (2010); Olafsson et al. (2008) including an overview of operations research (OR) techniques applied to data mining. Mathematical programming and heuristics for clustering clinical activities in Healthcare Information Systems has been applied in Gartner et al. (2015b) while the identification of similar LOS groups has been studied by El-Darzi et al. (2009). Similar to our problem, the authors study the application of approaches to cluster patient records with similar demographic and clinical conditions. Using a stroke dataset, they compare the performance of Gaussian Mixture Models, k-means clustering and a two-step clustering algorithm. Determining cluster centers for patients in the Emergency Department (ED) is studied by Ashour and Okudan Kremer (2014). Having defined similar patient clusters, they study the improvement on patient routing decisions based on the clusters. Similarly, Xu et al. (2014) focuses their clustering problem on the ED. Their objective is to cluster patients to resource consumption classes determined by length of treatment while patient demographics are taken into consideration.

The approaches proposed in our paper can be categorized and differentiated from the literature of clustering in length of stay management as follows: Using a descriptive data analysis we provide an overview about the characteristics of our length of stay data. Fitting several distribution types and parameters of the theoretical probability distribution, we underline the skewed property of the probability distribution from our data. In a next step, we define homogeneous patient groups with respect to demographic, clinical attributes and length of stay outliers. Having learned homogeneous groups of inpatients, we evaluate patient orders within the group that potentially contains length of stay outliers and may be responsible for increasing LOS in that group. In conclusion, this study may be considered to be the first to link the discovery of similar clinical and demographic attributes in appendectomy inpatients while, within length of stay outlier clusters, we evaluate possibilities for switching of orders and how they potentially reduce the number of LOS outliers.

3. Methods

Let $\mathcal{P}$ denote a set of individuals (hospital inpatients) and let $\mathcal{K}$ denote the set of clusters to which these individuals can be grouped. For each inpatient $p \in \mathcal{P}$, we observe a set of attributes $\mathcal{A}$ during the patient's LOS. Let $\mathcal{V}_a$ denote the set of possible values for attribute $a \in \mathcal{A}$ and let $v_{p,a} \in \mathcal{V}_a$ denote the value of attribute a for inpatient p. In the following, we will describe how we label patients as LOS outliers, followed by a two-stage clustering approach: The first stage assigns patients' attributes to homogeneous clusters while clusters with high likelihood to contain LOS outliers can be identified. In a second stage, we filter patients assigned to these clusters and evaluate which patient orders may be switched to reduce length of stay in the LOS outlier patient sub-population. The section closes with an illustrative example.

Given the observed LOS of patient $p \in \mathcal{P}$, denoted by l_p, the 25 and 75 percentile of the LOS distribution denoted by q^{25} and q^{75}, respectively then we assign a patient the flag "outlier" using the following expression (Pirson et al. (2006)):

$$o_p = \begin{cases} 1, & \text{if } l_p > q^{75} + (1.5 \cdot (q^{75} - q^{25})) \\ 0, & \text{otherwise} \end{cases}. \tag{1}$$

Now, let $\mathcal{A}^{\text{dem}}$ denote the set of binary demographic attributes and let $v_{a,p} \in \{0, 1\}$ denote the attribute value of demographic attribute $a \in \mathcal{A}^{\text{dem}}$ of patient $p \in \mathcal{P}$. Let $\mathcal{K} := \{1, 2, \ldots, K\}$ be a set of integers with maximum K which will be used for cluster indexing. Our objective is to find cluster centers of patient attributes in order to minimize deviations of each patient's attribute values with the ones of the cluster centres. One algorithm that minimizes this objective is the k-means clustering algorithm Jain (2010). The algorithm is a method of vector quantization. It seeks to partition observations into clusters in which each observation belongs to the cluster with the nearest mean which serves as a prototype of the cluster.

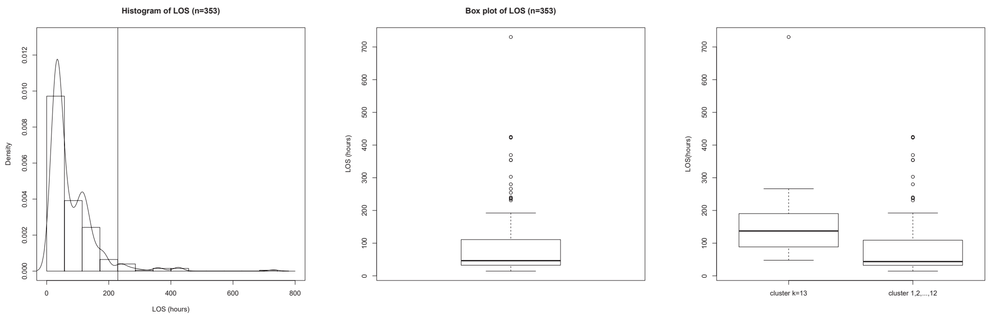
Once we have found patients with similar clinical, demographic and LOS characteristics, we wish to separate patients within the cluster that has the highest likelihood to contain LOS outliers. In this stage, we extract patients with these attributes and evaluate the order prescription behaviour for these patients between outliers and the false positively clustered outliers which actually belong to the group of non-outliers. Orders prescribed by clinicians to patients are, for example, the application of drugs, examinations and therapies. Having determined patients with high likelihood of belonging to the group of outliers, we introduce a set $\mathcal{A}_k^{\text{o, off} \to \text{on}}$ for cluster $k \in \mathcal{K}$ which allows experts to evaluate orders which were switched off for outlier patients and were switched on for non-outlieres. The set is determined by $\mathcal{A}_k^{\text{o, off} \to \text{on}} := \{a \in \mathcal{A}^{order} | v_{a,p^*(p)} - v_{a,p} = 1 \quad \forall k \in \mathcal{K}, p \in \mathcal{P}_k^{out}\}$. Similarly, we introduce the set $\mathcal{A}_k^{\text{o, on} \to \text{off}} := \{a \in \mathcal{A}^{order} | v_{a,p^*(p)} - v_{a,p} = -1 \quad \forall k \in \mathcal{K}, p \in \mathcal{P}_k^{out}\}$ to analyze which orders were given to LOS outlier patients while the reference patient didn't receive the order.

4. Results

The data for this study were obtained from a pediatric hospital in Pittsburgh. $|\mathcal{P}| = 353$ appendectomy patients were hospitalized for, on average, for 78.968 hours. Important variables extracted from the data warehouse include, among others, diagnosis codes, gender, age and 636 unique orders that were entered using Computerized Physician Order Entry. All patient-identifiable health information was removed to create a de-identified dataset for this study.

A histogram of the LOS distribution including a Gaussian kernel density curve is shown in Figure 1(a). We used Equation (1) to determine the outlier LOS threshold o_p which is 229.140 hours. The figure reveals a skewed distribution with a density maximum at the first interval. Another observation is a large proportion of patients after the outlier LOS threshold. A boxplot of the LOS is shown in Figure 1(b). One can observe that the median is very close to the first quartile and some LOS outliers can be observed after the 95 percentile.

To investigate whether a parametric model may be used to fit the data, we ran experiments with 9 distributions such as Beta, Log-normal, Weibull and Erlang. Our results revealed that the Beta distribution results in the best fit with respect to the squared error between the empirical and the best theoretical distribution. The log-normal distribution fits second best and its results of the fitting process will be analysed in more detail: Both the Chi-Square (CS) and the Kolmogorov-Smirnov (KS) test resulted in $p < 0.01$ while the CS-test run with 7 intervals and 4 degrees of freedom resulted in a $p < 0.005$. The optimal parameters of the (theoretical) log-normal



(a) (b) (c)

Figure 1: LOS distribution (a), LOS box plot (b) clustered patients' LOS (c)

distribution's expected value and variance come up to $\mu = 72$ and $\sigma^2 = 123$, respectively with a LOS-intercept of 14 (hours) based on the empirical minimum LOS value. Using this distribution to fit our data, the squared error comes up to 0.137. The result that the log-normal distribution fits very well is not surprising and confirms assumptions from the literature, see Min and Yih (2010).

In our first stage clustering, we varied the number of k until we reached a cluster in which the outlier flag was present. The first cluster was $k = 13$. The clinical and demographic information are shown in Table 1(a) and a summary statistics is shown in Table 1(b). The table shows that ICD-9 code 540.1 – 'Acute appendicitis with peritoneal abscess', an emergency type of 4, a moderate APR DRG severity and 'laparoscopic appendectomy' are the attributes in which outlier patients are most likely to be present. Figure 1(c) shows a LOS boxplot of patients of which the demographic and clinical attributes belong to this cluster vs. all other patients. In a second stage, we clustered based on orders to determine the switching patterns. Again, we run the k-means algorithm and now want to discover differences in the prescription of orders. We came up with two clusters with a total number of 306 orders. Table 1(d) shows the results of the second stage clustering. The table reveals that the number of orders more than doubles from cluster $k = 2$ to cluster $k = 1$. One explanation for this phenomenon is that the length of stay is longer and therefore more orders are likely to be prescribed to patients. Another observation is that in cluster $k = 2$ the LOS more than triples as compared to cluster $k = 1$. Now, comparing both clusters, we observed $|\mathcal{A}_{13}^{\text{o, on} \rightarrow \text{off}}| = 52$ occurrences with a switch from on-off while a off-on was only observed $|\mathcal{A}_{13}^{\text{o, off} \rightarrow \text{on}}| = 4$ times. In the latter case, we predominantly observed order switches in drug and diet prescriptions.

$\mathcal{A}$	v_a
Diagnosis code	540.1
Emergency type	4
APR DRG Severity	Moderate
Laparoscopic appendectomy	yes

(a)

Number of Data Points	17
Min Data Value	47.7
Max Data Value	730
Sample Mean	178.9
Sample Std Dev	156.5
1st quartile	88.5
2nd quartile	137.2
3rd quartile	190.4

(b)

Number of Data Points	336
Min Data Value	14.5
Max Data Value	424.9
Sample Mean	73.9
Sample Std Dev	66.7
1st quartile	32.2
2nd quartile	43.7
3rd quartile	109.1

(c)

cluster	#orders on	#orders off	Mean LOS
$k = 1$	90	216	371.6
$k = 2$	42	264	119.7

(d)

Table 1: Outlier cluster $k = 13$ (a), its summary statistics (b) and summary statistics of patients not belonging to it (c) and order switchings after the 2nd stage clustering (d)

As a consequence of our study, if we assume that the patient population in cluster $k = 2$ could be moved towards the patient population in cluster $k = 1$ through order switching, we can determine a lower LOS bound. Applied to our dataset, the total length of stay could be reduced from 78.97 to 76.11 hours which equals to a 3.8% LOS reduction. In practice and to create a decision support tool which involves clinicians, similar reference patients may be presented to a clinician when treating each particular patient. A clinician may then decide to what extent order switching is appropriate within the limits of clinical guidelines.

5. Summary and Conclusions

In this paper, we have developed a clustering approach of patients for the management of length of stay outliers for pediatric appendectomy. We provided a two-stage clustering method to cluster patients based on similar clinical, demographic and length of stay characteristics and applied it to a data set including more than 350 patients. We retrieved a cluster of patients in which LOS outliers are likely to occur. In a second stage, we compared order prescription for LOS outliers with the ones for patients who have similar clinical and demographic characteristics but are non-outlier patients. Future work will extend this work towards the LOS outlier management of chronic conditions such as asthma and to incorporate clinicians' feedback into our methods.

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A Machine Learning Approach for Brain Tissue Recognition of Human Brain Slice Images

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Abstract

This work presents a Machine Learning (ML) approach for classifying areas of brain tissue in a stack of high resolution human brain slice images. Compared with standard image segmentations algorithms, this ML approach provides more reliable results by concentrating on pixel classification. The presented ML approach is fourfold. First, four feature extraction methods were developed to extract features as a basis for the classification procedure. Second, two feature selection approaches were developed and implemented in order to construct feature vectors. Third, Random Forest (RF), Neuronal Networks (NN), and a novel ensemble Meta classifier constructed by different multilayer perceptron (MLP) were implemented in our classifier construction procedure. Finally, a post-processing method based on graph cut algorithm was used to enforce a smoother classification result into coherent regions. This paper details the feature extraction part and illustrates its application conceiving initial results of a small subset of brain slices.

1 Introduction

1.1 Problem definition & research questions

The basis of the presented work is a stack of colored (RGB) images taken during histological sectioning of a tissue block from a post-mortem human brain. The tissue block was frozen at -80°C and cut into 843 slices, each 70 µm thick. Images were taken right after the extraction of each individual slice using a high-resolution industry-grade camera. Both, the histological processing and image collection has been carried out in the lab of Prof. Katrin Amunts at the Institute of Neuroscience and Medicine (INM1) at Research Center Juelich in Germany. At INM1, such “block-face” images are successfully reconstructed into consistent 3D volumes, and used as reference data for the significantly more difficult 3D reconstruction of the subsequent histological scans that typically suffer from nonlinear distortions and artifacts. Such 3D reconstructions play an important role in the EU FET flagship “Human Brain Project”.

Due to the lack of contrast between the sectioning plane and the adjoining underlying brain surface, standard image segmentations algorithms often produce unreliable results for this kind of data. Therefore, neuroscientists in Juelich have spent significant manual effort to segment the sectional planes of brain tissue manually.

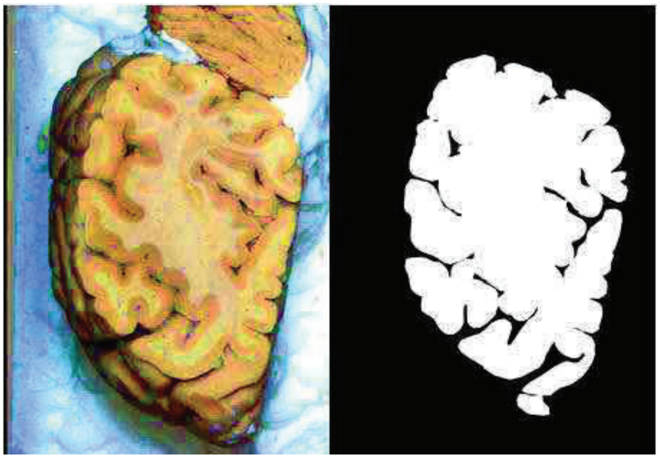

Figure 1.1 Image ressource of slice 450

In order to reduce the manual effort for marking areas of brain tissue, a ML approach needs to be developed. Since the manually labeled data has been provided together with the images, INM1 is particularly able to investigate supervised learning techniques to solve the problem. Based on supervised learning techniques, INM1 should be able to segment future datasets based on a small sample of manually marked image sections as training data. Based on the trained model, INM1 should be able to automatically segment the remaining images by classifying pixels of slice image into two classes- one identifying a pixel as part of the sectioning plane, and the other associating it to the background (Figure 1.1 - Left image is the original brain slice image. On the is the “blockface” image, which provides label data.).

2 Methodology

This project is a collaborative project of KIT, IBM and INM1 at the Smart Data Innovation Lab (SDIL), which is an initiative intended for cutting-edge research in the area of data engineering. INM1 plays a role as data sponsor and propose requirements. KIT academics jointly conducted this research project with support of IBM-provided software and infrastructure (Figure 2.1).

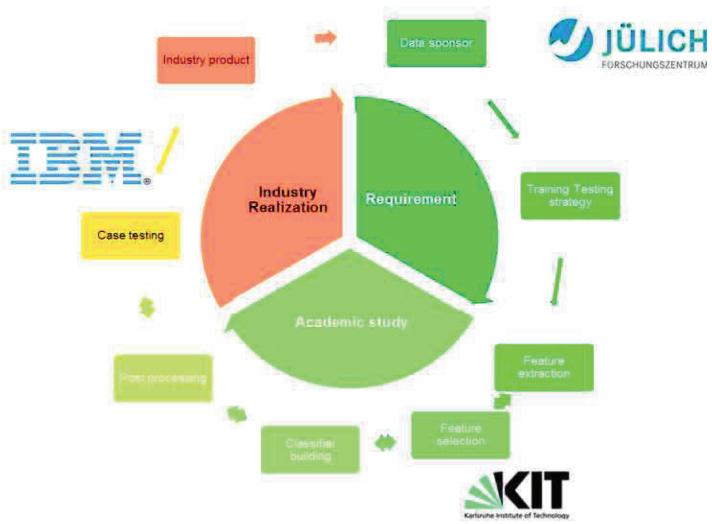

Figure 1.2 Consortium of smart brain project

2.1 Training Testing strategy

Strategy of training and testing laid the basis for each ML project. In order to improve the accuracy of models, classifiers learned by a certain slice are used for classification of neighboring slices. We define the distance between two training slice as scope N, number of training slice needed is 843/N. Training slices must be manually segmented, a large value of scope needs less slices for training, which reducing manual work obviously. In order to balance accuracy and manual work, scope distance is set as 20. Consequently only 5 percent of slices need to be manual segmented by INM1.

As an example, given training slices slice 450 and slice 470, testing scope of slice 450 is from slice 431 to slice 469. Our final generated images of slice 451 to slice 469 are created by classifiers, which trained by slice 450 and slice 470 indiviually.

2.2 Feature extraction

Each pixel is described by RGB values as a basis for feature extraction. We developed four feature extraction methods, which are presented in the following with an emphasis on the developed method based on LCH and linear regression.
First extraction method is filter based extraction method. We utilize three popular denoising filters to describe context information of pixel, i.e. Gaussian filter and two edge preserving filter Bilateral filter and Total Variation filter (C.Tomasi et al, 1998; Ivan W et al, 2010). Second method is the pre-segmentation extraction method. We append three additional image channels with help of Haematoxylin-Eosin-DAB color space (Ruifrok AC et al, 2001). Next feature selection method is used to emphasis edge pixel. Histograms of oriented gradients (HOG) and image entropy are chosen to implement this extraction method (Dalal, N et al, 2005; R.M. Haralick et al, 1985).
Last feature extraction method is based on LCH and linear regression. Main idea of this method is inspired by signal processing method. LCH generates red-green-blue signals of pixel by summarizing information of all pixels within the LCH window. Indeed, uniqueness of signals induces obvious difference between similar pixels, which meet the motivation of enhancing the difference between similar pixels thus improving descriptive ability of features (Figure 2.2).
For each pixel we use a LCH window to extract context information, i.e. the center of this window is the pixel we calculated for. All the pixels in this window serve for providing context information of this central pixel. Scale of LCH window is a critical parameter for the quality of features, since length of this window determines the scope of context information we calculated with. We set width (x’) and length (y’) of our LCH window as 151 with consideration of boundary limitations, i.e. for each pixel we utilize 151*151=22801 pixels to extract context information. In short, we translate feature extraction of pixel to feature extraction of

signals under the assumption that features describe the signals efficiently also describe pixels efficiently.

Intuitively, the peaks of each signal can be regarded as features. We developed a peak finding algorithm (interpolate) and extract the maximal value and interpolate central of peaks as features. Instead of mean value of signal we extract media value for features with consideration of non-repeatability. With the help of Dis-

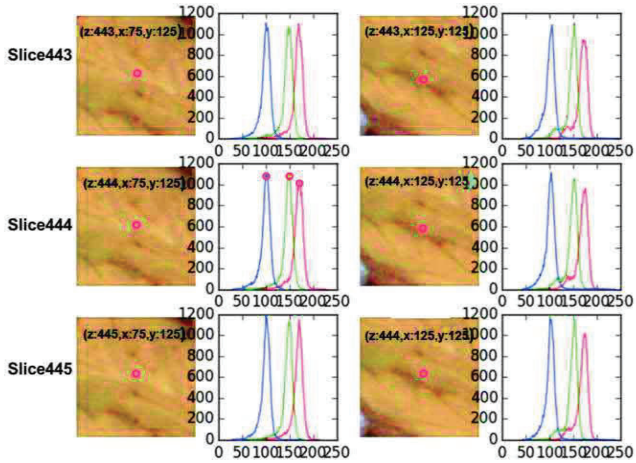

Figure 2.2 Red- green-blue signals of similar pixels

crete Fourier Transformation we utilize the mean amplitude of a specific frequency bands as feature. In conclusion, with described approaches we extract 12 features for red-green -blue signals.

Features extracted from local two color space coordinate system are based on linear regression. Discriminating of linear regression line of each pixel make it plausible that features extracted from linear regression can be served as efficient features. A linear regression line can be described exactly with only two values, or rater slope and intercept. For each pixel we extract 2*3=6 features by implement this approach (Figure 2.2).

We regard the dimension of width of image, length of image and slice stack as x, y, z coordinate system. From the xy plane we extracted 18 features with window size 151*151. For xz and xy plane we extract also 18 features with 151*65 as window size respectively.

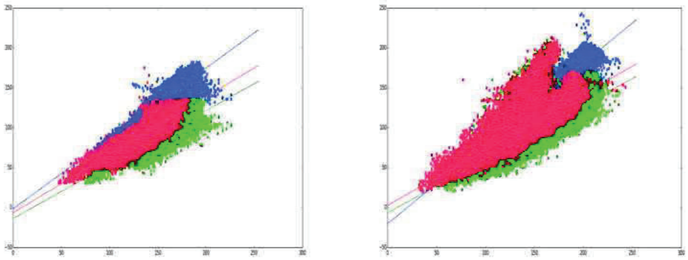

Figure 2.2 Linear regression of two similar pixels

Red-green-blue values are regarded as 3 basic features. We extracted another 81 features based on red-green-blue values. 22 features are extracted by filter based feature extraction algorithm, 3 features are extracted by pre-segmentation extraction method, 2 features are extracted by edge intensify extraction method, LCH provide most of the features, from 3 planes we extracted 54 features (Table 1).

Extraction method	Features number
basic	3
Filter based	22
Pre_segmentaion	3
Edge intensify	2
LCH	54
Total	84

Table 1 Overview of features

2.3 Feature selection

In consideration of loss original feature information widely used dimension reduction methods such as PCA, Autoencoder are not applied. Instead, two feature selection approaches are adopted. Feature filter method is implemented based on statistical test of the analysis of variance (ANOVA) with F-Score as ranking function (N. Elssied et al., 2014). In order to improve the performance of Filter feature selection method we also develop an Ensemble feature selection method, which implement a flexible forward selection strategy.

2.4 Classifier construction

Finding suitable classifiers are very important for testing result. We utilize IBM SPSS Modeler 17.1 to construct classifiers (IBM, 2015). Analytic server 2.1 of SPSS Modeler 17.1 supports Spark integration and provides the possibilities to integrate python and R. Hence, the feature extraction and selection algorithms can be also integrated into SPSS Modeler.

We choose two popular classification algorithms for classifier construction. Random Forrest (RF) is an ensemble learning method by constructing a multitude of decision trees during training time, which correct for decision trees' habit of overfitting (Ho. et al., 1995). Multi-layer perceptron (MLP) is chosen since our feature selection algorithm executes normalization for features. Normalization features proven to be efficient for MLP (Bishop et al., 1995). In order to avoid overfitting of MLP, we develop a method which implement ensemble method by changing topology and validation set of a series of MLPs.

2.5 Post processing method

Developing a method to post process our created image is helpful to improve quality of created images. We develop a post process algorithm for our created image with help of a graph cut algorithm and Gaussian smoothing algorithm (Egil Bae et al. 2009).

3 Preliminary results

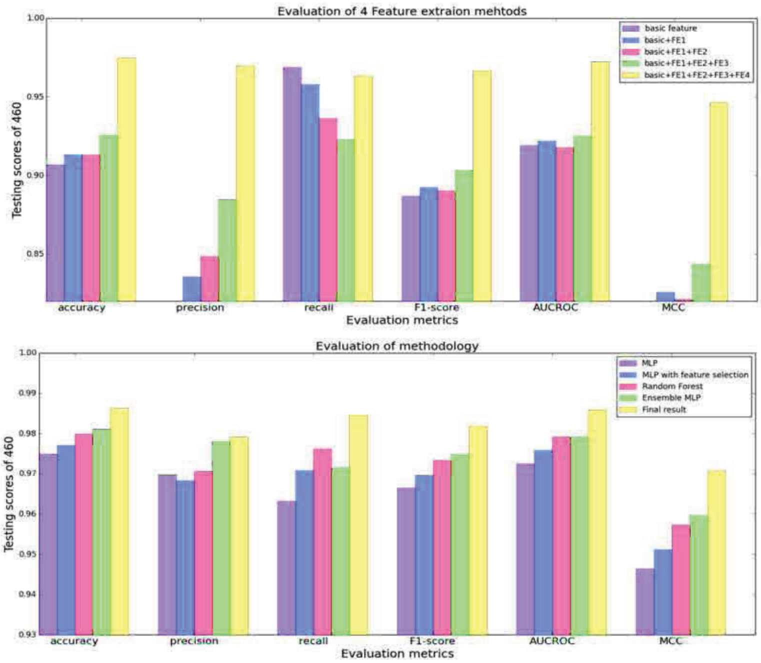

Figure 3.1 Evaluation of feature extraction methods

Preliminary evaluation results are conceived based on a set of 450 slices for training, 460 slices for testing, and the MLP classifier. These results illustrate the performance of those feature extraction methods. Another experiment denotes the final created image following described methodology. We utilize basic evaluation metrics to evaluate our created images, i.e. accuracy, precision, recall, F1-score, AUCROC, MCC.

Among different evaluation criterion features extract by LCH approach played an important role for the feature extraction procedure (Figure 3.1). FE1 denotes filter based method, FE2 denotes pre-segmentation method, FE3 denotes edge intensify method, FE4 denotes LCH based method.

4 Conclusion

This work presented a fourfold Ml approach for classifying areas of brain slice images. First, several feature extraction methods provide efficient features. Features extracted from LCH with help of signal processing and linear regression proven to be efficient that implicit enough contextual information of single pixel. In order to improve performance of classifier, we also utilize two feature selection methods to construct suitable feature vector. A classifier building module two popular classification algorithms RF and MLP is implemented. With purpose of handling of overfitting problem we develop another ensemble MLP classifier with help of IBM SPSS Modeler. Furthermore, post processing of result images is based on the implementation of graph cut algorithms. This provides a new way to combine different classified pixel created image, and proven to be an efficient outlier set reduction method. In conclusion, the initial results are promising and lay the basis for advancing this approach.

5 Acknowledgment

We would like to express our thanks to Dr. Timo Dickscheid and Dr. Stefan Koehnen for their suggestions and help during our research as well as reviewing of our paper. We are also thankful to Prof. Katrin Amunts, Prof. Morris Riedel and Christian Bodenstein for providing the source data, scientific material and allocating INM1 resources. We appreciate the responsiveness and support of the SDIL team, especially Erekle Magradze, Jan Erik Sundermann and Nico Schlitter.

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A smart service for the rheumatological care: Healthcare platform RhePort.de

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Abstract

The goal of the paper is to illustrate an innovative approach of the rheumatological care through smart digital services on an online platform and the establishment of a cross-sectoral network. The online platform RhePort.de will allow earlier diagnosis and treatment of rheumatic diseases, by which the quality of patient treatment will be increased and costs for the healthcare sector significantly reduced. The service platform is currently operating and being evaluated in the German region of Aachen, Dueren, Heinsberg and Moenchengladbach in order to prove increased effectiveness and efficiency of IT-based rheumatological care.

1 Current situation of rheumatic diseases

1.1 Background

Today, there are more than 100 different known symptoms of rheumatism worldwide, causing pain and functional disorders of the human locomotor system. Rheumatic diseases significantly burden the patients as well as the society. About 2% of the population is affected and the economic costs of rheumatic diseases are significant. On average 76% of female patients are declared incapable for work 8 days per month in the first year of illness. 25 - 42% of the patients are retired early during the first four years of a disease, a value that increases to 43 - 85% during the following years (Mau 2004). An early medical treatment may reduce the work disability (ter Wee et al. 2012). The later a treatment begins, the more difficult it is to individualize it to specific patients, resulting in tremendously increased costs. From a societal perspective, the annual indirect costs through lost productivity add up to about 11.222 € per person each year. Additionally, the costs for medication amount to 20.000 € and the costs for the health care system to 4.170 € each year (Boonen et al. 2011; Mau 2004). Even higher costs are possible through surgeries and consequential treatments, which are not included in these numbers yet.

1.2 Problem statement

Rheumatic diseases are often diagnosed in an advanced state. Due to ambiguous symptoms and long waiting times for consultation of a rheumatologist, the entire process takes too long (on average more than 1.1 years from the very first symptoms to a final medical diagnosis). Most serious and irreparable damages occur in the earlier stages of the disease and especially to women (Westhoff, Edelmann, Zink 2009). Many inflammatory rheumatic diseases are - although not curable - treatable nowadays. The earlier the treatment begins, the better are the chances to reach a state, which is similar to a cure of the disease (Schneider/Krueger 2013). Personal consequences of rheumatism could be prevented or at least be reduced and follow-up costs of the therapy could be decreased. For instance, more than half of the cases of rheumatoid arthritis can be stopped with today's options of treatment (Puolakka et al. 2004).

Common reasons for a delayed diagnosis and inadequate treatment are the limited level of awareness of rheumatism, the specific symptoms and consequences of the disease, the often delayed medical care due to lack of specialists, the insufficient prioritization/organization of the medical referral to a specialist, and discontinuous long-term care.

Despite the need for easy assessment, rapid appointment scheduling, precise diagnosis and efficient patient-centered treatment, today's health and patient care system is dominated by horizontally aligned "silos" for physical and digital service provision. These closed systems prevent cooperation between the stakeholders on the cost of the patient. (Kagermann et al. 2015; Kaplan 2015; Bates et al. 2010). IT- based health care is a promossing approach to address these problems.

2 IT-based healthcare services

Connected healthcare service platforms enable improved diagnostics and patient-care through the generation of Big Data and the utilization of individual patient treatment. Furthermore, easy and secure data-sharing across the healthcare ecosystem enables patients, insurance companies and doctors to exchance information efficiently and collaborate in real-time (Kagermann et al. 2015). In doing so, the information flow is improved between different stakeholders within the patients care pathway (Görlitz, 2014). This environment is simultaneousely a fertile soil for the establishment of additional providers that offer specific knowledge (i. e. the evaluation of X-ray-images) as a service to the relevant stakeholders (Kagermann et al. 2015).

An IT based Community seems to be a promising approach in order to use available resources efficiently, to transform tacit knowledge into tangible knowledge as well as to realize a modern network of supply structures. Within the discipline of rheumatism, there are no known established IT-based based communities, which focus on the improvement of early diagnosis. Besides Scheibe et al. (2015), who developed an electronic referral system, which focuses on the use of pre-consultation exchange of information through IT support systems. Moreover, the mobile application of Rheumabuddy.com assists patients on tracking treatment information of the disease itself in a diary (e.g. pain barometer), but these services are not connected to physiscans. The deficits of a missing IT-based approach to improve early diagnosis of the disease will be addressed by the RhePort.de plattform in an innovative and patient-centered way.

3 RhePort.de as a digital marketplace for rheumatism care

For these reasons the development of RhePort.de - Rheumatism Portal of the 21th century system - was sponsored by means of the European Union (Ziel2-Program) and the Ministry of Health, Equalities, Care and Ageing (MGEPA) of the state North Rhine-Westphalia. Enabled by platform technologies, the objectives of RhePort.de are to:

- diagnose the illness during an early stage, start therapy quickly and effectively and establish a coordinated acute-management to minimize the activity of the rheumatic disease,
- minimize the physical and mental interferences and avoid consequential damages,
- limit the high financial burden on the health and social care system, e. g. by avoiding expensive therapies during a difficult and severe course of the disease, limit incapacity to work and early retirement,
- indicate the gender specific effects of the rheumatic disease, apply adequate therapies and help patients to reduce negative consequences.

The online platform RhePort.de is based on two pillars (see Figure 1). Patients as well as primary care providers are able to use **RPAS** (Rheumatism Patient Assistant System) in order to receive general information, concerning the record of symptoms and discomfort to provide a direct diagnostic screening. Based on obtained knowledge and a developed algorithm, an allocation service quickly forwards patients to a rheumatism specialist within the local network. Comprehensive information about the patients completes the service.

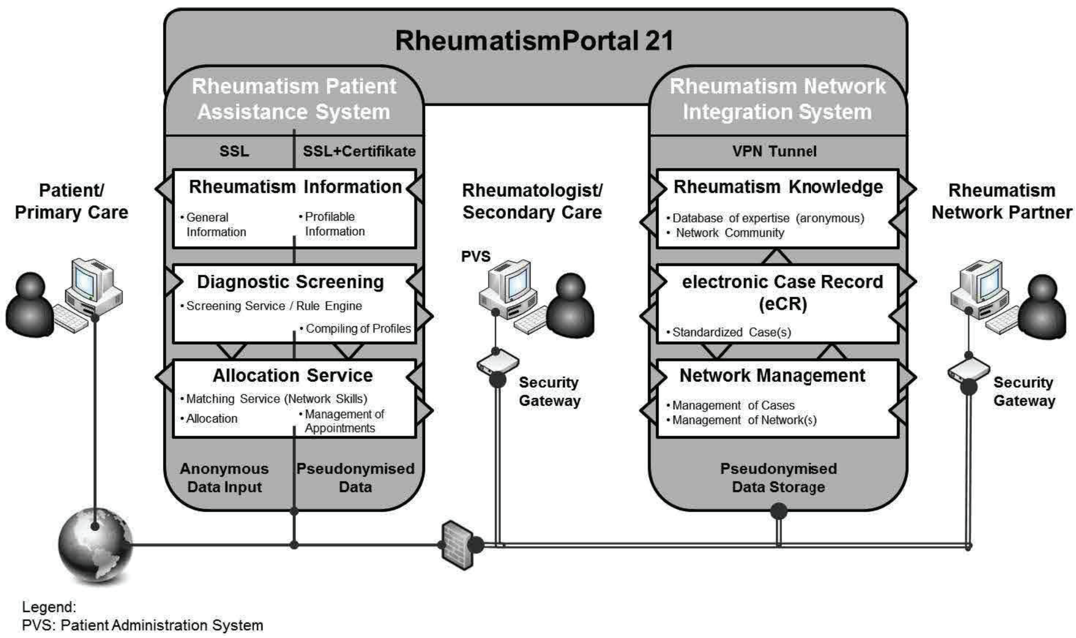

Figure 1: Schematic representation of the platform RhePort.de

Simultaneously, with **RNIS** (Rheumatism Network Integration System) the workflow and cooperation within the local network is improved. Substantial elements of the project were the development and deployment of an electronic Case Record (eCR), as well as a comprehensive support for the Community Management, especially for problems concerning rheumatology. Furthermore, a database about rheumatism knowledge was established. Medical examination and therapy methods are beeing discussed and agreed on by rheumatism experts. The upcoming paragraphs will describe the three main elements of RhePort.de briefly.

Diagnostic Screening: The screening function is a standardized, understandable and interactive procedure to record symptoms and discomfort (symptom guide). A questionnaire was developed as a self-assesment-tool by a working group of various rheumatologists, which is used to support the diagnostic and which is accessible to all patients and primary care providers for free. The online questionnaire and tool support systematic prevention as well as the early diagnosis screenings. During an interactive dialogue with the physician, the information is also used for medical assistance and appointments on-site.

Allocation Service: Based on the questionnaire, the patient is allocated into one of three categories, which shows the probability of the disease (e.g. group of patients with very high risk of rheumatoid diseases, group of patients without rheumatoid diseases, group of uncertain patient cases). In case of suspected rheumatism disease (or unsure cases), the patient automatically receives a list of short-term appointments for a rheumatism specialist (matching service) online, from which the patient can select an appointment. Parameters such as urgency, appointment availability and location of the patient are taken into account. Therefore a fast, early and valid diagnosis followed by an adequate therapy is achieved (appointment within 48 hours). First results show that the speed of the diagnosis is improved dramatically by this allocation service compared to the status quo in the german health care system. Based on the registration with only an email-address and a telephone number, only anonymized patient data is available. The possibility to add and publish additional health care data anonymously, taking the data protection into account, is very important for the RhePort.de concept. For this reason a security architecture is implemented (e. g. methods of pseudonomic encryption, authentication, authorization and performance assurance), which focuses primarily on specifications of eCR (electronic Case Record) and KV-SafeNet (interface of the association of panel doctors).

Electronic Case Record: In order to improve the collaboration and procedure of the various treatments within the rheumatism network, the development and implementation of a rheumatism specific medical electronic case record, consistent with the eCR standards, is crucial. Under consideration of scientific quality standards, eCR consistent pseudonomic medical case records were created. Only authorized rheumatology specialists within the network can access this data. A case record contains patient information concerning diagnosis, therapy and progress of the disease. The documents are developed for the RhePort.de community and all medical partners are connected to the online community.

The main characteristic of multi-sided communities is to connect different, but dependent groups of clients with each other. The creation of additional value between those groups is the main idea of Rheport.de. Among an automated appointment and an electronic case record system, the community also distributes various information to patients on one side and physicians on the other side. Thus, network effects are crucial for this approach. The more participants are registered, the more value can be gained.

4 Discussion and outlook

After going live in February 2015, first results of RhePort.de could be evaluated successfully. At the time of November 2015, voluntarily there are 32 physicians connected to RhePort.de from the above mentioned region. Within the first nine months 464 patients registered on the platform with over 460 allocated appointments at the rheumatologist. A first evaluation shows that approximately one third of all allocated patients were affected by rheumatism and were successfully helped by RhePort.de.

Further medical and statistical evaluation is still ongoing until end of 2016. The questionnaire has been updated in order to clarify missunderstandings from the patients' side. In the second phase of the evaluation an A-B study is conducted with patients who entered from RhePort.de compared to patients who started treatment by medical referral, which is common in Germany. Furthermore, male and female patients from various age segments and different regions are compared. The main question is, wheather RhePort.de can successfully reduce the time between the first patient complaint and the diagnosis through a physician. Studies prove that the patients' quality of life increases inversely proportional to this period of time (Mau 2004). Nevertheless, it is apparent that the approach of using an integrative healthcare service platform like RhePort.de is a great chance to enhance rheumatology care in the 21th century.

For the future it is plannend to increase the area of coverage and also add new value added services, like automated letters of physicians in order to co-found the network. Focus points for the future are: Scalability - enlarge stakeholder groups (e. g. health insurance funds, more physicians or pharma studies, etc.), Connectivity - add new functionality for smart devices (e. g. automated letters of physicians, apps to document pain of patients like rheumabuddy.com, integration of activity and movement trackers, etc.), Interoparability - use and license the platform to other medical disciplines (e. g. urogoly) in order to enhance a business model for RhePort.de.

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German data sets for comparing ambulance location models

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Abstract

Ambulance planning includes the problems of locating ambulances and bases as well as relocating ambulances throughout the day. Especially for determining (optimal) ambulance locations many different models and approaches exist. Most of them are presented for a special country or region. It would be interesting to study how they perform for other regions, especially for Germany. For doing so, a set of instances is needed that includes different characteristics. We therefore discuss accessible data and present a set of instances derived for Germany.

Keywords: Health Services, Ambulance Planning, Data Sets

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1. Introduction

For each Emergency Medical Service (EMS) system, the location of ambulances and bases is crucial for the main task of helping patients as soon as possible in case of an emergency. Operations Research can help finding good (optimal) locations with regard to an objective. Often, the (main) objective is to maximize the coverage. A demand location is usually called covered by a base location if it can be reached within a maximum time. Other objectives minimize the costs or maximize the survival probabilities.

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The first model to locate ambulance bases was introduced by Toregas et al. (1971). The Location Set Covering Model (LSCM) determine the minimum required number of bases as well as their locations to cover the entire region within a fixed time threshold. Church and ReVelle (1974) presented the Maximum Coverage Location Problem (MCLP) to maximize the coverage assuming a limited number of bases. Another important model is the Maximum Expected Coverage Location Problem (MEXCLP) by Daskin (1983) that explicitly takes the coverage depending on the expected busyness of every ambulance into account.

Relocation approaches are applied at the operational level of EMS planning. Gendreau et al. (2001) proposed one of the first real-time ambulance location models. Depending on the current state of the system good relocations are determined by solving a location approach that uses two coverage standards. Gendreau et al. (2006) published a similar approach that bases on the MEXCLP instead.

Many models assume an underlying graph with nodes representing demand and possible base locations. Edges are weighted by the driving times between the nodes. Other approaches assume a grid structure for the underlying city/region. It means that the city or region is divided into equally sized squares, e.g. of 1 km^2. Each square presents a demand location and a subset contains the potential base/ambulance locations. Often, Euclidean distances are used for these approaches and distances are measured between the centers of the squares. For example, Chanta et al. (2014) presented a bi-objective coverage location model that is solved for a data set with grid structure. Also, several relocation approaches base on a grid structure, as for example the multiperiod set covering location model for dynamic redeployment of ambulances by Rajagopalan et al. (2008).

To the best of our knowledge, only Ingolfsson has published EMS data, in this case for the EMS system in Edmonton that he used for his research. It is one (large) instance consisting of 180 demand nodes and 16 base location. The data set includes the following information: (1) the average busy time for ambulances (in seconds), (2) the average number of calls for each demand node, for each station-demand node pair (3) the average response times (in seconds), (4) the standard deviation of response times (in seconds), (5) and the deterministic coverage for an 8-minute threshold (as 0 or 1), (6) the survival probability for deterministic response times, (7) the expected coverage for probabilistic response times for an 8-minute threshold, (8) the survival probability for probabilistic response times, and (9) the capacities for each station (as the maximum number of ambulances).

Often, models are fitted to the concrete problem they were developed for which means also for the considered EMS system (country). This also involves the underlying structure, i.e. network or grid. It is unclear if a model that performs well for a grid-based instance is also good for a network instance and vice versa.

To study this instances must be available in both structures. To the best of our knowledge, these "double-structure instances" have not been presented so far.

One problem is that if the grid structure is not given, but must be defined first, this can be very challenging. This is especially true fur rural areas with small villages while for a city the grid structure seems more suitable. Figure 1 shows three possible arrangements of a demand location (e.g. a village) in a grid. Cases a) and b) show what often happened when we tried to put a grid over a rural area and case c) represents the ideal situation that we would want. In case a) the center of the square is near the center of the demand location, but small parts of demand location are situated in the adjacent squares. This means the distance calculation is acceptable but the demand is not well represented in the grid. In case b) the demand location is distributed on several squares evenly, but the center of the squares are not representing the actual position of the demand location. This not satisfactory for the distance calculation. In case c) the demand location is perfectly centered in only one of the squares, therefore we get an optimal representation of the demand location with the center of the demand location being used for the distance calculations. Note that also the size of the squares could vary. Often, 1 km^2 is chosen as this makes computations easy. But in some cases, this might be too small (e.g. for very large regions this would lead to too many squares) whilst in others it might be to large (e.g. when cities have a very fine structure or when rural areas consist of only very small villages).

One last aspect that we want to take into account for building the instances is that different internal city structures exist. Figure 2 presents three types of internal city structures. The concentric zone model is basically a generalization for cities. It was the first model to be published by Burgess (1967). Chicago is a well-known example. The sector model was published by Hoyt

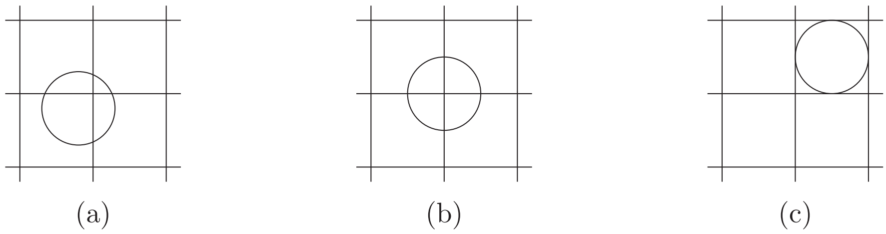


Figure 1: Grid structures

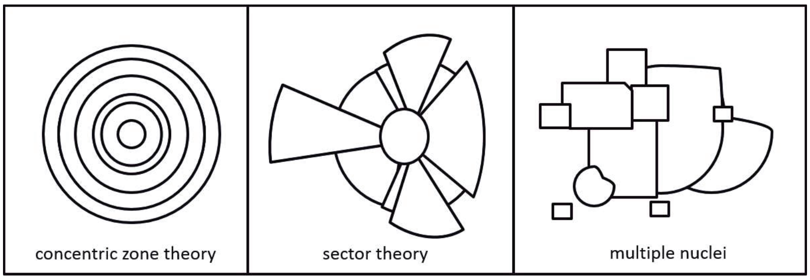


Figure 2: Generalization of internal structure of cities [Harris and Ullman (1945)]

(1939). With this model the arrangement of the sectors varies from city to city. The multiple nuclei model by Harris and Ullman (1945) represents many cities quite nicely. Figure 2 shows only one possible pattern among innumerable variations.

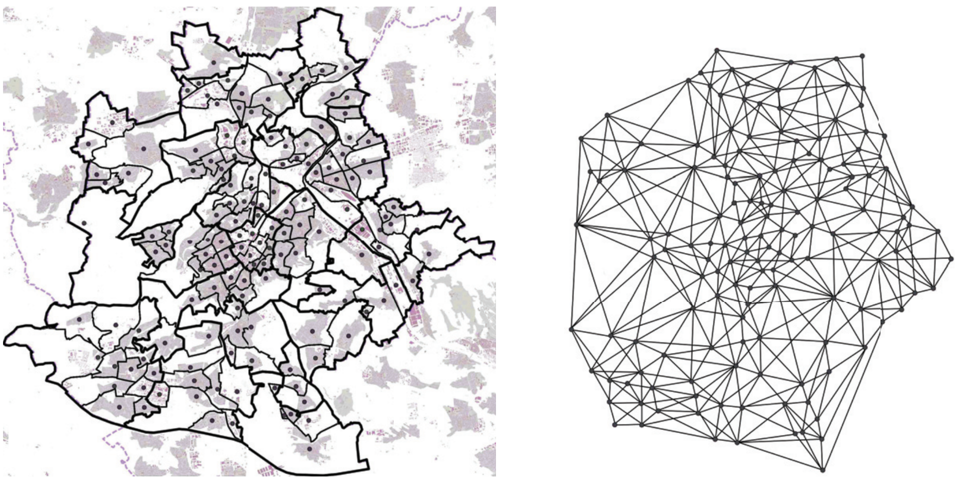
Examples for the three models in Germany are (1) Düsseldorf, (2) Hamburg and (3) Berlin.

2. German EMS Instances

The data set we developed contains instances with the network and the grid structure for cities as well as rural ares. The demand for the nodes/ squares is first expressed as the number of inhabitants. For the network structure, the inhabitants per district were used. For the grid structure, the inhabitants had to be divided between the squares first. We assume a linear relation between the number of inhabitants and the expected demand and can therefore also assign single values for the demand.

We built instances with a grid structure for cities of Stuttgart, Karlsruhe, Freiburg, Düsseldorf, Hamburg and Berlin. Distances between squares were calculated with the l2-metric and each square was indicated by its center.

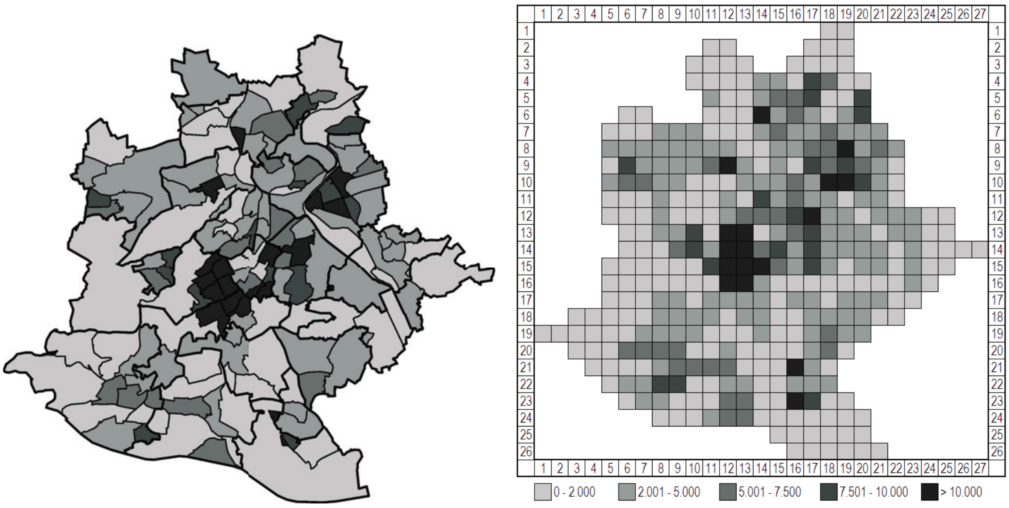
Instances with a network structure were developed for: the city of Stuttgart, the city and county of Karlsruhe, the city of Freiburg and the county of Breisgau-Hochschwarzwald, the cities of Heidelberg, Mannheim and the county of Rhein-Neckar and the county of Schwarzwald-Baar as representative of a rural region. For these instances the position of buildings and residential areas indicated by OpenStreetMap were utilized to pinpoint a suitable location of the demand node in the network. We needed exact coordinates for the representatives of the districts/nodes to calculate distances using the Google Distance Matrix API.



(a) Map and districts (b) Network structure

Figure 3: Stuttgart - network instance

Figures 3 and 4 show both structures for the city of Stuttgart. First, we have the city map showing the 148 districts and the chosen representation points. These points then form the network. Note that for determining the arcs several possibilities exist: (1) all nodes are connected which makes the network often quite large, (2) only those nodes are connected that can directly be reached from one another or (3) an edge is only drawn if a node can be reached from the other within the given response time. Figure 3 b) shows only a subset of the 3225 edges for case (3) (when assuming a maximum driving time of 15 minutes) to make the general structure of the network



(a) Population density (b) Grid structure

Figure 4: Stuttgart - grid-based instance

visible. For the grid structure we first coloured the districts depending on the population density and then fixed the grid structure. The demand was then set according to the population density in each square.

Other parameters that describe the instances include: (1) the possible locations for bases; either all demand locations are feasible, e.g. for a completely new analysis of the considered region or only a subset of nodes/squares is available. As far as we got the information we incorporated already built bases and reasonable new locations, e.g. large parking lots or empty spaces. (2) The number of emergency medical vehicles, in total and for each possible base location separately. (3) The time threshold(s) for the response time. (4) Further parameters that are only needed for a subset of models as busy fraction(s), service level(s) and reliability factors.

3. Conclusion and Outlook

In this paper we have explained the need for data sets in order to compare approaches for ambulance planning. We have discussed accessible data and presented a set of instances for several German cities and regions. They cover both the network and the grid structure. As some instances are developed for both structures, it is possible to compare approaches that use either one of the structures.

An obvious next step is now to use the instances to test and compare different approaches for the location and relocation of ambulances. Additionally, we want to send the instances to the coordination centers in charge to hopefully get some feedback on how good we modeled practice with our instances.

It would be nice to also include the information on emergency doctors (their locations and numbers) and build models and/or simulations that explicitly take both, ambulances and emergency doctors, into account.

Once we successfully used the instances to compare approaches and studied their applicability for Germany, we plan to make the instances accessible.

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Modeling Indirect Waiting Times with an M/D/1/K/N Queue

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Abstract

Indirect waiting times or access times of patients are an important indicator for the quality of care of a physician. Indirect waiting times are influenced by the panel size, i.e., the number of patients regularly visiting the physician. To study the nature of this influence we develop an M/D/1/K/N queueing model where we include no-shows and rescheduling. In contrast to previous work, we assume that panel patients do not make new appointments if they are already waiting. For a given panel size we calculate the steady state probabilities for the indirect queue length and further aspects such as the effective arrival rate of patients. We compare those results to the outcomes of a simulation and show that the simplifications we used in the analytical model are verified. The queueing model can help physicians to decide on a panel size threshold in order to maintain a predefined service level with respect to indirect waiting times.

Keywords: Health Services, Panel Size, Traditional Appointment Policy, Access Time, No-shows, Queueing Model

1. Introduction

Appointment planning matches patient demand and health care provider supply. Good reviews of this research area can be found in (Cayirli and Veral,

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2009) and (Gupta and Denton, 2008). A more recent review of online appointment planning can be found in Chapter 2 of the PhD thesis (Braaksma, 2015).
Patients can stay informed about health care providers for example through evaluation portals. Hence, there is an incentive for doctors to pay more attention to service aspects such as waiting times. In this paper, we focus on the indirect waiting time or access time, defined as the elapsed time between the moment the appointment is made and the actual appointment time. Long indirect waiting times can lead to a deterioration in patients' health. Some studies also show that they may increase the probability of a patient being a no-show (Gallucci et al., 2005). Consequently, doctors should reduce their indirect waiting times in order to deliver better service to patients and avoid idle time.
For our investigation, we assume that each doctor has a panel, i.e., a group of patients who visit on a regular basis. We also assume that all the demand comes from that panel. The doctor could fix an indirect waiting time service level; e.g., on average, patients should not wait more than two weeks for treatment. Then, the doctor must manage the size of the panel in order to achieve this service level.
Our aim is to model the scheduled appointment queue in order to relate panel sizes to indirect waiting times.

2. Literature

The model presented in this paper is based on one of the models of (Green and Savin, 2008). They present two queuing models (M/D/1/K and M/M/1/K) in order to link the panel size with the average indirect queue length. They assume that appointment requests are only coming from the panel and that they come with a constant rate which is independent of the indirect queue length. Their aim is to find panel sizes which allow the doctor to implement an open access policy where patients can only make appointments for the same day. They presume that an open access system can be installed if the expected probability of getting a same day appointment for a patient is above a certain threshold, e.g., 80%. This means that 80% of the time the indirect queue length is shorter than a day. Given the threshold, an upper bound for the panel size can then be determined.
In (Liu and Ziya, 2014) they decide about the panel size and the offered

capacity in order to maximize profit. There is a fixed reward for treating a patient and they assume costs for overtime.
In (Zacharias and Armony, 2013) both direct and indirect waiting times are considered. Again decisions on panel sizes and capacities offered are made in order to maximize profit.
Further, we mention (Balasubramanian et al., 2010) and (Ozen and Balasubramanian, 2013) where patients are divided into groups representing different demands, e.g., average number of appointment requests per year. In a multi-provider clinic patients can then be relocated from one doctor panel to another in order to achieve a workload balance between the doctors such that a minimum number of patients have to change their doctor.
In contrast to (Green and Savin, 2008), we also want to investigate indirect queues of doctors that operate under a traditional appointment policy, i.e., every patient has to make an appointment in a given planning horizon. In general, the panel sizes under consideration can be bigger than those suitable for open access as waiting times greater than one day are allowed. But then a substantial part of the panel might be waiting in the indirect queue. Assuming that patients waiting do not make new appointments makes it necessary to make the demand rate dependent on the indirect queue length. Hence, our contribution is to extend the model of (Green and Savin, 2008) in order to include the analysis of traditional appointment systems.

3. Model

We present a queueing model and a simulation model which extend the M/D/1/K queueing model and the simulation model presented in (Green and Savin, 2008). We assume a single server queue modeling the appointment schedule and therefore the indirect waiting time. Here, we assume that appointment requests are only coming from the panel and that patients always accept the next available appointment. The difference to (Green and Savin, 2008) is that we assume that patients waiting in the queue will not make new appointments whereas in (Green and Savin, 2008) the rate of appointment requests is constant independent of the queue length. We will use the same notation as in (Green and Savin, 2008). We assume that the doctor can treat a fixed number of patients every day and therefore we assume deterministic service times of length T. By λ we denote the individual patient appointment request rate. We approximate the arrival process for every service period as a Poisson process with a parameter dependent on the number of panel patients not waiting or getting treatment. Therefore, the panel size being N, we define $\alpha_i(k) = \frac{(\lambda(N-i)T)^k}{k!}e^{-\lambda(N-i)T}$ as the (approximate) probability that k patients arrive during a service period given that i patients are in the system (waiting or getting treatment). Further, we assume a finite queue capacity of K (corresponding to a finite booking horizon). Following the notation of (Osaki, 1992, p. 233) we denote our model as an M/D/1/K/N queue.

As in (Green and Savin, 2008) we will use a no-show function γ which gives the now-show probability of patients dependent on their indirect waiting time. For tractability reasons we calculate the no-show probability based on the queue length at the time of a patient's treatment rather than on his or her time of arrival. In addition, no-shows will schedule a new appointment with probability r.

With a similar argumentation as in (Green and Savin, 2008), we derive analytical expressions for the stationary distribution of the number of patients in the system, $\pi(k)$ being the probability that $k = 0, \ldots, K$ are in the system. We use $\rho = \lambda NT$.

Proposition 1. *The stationary distribution of the number of patients in the system is given by*

$$\begin{aligned}
\pi(0) =& \frac{1 - r\gamma(K)}{1 - r\gamma(K) + \rho(\sum_{i=0}^{K-1} f(i)) - r\sum_{i=1}^{K-1}(\gamma(K) - \gamma(i))f(i)} \\
\pi(k) =& \frac{(1 - r\gamma(K))f(k)\frac{N}{N-k}}{1 - r\gamma(K) + \rho(\sum_{i=0}^{K-1} f(i)) - r\sum_{i=1}^{K-1}(\gamma(K) - \gamma(i))f(i)}, \\
k =& 1, \ldots, K-1 \\
\pi(K) =& 1 - \frac{(1 - r\gamma(K))(\sum_{i=0}^{K-1} f(i)\frac{N}{N-k})}{1 - r\gamma(K) + \rho(\sum_{i=0}^{K-1} f(i)) - r\sum_{i=1}^{K-1}(\gamma(K) - \gamma(i))f(i)}
\end{aligned}$$

where $f(k)$ is a recursion with

$$\begin{aligned}
f(0) &= 1 \\
f(1) &= \frac{1}{(1 - r\gamma(0))\alpha_0(0)} - 1 = \frac{e^{\rho}}{1 - r\gamma(0)} - 1
\end{aligned}$$

$$f(k+1) = \frac{1}{(1-r\gamma(k))\alpha_{k+1}(0)}(f(k) - (1-r\gamma(k))\alpha_0(k) - r\gamma(k-1)\alpha_0(k-1)) - \frac{1}{(1-r\gamma(k))\alpha_{k+1}(0)}(\sum_{i=1}^{k}((1-r\gamma(k))\alpha_i(k+1-i) + r\gamma(k-1)\alpha_i(k-i))f(i)),$$
$$k = 1, \ldots, K-2$$

We also build a simulation model again following (Green and Savin, 2008) in order to avoid the approximation we used employing the no-show function. Further, the arrival process can be approximated by a binomially distributed random number for every service period. This way we do not make an approximation error for cases when almost the whole population is waiting in the queue. Moreover, as in (Green and Savin, 2008) the assumption that every patient accepts the next free appointment can be relaxed.

4. Numerical Experiments

We use the same parameter settings (see Table 1) as in (Green and Savin, 2008). We assume 20 appointment slots per day.

Parameter	Definition	Value
K	Queue capacity	400
λ	Individual arrival rate	$\frac{0.008}{day}$
T	Service time	$0.05\,days$
r	Rescheduling probability	1
γ_0	Min no-show probability	0.01
γ_{max}	Max no-show probability	0.31
C	Sensitivity parameter	$50\,days$

Table 1: Parameter settings

We also use the same no-show function: $\gamma(k) = \gamma_{max} - (\gamma_{max} - \gamma_0)e^{-\lfloor kT \rfloor / C}$ where k is the queue length and $\gamma(k)$ the probability of being a no-show. In Figure 1 the average queue length dependent on the panel size is depicted for different models.

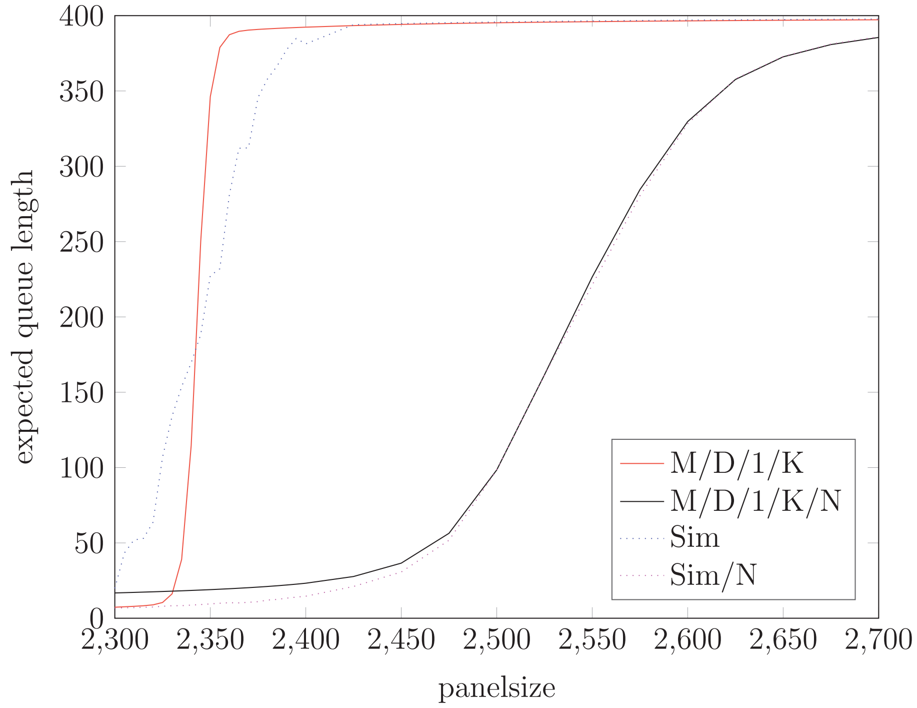

Figure 1: Expected queue length for different panel sizes for the two models and the corresponding simulations

The models M/D/1/K and Sim correspond to the models from (Green and Savin, 2008) whereas the models M/D/1/K/N and Sim/N correspond to the models presented in this paper. Both simulations started with an empty queue and were simulated for 40000 warm-up periods (corresponding to 7 years) and 10000 more periods to collect data. The implementation is based on (Koza, 2014). First, our results for the M/D/1/K model differ slightly from the results presented in (Green and Savin, 2008). The fundamental behavior of the curve is the same but the transition from an almost empty to an almost full schedule happens for bigger panel sizes. Comparing the different model approaches, the increase of the M/D/1/K curve is much steeper and happens for smaller panel sizes than the increase of the M/D/1/K/N curve. Further, we see that the difference between the results of the analytical model and the simulation are much smaller in our case.

It is also interesting to note that the queue length distributions are fundamentally different between M/D/1/K and M/D/1/K/N. In Figure 2 queue length distributions with an expected queue length of circa 200 for the two models are depicted. For the two models this expected queue length is attained for different panel sizes.

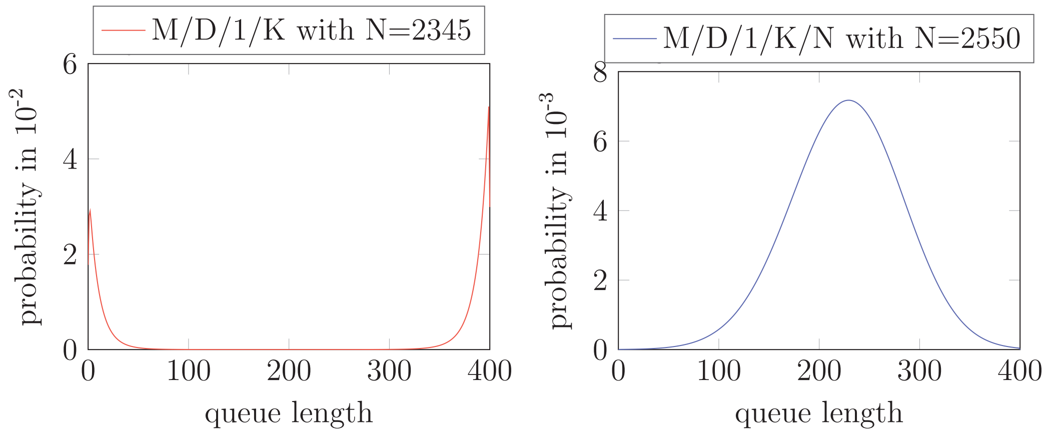

Figure 2: Queue length distributions in comparison

In our model the queue length will most likely be found around the expected value whereas for the M/D/1/K model the queue length oscillates between empty and full which is of course an unattractive behavior. It can be shown with the simulation that the initial queue length has a great influence on the queue length even after a lot of simulation periods because the queue either tends to a fully booked schedule or to an empty schedule and then stays there for a long time.
By rate we denote the request rate only generated by the patients not waiting or rescheduling. We assume that patients in the indirect queue do not make new appointments. That means that for long indirect queues patients in the queue do not make appointments but they would if they were not already waiting. We call this the hidden demand. Hence, the demand seems smaller than it should actually be. Conversely, due to the effect of rescheduling (also more prominent for long indirect queues) there is an extra demand in addition to the rate leading to a higher effective demand rate. Moreover, it is important to note that patients get rejected when the indirect queue is very long. In Table 2 we quantify those effects for different panel sizes. The calculations of the effects are based on the analytical model.

Effect/Panel size	2500	2600	2700	2800
Average rate	19.21	18.16	18.52	19.26
Average hidden demand rate	0.79	2.64	3.08	3.14
Average effective rate	19.97	20.04	20.63	21.41
Proportion of rejected patients	0.00	0.00	0.03	0.07
Proportion of no-shows	0.04	0.09	0.11	0.11

Table 2: Effects for different panel sizes, rates are measured per day

As you can see in Table 2, the average rate does not change much for large panel sizes but the effective rate increases due to the increasing proportion of no-shows that reschedule. In addition, the hidden demand rate increases substantially and the proportion of rejected patients is significant starting from a panel size of around 2600. This shows that a doctor should not only consider the average indirect waiting time but also the proportion of rejected patients and the hidden demand rate as those are indicators for a possible lack of care.

5. Conclusion and Outlook

We present a queueing model and a simulation model in order to connect panel sizes with the distribution of indirect waiting times. The model can help doctors operating under the traditional appointment policy to decide about a maximal panel size in order to achieve a service level with respect to their indirect waiting times and other effects such as the proportion of rejected patients and the hidden demand rate. Mathematically, the contribution of this paper is the analytical distribution of an M/D/1/K/N queue where the arrival rate is dependent on the queue length.
Possible future work on the model include a sensitivity analysis for the model parameters and numerical experiments considering measures such as seeing a given share of the patients in a fixed time period. Then, other patient behaviors such as balking, rescheduling directly (even if not being a no-show) if the queue is very long or leaving the panel because of long indirect waiting times could be integrated. Moreover, patients could book several appointments at a time. They may not always book the next available appointment. In general, physicians do not operate under a purely traditional appointment system (only patients with appointments are treated) but also allow for walk-ins, e.g., urgent cases. This option should be included in the model

considering that the longer the indirect queue the more likely patients will just walk-in. Furthermore, the idea of (Balasubramanian et al., 2010) and (Ozen and Balasubramanian, 2013) that patients belong to different demand groups could be integrated. Then, not only the panel size but also the case mix is relevant. In addition, the model could be extended to a vacation queueing system as in (Creemers and Lambrecht, 2009a) and (Creemers and Lambrecht, 2009b).

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Performance evaluation of closed-loop logistics systems with generally distributed service times

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Abstract

The performance evaluation of hospital logistics is becoming more and more important to guarantee efficient services in health establishments. Therefore, we propose a new discrete-time approach for the steady-state analysis of closed-loop queueing systems with arbitrary topology and generally distributed service times. Based on a finite Markov chain, it is possible to compute the complete cycle time distribution of service systems with a population constraint. In addition, the distribution of the number of customers at each service station can be obtained. The method is applied to the analysis of a sterilization process of medical devices. To verify the method, we compare the results of our discrete-time approach to the results that are obtained by a simulation model.

Keywords: Performance evaluation, Queueing networks, Closed-loop, General service process, Cycle time distribution, Hospital logistics

1. Introduction

As health establishments are faced with growing health expenses, more and more research is done in order to make service processes more efficient. Therefore, some authors started with the performance analysis of support services

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in health establishments, e.g., the sterilization of medical devices. Starting with a simulation model of a generic sterilization process (see Di Mascolo et al. (2009)), analytical methods which were previously used to analyze the material flow in production systems, were applied to analyze the sterilization service in health establishments (see Matzka (2011), Stoll and Di Mascolo (2013)). Discrete-time queueing models have been used as a method to achieve a fast and quite accurate way of determining performance figures of service systems. While with classical general queueing models in continuous-time domain, characteristic values are calculated only on the basis of means and variances (for a detailed overview of methods for closed queueing networks see Lagershausen (2012)), in discrete-time modeling all input and output variables are described with discrete probability distributions. This enables the derivation of quantiles of performance measures, which are often needed for the design of logistics systems.

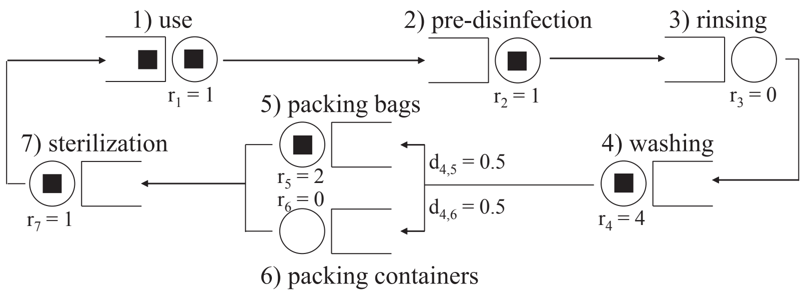

Figure 1: Representation of a sterilization process (see Matzka (2011)) as a closed queueing system

In the previous works, the sterilization process was modeled as an open discrete-time queueing network, as the according discrete-time queueing models were only applicable to open networks (see Matzka (2011), Stoll and Di Mascolo (2013)). As the sterilization process becomes a loop when the use-step is integrated (see figure 1), a more realistic model is achieved, when the sterilization of medical devices is modeled as a closed queueing network. In this paper, we present a method for the performance evaluation of closed-loop queueing systems in discrete-time domain with generally distributed service times that can be used to analyze the sterilization process of health establishments.

2. System description

The system under investigation is a closed queueing system in discrete-time domain with arbitrary topology. It consists of V stations with one server and one waiting room each, as well as $\hat{K}$ customers that circulate in the system. The routing of the customers to the subsequent stations depends on the routing matrix D. Its generic element $d_{h,i}$ defines the probability to be routed from station h to station i. The system is observed at equally spaced time periods with a length of t_{inc}. It is assumed that the beginning and the end of service as well as the routing to the subsequent stations take place immediately prior to the periods. The customers that cannot be processed immediately stay in the waiting room, which has infinite queueing capacities, and are served based on a first come first serve discipline. The service time at station i is assumed to be independent and identically distributed (i.i.d.) according to the random variable B_i, where $b_{i,j}$ denotes the probability that B_i takes value j. Furthermore, the service time distributions have finite upper supports $b_{i,max}$. The performance measures of interest are the distribution of the number of customers K_i in the stations at random periods and the total cycle time distribution S through the system starting from station $\hat{i}$, i.e., that for each customer the entry in that station determines the end of the current cycle time and the beginning of a new one. A closed queueing system, which will be used in the following section to clarify the algorithm to determine the performance measures, is depicted in figure 2.

3. Computation of the performance measures

3.1. Steady-state probability computation

To obtain the performance measures, a finite Markov chain which governs the behavior of the system by $2 \cdot V$ parameters is created. V parameters k_i are needed to define the number of customers at each station and V more r_i to define the residual time of their currently served customer ($r_i = 0$ if there are no customers in the i^{th} station). As a result, a system state can be represented as follows:

$$\begin{gathered} z = (\ r_1\ r_2\ ...\ r_V \quad k_1\ k_2\ ...\ k_V\ ) \\ \text{with } r_i \in \{0, 1, ..., b_{i,max}\}, k_i \in \{0, 1, ..., \hat{K}\}, i \in \{1, ..., V\} \end{gathered} \tag{1}$$

For example, the system state of the queueing network depicted in figure 2, is defined by $z = (\ 1\ 1\ 1\ 1\ )$.

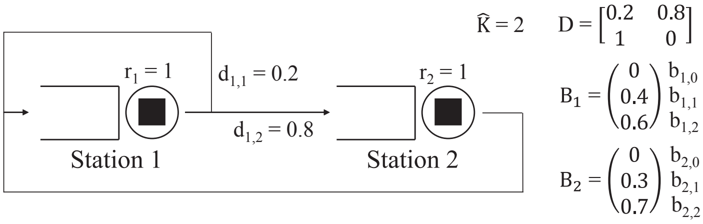

Figure 2: Example of a closed queueing system

The possible system states are determined iteratively by starting from one initial possible state and by computing all the possible states for the next time period. In particular, the beginning of a new time period reduces the residual time of each customer in service by 1 and the end of the service (r_i from 1 to 0) leads to a customer transition to a subsequent station. If a new service starts, the residual time can assume any value of the service time distribution B_i. The routing of the leaving customers is dependent on the routing matrix D, whereas the residual time at the beginning of a service is dependent on the service time distribution B_i. The combination of the possible customer transitions and new residual times determines the possible number of new states, while the routing probabilities and probability distribution of the service times are used to determine the transition probabilities to the correspondent subsequent states. If new states are found, the same reasoning is applied to them to find new states, otherwise the iteration stops. At the end of the iterations, all N possible states are found and denoted as z_n and their set $\mathcal{Z}$ is created. The state transition matrix U can be then computed, i.e., a matrix which contains the probabilities $u_{m,n}$ to go from the state z_m to z_n in the next time period. Once the matrix U is defined, the steady-state probabilities p_n can be computed using standard techniques like the Power Method (Bolch et al., 1998) or the ones explained in Stewart (2009).

3.2. Distribution of the number of customers K_i

The distribution of the number of customers K_i in station i at random periods can directly be obtained from the steady-state probabilities. Hereby, $k_{i,j}$

denotes the probability that K_i takes value j.

$$k_{i,j} = \sum_{\forall z_n \mid k_i = j} p_n \tag{2}$$

3.3. Calculation of the total cycle time distribution S through a chosen station $\hat{i}$

To obtain the total cycle time distribution S, the computation of the contribution S_n to the cycle time for each state z_n is carried out. The method uses a similar strategy as Colledani et al. (2015), where the computation of time distributions starts when a new customer enters the considered subsystem and ends when it leaves the subsystem. In our case, the computation starts when a new customer enters station $\hat{i}$ and ends when he comes back to station $\hat{i}$. In particular, for each z_n the set of the following states $\mathcal{Z}_n^0$ (referring to the period $t = 0$ of the cycle time computation) is computed along with their probability $p_{n,m}^0$ (with $m \in \{1, ..., M_n^0\}$ and M_n^0 the state number contained in $\mathcal{Z}_n^0$).

In order to track the customers through the system, a new state vector a_n^t, which contains also the station number i_s and the position i_p in the station, must be used. The position i_p takes value 1 if the customer is in service and value $2, ..., \hat{K}$ when he waits for service. The vector represents a generic state after t periods which has been originated from the n^{th} state of the system. As a result, a system state can be represented as follows:

$$\begin{gathered} a_n^t = (\ r_1\ r_2\ ...\ r_V \quad k_1\ k_2\ ...\ k_V \quad i_s\ i_p\ ) \\ \text{with } r_i \in \{0, 1, ..., b_{i,max}\}, k_i \in \{0, 1, ..., \hat{K}\}, \\ i_s \in \{1, ..., V\}, i_p \in \{1, ..., \hat{K}\}, i \in \{1, ..., V\} \end{gathered} \tag{3}$$

A new set $\mathcal{A}_n^0$ is created. It contains all the states at t=0 originated from z_n, which are identified with the index $q \in \{1, ..., Q_n^0\}$, where Q_n^0 is the number of states in $\mathcal{A}_n^0$. They are filled according to the following procedure:

- The transitions from the state z_n to all states $z_{n,m}^0$, i.e., the ones included in $\mathcal{Z}_n^0$, are considered.

- For each transition, if no customer enters the station $\hat{\imath}$, no states are added to $\mathcal{A}_n^0$.
- If c customers have just entered the station $\hat{\imath}$, c state vectors a_n^0 are added to $\mathcal{A}_n^0$. Those vectors are created in the following way: the first $2 \cdot V$ parameters coincide with the correspondent vector in $\mathcal{Z}_n^0$, the station number i_s equals $\hat{\imath}$ and the corresponding probability $p_{n,q}^0$ coincides with the probability $p_{n,m}^0$ of the correspondent state in $\mathcal{Z}_n^0$. They only differ for i_p, since the customer of interest may enter the station as the $1^{st}, ..., c^{th}$ customer.

For the previously depicted queueing system (see figure 2), a numerical example of the computation of the set $\mathcal{A}_1^0$ is provided in figure 3, i.e, for set $\mathcal{A}_{n=1}^0$ that comes out from the first system state. For the sake of simplicity, the probabilities at each step are computed as if $p_1 = 1$, but in general $p_n < 1$.

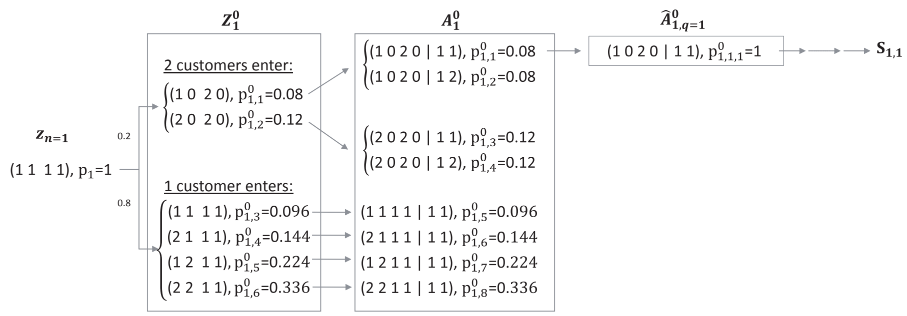

Figure 3: Numerical example of the computation of the set A_n^0

At this point, the cycle time distribution $S_{n,q}$ for each state of $\mathcal{A}_n^0$, namely the probability that the tracked customer returns to the station $\hat{\imath}$ at each time period, must be computed as follows:

1. Initialize t=0 and create the set $\hat{\mathcal{A}}_{n,q}^0$.
2. Add a copy of $a_{n,q}^0$ to the new set and assign a correspondent unitary probability to it. That new state is denoted as $\hat{a}_{n,q,1}^0$
3. Increment to t = t + t_{inc}.
4. Considering all the states of $\hat{\mathcal{A}}_{n,q}^{t-t_{inc}}$, determine the states for the current time step. It must be considered that if the tracked customer leaves a station, the i_s and i_p indexes must be recomputed accordingly. Add the

new states to the set $\hat{\mathcal{A}}^t_{n,q}$. The index $w \in \{1, ..., W^t_{n,q}\}$ denotes each state $\hat{a}^t_{n,q,w}$, whereas $W^t_{n,q}$ corresponds to the total number of states included in $\hat{\mathcal{A}}^t_{n,q}$.

5. Determine the correspondent probabilities $p^t_{n,q,w}$ of the new states by considering the routing probabilities and service time probability distribution of all stations which serve a new customer.
6. If the tracked customer arrives at a station simultaneously with n other customers, all $n+1$ possible positions i_p must be considered and, as a result, $n+1$ different states must be added to $\hat{\mathcal{A}}^t_{n,q}$. Furthermore, the correspondent probability must be equally split and shared among those $n+1$ states.
7. If the tracked customer has just returned to station $\hat{i}$, add its probability $p^t_{n,q,w}$ to $S_{n,q}$ in the t^{th} position and delete the state from $\hat{\mathcal{A}}^t_{n,q}$.
8. Repeat the algorithm from step (3) until the set $\hat{\mathcal{A}}^t_{n,q}$ is empty or the total probability of its states is smaller than a given ϵ (in case of a possible infinite cycle time).

For the previously depicted queueing system (see figure 2), a numerical example of the computation of $S_{1,1}$ is provided in figure 4.

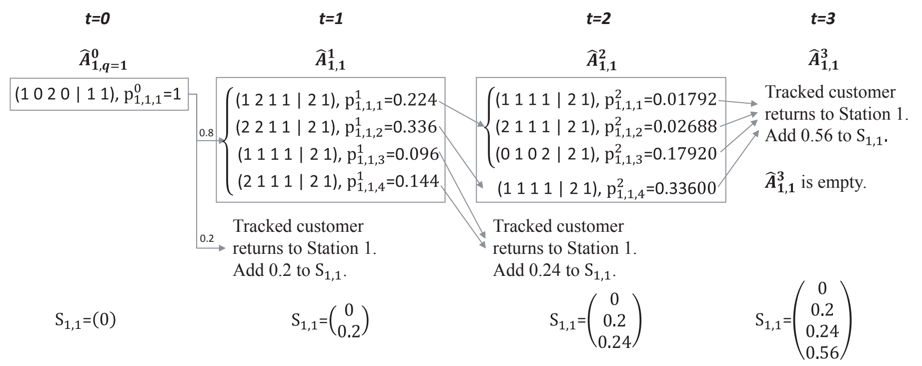

Figure 4: Numerical example of the computation of the cycle time distribution $S_{n,q}$

Once all the cycle time distributions of the tracked customers $S_{n,q}$ are computed, the cycle time distribution S_n of the n^{th} state is computed as follows:

$$S_n = \frac{\sum_{q=1}^{Q^0_n} p^0_{n,q}\, S_{n,q}}{\sum_{q=1}^{Q^0_n} p^0_{n,q}} \tag{4}$$

The numerator results in a weighted sum of the cycle time distributions $S_{n,q}$, while the denominator normalizes the sum in such a way that the sum of the vector elements is equal to 1. In order to exactly compute the overall cycle time distribution S through the station $\hat{\imath}$, the cycle time contributions of all states are combined with the following formula:

$$S = \frac{\sum_{n=1}^{N} p_n \, S_n}{\sum_{n=1}^{N} p_n} \tag{5}$$

4. Numerical evaluation

In the following section, we apply the presented calculation method to the analysis of a sterilization process of medical devices. In a sterilization process, reusable medical devices are re-injected in the process after their use in the operation room. When we integrate the use step, the sterilization process becomes a sterilization loop as seen in figure 1.

Table 1: Discrete probability distributions of the single process steps

	Process Steps						
t_{inc}	**1**	**2**	**3**	**4**	**5**	**6**	**7**
1	0	0.5	1.0	0	0.9	0.1	0
2	0.1	0.5	0	0	0.1	0.9	0
3	0.3	0	0	0	0	0	1.0
4	0.1	0	0	1.0	0	0	0
5	0.2	0	0	0	0	0	0
6	0.3	0	0	0	0	0	0

The pre-disinfection step is done directly after the use in the operation room. The medical devices are placed in a disinfectant liquid to decrease the population of micro-organisms present on the soiled equipment, in order to protect the staff during the manipulation and to facilitate the later washing. During the pre-disinfection step, the used medical devices (MDs) are transferred from the operation rooms down to the sterilization area. At the sterilization area, the MDs are rinsed. Furthermore, the MDs are washed in machines to eliminate stains to obtain a clean medical device. After washing, the MDs are packed into containers or bags to constitute a barrier against micro-organisms. In the sterilization step, the MDs are placed in an autoclave where they are treated with saturated steam. After the sterilization, the MDs are stored close to the operating rooms.

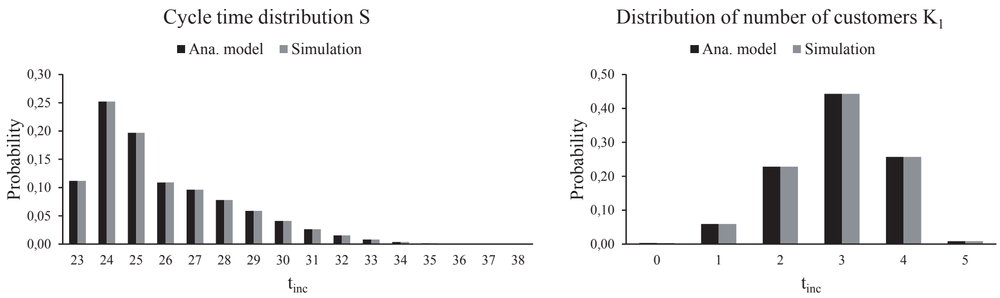

Figure 5: Comparison of analytical and simulation results of a closed network with 6 customers

In table 1, exemplary service time distributions of the single process steps are given ($t_{inc} = 10min$). We used this input data in order to compare the results of the discrete-time model with the ensemble averages of 10 independent replications of a discrete-event simulation that models the same assumptions as the analytical model. Each replication contains 10,000,000 customer cycles. We analyzed the closed queuing network with 2 to 6 MDs in the system. Figure 5 shows the probability distributions of the cycle time and the number of customers in queueing system 1 when the network contains 6 customers. Table 2 gives the results for the mean cycle time $E(S)$, the 95 % quantile of the cycle time $S_{0.95}$, the average number of MDs $E(K_1)$ in queueing system 1, and the probability $k_{1,0}$ that at station 1 zero MDs are present. For each parameter, we can see that the analytical results are equal to the simulation results, as our method is exact. We can see, that for 6 MDs, queueing system 1 is only empty in 0.34% of the cases and MDs are ready for use. Besides, we provide the total computation time for the analytical model and the simulation. We can see, that for 6 customers in the network, the analytical computation time for all parameters is already half of the simulation length. But note, that the computation of the system states only needs 1.4% of the total computing time. Therefore, our method provides performance figures in an acceptable time.

Table 2: Performance parameters for networks with 2 to 6 customers

	$E(S)[t_{inc}]$		$S_{0.95}[t_{inc}]$		$E(K_1)[cust.]$		$k_{1,0}[\%]$		Comp. time [s]	
$\hat{K}$	Ana.	Sim.	Ana.	Sim.	Ana.	Sim.	Ana.	Sim.	Ana.	Sim.
2	15.59	15.59	18	18	0.57	0.57	44.83	44.83	0.43	434.92
3	16.24	16.24	19	19	0.90	0.90	20.58	20.58	4.44	408.58
4	18.21	18.21	22	22	1.39	1.39	5.56	5.56	9.00	450.75
5	21.78	21.77	26	26	2.08	2.08	1.26	1.26	54.32	396.04
6	25.89	25.89	31	31	2.92	2.92	0.34	0.34	224.36	401.20

5. Conclusion

In this paper, we propose a new approach for the steady-state analysis of closed-loop queueing systems with arbitrary topology and generally distributed service times. Based on a discrete-time Markov chain, the method provides an exact computation of the cycle time distribution and the distribution of the number of customers at each service station. The method is applied to the analysis of a sterilization process of medical devices. Moreover, we verify the results of our model by comparison to a discrete-event simulation. Future work will be dedicated to the extension of the approach to systems with finite queueing capacities and the application of this approach to case studies in health establishments.

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Towards a Process Meta-Model

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Abstract

Process modelling has a long and established research tradition, in the context of formally capturing sequences of activities, as well as the involved parties and the exchanged data. It will, without a doubt, continue to play a major role in the context of supporting the development of added-value services industry 4.0. In the medical domain, clinical pathways are a specific form of process modelling. They are an evidence-based response to particular problems and care needs in clinics. Current developers and latest technologies, improve and refine, among others, also the expressivity of clinical pathways. As a result, advanced pathways modelling optimises the treatment procedures in clinics (i.e. by reducing the stay of a patient or the mortality rates). However, as a side-effect of this trend, clinical pathways become increasingly complex and it becomes harder to keep up to date with the latest published processes. In oder to address the challenge of analysing clinical pathways, we provide an approach to capture information about activities and annotate the modelled pathways with references to external data sources. We demonstrate the practical applicability of our approach by using our system to model an actual clinical pathway, and enrich it with meta-information and references to external data sources, such as PubMed. We show the use and expressivity of our data model by querying the captured data.
Keywords: Medical Services, Process Modeling, Business Process Model and Notation, Clinical Pathways, Semantic Media Wiki

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Preprint submitted to Elsevier *January 20, 2016*

1. Introduction

Clinical Pathways are guidelines used in clinics to support physicians by providing recommendations of the sequence and timing of actions necessary to achieve an efficient treatment of patients Panella et al. (2003); Kinsman et al. (2010). They are evidence-based and use insights of former treatments of patients. However, due to the increasing volumes of data and developments in the medical domain, the clinical pathways become more complex. Each clinic has its own pathway based on its evidence and experience. Therefore, there are multiple pathways available that target different problems and care needs Zand (2002); Kris Vanhaecht et al. (2006); Hindle and Yazbeck (2005). They can be distinguished in their degree of complexity, in execution, and can be grouped according to the specific problems and care needs that they target. In order to capture meta-information about clinical pathways and activities, to compare, analyse and group them, we present a system that allows to capture meta-information about the activities. This information can be used to provide healthcare services i.e. planning resources and improve the outcome of clinical pathways.

We demonstrate the applicability of our solution by modelling a concrete perioperative pathway. The used methods and an overview of the system are described in Section 2. Overall, we address the following research questions:
1. How can we capture meta-information in clinical pathways?
2. How can we implement the infrastructure necessary for storing, accessing, and processing the meta-information?
We show that our approach is easy to use and extensible to capture further meta-information (Section 2). Furthermore, we show that our approach is sufficient to query and process the captured information (Section 3). A short discussion and lessons learned are given in Section 5.

2. Material and Methods

Our approach to capture meta-information is hierarchical (Figure 1 illustrates our hierarchical model). The hierarchy has at least two levels. The highest level (Level 1) represents an abstract element of a modelling language. The elements in the following levels inherit from elements located in the previous level. Therefore, each attribute modelled in the superclass, is available in the subclass. The relationship between the superclass and its subclasses is $1 : n$. Hence, a subclass does not inherit from multiple superclasses, but a superclass can be used as a generalisation for multiple subclasses.

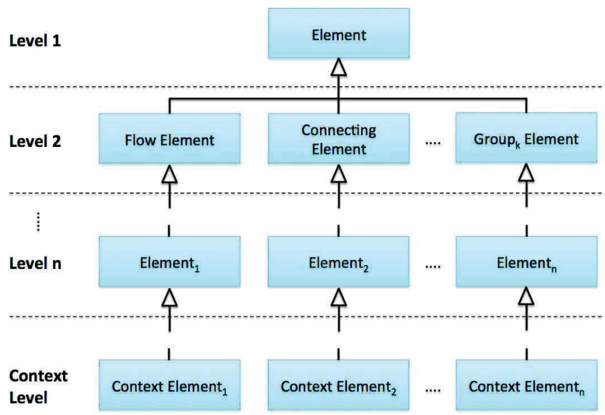

Figure 1: Hierarchical model to capture meta-information.

The elements in the second level (Level 2) inherit from the abstract element. Therefore, each attribute modelled in the superclass is available in the subclass. Usually modelling languages consists of nodes (Flow Elements) and edges (Connecting Element) between the nodes. These two kind of elements are arranged in the second level (Level 2) of our meta-model. Some modelling languages (i.e. BPMN) distinguish between more elements than Flow Objects and Connecting Objects. These additional objects can be arranged in Level 2. Following, more levels can be append and enriched with elements that inherit from elements located in the previous level. The specific inheritance depends on the chosen modelling language. I.e. BPMN distinguish between three flow elements: events, activities, and gateways. These elements are arranged in a following layer (Level 3) in the hierarchical meta-model. However, a Petri net distinguish only between places and transitions.

The last level (Context Level) is an optional level that allows to create use case-specific distinctions of each element from the last layer. For instance tasks in clinics can be divided into preoperative and surgical tasks.

3. Evaluation

For validation of our approach, we applied the hierarchical model to capture meta-information about a perioperative pathway. Figure 2 shows the perioperative process modelled in BPMN.

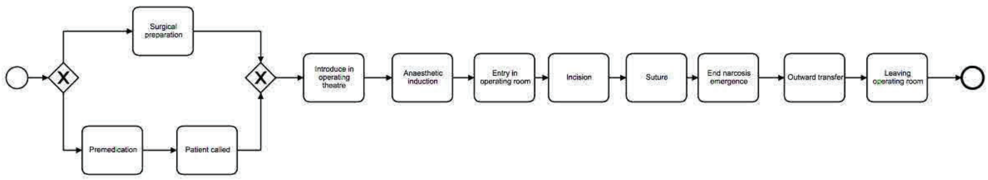

Figure 2: Perioperative process, modelled in BPMN.

We use a Semantic Media Wiki[1] to capture the activities, workflow and the meta-information. SMW is an open-source collaborative knowledge management system to store and query data. We used Semantic Forms[2] to provide forms in order to facilitate the input of meta-information.

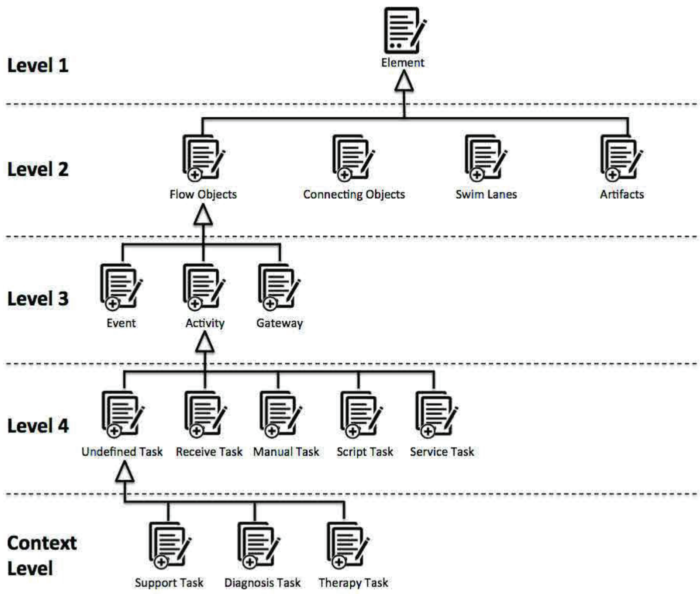

Figure 3: Extract of the implemented hierarchical meta-model.

Figure 3 illustrates the links and inheritances of the semantic forms. Forms from successive levels inherit from their superclass and consist of the form of the superclass enriched with attributes, captured on this hierarchical level.

[1] https://semantic-mediawiki.org
[2] https://www.mediawiki.org/wiki/Extension:Semantic_Forms

On the top level (Element) we introduced the attributes *Label*,*Comment* and *Reference*. Forms in the lower level inherit from this form and enrich it with further attributes. Thus in the form Flow Objects we introduced the attributes *Responsible Person*, *Goal*, *Condition* and *Guideline*. Some attributes can be mandatory, allow only specific values or have multiple manifestations. For instance we choose *Responsible Person* as a mandatory attribute. Thereby, each flow object is connected to a responsible person, so that in case of doubt one has a contact person.

On the lowest level there are twelve attributes. We use an existing classification Braun et al. (2014) to classify different medical tasks in more detail on the context level. They slightly differ in their attributes. Thus, the Therapy Task has an attribute *Planned Therapy*, and the Diagnosis Task has an attribute *Supposed Disease*.

We enrich the BPMN elements with meta-information according to the provided forms. As a results, we can query for the following information:
1) Total runtime of the complete process; 2) Number of Elements contained in the process; 3) Responsible person, for specific tasks and processes; 4) Number of decisions within a process. The structured data in the SMW is stored in Resource Description Framework (RDF). Elements in RDF are represented by HTTP URIs We can use SPARQL[3] in order to retrieve queries on the data. SPARQL is a semantic query language for RDF. A concrete SPARQL query to request the total runtime of the perioperative process is given in the following.

```
PREFIX aifb: <http://aifb-ls3-vm2.aifb.kit.edu>

SELECT sum(?runtime) WHERE {
 aifb:BPMNProcess_Perioperative
 aifb:Property-3AHas_element ?Element .
 ?Element aifb:Property-3AHas_Runtime ?runtime .}
```

4. Related Work

The Dublin Core Schema[4] consists of a set of metadata terms that can be used to describe resources. However, it does not stipulate the model that must be used.

[3]http://www.w3.org/TR/rdf-sparql-query/
[4]http://dublincore.org

The Learning Object Metadata (LOM) is an open standard, published by the Institute of Electrical and Electronics Engineers (IEEE), to describe learning objects. Learning objects are the smallest contents in which learning sources can be resolved. The LOM stipulates the attributes and their connection. The structure of LOM consists of nine categories but they are not arranged in a hierarchy.

The Computational Independent Metamodel (CIM) Yang et al. (2009); Kutsche et al. (2008) describes scenario requirements. It abstracts from the business process and data flow model. Platform specific metamodels (PSMM) describe technical aspects of systems including the structure, behaviour and communication of the interfaces. PSMM supports information like interface semantics, remote addresses, signatures and communication properties Yang et al. (2009); Kutsche et al. (2008). In contrast, Platform Independent Metamodels (PIMM) Yang et al. (2009); Kutsche et al. (2008) abstract from platform-specific properties and interface descriptions.

A semantic meta-model by Yang et al. (2009) represents the information in a graph, similar to RDF. Subjects and objects are modelled as classes and linked via predicates. The meta-model contains predefined predicates, but can be extended with specific predicates.

5. Conclusions

The long-term goal of our work is to develop a system that analyses processes, while making use of all available knowledge. To this end, we introduced a new concept for modelling, processing, and accessing meta-information. The used approach abstracts away from a specific modelling language. Moreover, it is adaptable to different use case scenarios.

We actively use the presented infrastructure for data collection and processing. SMW provides a suitable environment to model, store and access meta-information about processes and allows references to external data sources. In order to investigate the benefit of our approach, we will focus on capturing further processes in the medical domain, as well as in other domains.

Future work includes the analysis of processes with respect to uncertainty. Clinical pathways have already been analysed in previous works, i.e. Yang et al. (2012), however we will not focus on clinical pathways in particular but on processes in general.

In conclusion, we introduced a hierarchical meta-model to capture meta-information in processes.

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Participation & Crowd Services

Shouldn't Collaboration be social? - Proposal of a social Real Time Delphi

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Abstract

Real Time Delphi (RTD) is an advanced online implementation of the Delphi Method (DM), designed to speed up the period of time needed to conduct a survey using nowadays internet technology. However its overall design is still very restricted and does not leverage the full potential for collaboration of this new Information and Communications Technology (ICT) channel. In this paper we propose two design elements that introduce social interaction in RTD to leverage positive effects, while not harming anonymity as a key feature of the DM. The contribution of this work is to enhance the RTD Method in a way that allows anonymous but social interaction amongst participants, addressing weaknesses of the current method regarding drop-outs of participants and the organizing and control of content.

Keywords: Participation and Crowd Services, Real Time Delphi, Anonymity, Forecasting, Survey Design

1. Introduction

Since the introduction of the internet the ways we collaborate changed enormously. The DM is a special survey design, developed in the 1950s, aiming to synthesize the expert judgments and create a group consensus (Turoff,

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1970). In the beginnings this collaboration took place with paper and pencil. Remote experts had to be included postal. Due to the internet and its new possibilities the DM became "online" (Linstone and Turoff, 2011), but the process itself did not change and therefore all weaknesses of the old process were adopted. One shortcoming in the method is the long time period that is needed to carry out a Delphi Study, which sometimes may take several months (Landeta et al., 2008). This issue was addressed by Gordon and Pease (2006) with the Real Time Delphi (RTD) Approach. However, we argue that the full potential of online collaboration for the DM is not yet harnessed and propose to improve the method with two social elements, without harming anonymity, one of its key characteristics. The first proposed element is the possibility to label arguments by a fixed set of labels. Second, we propose to enrich the arguments with a generated user name which is only valid within one question. We argue that this two elements help self organizing of the content as well as create a higher sense of social presence which raise quality of discussion and lower drop-out rates. Therefore we form following hypotheses:

- *H1: Introducing labeling and generated user names in RTD increases perceived social presence.*
- *H2: Social presence in RTD lowers the drop-out rate.*
- *H3: Introducing labeling helps structuring the discussion and improves usability.*

The paper is structured as follows: In section 2 a brief theoretical background on DM, RTD and online collaboration in general is given. Section 3 examines how social presence can positively affect RTD. Section 4 explains the proposed design of a social RTD (sRTD). Finally, the paper will finish with a conclusion and outlook.

2. Background

2.1. Delphi Method and Real Time Delphi

According to Dalkey et al. (1969) three main features are characterizing the DM: i) *anonymity*, ii) *controlled feedback*, and iii) *statistical group response*. The first feature reduces the effect of dominant individuals in the group, so

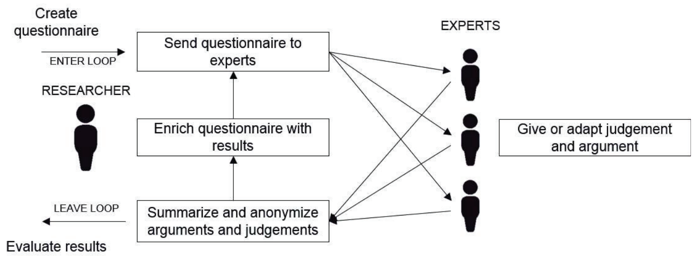

Figure 1: Controlled Feedback Loop of Delphi Method

that pressure to conformity or reputation do not affect the truthful revelation of opinions. Controlled feedback as the second feature aims to reduce noise. The third characteristic, the statistical group response lowers group pressure on conformity and reassures that the opinion of every member is represented in the final response. Statistical group response is usually provided as the mean, the number and the variance of all estimations or another suitable visualization of the distribution of the estimations. Landeta et al. (2008) and Rowe and Wright (1999) add a fourth characteristic, the "iterative process". The basic idea is that the controlled feedback loop creates consensus between the experts in the Delphi study as a result of that the experts can adapt their opinion in each loop and react to the arguments and summarized judgments of the group. The process is illustrated in figure 1.

In contrast to the pure implementation of the DM as an online process, the RTD approach changes the feedback loop, so that a participant can see the responses of the group members immediately after he has given his first opinion (and optionally an additional argument). There is no explicit second round, but the participant has the option to return at any point of time and change his submitted judgement. By then others may have contributed or adapted their opinions so averages or medians have changed (Gordon, 2008). As the online channel completely hides the identity of the participants it is also possible to conduct RTD synchronously in conference rooms or the like. Additionally the RTD technique is a way to open the DM for larger panel sizes as distribution and collection of the questionnaires is not necessary and there are no additional cost of more participants (especially in remote locations) (Linstone and Turoff, 2011). According to Gnatzy et al. (2011) the DM and RTD produce similar results. To our knowledge in none of the existing implementations of RTD or accompanying research and publications the enhancement of the method in terms of social elements is considered or discussed. Major other contributions to RTD where made by Gordon (2008) and Gnatzy et al. (2011). In Gordon (2008) the focus is laid to argue that all key features of the DM are completely implemented. Gnatzy et al. (2011) introduced visual feedback as well as a *consensus portal* that is basically an overview on the questionnaire, that signalizes where ones opinion is in line with the group or where there is strong disagreement.

2.2. Online Collaboration

"Collaboration begins with interaction" (Murphy, 2004, p. 422). The awareness of social presence in online settings makes people to interact as a group which enriches interaction and the sense of community. In a collaborative community members do not only share perspectives, but are starting to challenge other opinions, reshape their own, and restructure their thinking. This process leads finally to a *shared meaning* (which is also characteristic to the DM). However, social presence in online collaboration has the ability to start some more processes: New perspectives and meanings as well as shared goals can evolve (Roschelle and Teasley, 1995). Especially second is interesting, as it leads to the production of shared artifacts and the intention to "add value" (Kaye, 1992). It is not yet discussed, if these processes lead ultimately to better results in every case, but intuitively one would say, that it may improve the result in some dimension. Leveraging this improvement for RTD has not yet happened and Linstone and Turoff (2011) say *"[...] [T]he future of Delphi will be in collaborative organizational and community planning systems that are continuous, dispersed, and asynchronous."*

3. Social Presence and possible Effects on Real Time Delphi

Usually the DM as well as RTD build on absolute anonymity (or quasi-anonymity as in Kochtanek and Hein (1999)). Gordon (2008) states the concern about spurious factors, such as reputation, status or other social behavior that intrude in face-to-face interactions among experts lead once to the feature of anonymity in the beginning of the DM. Since then anonymity is a key feature of the DM and it was adopted in RTD. We argue that anonymity is not an end in itself, but that the goals it wanted to achieve can be, using nowadays technology, achieved while leveraging the positive effects of social

interaction and collaboration.
One problem with the traditional DM is the drop-out rate of the participants and the corresponding low response rate during the rounds, which should be at least 70% (Mullen, 2003; Walker and Selfe, 1996). Reid (1988) notes, that the panel size has a strong influence on the drop-out rate. Large panels tend to have higher drop-out rates than small panels with 20 members. Okoli and Pawlowski (2004) argue that the researcher has the possibility to contact the drop-outs and ask them to participate, but this can be – depending on the budget – related to a disproportionate effort (Ishikawa et al., 1993). However, the technological concept of RTD and it's asynchronous character would allow distinctly larger panels. To draw this potential it is necessary to bind users stronger to the platform and the questionnaire, which can be supported by social presence and therefore social reputation, that can be built. Bolger and Wright (2011) found, that in "traditional" Delphi studies the promise of gaining social reputation raise motivation to commit to the study and decreases the drop-out rate.

To tag content in "social question answering" (e.g. Yahoo! Answers or Live QnA), can open opportunities for richer user interaction (Rodrigues et al., 2008) and is not a new idea at all. According to Ames and Naaman (2007) there are mainly two reason to tag social content[1]: i) Providing ones opinion on something (social interaction) and ii) help others/oneself to find something (self/organization). Additionally Rainie (2007) puts that tagging allows groups to form around points of view and similarities of interest. If persons use the same tags, they may get the impression that they probably share some deep commonalities. Tagging can therefore contribute to RTD in multiple ways: First it enables users to express their opinion about arguments and gain reputation. Second it enables users to express "common sense". Both leads to higher social presence and therefore raise user binding to the platform. Third tagging is a strong instrument of (self)organizing content. Especially for larger panels, online discussion can quickly become confused if there are no means to structure and distinguish important from the unimportant or interesting from the uninteresting. Lots of large online platforms as Twitter, Facebook or GitHub use tagging or labeling as a mean to allow structuring and organizing the content. Turoff et al. (2004) already used labels to organize content in a study which he attested a "Delphi-structure".

[1] In case of Ames and Naaman (2007) photos.

However, his implementation did not fit the anonymity criteria, as names of argument's authors were visible.

4. Design of a social Real Time Delphi

Key to our design proposal is keeping anonymity where needed in sRTD while introducing social elements to leverage the afore effects mentioned. Therefore we propose two design elements: i) Randomly generated user names only valid within a question and ii) a fixed set of labels in the discussion.
The idea behind i) is to enable the participants to argue with and relate to each other. The effect is that each participant can be addressed directly[2]. This leads to the impression of social presence and can nudge the processes mentioned in section 3. As the user names are randomly generated for each question anonymity is completely given and social reputation or status can not be transferred between questions and questionnaires. In addition no linkage to the real person is possible, hence we can argue that anonymity as a key feature of the DM is not violated. In contrast to standard RTDs the generated user names are displayed to every given argument as well as in the argument-creation form as "You are posting as [generated user name]"[3].
The second design element uses the idea that participants get a social reward if good content is provided. Arguments can be labeled by a fixed set of tags as for example "helpful", "strong" or a simple "like" (or "vote" as used in Turoff et al. (2004)). Contributions to the "shared goal" are rewarded on this way, which satisfies the author as his demand for social reputation is fed. As the author wants to maintain his social reputation we expect him to participate on a more regular basis (Linstone and Turoff, 2011). Goluchowicz and Blind (2011) found that participants, who felt as experts had a lower probability to drop out in Delphi studies. The social reward that participants get may make them feel as experts somehow. In addition *labeling* has the potential to make the argumentation more efficient and to introduce some kind of self-control and therefore raise the argumentation quality (Linstone

[2]Publicly in the group but only within this question.
[3]We are aware that the referenceability of persons within the context of a single questions may lead to a group discussion. However, it is not investigated yet (to the best of our knowledge), if this affects RTD, respectively the forecasting task in a positive or negative way.

and Turoff, 2011). In contrast to tagging (unrestricted labeling), the fixed set allows a certain degree of control to ensure that very personal tags that may be only used by one person do not allow linkage of this person throughout the questionnaire, as they are reported in (Rodrigues et al., 2008). In contrast to standard RTDs where arguments allow no interaction, sRTD shows the users a list of labels which can be added. Every label can be added only once per user and argument. It is not displayed, which user added the label.
To test hypothesis H1 we plan to conduct an online experiment with A-B testing (with and without i) and ii)). Afterwards a questionnaire is conducted to measure perceived social presence in both groups. To evaluate H2 we compare the actual drop-out rate to the results of the questionnaire. To evaluate H3 the questionnaire will contain items about usability and informativeness of the platform.

5. Conclusion and Outlook

The future of RTD is to leverage the possibilities, that come with its technology. In this paper we draw a picture of the potential of making RTD more social by proposing to add the two elements of randomly generated user names per question and labeling in the design. Both elements arouse the impression of social presence in the sRTD and allow building sense of community and social reputation by not harming the key feature of the DM: "anonymity". In our design it is not possible to link participants to real persons nor to build a social reputation in a way that may affect unbiased[4] forming of opinions. We expect introducing this social elements to raise the binding of the users to the platform. Additionally labeling can contribute to the efficiency of the argumentation and helping to organize it, which we expect to increase discussion quality. The contribution of this work is to enhance the RTD Method in a way that allows anonymous social interaction amongst participants, addressing weaknesses of the current method regarding drop-outs of participants and organizing and control of content. Next steps contain the implementation of a sRTD platform including these proposals and verify that anonymity is not violated. Future work will test our three hypotheses and further improve sRTD by trying to decrease drop-out rate, improve discussion, and raise overall result quality of the prediction.

[4]By means of social reputation or status.

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Emotional Arousal Effects in Participatory Budgeting Decisions*

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Abstract

Participatory budgeting is applied by an increasing number of municipalities and organizations. Citizens can decide over an institutional budget. The allocation mechanism can affect emotional arousal, which influences the choice evaluation in the decicion-making process. Building on the endowment effect, we conduct an experiment testing a novel participatory budgeting approach that includes an element of crowdfunding. We measure participants' heart rate to determine emotional arousal. This is one of the first studies to investigate the arousal of participants in participatory budgeting procedures. Our findings suggest that institutions can engage their citizens in such a process without having to expect an endowment effect.

1 Introduction

Participatory budgeting is ever increasing in popularity and a powerful instrument to increase participation of citizens. Participatory budgeting uses an institutional budget that is allocated by citizens. Questions that often arise are: Do citizens take that responsibility seriously? Do they feel engaged with the decision? In this work we want to address the research question: *Does investing one's own budget instead of an institutional budget correlate with a higher emotional arousal?* Thus, we seek to establish a link between different mechanisms and endowments with emotional

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* The authors thank Ewa Lux, Anuja Hariharan and three anonymous reviewers for their valuable comments.

arousal as well as how arousal affects decision-making processes.We address this question in a laboratory experiment that is based on suggestions by Niemeyer et al. (2015). First results on investment behaviour were already analysed (Niemeyer et al., 2016).

2 Literature

The research question addresses two fields of research: On one hand, investment decision-making behaviour in the context of participatory budgeting and, on the other hand, emotions.

2.1 Participatory Budgeting

Participatory budgeting constitutes processes in which governments (or other public agencies) involve their citizens and relevant stakeholders in an iterative and deliberative participation process over budget decision-making (cf. Sintomer et al., 2010). There are several municipalities which adopted the approach in practise. For instance, 53 German municipalities implemented participatory budgeting in 2014 (Ermert et al., 2015). Niemeyer and colleagues (2015) extended the idea of participatory budgeting with the element of crowdfunding. They proposed a mechanism whereby institutions allocate financial resources to the participants of a crowdfunding platform. Just as in participatory budgeting, citizens and stakeholders can then decide to invest money into certain projects. In such settings, the design of the investment mechanism is crucial (cf. Wash and Solomon, 2014).

2.2 Emotions and Investments

Research suggests that when people take investment decisions, they do not always act as rational agents. People are often framed within perceived domains of gains or losses (Wilkinson, 2008; Chang, Yen & Duh, 2002). These framing effects shape people's responses in terms of values, attitudes and, most notably, preferences (Slovic & Lichtenstein, 1983; Tversky et al., 1990). For instance, through the endowment effect people attach more value to things simply because they own them

(Kahneman et al., 1990). This leads them to perceive gains and losses differently, in effect changing the decision-making process. In a review of nine studies examining the endowment effect, Shu and Peck (2011) find that the concept of emotional attachment explains many of the findings, particularly psychological ownership and affective reaction. Hence, emotional attachment might influence investment decision making.

In this work we experimentally investigate emotions in an economic context of investment decision-making. Adam et al. (2011) introduce this extension of the methodology of experimental economics by "physiological measurements of participants as proxies for their individual emotional processing" as *Physioeconomics*, which is now commonly referred to as NeuroIS. Since decision-making is a cognitive as well as an affective process and not only the homo economicus' maximisation of utility, the measurement of physiological data can help to better understand decision behaviour (Thaler, 2000; Adam et al. 2011). Arousal is mainly measured in two ways: Skin conductance is used to measure general arousal and short sympathetic activities; Electrocardiogram (ECG) measures the electric activity of the heart. For the latter, the time between successive R-waves in the ECG is necessary for the analysis of arousal (Jennings et al., 1981).

In neuro science and NeuroIS, there is initial evidence that supports the notion of emotional influences and the endowment effect in the decision-making process. Adam and colleagues (2015) were also able to show that people were emotionally aroused in auctions. They increased social competition and demonstrated that so-called auction fever leads to higher bids. Moreover, emotional arousal also depends on whether participants face human or computer agents in a competition (Teubner et al., 2015).

3 Experiment and Results

3.1 Hypothesis

Our study seeks to investigate whether different forms of endowment in a participatory budgeting setting affect emotional arousals. With regards to the endowment

effect, we assume that participants will react differently when they own (parts of) the budget as opposed to when they can only invest the money provided by an institution into projects in a participatory budgeting setting. Emotional engagement/arousal is measured by ECG in heart rate. Therefore, we propose
H1: Participants are more emotionally engaged with a decision if they invest their own budget than if they decide on an institutional budget.

3.2 Experimental Design

The hypothesis was tested in a novel approach by Niemeyer et al. (2015) combining crowdfunding with participatory budgeting. In a threshold public goods game with four goods and groups of six, participants faced the decision of allocating a budget of 150 MU (monetary units) to four projects with heterogeneous costs (100, 200, 300 and 400 MU respectively). This is based on the experimental design of Wash and Solomon (2014). If the threshold of a project was met, each participant profited with a certain (heterogeneous) utility, independent of what the participant had invested. In the experiment we distinguish between two treatments. In the *S100 treatment*, participants can keep the budget if they do not want to invest in the projects. This corresponds to a private budget. In the *S0 treatment*, they can only invest the budget. Not invested money will go back to the institution. This corresponds to an institutional budget.
In each session, 12 participants were connected to an electrocardiogram device that recorded the heart rate over the course of the experiment. Instructions were then handed out and read out aloud to all participants. After participants had answered 10 control questions and a three minute period of rest, 24 periods of project funding were played, followed by a final questionnaire. In each of the 24 periods, two new groups of six participants were formed, each of them investing in four different projects. The pilot study experiment was conducted in June 2015 with 24 students of a large German university. Participants were invited via ORSEE (Greiner, 2004) and were on average 21 years old. Each student participated only in one treatment. The sessions took 70-80 minutes and participants earned on average 13.87 EUR. The experiment was implemented using Brownie (Müller et al., 2014).

3.3 Results

Heart rates (HR) were derived from the ECG data and normalised by taking the ratio of the individual HR during three minutes in the middle of the period of rest. Physiological data of 5 of 24 participants could not be used due to technical problems during the recording.

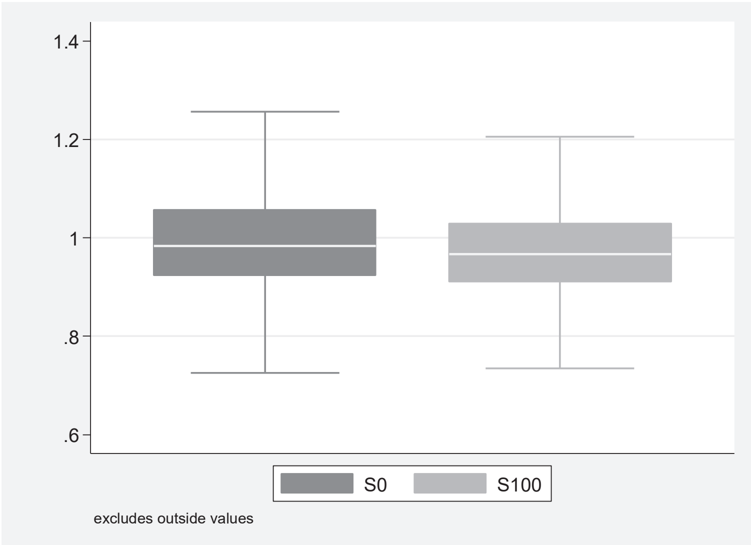

Figure 1: Average normalized HR by treatment.

The average normalised HR in the *S0 treatment*, where participants invest institutional budget is 0.994, in the *S100 treatment*, where participants can also keep the money, 0.966 (se Figure 1). A paired sample t-test reveals that there was no significant difference in arousal between the treatments ($p = 0.203$). Also we do not find a correlation between the average normalised HR and investments.

However, a closer look reveals additional interesting results. Over the course of the experiment, participants' HR (and therefore average normalised HR) decreased in both treatments as can be seen in Figure 2.

In a linear regression we controlled for participants and used the average normalised HR as dependent variable, a treatment dummy (which is 1 if the participant was in treatment S100) as independent variable and a period variable (1-24). The regression ($R^2 = 0.043$) shows no significant treatment effect (coef. = -0.0246, $p = 0.461$). However we can observe a significant period effect (coef. = -0.0018, $p = 0.014$), participants' HR significantly decreases over the course of the experiment. This is in line with the literature (cf. Wilson, 1992; Bradley et al., 1993).

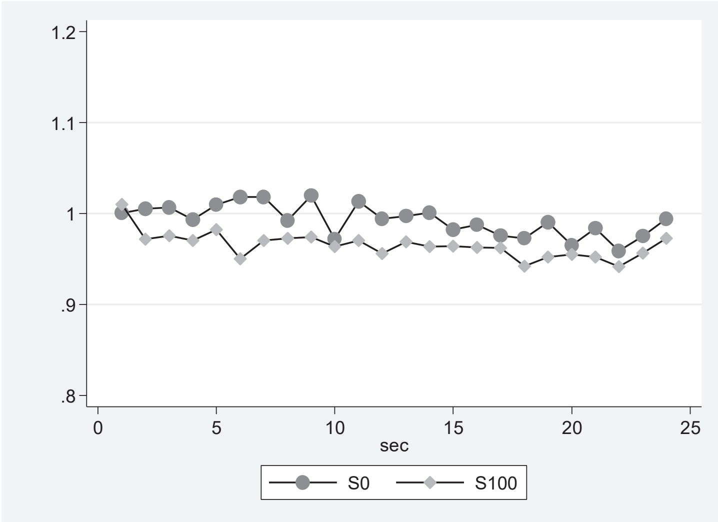

Figure 2: Average normalized HR by treatment per period.

4 Conclusion

With our work we presented to first attempt to investigate emotions in participatory budgeting in a controlled experimental setting. There is no measurable evidence for an endowment effect in terms of emotion when investing money that could or could not be kept as an outside option. This implies that institutions who offer participatory budgeting as budget allocation, without giving citizens the opportunity to keep the money, do not have to worry that citizens are less engaged. There even is an insignificant tendency that they are more aroused without the possibility to keep the money. As our sample size of 24 participants was quiet small and the data set did not allow for a period-related decision phase analysis, an upcoming conduction of more sessions with more than 200 participants will further investigate our conjectures.

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Towards a Guideline for Conducting Economic Experiments on Amazon's Mechanical Turk

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Abstract

During the last decade Amazon Mechanical Turk has evolved to an established platform for conducting behavioral research. However, designing and conducting economic experiments on online labor markets remains a complex and ambitious task. In comparison to laboratory environments, a set of specific challenges (such as synchronization and control) has to be thoroughly addressed. In order to support researchers in fulfilling this task, we provide a framework of a continuously updating guideline for conducting economic experiments on Amazon's Mechanical Turk. Our main contributions are the proposition of (i) a challenge-oriented view based on common experimental economics practices, and (ii) a collaborative continuous guideline approach.

Keywords: Crowd Services, Crowd Work, Crowdsourcing, Guideline, Online Experiments, Behavioral Experiments, Experimental Economics

1. Introduction

In recent years, researchers from various fields have recognized and started to harness the potential of conducting experiments on crowd work platforms such as Amazon Mechanical Turk (MTurk). The validity of such experiments

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in comparison to economic laboratory experiments was comprehensively discussed in the literature (Paolacci et al., 2010; Chilton et al., 2010). In recent years a variety of experiments was conducted on MTurk and in fact the number is still growing fast. Reasons for that are inter alia the large subject pool and low cost labor (Mason and Suri, 2012; Paolacci et al., 2010). However, compared to classical laboratory experiments, researchers are facing several challenges while conducting experiments in the crowd, e.g. synchronization and control. To overcome such issues on crowd work platforms, guidelines leading through the process of conducting experiments are needed.

A set of comprehensive guidelines for behavioral research on crowd work platforms has already been published (Mason and Suri, 2012; Horton et al., 2011; Paolacci et al., 2010). However, these guidelines often do not focus on economic experiments but on behavioral research in general. Furthermore, against the background of the fast growing number of experiments, especially on MTurk, workers start to get used to certain experiment types (Chandler et al., 2014). As a consequence, guideline-based experimental design approaches become outdated rapidly. Solutions to overcome this issue need to be developed steadily since researchers have to address the new insights of crowd workers. This stresses the need for a continuously updating guideline with a specific focus on economic experiments.

This paper proposes the outline of a state-of-the-art guideline for crowd experiments including common challenges and best practices from the experimental economics literature. We use the work of Friedman and Sunder (1994), depicted in figure 1 as a starting point and transfer it to a conceptual framework. To this end, the experimental design stage is used to exemplify our concept. Furthermore we propose an architecture of an open platform facilitating continuous updates of the guideline. Therefore, section 2 introduces the conceptual framework of a new guideline structure based on state-of-the-art literature on experiments in crowdsourcing environments. Section 3, includes a proposal for an architecture that enables researchers to collaboratively build a continuously updating guideline. Section 4 summa-

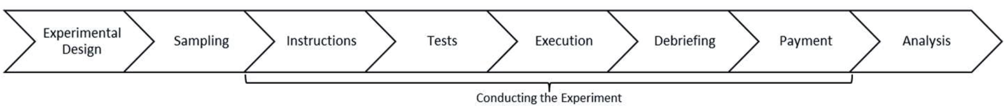

Figure 1: Process of conducting experiments based on Friedman and Sunder (1994).

rizes this work and outlines the next steps for future research.

2. Guideline for Designing a Crowd Work Experiment

We base our guideline concept on an established process from the experimental economics literature (Friedman and Sunder, 1994) as depicted in figure 1. The process can be divided in (i) the experimental design stage focusing on which experimental setup suits the research question best, (ii) the sampling or recruitment of subjects, conducting the experiment, and (iii) the analysis of the results. When transferring these steps to crowd experiments, researchers have to address certain challenges to secure result quality. In our guideline approach we highlight these challenges and suggest possible solutions retrieved from literature. In the following we present an example of our approach for (i) the experimental design stage.

2.1. Outline of a Guideline for the Experimental Design Stage

One of the first steps in experimental research is to decide which experimental design suits the research question best. Common design decisions comprise whether an experiment requires (a) asynchronous or synchronized decision-making and if it should be conducted as (b) a field or a laboratory study (Friedman and Sunder, 1994).

(a) In asynchronous as opposed to synchronous experiments subjects do not compete simultaneously against each other. Since in laboratory studies subjects usually are in the same room during the observation, it is easy to implement both setups. On MTurk however, the implementation of synchronous experiments is challenging. Usually tasks on MTurk are designed as open calls (Howe, 2006). It is unclear if or when a worker starts completing the task. This makes it difficult to realize experiments where two or more participants have to compete simultaneously against each other due to unknown arrival times of workers (Mason and Suri, 2012; Mao et al., 2012).

Challenge 1: Synchronization and arrival times.

First, it should be checked, whether the underlying research question can be addressed with an asynchronous experiment design as well. If possible, the experiment can be redesigned in an asynchronous setup. Second, if subjects do not have to compete live against each other, playing against historical data from an earlier observation is possible (Amir et al., 2012; Suri and Watts, 2011; Straub et al., 2015). Third, if the live interaction and reaction between subjects is indispensable a waiting room can be implemented (Mao et al., 2012; Mason and Suri, 2012; Paolacci et al., 2010). However, a shortcoming of this approach is that it is unclear how long a subject has to wait, since arrival times vary. Paying a fixed fee after a certain amount of waiting time or using bots in case that waiting times are too long are possible approaches to address this (Horton et al., 2011).

(b) In a field experiment subjects usually do not know that they are being observed and the experimental setup is camouflaged. This leads to a high external validity but lower internal validity. In Laboratory studies the actions of a subject are observed in a controlled environment - the laboratory. Isolated cabins prevent unregulated contact and ensure that subjects are not influenced by uncontrolled stimuli. Variance in noise, light, and technical factors like input devices, monitors, etc. can be prevented. Therefore external confounding factors are minimized and internal validity is higher (Friedman and Sunder, 1994). In theory both, field and laboratory setups, can be realized on MTurk. However, the internal validity of experiments on MTurk compared to laboratory settings might be lower due to less possible control. To be more specific, workers might not pay attention during the observation (Paolacci et al., 2010; Horton et al., 2011; Mason and Suri, 2012). Since subjects on MTurk usually work from their own computer it is impossible to control their environment during the observation (Chandler et al., 2014; Crump et al., 2013; Rand, 2012). Chandler et al. (2014) find that subjects are watching TV or listening to music while working on MTurk. Another problem with crowd work is that some of the workers try to maximize their payout by finishing as many tasks as possible, often just clicking through them. So called malicious workers or "spammers" are not paying attention and jeopardize the overall data quality of results.

Challenge 2: Control and attention.

First, the overall task design can be aligned to incite workers to take the task seriously. Tasks that are fun, interesting, and meaningful incite subjects to pay attention (Kittur et al., 2013; Crump et al., 2013). Layman and Sigurdsson (2013) show that tasks designed as a game are more satisfying for a subject and thereby motivate to pay attention. Furthermore, researchers could state the expected result quality and give context about the overarching goal in the instructions to give the task a meaning (Oh and Wang, 2012; Oppenheimer et al., 2009). Stating that the task is an experiment and participation helps research can as well give the task a meaning, if experimenter bias is not a problem (Orne, 1962). Second, besides redesigning the overall experimental task, experimenters can try to exclude subjects who do not pay attention before the actual observation. Many researchers test if a subject is paying attention during the instructions and exclude those who fail the respective test from the sample (Paolacci et al., 2010; Peer et al., 2013; Oppenheimer et al., 2009; Paolacci and Chandler, 2014). Oppenheimer et al. (2009) introduced the instruction manipulation check, which was recently applied by many researchers (Straub et al., 2015; Hall and Caton, 2014). The fundamental idea of the instruction manipulation check is to trick inattentive subjects with a question or free text field which is easy and at best straightforward to answer, e.g. "What is your age?". The instructions state at one point that this particular question should be ignored. Consequently subjects who do not read the instructions carefully, e.g. stating their age, can be excluded from the task (Goodman et al., 2012).

3. Framework for a Collaborative and Continuous Guideline

A continuously updating guideline can be successfully put into practice within a collaborative process. We propose that researchers should work together to integrate their (new) insights to an online platform. The proposed framework is structured as follows: First, if researchers decide to conduct a crowd experiment they can retrieve the most recent version of the guideline from the platform (as depicted in figure 2 of the appendix). Second, challenges that apply to the experimental setup can be identified and solutions can be found in the registered insights from other researchers. Third, researchers can either incorporate these solutions to their experimental setup or develop new solutions based on the challenges and hints from the platform. Fourth, after the researchers conducted their experiment they can update the platform based on their findings, e.g. if and how good the applied solutions worked. Through this process continuous updates to the guideline are facilitated based on collaborative input from researchers and the community. However, certain requirements (req.) should be implemented. Malicious workers might try to trick the system by accessing the platform in order to get defective insights. Therefore access should be restricted to researchers. Login systems only giving access to "edu" domains or account confirmation must be implemented.

Req. 1: Access should only be given to researchers.

Overall the most important factor for a continuously updating guideline is the integration of new insights and results. Therefore researchers must be incited or enforced to incorporate their knowledge to the platform. Social rankings raising reputation and chances for citations might incite participation. Another conceivable way would be to enforce participation by restricting access with a fee, which a researcher gets back once he updates the platform.

Req. 2: Incentives or enforcements to update the platform are needed.

To secure an overall style of the guideline design principles must be set. Overarching categories with examples should be derived to make the platform easy to use and accessible for researchers.

Req. 3: Design principles should be derived for updating the platform.

4. Summary and Outlook

In this paper we proposed a guideline structure with a challenge and solution oriented view on conducting behavioral experiments on crowd work platforms. Such a guideline gives behavioral economists an easy introduction to crowd experiments with a clear and familiar structure. Furthermore we proposed a framework for an online platform where researchers could collaboratively and continuously update such a guideline. Both guideline and platform are currently in a conceptual stage. Following the notion of collaborative work, crowd work, and open innovation we plan to develop a demonstration version to incorporate practitioners and community feedback in future iterations. Hence, the next steps of future work comprise elaborating and finalizing the guideline concept and integrating it in a platform to facilitate a live deployment. Future work should analyze how researchers could be motivated to participate and how the platform could be extended. Possible extensions include experimental databases to look up which experiments other researchers already conducted and worker databases to block users who already participated in similar experiments as proposed by Chandler et al. (2014).

Acknowledgements
We would like to thank Sarah Kexel for her active support and contributions to the development of this guideline concept.

Appendix

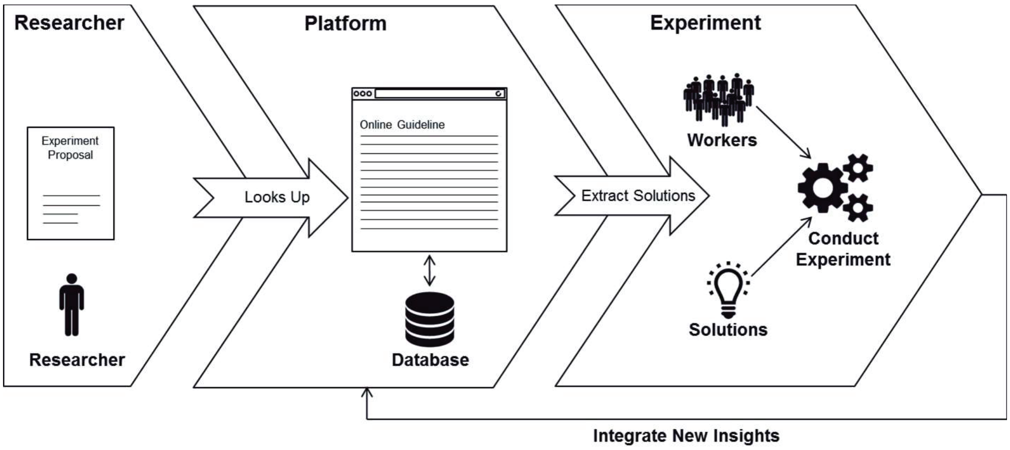

Figure 2: Framework of an online platform for a collaborative and continuous guideline.

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Towards a Requirement Framework for Online Participation Platforms

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Abstract

Online participation platforms (OPPs) are frequently used by public institutions to involve citizens in political opinion forming and decision making. A literature review reveals different approaches to evaluate these OPPs. These approaches focus only on partial requirements of participation processes. In this research in progress, we develop and pretest an interdisciplinary literature-based requirement framework. It includes the categories usability, security, information, transparency, integration, and mobilisation. Our aim is to close the research gap of a context-specific analysis and evaluation of OPPs.

1 Introduction

Modern parliamentary democracies can be described as interdependent systems of conventional and non-conventional, direct and indirect, constituted and non-constituted instruments and processes of political participation (Nanz & Fritsche, 2012). Information and communication technologies (ICTs) are thereby often used to support, complement or even replace common offline participation instruments. The possibilities for public institutions to include citizens in decision making are as diverse as developed technologies and software available (Kubicek et al., 2011).

However, the success of such technologies is evaluated differently by different researchers, suppliers and users (Escher, 2013), since it can be measured from a number of perspectives (Kubicek et al., 2011). It males sence to question which requirements are fulfilled when talking about successful online participation and how can success be assured. Therefore, the aim of this work is to develop and design an interdisciplinary requirement framework that facilitates a holistic evaluation of OPPs. In our investigation we focus on platforms implemented for civic participation processes of public institutions.

For the development of the requirement framework we first review existing evaluation criteria and models in Chapter 2. In Chapter 3, existing criteria are extended and combined with a focus on context-specific characteristics of political OPPs. In Chapter 4, technical and context-related requirements as well as interactivity requirements are developed. Furthermore, subcategories for their evaluation are suggested. We conclude and give an outlook in Chapter 5.

2 Literature Review

Published works on the impact, correlation and success of OPPs usually have a social or humanistic background and focus on individual cases (i.e., Große et al. 2012 for enquetebeteiligung.de). More comprehensive studies that allow for comparative statements rarely focus on the technical concept and realisation of OPPs. For example, The Alexander von Humboldt Institute for Internet and Society (HIIG, 2014) investigates user expectations and behaviour of 13 political and enterprise OPPs in the German-speaking area. Kubicek et al. (2011) compare twelve political OPPs worldwide and identify criteria for success (solution-relevant information, range, inclusivity, increase of acceptance of measures, democracy support, influence on result, efficiency) as well as factors for success (well-defined purpose, activity of decision makers in the process, mobilisation of participants, transparency, connectivity, resources and urgency of the topic). The authors do not focus on any technical aspects. However, the application of ICT offers additional requirements due to the OPPs’ characteristics as websites. A number of research works suggests evaluation procedures and criteria for websites (Madan & Dubey 2012). Signore

(2005) for example differentiates between five dimensions of requirement: correctness, presentation, layout, navigation, and interaction. Furthermore, there are special approaches for the usability of websites. While Levi and Conrad (2001) suggest five categories for evaluation (attractiveness, controllability, efficiency, helpfulness, and learnability), Kirakowski and Corbett (1993) focus on user perception of software usability. In our requirement framework we include the suggested and validated dimensions by Signore (2005) and Levi and Conrad (2001) and adapt them to our civic approach.

3 Methodology

In our requirement framework of OPPs we combine requirements of civic participation procedures and websites. For this purpose, we used different theoretical approaches to integrate six main requirement criteria of which each criterion contains different subcategories. Since this research focusses on political online participation we used theoretical models referring to the interaction between citizens, public institutions, and ICTs, to identify necessary criteria.

3.1 Citizens & ICT

For the description of citizens' behaviour on websites we refer to the validated Technology Acceptance Model (TAM, Davis et al., 1989) that deals with human-computer-interaction and describes user behaviour as perceived usefulness and perceived ease-of-use. TAM was been reviewed and extended several times. The advanced models, including TAM2 (Venkatesh & Davis, 2000), the Unified Theory of Acceptance and Use of Technology (UTAUT, Venkatesh et al., 2003) as well as UTAUT2 (Venkatesh et al., 2012), add aspects of social influence (job relevance, image, subjective norms, experience, and voluntariness), four constructs of behaviour acceptance (performance expectancy, effort expectancy, social influence, and facilitating conditions), and individual differences (gender, age, and experience). Aladwani (2006) and Aladwani & Prashant (2002) specify UTAUT for websites by integrating dimensions of website quality (Aladwani, 2006, Aladwani & Prashant, 2002). Website quality is defined as targeted content, content quality, image, and technical adequacy. In our framework we integrate the presented categories in the criteria regarding technical and content-related requirements.

3.2 Citizens & Institutions

To describe the relationship between citizens and political institutions (in parliamentary democracies) we use the principal agent approach (Gilardi & Braun, 2002), that identifies delegation chains within representative systems between the citizens as the sovereign (principal) delegating tasks and responsibilities (e.g. the provision of public goods) to political institutions (agents). Due to a relation-dependent moral hazard and information monopoly there is a need for incentives and control mechanisms to combine interests of agents and principals. OPPs can hereby act as communication tools to express and underline the citizens' preferences on political topics (Roleff, 2012). To change the relationship between principal and agents, OPPs have to actively provide the topic-relevant information to users (Kubicek et al., 2011). Furthermore, the impact of OPPs on decision making processes can only be assured by a binding (or even mandatory) integration of the OPPs in existing work and decision structures of the involved institutions (Kubicek et al., 2011). Finally, discussion or voting results of OPPs can only interpreted as a representative set of opinions, if sufficient citizens were mobilized (Große et al. 2012).

3.3 Institutions & ICT

For the interpretation of when, why, and under which circumstances political institutions use ICTs we use research approaches from the field of E-Government. Public authorities routinely have been using ICT systems in order to improve the access and more efficiently provide government information and public services (Yildiz, 2007, Mulgan, 2014). Analysing different implementation concepts of E-Government initiatives, a change in the perception of e-government towards a particularly security-oriented usage of ICT can be stated (Yildiz 2007). As a result, principles of e-government such as an improved information access, Open Government and a higher degree of responsiveness, are complemented by security aspects. That is why we also consider security as a necessary requirement criterion.

3.4 First Evaluation

We pretested all six identified criteria in a survey on civic online participation (to be published in 2016). A partly standardized questionnaire was developed and evaluated via experts reviewing wording, structure and order of the questions. We then sent the questionnaire to public officials and platform providers of 20 OPPs and received positive feedback from political officials and providers of 14 OPPs. We additionally conducted five guided interviews by telephone, which were strongly bound to the questionnaire, to clarify misunderstandings. A qualitative analysis of replies from 14 OPPs (nine national and five international ones) led to a revision of our requirement criteria.

4 Requirement framework

In the following chapter, the six literature-based and pretested criteria (usability, security, information, transparency, integration, and mobilisation) are presented including suggested subcategories. They are grouped in technical, content-related and interactivity requirements.

4.1 Technical Requirements

The entire participation process is based on technical functionalities of an OPP. Technical requirements can be divided into two subcategories (usability and security): *usability* (Levi & Conrad, 2001, Signore, 2005, Davis, 1989) includes (1) navigation (menu/ page structure, links), (2) design (text, picture/ page layout, presentation on mobile devices), (3) multimedia (videos, sounds), (4) efficiency (effort to find information; effort to actively participate at a voting or discussion, etc.), and (5) help system.

Security includes security of information (integrity, authenticity, commitment, availability, and confidentiality), as well as privacy aspects (pseudonymisation and anonymisation) (Yildiz, 2007, Mulgan, 2014).

4.2 Content-related Requirements

Content-related requirements refer to content provided on the OPP. They are divided into two subcategories (information and ransparency/tracebility): *information* includes (1) correctness (of the information), (2) completeness, (3) actuality, and target-group orientation/ inclusivity (i.e., multilinguism, accessibility, gender neutrality) of the decision relevant information. *Transparency/ traceability* (Kubicek et al., 2011; Venkatesh und Davis, 2000, Signore, 2005) refers to (1) participation processes as such (disclosure of different user groups, FAQs, conditions of use) and (2) the provision of information and data (readability, information set-up) and information structure (number of headings and subheadings, paragraph length, etc.).

4.3 Interactivity Requirements

Interactivity requirements include all requirements that relate to the interaction of institution, citizens, and website during the process. Two subcategories are defined (integration and mobilisation): *integration* (Venkatesh et al., 2003, Kubicek et al., 2011) involves (1) institutionalisation/automatisation of the OPP to assure the possibility of a continuation, as well as (2) commitment in dealing with results. *Mobilisation* (Große et al., 2014, Venkatesh et al., 2003, Kubicek et al., 2011) can be divided into (1) marketing / PR (online and offline), (2) media impact, (3) integration of online and offline steps and (4) topic relevance.

5 Conclusion & Limitations

The proposed requirement framework includes evaluation approaches for website quality and interaction of citizens and institution to enhance a context-specific and practical evaluation of OPPs. Technical requirements are prerequisites for the acceptance of OPPs by participating citizens. Context-related requirements necessitate the political functionality. Interactivity criteria are ultimately responsible for the success of the process. To the best of our knowledge there is no other requirement framework that focuses on such instruments and comprises such a broad evaluation. All suggested criteria were pretested by experts from research as well as public officials and providers of OPPs. The integration of different theoretical perspectives aims to enable a systematic and objective analysis of OPPs in the future. Furthermore, the comparability will be faciliated.

Our current research focusses on the concretisation of the requirement criteria. The questionnaire is modified to also include users in the evaluation process of the framework. As a next step we aim to find reliable instruments and tools to empirically test platforms referring the six requirement criteria.

In future research, we plan to expand the requirement framework by other non-political domains, e.g. in the context of enterprise participation. But also include more specific requirements such as the choice of mechanisms in participatory budgetings (Niemeyer et al. 2015). The main goal, however, is to create a utilisable and demand-oriented requirement framework for the evaluation of existing OPPs.

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Smart Services and Internet of Things

Utilizing Ontological Classification Systems and Reasoning for Cyber-Physical Systems

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Abstract

This work presents a novel ontology-based approach for the complementation of technical specifications of cyber-physical system components using ontological classification and reasoning. We build on the AutomationML standard and outline how data represented with it can be transformed into an RDF instance graph. We exemplarily show how complementary information about a component's functionality, its operation environment and purpose can be inferred through a combination of automatic classification with the linkage of different domain classification systems. The general applicability of the presented approach is demonstrated by a concrete use case from the ReApp project.

Keywords: Industry 4.0, Knowledge Representation, Cyber-Physical Systems, Semantic Web Technologies, AI Reasoning Methods

1. Introduction

In this work, we concisely present a novel ontology-based approach for complementing technical specifications of hardware components found in cyber-physical systems (CPS) using ontological classification and reasoning. The main feature that distinguishes this approach from most related ontology-based knowledge representation approaches in robotics and CPS is that we exclusively describe such information in the terminological part (*aka TBox*), i.e., the schema part of ontologies in order to fully exploit the formal, model-theoretic semantics of the underlying ontology language and the logical entailments that can be computed from it by a reasoner (Rudolph, 2011; Krötzsch et al., 2014; Zander and Awad, 2015). The deduced terminological knowledge can then be used to

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complement the description of CPS components with information that is not explicitly asserted in their original technical specifications. We specifically use Description Logics (DL) as knowledge representation framework since they provide well-understood reasoning complexity and tractability (Baader et al., 2003; Gil, 2005; Krötzsch et al., 2014). As a consequence, the semantics upon which complementary information is deduced can be shared, extended, or adopted by other CPSs in order to reason about component descriptions.

2. Expressing Technical Specifications using AutomationML

AutomationML[1] (AML) is a well-known and fast growing standard that already caught the attention of Industry 4.0 communities (RAM, 2015). It covers engineering aspects including topology, geometry, kinematics, logic and communication (Drath et al., 2008) that can be used for describing properties and functionalities of a CPS component. Data contained in the AML description of one component can be exposed to the communication network of a CPS system and consumed by other components (Schleipen et al., 2014). From a modelling perspective, AutomationML is based on the object-oriented paradigm and supports fundamental techniques like class-instance relationship and inheritance hierarchy. The architecture of AutomationML contains the following blocks:

- RoleClass library: Domain-specific concepts are modelled as RoleClasses and organized as taxonomy in the RoleClass library. AutomationML provides a predefined set of RoleClass libraries for the domain of automation and manufacturing that covers abstract concepts like product, process, and resource, and specific components like robot or conveyor. These can be extended to cover individual requirements of the application domain.
- InterfaceClass library: InterfaceClasses define relations between objects. AutomationML predefines some abstract interfaces for general automation systems, that can be further extended by user.
- SystemUnitClass library: Component models in the production system can be modelled as SystemUnitClasses. These are specific user-defined AML classes and typically manufacturer-dependent. A SystemUnitClass can reference multiple RoleClasses by means of SupportedRoleClass to demonstrate its semantics.
- InstanceHierarchy: Concrete instances of component models can be stored in the InstanceHierarchy. These instances carry project data and represent the real plant setup in the digital world.

However, none of these elements exhibit an explicit machine-readable formalization of its semantics. To accurately interpret data, special software with

[1] www.automationml.org

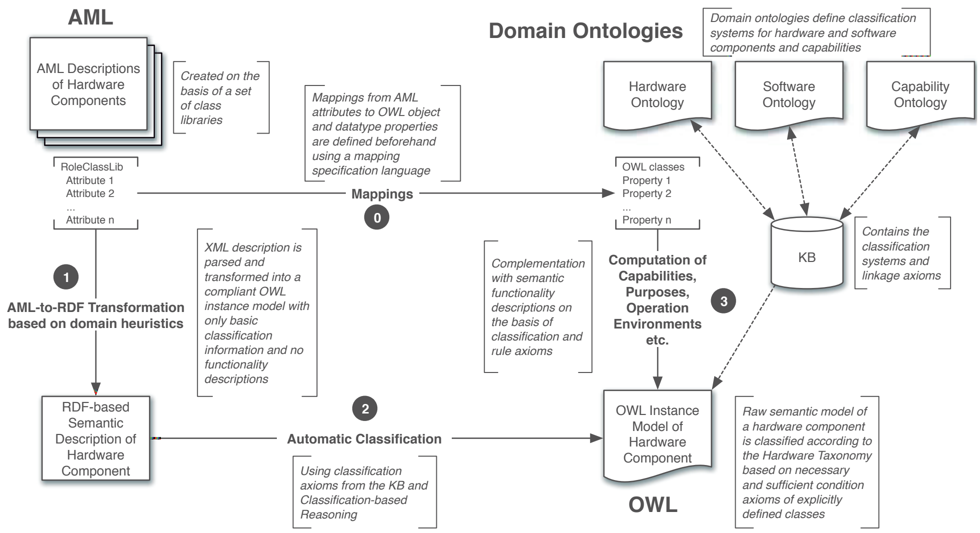

Figure 1: Overview of the presented approach showing uplifting, classification, and complementation phases for hardware component descriptions

hard-coded knowledge and application logic has to be implemented. Developers are assumed to have the correct understanding of the elements' semantics, which is often error-prone. Although AutomationML carries basic semantic information of a SystemUnitClass or its instance (in the InstanceHierarchy), the data exchange process is merely a serialization and deserialization of XML files that enables syntactic interoperability only (Biffl et al., 2014).

3. Approach

The presented approach presupposes the existence of an AML description of a hardware component.An AML description is analysed and transformed, i.e., *uplifted* into a compliant RDF description using transformation rules and domain heuristics (Section 3.1). The attributes contained in the generated RDF instance graph are then processed by a DL reasoner for automatic classification according to types defined in domain ontologies (Section 3.3). This is important as it builds the basis for inferring additional terminological knowledge by linking classification systems of different domain ontologies (Section 3.2). The inferred knowledge can the be added to the uplifted RDF instance model to provide a more complete and expressive representation (see Figure 1 for an overview).

3.1. Transforming AML Descriptions into RDF Graphs

Some initiatives already aimed at complementing AML with ontological semantics: Persson et al. (2010) introduced the transformation of AML documents into RDF triple stores which can be queried with SPARQL. Kovalenko et al. (2015) tried to lift AML data into an ontology by directly converting the underlying XML schema of AML into the Web Ontology Language (OWL). A domain ontology was adopted in Björkelund et al. (2011) to extend semantic expressivity of AML for robotics. In contrast to these works, we use ontological reasoning in order to complement uplifted AML descriptions with additional semantics. We focus on SystemUnitClasses, because they represent reusable models of CPS components that contain richer information of functionalities. The following rules are applied to extract the implicit semantics of a SystemUnitClass into explicit form in RDF.

1. A SystemUnitClass will be transformed into one RDF graph.
2. Each SupportedRoleClass corresponds to a RDF TBox concept in the domain ontology. For each of them in the SystemUnitClass, we assign a TBox concept to the ABox instance.
3. We defined a direct mapping between all attributes and the properties defined in the ReApp domain ontologies.

Once all AML-specific notations are transformed, i.e., uplifted into an RDF graph that uses the terms defined in the domain ontologies to equivalently represent the AML classes, attributes, and values, it can be used for automated classification and the computation of implicitly contained knowledge.

3.2. Linking Classification Systems for Expressing Features of Components

In the ReApp-project[2] (Zander et al., 2015), we developed three different kinds of ontologies for encoding different types of domain knowledge. The *hardware* and *software ontologies* provide classification systems for technical components whereas the *capabilities ontology* defines a classification system for functionalities hard- and software components are able to perform. These different kinds of ontologies are linked together via a *base ontology* that defines the basic terms used to express the set of capabilities a certain hard- or software type exhibits per default.

As demonstrated in Zander and Awad (2015), capability information can be axiomatically linked to component classification systems via *role restriction axioms* to assert that a given capability (and all the capabilities it is subsumed by) is the default capability for a given classification type. Role restriction axioms in general interlink roles, concepts, and quantifiers[3] (Rudolph, 2011; Krötzsch et al., 2014) by forming an anonymous super class that contains all the individuals that satisfy the given restriction (Horridge et al., 2004). The following axioms exemplarily demonstrate how a hardware classification for SafetyLaserScanner

[2] http://www.reapp-projekt.de
[3] More expressive DLs even allow for the specification of multiplicity constraints

can be linked to a capability classification SafeMonitoringOf2DFields that acts as its default via a role restriction along the property hasCapability (Axiom 1) and what additional capabilities can be inferred via subsumption reasoning (Axiom 2 and 3):

$$\mathsf{SafetyLaserScanner} \sqsubseteq \exists \mathsf{hasCapability.SafeMonitoringOf2DFields} \tag{1}$$
$$\mathsf{SafetyLaserScanner} \sqsubseteq \mathsf{LaserScanner} \tag{2}$$
$$\mathsf{LaserScanner} \sqsubseteq \exists \mathsf{hasCapability.MonitoringOf2DFields} \tag{3}$$
$$\mathsf{MonitoringOf2DFields} \sqsupseteq \mathsf{SafeMonitoringOf2DFields} \tag{4}$$

With Axiom 2 the reasoner can deduce that a SafetyLaserScanner also has the default capability MonitoringOf2DFields and materialize this information for classified components. Once different domain classification systems are linked together, certain conditions can be defined that need to be satisfied by an individual component in order to be classified accordingly.

3.3. Defining Conditions for Automated Classification

By specifying *necessary* and *sufficient conditions* for class membership, a reasoner is capable to automatically classify random instances on the basis of the relationships they participate in (Horridge et al., 2004). This enables the automated classification of uplifted RDF component specifications according to the attributes extracted from its AML representation (see Figure 1). The formal interpretation of which is that the given conditions are not only necessary for determining class membership, they are also sufficient in a way that any random individual that satisfies these conditions becomes member of a class. The following axioms allow a reasoner to classify an uplifted component as 7AxisRobotArm, iff it is a RobotArm and participates in a numberOfAxis relationship, the value of which must be 7, i.e., iff it has exactly seven rotational axes:

$$\mathsf{7AxisRobotArm} \equiv \mathsf{RobotArm} \sqcap \exists \mathsf{numberOfAxis}.(=, 7) \sqcap (\leqslant 1\ \mathsf{numberOfAxis}) \tag{5}$$
$$\mathsf{7AxisRobotArm} \sqsubseteq \mathsf{RobotArm} \tag{6}$$
$$\mathsf{RobotArm} \sqsubseteq \exists \mathsf{hasCapability.ReachPose} \tag{7}$$
$$\mathsf{7AxisRobotArm} \sqsubseteq \exists \mathsf{hasCapability.FlexibleConfiguration} \tag{8}$$

When a component is classified as 7AxisRobotArm, the reasoner can infer that it offers the two default capabilities ReachPose and FlexibleConfiguration. Formally, this means that the class 7AxisRobotArm is subsumed by the two complex class expressions ∃hasCapability.ReachPose and ∃hasCapability.FlexibleConfiguration.

These additional subsumption relations can then be used for complementing a component's specification by *materializing* (see Domingue et al. (2011)) all the implicit knowledge inferred by a reasoner and add it to the component's instance model. The materialization is important as it allows all the inferred knowledge about a component to be indexed by a triple store and retrieved through RDF query languages such as SPARQL (SPARQL, 2013). For the materialization of capability information, we employ the concept of *DL nominals* (cf. Baader et al. (2003); Rudolph (2011); Krötzsch et al. (2014)) to use them both in ABox and TBox axioms and ensure their *singularity*.

In the last part, we demonstrate how this axiomatic knowledge can be used for complementing the technical AML specification of a Sick S30B laser scanner. The following code excerpt shows the uplifted RDF representation[4]:

```
<urn:uuid:f81d4fae-7dec-11d0-765-00a0c91e6bf6>
  :hasManufaturer "Sick" ; :hasModelName "S30B-2011GA" ;
  :startAngle "135"^^xsd:integer ; :endAngle "135"^^xsd:Integer ;
  :maxMeasurementRangeInMeter "40"^^xsd:integer ;
  :maxProtectiveFieldRangeInMM "2000"^^xsd:integer ;
  :maxWarningFieldRange "8000"^^xsd:integer ;
  :maxSimultaneousFieldEvaluations "0"^^xsd:integer .
```

By employing automatic classification in combination with reasoning on the terminological part of domain ontologies, the RDF representation can be complemented by the following inferred and materialized information:

```
<urn:uuid:f81d4fae-7dec-11d0-a765-00a0c91e6bf6>
  rdf:type :2DSaftyLaserSensor , :LaserSensor , :Hardware Component ;
  :hasCapability :{SafeMonitoringOf2DFields} , :{MonitoringOf2DFields} , :{Monitoring} ;
  :hasPurpose :{HazardousAreaProtection} , :{AccessProtection} , :{PersonnelSafety} ;
  :hasOperationEvironment :iIndoor, iOutdoor .
```

The annotation model now contains information about its concrete type, capabilities, purposes and the operation environments in which it can be used.

4. Conclusion

In this work, we presented an approach for complementing the technical specifications of CPS' components by utilizing the formal, model-theoretic semantics encoded in DL ontologies using reasoning. We introduced AML as an XML-based technical specification language that facilitates data exchange between CPSs but has only limited semantic expressivity. We outlined how different classification systems can be linked together to express features and other relevant characteristics, how conditions can be defined to enable an automated classification of uplifted RDF component descriptions, and how implicitly inferred information can be used to complement component descriptions. In use cases from the ReApp project, we could demonstrate that the technical AML specifications can be complemented in useful ways to enable a formal verification and validation of component orchestrations, to foster reusability, and to compute advanced capabilities for compound components.

[4]We omitted namespaces for reasons of readability and comprehensibility.

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Enabling companies to make use of industrial clouds - Foundations for Evidence-Based Engineering of Service Systems (Dissertation Proposal)

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Abstract

Cyber-physical systems (CPS) and their underlying technological manifestations have a deep impact on various industry sectors, e.g. manufacturing or logistics. The conjunction of machine intelligence with human intelligence together with the ubiquitous availability of data and vast opportunities for automation allow for new forms of service provision. To date, however, the lack of design knowledge on such architectures limits the opportunities for taking advantage of recent technological developments to engineer innovative service. Gaining this design-knowledge represents a challenge since value creation in the field of services strongly relies on their conceptualization as being contextual and collaborative. The complex socio-technical context of service systems and the central role of interactions among the participating actors are limiting the opportunities for meaningful research in laboratory settings. Hence, in order to generate design knowledge with strong validity, research has to be embedded within existing service systems or within the engineering of respective novel socio-technical entities. By this, evidence-based knowledge can be aggregated and instrumentalized for the design, implementation and evaluation of real-world service systems in the course of service systems engineering (SSE).

1 Introduction

Service engineering with its tools and methods primarily addresses the service economy. Over time, this economic sector is facing a set of changes in terms of content and structure (Hartmann, 2002). Services in the context of B2B or B2C relationships are in a state of flux and new forms of service provision are arising. A phenomenon contributing to these changing market environment deals with the rise of cyber-physical systems. Their technical architecture can be identified as one of the biggest factors influencing the service ecosystem (Zolnowski, Schmitt, & Böhmann, 2011). This specifically applies to their impact on industrial product manufacturers. By equipping industrial products with sensors and connectivity, manufacturers might still collect data from the equipment that is already sold which enables them to provide additional service (Herterich, Uebernickel, & Brenner, 2015b). In this sense, remote services, teleservices, or remote maintenance services facilitate monitoring and maintenance of industrial machines and whole plants by utilizing ICT (Holtbrügge, Holzmüller, & von Wangenheim, 2007). Moreover, the substitution of reactive services by proactive or even predictive approaches is fostered by data pooling and data analysis methods in order to calculate maintenance intervals and failure probability in the forefront of a potential breakdown (Muller, Crespo Marquez, & Iung, 2008). In the context of recent developments, open cloud platforms, so called industrial clouds, are utilized which provide smart data tools for data analytics, data visualization or business intelligence to multiple stakeholders. By contextualizing big data, which is per se non-descriptive, with additional domain information, smart data is generated (Siemens, 2014, 2015). These data sets bear high potential for innovating new services since they are based on evidence from real-world settings. Arising from this perspective, industrial clouds enable the aggregation of evidence for engineering new service systems.

Concomitant with these technologically connoted developments, also a shift regarding the underlying mechanisms of value creation becomes apparent. Due to increased interdisciplinary and complexity, more players are involved in product and service offerings, and the market and the ecosystem are getting more complex (Zolnowski et al., 2011). Service provision is increasingly manifested by cooperative service networks (Klostermann, 2008) where value is not only created in a dichotomy of provider and customer. In fact, in a multi-sided value logic, value creation takes place in the course of collaboration among multiple stakeholders (Benkler, 2006). This increased complexity in service provision constitutes a need for expanding its conceptual understanding. Thus, not merely concrete services, but rather complex service systems are the object of observation (K. Meyer & Böttcher, 2011).

The incorporation of industrial clouds in conjunction with the thereby precipitated increased complexity in service systems and networks requires input from disciplines and expertise outside the traditional service research arena. Here, the potential of theories from design science and engineering can be leveraged. An example in this context is systems engineering, which can be regarded as a promising approach for integrating IS expertise with other aspects of service design (Ostrom, Parasuraman, Bowen, Patricio, & Voss, 2015). Arising from this perspective, service systems engineering seeks to advance knowledge on models, methods, and artifacts that enable or support the engineering of service systems (Böhmann, Leimeister, & Möslein, 2014).

There is already a solid knowledge base on traditional service engineering which provides simple and easy to handle models, methods and tools (Bullinger, Fähnrich, & Meiren, 2003; Bullinger & Scheer, 2006; Fähnrich, Meiren, & Barth, 1999; Luczak, 2004) for engineering new services in a systematic way. However, these approaches do not take full advantage of the opportunities for systemic, interactive, and collaborative service innovation arising from the advances in ICT (Böhmann et al., 2014). Novel approaches face this challenge by setting up complex toolkits for engineering new services systems (Hermann, Ganz, & Westner, 2013; L.-P. Meyer & Meyer, 2013; Westner & Hermann, 2015). These approaches address industrial application contexts where services are developed professionally. Large firms can manage these processes by creating structurally separate business units whereas SMEs and traditionally oriented companies that want to make a shift towards providing services commonly suffer from limited slack resources so that only limited competence in this field can be maintained (McDermott & Prajogo, 2012). Therefore, companies with limited design knowledge in the field of service engineering are mostly not capable of making use of the value creation potential (Herterich, Uebernickel, & Brenner, 2015a) fostered by the rise of CPS, i.e. open cloud platforms.

Against this backdrop, novel work should seek to strike a balance between the two manifestations described above. Thus, there is a need for new models, methods and tools in the field of service systems engineering which are simple and easy to handle on the hand, but also make use of the recent developments in connection with CPS, i.e. industrial clouds. Guided by this, the following research question can be identified: Which models, methods and tools are suitable for making use of the incorporation of industrial clouds among companies with limited design knowledge in the field of evidence-based engineering of service systems?

2 Theoretical framework

In the course of contributions from Vargo and Lusch, a rethinking in service research is postulated and the idea of a systemic approach is propagated (Vargo & Lusch, 2004; Vargo, 2009). From a systems perspective (Kast & Rosenzweig, 1972), service systems enable value co-creation through the configuration of actors and resources (Vargo & Lusch, 2004).

In the context of industrial clouds, the underlying technological system predetermines the role of actors and resources. Based on that, a distinction in between data providers, cloud provider, and data receiver can be made. The roles of actors and resources, respectively the roles of service provider and user are changing according to the different value creation constellations. Based on this assumption, potential service providers shall be identified and enabled for engineering their service systems as a subsystem of the whole system. A framework will be developed as an initial foundation for further research and will be adjusted accordingly by applying the research methods mentioned in the further course.

3 Research Design

By applying action design research as a research method, design knowledge for engineering new services systems on the fundament of industrial data clouds will be aggregated. In order to aggregate this knowledge, three studies with respective focuses will be conducted.

The first study will consist of setting the stage for the use of industrial data clouds among various companies from various industry sectors and various degrees of knowledge in service engineering. Therefore, a state of the art review of industrial data clouds will be conducted with the aim of identifying various value creation constellations and according requirements concerning the use of the cloud infrastructure on behalf of the respective service provider. In a first step, a framework is created which incorporates all actors and relevant resources in the service ecosystem constituted by the cloud infrastructure. This framework is applied to various use cases of the industrial data cloud among companies which could potentially engineer new services in this environment. In the course of action design research, interviews with corresponding companies and workshops will be held. By this, a holistic and widely applicable model representing the whole service system shall be created iteratively. Furtheron, the framework will be used to determine emerging value creation potentials from the perspective of different actors in the whole service system. In order to ensure a broad transferability of the evidence generated, a widely applicable theoretical foundation, such as the work systems framework by (Alter, 2008, 2012) will be instrumentalized. By this, resulting partial service systems can be conceptualized as subsystems of the overall service systems derived from the cloud infrastructure and all of its incorporated actors and resources. Based, on that, inherent requirements for the use of industrial clouds will be aggregated from the respective value creation perspectives identified beforehand.

In the course of the second study, existing methods in service engineering will be identified, analyzed and evaluated in terms of their potential for engineering new service systems in the context of industrial clouds. Against this backdrop, a literature review will be conducted where methods are contrasted with the value creation constellations and according requirements identified beforehand. Based on that, a model for engineering service systems is set up. This model incorporates stages in which cloud-based tools can be applied in the course of evidence-based engineering. The approach determined in the course of action design research in the first study will be incorporated as an initial phase.

The core of the third study is to apply the service system engineering process developed beforehand in different value creation constellations. As mentioned above, the first study also depicts a phase in this process which determines the service system to be engineered by the respective service provider within the whole system constituted by the cloud infrastructure. Arising from various perspectives of value creation among the different companies involved, different requirements for the engineering process and according cloud-based tools are relevant. The resulting scenario-dependent service engineering processes are evaluated in a multiple case study setting in order to determine their applicability and to adjust them by means of action design research.

4 Research Contribution & Managerial Implications

The dissertation to be conducted will provide valuable contributions in this context. By applying a systemic perspective, services can be regarded as complex socio-technical systems, i.e. service systems. In the course of applying this perspective, crucial factors in terms of service provision, i.e. the integration of industrial clouds with the thereby induced increased complexity in the underpinning ecosystem, can be challenged. In this sense, besides generating evidence-based knowledge on real world service systems by recognizing the connectedness and complementarity of their elements, the aim of this work is to provide simple and lightweight models, methods, and tools for service systems engineering which are fully making use of recent developments in ICT, but also facing the challenges of multi-sided value co-creation. In the course of piloting service innovation within real-world environments, these models, methods, and tools can be created on the foundation of evidence-based design knowledge which promises a broad applicability. By formalizing the research findings, a valuable contribution to the approach of service systems engineering as a whole is accomplished.
In a managerial context, a valuable contribution is made in terms of enabling companies with only limited knowledge in engineering services in complex environments to extend their business opportunities. By providing an end-to-end guideline which helps to sensitize respective companies for the potential of making use of industrial clouds on the one hand and providing an easy to handle and scenario-dependent service system engineering process on the other hand, especially SMEs, which can be regarded as the backbone of the German economy, are capable of getting their share out of recent technological developments.

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Requirements on a Service Tool to Foster Demand-Side-Management Under Changing Climate Conditions

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Abstract

Several countries in Europe, e.g., Spain, Turkey or Poland and worldwide, are already struggling with the existing impacts of climate change, such as long lasting droughts leading to a higher water demand for agricultural as well as industrial cooling processes (IPCC, 2014). As a result of higher insolation and rising temperatures (as predicted for the future), a higher demand for cooling systems for private as well as public buildings arises. If there is not enough water available for cooling conventional power plants during droughts, power plants have to restrict their amount of electricity generation in order to prevent an overheating of the river water. Additionally, droughts affect hydroelectric power plants as well, as they need certain minimum water levels to run the turbines. In countries with a large share of electricity generation from conventional and nuclear power plants, electricity generation from renewable energies such as wind turbines and photovoltaics can ease this problem. Nevertheless, renewable energy can lead to high fluctuations within the electricity grid as it is not available at all times. In that case, energy supply can neither be secured by the conventional and nuclear power plants nor by renewable energies. Besides alternative cooling technologies, demand-side-management (DSM) is an option, as it can adjust the demand to the actual market situation of water and energy. DSM can help to secure electricity supply by stabilising the operation of the electricity grid: electricity demand can be decreased and/or shifted to times of, e.g., high electricity feed in from renewable energy sources.

Aim of this paper is to define and establish the requirements on a service tool for the distribution of water and electricity, in order to secure energy supply by fostering DSM under changing climate conditions.

1 Dependency of the Security of Electricity Supply on Water Availability

1.1 The Energy-Water-Nexus

The USAID Global Environment Center in Washington D.C. already recognised in 2001, that energy and water have much in common and that energy is necessary to be able to use water and vice versa (Hurdus, 2001). However, the World Economic Forum states, that the International Food Policy research Institute (IFRI) expects a 30 % increase in water demand by 2030 (World Economic Forum, 2011), while the International Energy Agency (IEA) forecasts an increasing energy demand of 25 % by 2040 (IEA, 2015).

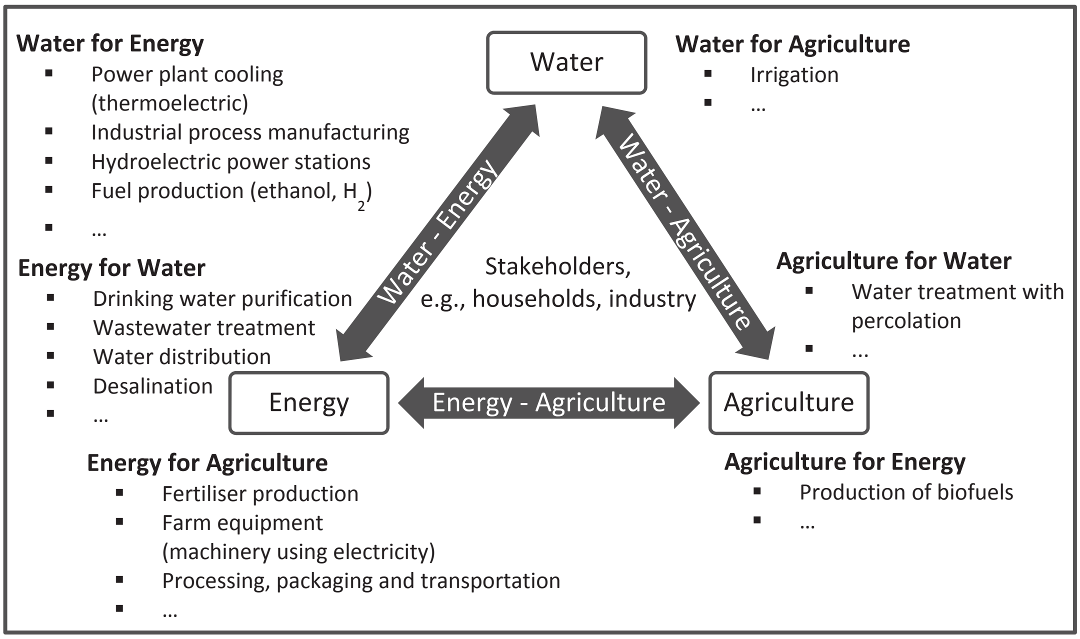

Figure 1.1

Supply triangle water, energy and agriculture (Newiadomsky & Tietze, 2015)

As it can be seen in Figure 1.1, water is needed for several industrial processes (production, cooling etc.) as well as for irrigation for agriculture (Halstead, Kober, & van der Zwaan, 2014). Moreover, energy is necessary for water supply (treatment, purification, distribution etc.) while it is also crucial for the production of fertilizers, biofuels or transport for the agricultural industry (Thirlwell, Madramootoo, & Heathcote, 2007). Products of the agricultural industry are in turn indirectly important for water treatment, e.g., purification via percolation (OECD, 2014). Households as well as industry are located in the middle of the described supply triangle, as they are depending on all three sectors in order to secure their demand. Industry depends additionally on these sectors in order to secure their supply (Newiadomsky & Tietze, 2015). A vicious circle can be observed, when countries depending on hydroelectricity have to turn to other energy sources leading to higher emissions and thus, influence the climate change (Thirlwell, Madramootoo, & Heathcote, 2007; Halstead, Kober, & van der Zwaan, 2014).
Depending on the plant size and the power plant type, different amounts of water are needed for cooling purposes, e.g., a nuclear power plant with once-through cooling withdraws between 95 to 227 m³ of water per MWh electricity, while cooling with a wet tower would lead to only 3.0 – 4.2 m³/MWh and with a pond to 1.9 – 4.2 m³/MWh. Water is necessary for every conventional plant type producing electricity, which shows the dependency on this resource (Davies, Kyle, & Edmonds, 2013). Regarding the amounts of water needed, it is crucial to find a solution to maintain energy security.
Apparently, there are conflicting interests between the sectors agriculture, water and energy as well as between the stakeholders, e.g., electricity versus water suppliers. Each stakeholder has its own focus, not necessarily considering the focus of the other stakeholders.

1.2 Climate change and energy security

Several studies on the impact of climate change on the environment predict an increase of air temperature (IPCC, 2013; Christidis, Jones, & Stott, 2015). This leads to increased evaporation from the water surfaces and an augmented need for water for, e.g., cooling in power plants (Colman, 2013) or for irrigation of agricultural areas. Simultaneously, water temperatures increase and industrial cooling is impeded (Zammit, 2012). Although rising temperatures lead to melting glaciers, which could increase the regional water supply again, the glaciers are melting faster than they can build up again during the winter months. Due to rising air temperatures, the clouds would rather start raining than snowing during the winter months. In the foreseeable future, the additional inflow from glacial waters would no longer be available and the regional water supply can be significantly reduced in the summer months (IPCC, 2013). An overview about possible climate change impacts on energy supply gives Schaeffer et al. (2012). Reports from summer 2003 deliver an example of the impeded industrial cooling, in which 15 coal-fired power plants in Germany (Strauch, 2011) and 30 nuclear power plants in Europe (IAEA, 2004) were affected by the unusually high temperatures. In Germany, seven of the 30 European nuclear power plants as well as the aforementioned 15 coal-fired power plants had to reduce their electricity generating capacity by up to 78 % in the months of May to October due to the high water temperatures and the legal maximum temperatures for returning cooling water (Strauch, 2011).

Higher global temperatures will increase the possibility of droughts or floods: Due to rising temperatures, polar caps and glaciers melt and in turn result in rising sea levels. Furthermore, the temperature increase reduces the quality, quantity and accessibility of water resources: They lead to higher evaporation in lakes as well as rivers, which could lead to drying and thus, restriction on aquatic habitat and lowered water quality due to increased pollutant concentrations and oxygen deficits (IPCC, 2013). Accordingly, higher temperatures will lead to higher energy use to treat low quality water or to pump water from greater depth (U.S. Department of Energy, 2007). In turn, increased energy use will cause an increase in greenhouse gas emissions, while lower water availability leads to trade-offs between water users, such as agricultural industry and electricity suppliers, e.g., conventional and nuclear power plants (cf. Figure 1.1).

1.3 Rising generation costs due to lack of water

Evidently, increasing temperatures followed by more evaporation and less water availability, will force conventional power plant operators to decrease the amount of electricity generation (van Vliet, Yearsley, Ludwig, Vögele, Lettenmaier, & Kabat, 2012; Hoffmann, Häfele, & Karl, 2013) until the power plant has to be shut down. According to Flörke et al. (2012), the average water availability during summer is decreasing until 2050, so the competition for water resources increases for conventional power plants. Consecutively, the generation costs of the conventional power plants are likely to increase, as it will get more and more difficult to run the power plants with enough water, while water treatment will exacerbate because of the lack of electricity for treatment and distribution (van Vliet, Yearsley, Ludwig, Vögele, Lettenmaier, & Kabat, 2012).

2 Methodology

A solution to the problems of a secure electricity supply is a service tool considering Demand Side Management (DSM), amongst others. The consideration of DSM assists in fulfilling electricity and water demand to the possible extend: efficient appliances reduce water and electricity demand in times of low electricity availability and intelligent appliances shift demand to times with high water and electricity availability. A service tool considering DSM will be assembled as computer model, which is fed with information on water and electricity demands by the stakeholders as well as the availability of central and decentral electricity-generating systems. External web services and data sources, clouds or sensor data can additionally be included. Basis for the service tool is a matrix showing in detail the information needed. These data are rule-based processed to a decision support matrix for each stakeholder, highly depending on the prevailing or predicted weather. It provides detailed information for the distribution of water and electricity under different circumstances. Aim of the service tool is, to provide decision support for the water distribution and to secure electricity supply: The individual water demands are differentiated into initial demand and minimal demand accompanied by a priority scheme for the individual demands. In order to ensure energy security, the service tool has to find the point of electricity balance by weighing the demands and possible supply as well as by weighing between smart grid systems and electricity from renewable energy power plants.

3 Requirements and Specifications on a Service Tool

3.1 Approaches for a service tool for the distribution of water and electricity

Hoffmann, Häfele & Karl (2013) conducted a first model approach with projections up to the year 2070, considering several climate data projections, selected thermal power plants as well as their respective cooling systems and the legal threshold values for returning cooling water into waterbodies. Main aim of Hoffmann, Häfele & Karl is to analyse the impact of climate change on the efficiency of electricity generation with thermal power plants under consideration of different cooling technologies. The efficient distribution of water and electricity were not included in the study.

Several approaches exist with regard to energy management in industry, e.g., DIN EN ISO 50.001. Schieferdecker, Fünfgeld & Bonneschky (2006) describe for example the necessary parametrisation of industrial appliances for efficient energy controlling and load management. In order to cover the part for water distribution, similar information should be provided for water management. Additionally, information about the interdepending relation between electricity and water management has to be analysed.

A universal service tool to connect models for water resources management, energy management and energy system analysis is missing.

3.2 Establishment of a service tool

In order for a service tool to be used as decision support for the stakeholders, it has to provide information concerning energy and water management. Depending on the current and forecasted weather as well as the stakeholders' demand, river basin managers get decision support concerning a beneficial distribution scheme for water. The same information is of interest for electricity and water suppliers: Water suppliers can plan when to treat water and how to distribute the available water to the subsequent stakeholders (e.g. households). Whereas electricity suppliers (e.g. conventional power plants) can plan their amount of electricity generation according to available cooling water amounts and receive information for a beneficial electricity mix for feed-in into the grid. Households, industry and the agricultural sector receive decision support in terms of how to shift energy and/or water intensive processes (e.g. use of washing machines) into times of high water / electricity availability. Additionally, these three groups receive decision support concerning, e.g., the use of energy efficient equipment. Transmission system operators and distribution grid operators receive decision support in terms of a beneficial mix of electricity from conventional, renewable and smart-grid sources to secure electricity supply. Apparently, the service tool is a solution to increase the service level of each stakeholder by offering a decent distribution solution for all stakeholders concerning the conflicting interests. For this, the service tool is developed as computer model, containing near-realtime data of and from the stakeholders, climate predictions as well as recommendations for DSM and water distribution. At first, a stakeholder analysis is conducted in order to consider all affected parties. On the one hand, an input matrix is build, including each stakeholder and, e.g., its necessary amount of water and electricity to operate. On the other hand, the required information from the service tool for each stakeholder has to be determined, in order to offer the stakeholders an incentive to use the service tool for decision support. An obvious incentive may be driven by economic behaviour, but in case of negative effects, political or legal incentives become necessary.

Table 1 shows an exemplary requirements matrix for the service tool from the stakeholder's point of view. It shows the expected information from the service tool. In the example matrix are eight stakeholder groups, who are affected by electricity and/or water supply: Industry, households, the agricultural sector, river basin management, the distribution grid operator, the transmission system operator as well as water and electricity suppliers (e.g. power plants, public services). Obviously, there are stakeholders from different organisational levels (national, regional, local etc.). The number of stakeholder groups can increase when dividing into smaller subgroups. As an example, the "electricity supplier" can be aggregated firstly by power plant type, e.g., nuclear, and secondly by cooling technology. Each stakeholder group focusses on different requirements for decision-making.

Table 1: Exemplary requirements matrix for a service tool (to be extended)

Stakeholders	**Weather forecast (short-term)**	**DSM options electricity**	**Distribution options water**	**Allotted amount of electricity in kW**	**Allotted amount of water in m³/h**
Transmission system operator	To prevent power failure of the grid	To secure electricity grid	NR[1]	NR[1]	NR[1]
Distribution Grid Operator	To prevent power failure of the grid	To secure electricity grid	NR[1]	NR[1]	NR[1]
Electricity Supplier	To estimate electricity feed-in to the grid	Increase efficiency on the user-side of the electricity meter	NR[1]	NR[1]	To plan amount of electricity generation
River basin manager (water)	To distribute water according to contracts	NR[1]	To distribute water by demand	NR[1]	NR[1]
Water Supplier	To estimate water supply to stakeholders	NR[1]	NR[1]	To plan water treatment	NR[1]
Agricultural Sector	NR[1]	NR[1]	NR[1]	e.g., for use of farm equipment	e.g., to plan irrigation
Households	NR[1]	e.g. use of energy efficient equipment	NR[1]	e.g., for cooking	e.g., for washing
Industry	NR[1]	e.g. demand shift	NR[1]	e.g., for manufacturing	e.g., for boiling processes

[1] Not Relevant

In the example matrix, several requirements of the stakeholders on the service tool are included: short-term weather forecasts, DSM options for electricity, distribution options for water as well as the allotted amounts of electricity and water. The matrix states, how each stakeholder group can use the given information. Not yet included are targets of each stakeholder to reduce their specific demand of electricity and water as well as the future climatic projections, which also have to be taken into account in order to let the service tool help the stakeholders in decision making for the distribution of water and electricity. To date, distribution decisions are mainly business-driven. Water distribution is depending on current contracts with stakeholders and the available water amounts. Electricity distribution is depending on the standard load profile of households or the individual load profiles of each company as well as on the current contracts with the stakeholders. Grid and system operators provide energy security with the merit order curve, implicitly taking into account the current feed-in from renewable energy sources and conventional power plants; they decide under consideration of the current energy acts, which power plants have to uncouple from the grid or have to couple to it, in order to secure electricity supply.

Depending on the prevailing or predicted weather, the results from the service tool change and it is defined, how the water distribution should look like. As soon as it is, e.g., not possible to distribute enough water to the power plants and they have to reduce their electricity outputs, the service tool has to determine, how much electricity is needed to stabilise the grid.

4 Conclusion & Outlook

In order to set up a functioning and reliable service tool for the distribution of water and electricity, every stakeholder and all influencing conditions have to be taken into account, e.g, future water and electricity demands and supplies, future climate projections, future political decisions as well as service tools already in use. Besides alternative cooling technologies for power plants and distribution systems already in use, DSM can additionally be taken into account for securing water and electricity supply, particularly when considering upcoming climate change impacts, i.e., droughts or increasing ambient air temperatures.
The presented approach of a reliable service tool tries to include all before mentioned information concerning supply and demand as well as the nexus approach, in order to be used as decision support for the distribution of water and electricity. With the aim of gathering all necessary data to establish the matrices for the service tool, it is crucial to work closely with the stakeholders. Based on this infor-

mation, decision support with the service tool cannot yet be given to the stakeholders based on political, ecological, economical as well as social evidence.

Further research has to be done about the future technical improvements for energy saving measures, future political decisions, targets of each stakeholder to reduce their specific demand of electricity and water, possible incentives for the stakeholders to participate in the DSM service tool as well as the future climatic projections. Additionally, necessary correlations between water and electricity demand have to be deduced and reasonable distribution patterns developed. Furthermore, a literature review concerning available service tools, an analysis about the existing gaps, possible extensions or meaningful combination of several applications should be made, in order to include this information into the service tool in addition to the matrices.

The more detailed data can be fed in into the service tool, the better will be the results for decision support concerning water distribution and securing the electricity supply for all stakeholders. Additionally, the service tool should be easily operating, to assure the use by the stakeholders. Finally, one has to bear in mind that the integration of the service tool should not be underestimated: On the one hand, a solution based state of the art has to be developed as well as emerging technologies for the technical and semantical integration of the very heterogeneous data sources. On the other hand, it has to be investigated, how current solutions for sufficient water supply to the stakeholders, while securing electricity supply, look like, e.g., how energy markets are organized and how a potential DSM could be integrated.

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Sourcing Strategies for Virtualized Services: An Intuitionistic Fuzzy Risk-based Approach

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Abstract

An example for sourcing of virtualized services is "cloud bursting" as a deployment model in which applications run in a private cloud or data center and 'burst' into a non-private cloud when more computing capacity is needed [1],[2]. The availability of free burst capacity is not guaranteed, so 'burst' has a cheaper cost but comes with a higher risk that the Service Level Agreement (SLA) e.g. in terms of application response time are not met for peak-traffic events. To balance risk versus costs the impact of service levels (e.g. committed vs. burst capacity) of technical services on customers' business processes need to be understood. But there are rarely accepted engineering methods available to recommend on cost-vs.-risk efficient service levels. In a SLA-aware service composition problem for minimizing cost without compromising the service quality, there is a great research interest in integrated management tools that automatically control the quality of multi-tier sourcing applications and autonomously warn for arising problem on frontend impacts to end-users or other business process implications. The proposed concept is providing a bridge between business impacts to distributed infrastructure systems to recommend for capacity and quality of technical components by defining fuzzy dependency couplings in a practical and feasible manner in order to satisfy aspects of the distributed nature of SLA dependencies.

1 General Approach

When considering the trade-off between costs and benefits in the service design phase, a key challenge is the derivation of business-relevant performance metrics and associated cost-efficient target values. We propose as the efficient Service Level Objective (SLO) to select the minimum sum of business opportunity cost based on the associated customer business risks and the cost of delivery/capacity for the service provider. This implies that neither the service provider nor the customer can find the efficient service level objective by their own as this is the aggregation of both views and interests. In the following we address the risks based on negative consequences associated with a service incident (Cost-of-Failure). Thus, the negative impact on process performance with regard to a chosen service level is translated into its monetary equivalent. This can be called an adverse business impact in service offers [3]. Considering in addition the coupling for each service to possible adverse business impacts, quantitative assessments of service value and monetary consequence can be elaborated. Thus chaining the critical relationships between business impact and IT assets allow service provider to balance between cost of service delivery or capacity for a service level to the associated business risks. This coupling approach can also be leveraged to justify costs for improvements to the backend IT infrastructure that improve the Quality of Services (QoS) on the front-stage or end-user level, by demonstrating how the proposed improvements deliver monetary benefits to the business.

2 Defining Dependence Couplings by applying Fuzzy Set Theory

2.1 Estimating the Degree of Coupling

Dependence Coupling is a measure that we propose to capture how dependent the component or service is on other services or resources for its delivery. Loose coupling describes an approach where integration interfaces are developed with minimum assumptions between the sending/receiving parties, thus reducing the risk that failure in one module will affect others. Tight coupling on the other hand indicates that successful delivery of other services or availability of resources is a prerequisite for the completion of a service. In very most cases the relationship between technical performances attributes and dependent business services cannot be exactly mathematically described [4]. When the dependency is between a service and some resource it uses, coupling will essentially be a function of how often the resource is used. For instance, the dependence of a service on the network layer might be measured by how often it is making a socket call, or how much data it is transferring [5]. For web-services we can examine environmental coupling which is caused by calling and being called. More advanced are coupling measures to evaluate the coupling level real-time by runtime monitoring, introduced as dynamic coupling metrics. Within an inductive approach to investigate for coupling dependencies between infrastructure components and their relying services, historical data is collected from the whole application environment network and the performance behavior of related components is analyzed.

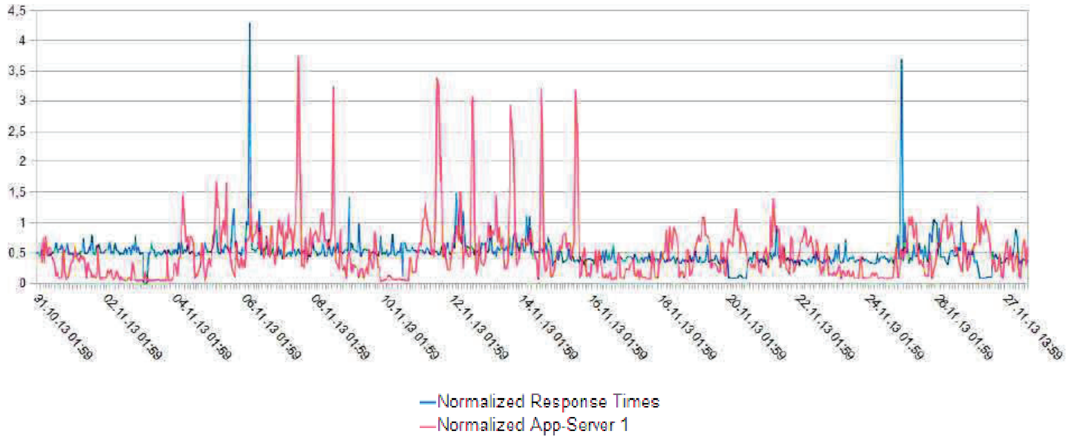

Figure 1: Inductive Comparison of User Response Time to Application Server Load

As opposite, using a deductive method dependencies are not calculated based on data the system produces, but rather the system itself [6],[7].

A key principle of realistic impact simulations is the idea of considering both, positive and negative aspects of dependency relations and simultaneous consideration by pulling these strengths together. The negative effects are the dependencies through transactional interactions (in case an incident happens), the controversy mitigation ability are the built-in systeme resilience capabilities. The simultaneous play of contrary forces, dependence and resilience together, considering direct and also indirect interactions, will define the overall system behaviour and expected impact to the end-user experience and business processes.

An initial gradual and bi-polar concept called IFSFIA (Intuitionistic Fuzzy Service Failure Impact Analysis) was first published in [8], which describes a seven step approach for assessing impacts by means of fuzzy-related components to a business service and has been developed at University Fribourg, Switzerland [9].

2.2 *Mathematical Background on Intuitionistic Fuzzy Sets (IFS)*

Let E be a fixed universe and A is a subset of E. The set $A^* = \{\langle x, \mu A(x), \nu A(x)\rangle | x$ ■ $E\}$ where $0 \leq \mu A(x) + \nu A(x) \leq 1$ is called Intuitionistic Fuzzy Set (IFS) [10]. Every element has a degree of membership (validity) $\mu A(x)$: $E \rightarrow [0,1]$ and a degree of non-membership $\nu A(x) : E \rightarrow [0,1]$. Intuitionistic Fuzzy Sets (IFS) have only loosely related membership and non-membership values unlike classical [Zadeh] fuzzy sets. An IFS is a generalization of the classical fuzzy set [11] which defines another degree of freedom into the set description, the independent judgment of validity and non-validity. For each IFS A in E, $\pi A(x) = 1 - \mu A(x) - \nu A(x)$ is called the intuitionistic index of x in A which represents the third aspect, the degree of uncertainty or limited knowledge.
Let now *a* be the intuitionistic fuzzy logical statement of coupling with membership and non-membership $\langle \mu_{a,}\ \nu_a \rangle$. The coupling degree of truth is $\langle \mu_a \rangle$ and degree of falsity $\langle \nu_a \rangle$ with possible values between zero and one omitting that the sum of both degrees of truth is equal or less than one. Pulling the positive and negative coupling aspects together in one fuzzy index is further called the Intuitionistic Fuzzy Direct Coupling Index (IFDCI) between two components.

2.3 *Calculation of Indirect Coupling Effects*

A property graph is an attributed, labelled, multi-relational graph which contains connected entities and which can hold attributes in the form of key-value pair [12]. This graph is applied to model multi-level business service dependencies to component services. Any Configuration Item (CI) can be presented as a node of the property graph which has a directed association to one ore more other nodes.

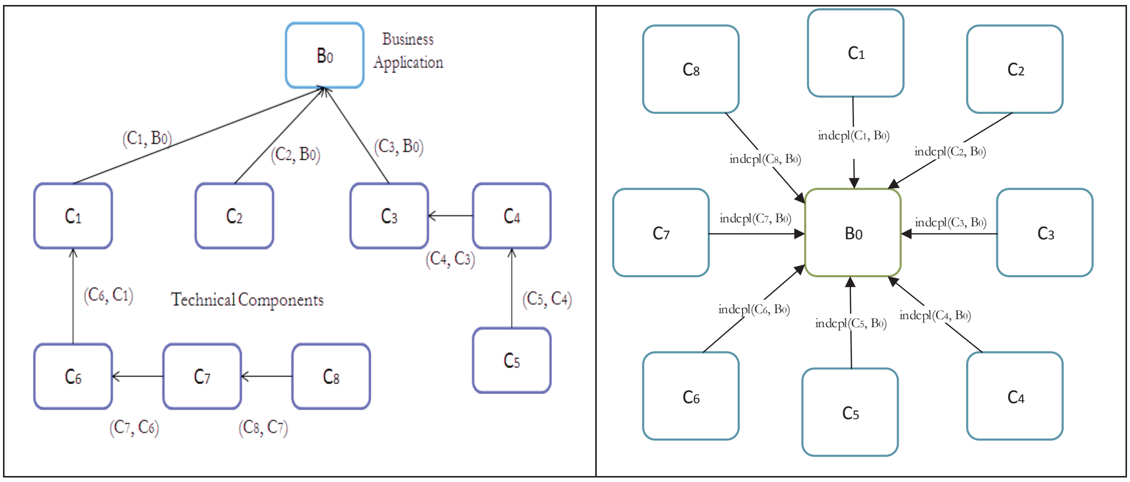

Figure 2: Directed Dependency Property Graph Model with Indirect Couplings

The edge reflects the relationship between two nodes which always has a direction, a dependent and an antecedent. The edge can be named and like nodes can have properties such as weights, distances, costs, ratings etc.

After definition of the direct impacts, the indirect coupling between components or services can be automatically calculated considering the degrees for direct coupling as invented by [13] within a Fault Tree Analysis concept and extended by [14]. The partial impact between components or services can now be expressed by means of intuitionistic fuzzy values carrying probabilistic information. Depending on which operations are applied, classical or probabilistic, the results will be greater or smaller (interpreted as classical, moderate, worst and best case).

Worst case impact analysis $V(p \wedge q) = \langle \min(\mu(p), \mu(q)), \max(\nu(p), \nu(q)) \rangle$ $V(a \vee b) = \langle \mu(a) + \mu(b) - \mu(a).\mu(b), \nu(a).\nu(b) \rangle$	**Best case impact analysis** $V(p \wedge q) = \langle \mu(p).\mu(q), \nu(p) + \nu(q) - \nu(p).\nu(q) \rangle$ $V(a \vee b) = \langle \max(\mu(a), \mu(b)), \min(\nu(a), \nu(b)) \rangle$
Moderate impact analysis $V(p \wedge q) = \langle \mu(p).\mu(q), \nu(p) + \nu(q) - \nu(p).\nu(q) \rangle$ $V(a \vee b) = \langle \mu(a) + \mu(b) - \mu(a).\mu(b), \nu(a).\nu(b) \rangle$	**Classical fuzzy impact analysis** $V(p \wedge q) = \langle \min(\mu(p), \mu(q)), \max(\nu(p), \nu(q)) \rangle$ $V(a \vee b) = \langle \max(\mu(a), \mu(b)), \min(\nu(a), \nu(b)) \rangle$

Figure 3: Calculation on Intuitionistic Fuzzy Indirect Couplings

The intuitionistic fuzzy dependencies may have different kinds of semantics (functional and probabilistic) depending on the type of information they represent.

Example: Considering the best case impact scenario between component C2 and service B0, the coupling relation is calculated as $indcpl_{best}(C2,B0) = (0.36,0.51)$. Using probabilstic semantics it means that in case the component C2 fails, the expected probability that business service B0 breaches the SLA is 36% and 51% that the performance of B0 stays within the tolerated thresholds. An uncertainty of 13% is estimated which means this coupling relation is seen as quiet mature.

As an example for a functional semantical interpretation using best an ordinary measurable coupling relationship this statement would mean that the service B0 is expected to be functional degraded or partly available (e.g. response time goes down by 36%) in case the component C2 performance fails. This allows a notion of having the business service still usable with some kind of degradation.

3 Cost Models and Cost-of-Failure

Virtual Capacity Units (VCU), which may represent several technical elements in the IT system that are related to the virtualization services offered to the clients.

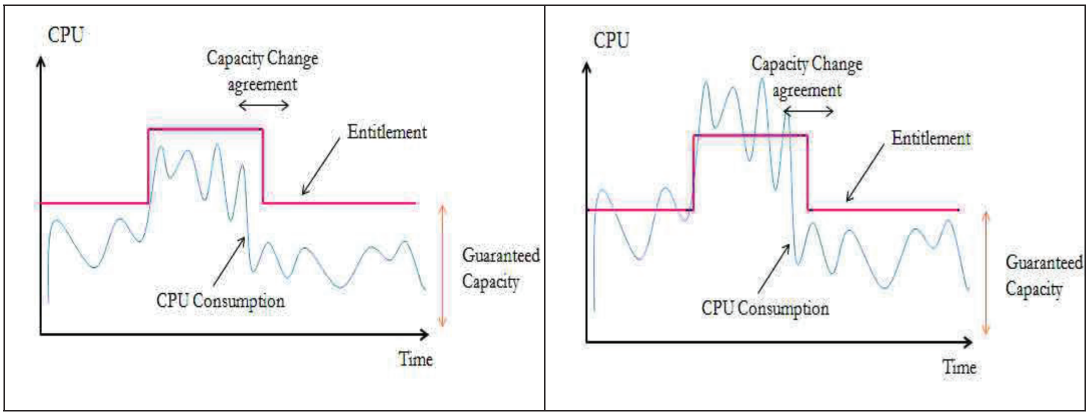

Figure 4: Baseline Model versus Consumption Based Model

Within Baseline Model the customer books a fixed capacity in VCU on a shared system. He is able to change this capacity by notifying a change request to the service provider. The customer pays the booked capacity independent of the actual usage. Despite in a Consumption Based Model (CBM), the consumer books an entitlement in VCU, the logical partition is allowed to burst over that entitlement and this burst is not guaranteed. At the end of the billing period Bursting is measured and charged. The catalog service products offer a different booked and committed capacity that the clients can choose depending of their needs. As closer the entitlement is to 100%, which is the case only for the Platinum Service Level, the better availability and performance conditions apply. But the higher the entitlement, also the higher the cost to pay for the service usage, here the consumed VCU units. Each Service Level has an associated negative Bussiness Impact or Cost-of-Failure based on the expected numbers of incidents (like too slow responses) which is contrary to the capacity entitlement of the chosen Service Level.

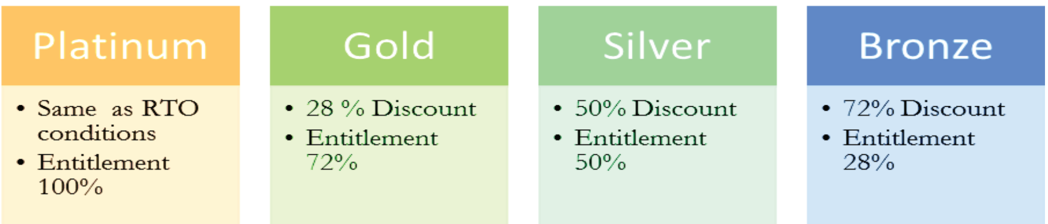

Figure 5: Service Levels with Capacity Entitlements and corresponding Discounts

The expected total Cost-of-Failure is related to the booked Service Level, we summarize this cost of lost business further as Business Opportunity Cost.

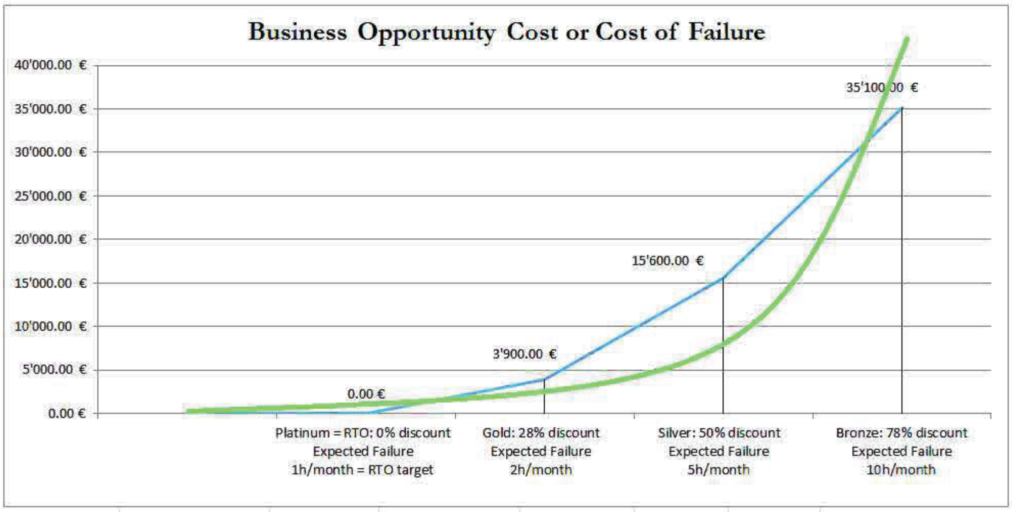

Figure 6: Business Opportunity Cost Curves: Real (Blue) and Ideal (Green)

4 Intuitionistic Fuzzy Service Failure Impact Analysis (IFSFIA)

A complete methodical assessment approach was developed, which is practically usable in datacentre environments, with several sequential steps to be processed. It starts from automated discovery of the details of the managed resources and backend components, the grouping of components to impacted frontend services and the enrichment in several tasks and calculation steps up to the gradual business impact assessments, including monetary cost-of-failure information and business objectives [14]. The overall frame for incorporating all data is a grid with service components on one axis and impacted business services on the other. This matrix can be freely extended with different kind of variables showing failure modes, reliability parameters, financial data or operational capabilities and extends the pure system view to include also the processes, tools and people that are necessary for functioning of a distributed information system.

The result of the IFSFIA method is a sorted intuitionistic fuzzy distribution of dependencies, providing an ordered set by the probability of incident root causes.

Extended IFCFIA Grid with indirect Couplings and Cost of Failure			Cost of Failure per Hour 10000 Euros; RTO and RPO for 1 hour; B0; FCC Coupling to B0		Total Failure Cost Per hour		
Component	Failure Mode and Effect	Direct Impact (IFS)	Prob. Failure	Prob. Resilience	Failure	Uncertainty	Resilience
C1	Outage	(0.4,0.4)	0.47	0.47	4'700.00 €	600.00 €	4'700.00 €
C2	Outage	(0.8,0.1)	0.39	0.54	3'900.00 €	700.00 €	5'400.00 €
C3	Outage	(0.6,0.3)	0.63	0.33	6'300.00 €	400.00 €	3'300.00 €
C4	Limited Function	(0.5,0.5)	0.47	0.47	4'700.00 €	600.00 €	4'700.00 €
C5	Slow Response	(0.4,0.5)	0.39	0.54	3'900.00 €	700.00 €	5'400.00 €
C6	Limited Function	(0.3,0.4)	0.63	0.33	6'300.00 €	400.00 €	3'300.00 €
C7	Slow Response	(0.5,0.3)	0.63	0.33	6'300.00 €	400.00 €	3'300.00 €
C8	Slow Response	(0.4,0.4)	0.47	0.47	4'700.00 €	600.00 €	4'700.00 €
Technical Support	Slow Repair	(0.8,0.1)	0.39	0.54	3'900.00 €	700.00 €	5'400.00 €
User Experience	Quality Issue	(0.6,0.3)	0.63	0.33	6'300.00 €	400.00 €	3'300.00 €

Figure 7: IFSFIA Matrix with Couplings and Financial Impacts per Component

Here Repair Time Objective (RTO) and Recovery Point Objective (RPO) are roughly speaking based on setting the time objective for "the amount of time the business can be without the service”. This means in case the defined service level enables a full restoration within these time limits no severe effect on the business will be assumed and the Cost-of-Failure calculation starts after this grace period.

5 Recommendation on efficient Service Levels

Each service linked to the business impacts in terms of Business Opportunity- or Failure Costs and can be matched against the Cost of Capacity or Delivery Cost.

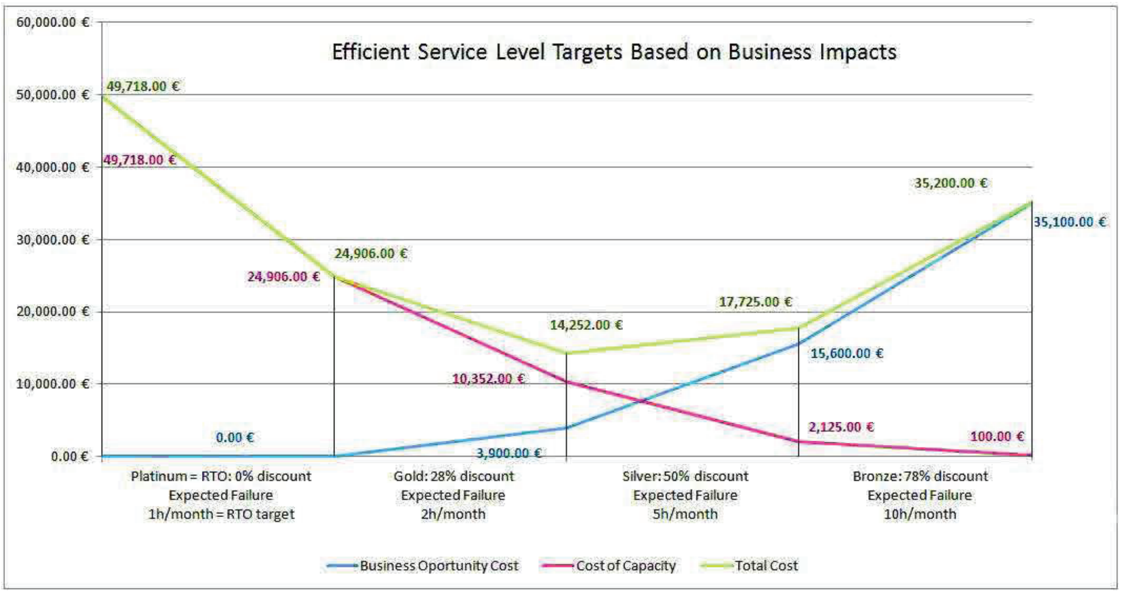

Figure 8: Efficient Service Level Targets Based on the Business Impacts

The expected business impact can be compared against the discounts indicating the cost benefits for chosing a lower SLO capacity target. The minimum point of a total cost (not be necessarily the intersection between the Business Opportunity Cost and Cost of Capacity) is below be determined as an approximation.

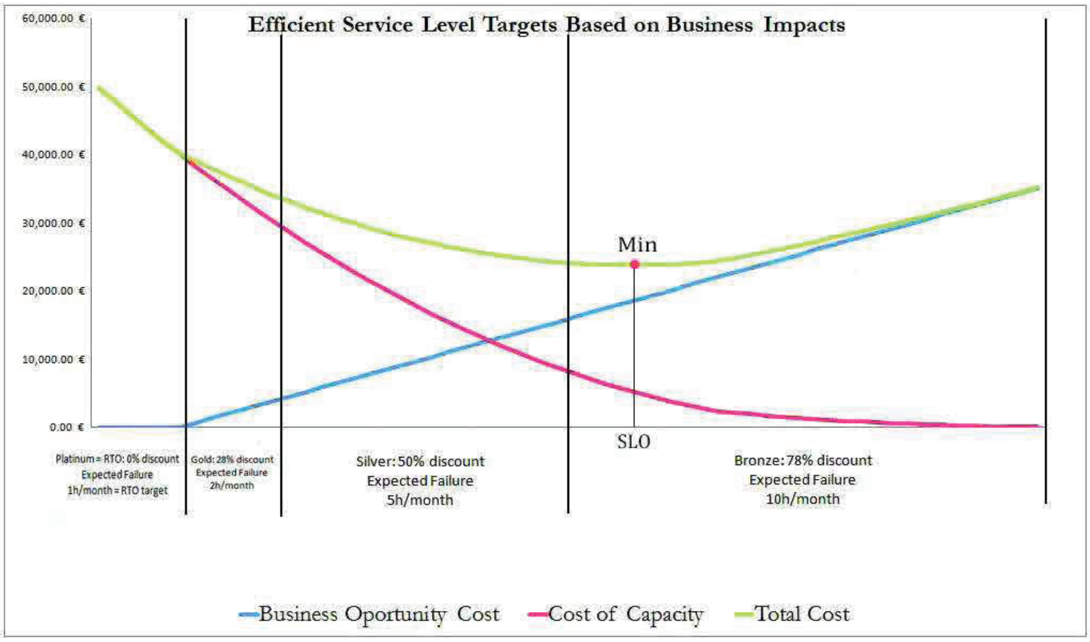

Figure 9: Efficient SLO targets with minimized overall total cost.

The cost-optimized Service Level Objective (SLO) has a total cost of 23813.06 € as a value and the point is located on the Bronze Category. Thus the best product to select minimizing total costs and better overall business opportunity for client and service provider is the bronze category. The proposed method can be taylored to choose services depending on the individual customers' business model.

Conclusion: Combining well-grounded academic research for Service Level Engineering, as also contributed in related research work [5],[15],[16], with practice oriented scenarios provides high value to the service business. By expanding IT reliability engineering with fuzzy mathematical models the framework can transform performance data into knowledge that allows understanding the impact of incidents on the business and recommend on efficient service level objectives. Instead of tightening SLAs across the board, which is a costly approach, individual service levels should be directly driven by business needs where the organization benefits by projecting and paying for only what is required.

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Towards a Meta-model for Context in the Web of Things

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Abstract

The Web of Things (WoT) uses Web technologies to engage connected objects in applications. Building context-aware WoT applications requires modeling and reasoning about context. In this paper, we overview different context modeling approaches related to the WoT, before studying the architecture of WoT applications. We then propose a multi-level, multi-dimensional and domain-independent context meta-model to help WoT applications identify, organize and reason about context information.

Keywords: Web of Things, Context modeling

1. Introduction

The Web of Things (WoT) applies to various domains such as homes, enterprises, industry, healthcare, city or agriculture. It builds a Web-based uniform layer on top of the Internet of Things (IoT) to overcome the heterogeneity of protocols present in the IoT networks. Today's WoT applications (WoT apps) need relevant context models to exhibit context-adaptive behavior. Basically, a WoT app provides added value by combining access to connected objects and external data sources (i.e. Web services). It requires an accurate description and exploitation of WoT apps context, hence

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justifying the need for context models. As a consequence of the diversity of use-cases and applications, numerous domain-specific models relying on different formalisms and reasoning mechanisms have been designed (Perera et al. (2014)). However, a single context modeling framework for WoT apps is still missing. In this paper, we propose a context meta-model as a first building block for a framework that allows reusing the same reasoning tools in the diversity of WoT use-cases. In Section 2, we study general definitions for context and the major existing context models. In Section 3, we draw conclusions on existing work and study the different parts of WoT apps to identify the elements that will contribute to build our meta-model. In Section 4, we discuss our solution according to a set of evaluation criteria. In Section 5, we summarize our results and give perspectives for future work.

2. Describing Context: Related Work

While Schilit and Theimer (1994) define context-aware computing as *"the ability of applications to discover and react to changes in the environment"*, context can be seen as the information thats answers to the *Where*, *Who*, *When* and *What* questions as discussed in Abowd et al. (1999). Dey (2001) defines context as *"any information that can be used to characterize the situation of an entity. An entity is a person, place, or object that is considered relevant to the interaction between a user and an application, including the user and applications themselves"*. Chaari et al. (2005) define a situation as an instance of a set of contextual attributes. Context information described in Schilit et al. (1993) include environmental and geospatial information, such as location, co-location (i.e. what is nearby), time, etc.. Most work Schmidt (2003); Zimmermann et al. (2007); Abowd et al. (1999) structure context as multi-dimensional views. Some work describe context with a specific focus, such as privacy in Dey et al. (1999), or computing resources (availability, remaining battery power) and network information (types of connection, services in reach, distances, disconnection rates) in Gold and Mascolo (2001); Mascolo et al. (2002); Musolesi and Mascolo (2009).

Network context is often combined with other context elements such as user profile or preferences in Wei et al. (2006); Raverdy et al. (2006); Yu et al. (2006). Users are of major importance in context-aware applications as shown in Cao et al. (2008, 2009); Xiang et al. (2010). In Brézillon and Pomerol

(1996); Brézillon (1999); Bucur et al. (2005) the user and its environment have a central place in the context model together with its interaction and domain-specific information. Brézillon and Pomerol (1999) use context for helping users with decision making, later with different knowledge sources as in Brézillon (2003) and with the notion of situation as in Bazire and Brézillon (2005). Context information may be domain-specific as mentioned in Munnelly et al. (2007), or related to the application architecture as discussed in Truong et al. (2007, 2008); Kirsch-Pinheiro et al. (2004). More recently Coppola et al. (2010) include meta-information about context (Probability, Importance, Description and Name).

3. Modeling Context for Web of Things applications

The related work presented above highlights the diversity and complexity of context. Each work propose a unique combination of device, user, network, and application context elements. The traditional semantic heterogeneities can be found between context models, i.e. polysemy, heteronymy, and so on. In the following, we discuss these approaches and then present our arguments for a context meta-model.

3.1. A Context Meta-model for the Web of Things

In our work as part of the ANR ASAWoO project[1], physical object functionalities and applications are exposed as RESTful services. Based on the context model and instances, the framework should be able to activate or deactivate functionalities or applications. The latter might not be available due to physical constraints, security, privacy, or other policies, which can vary according to the use-case.

Hence, we design a context meta-model for WoT apps to control the instantiation of domain-specific models and to reuse the same reasoning mechanisms. We rely on the different context information studied in the literature to justify our choices, and organize our meta-model into levels that characterize the different parts of a WoT app. As depicted in Fig. 1, mobile and distributed clients communicate with the WoT app, which itself communicate

[1] `http://liris.cnrs.fr/asawoo/`

with physical objects and data sources. A client could be a user (via a smartphone or computer), or another software application to allow for composite applications.

According to Fig. 1, we organize context information in four levels. The *Physical* level (1) describes context information about physical objects, including their internal states and information coming from their sensors that describe the objects' environment. The *Application* (2) level describes the application architecture, its state, its configuration, as an application can rely on different architectural paradigms, such as components or services, and can be either locally stored or distributed. The *Communication* (3) level describes the context of links between the application and clients, physical objects and data sources. It includes information such as the state of the network, bandwidth, latency, or the type of connection, such as wired or wireless. The *Social* (4) level characterizes the client's environment. It includes cognitive aspects such as user roles withing an organization, user behavior, and types of users (human, software).

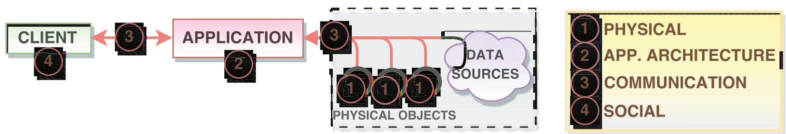

Figure 1: A typical WoT app architecture and its context dimensions

Fig. 2 shows an UML representation of our meta-model. The `Model` class aggregates the four levels presented above, which themselves compose the dimensions. For each level, the `Dimension` class contains a `name` URI that provides the ontological concept that describe the `value` object.

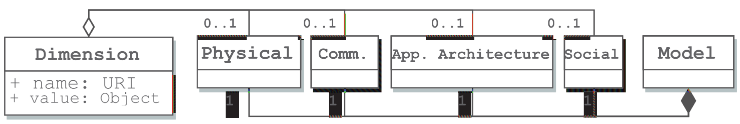

Figure 2: UML representation of our meta-model

Our meta-model presents the following advantages. First, it allows WoT app developers for high flexibility with an unrestricted numbers of dimensions to be created. Second, all the models will follow the same description language

(DL) thus allowing the reasoning process to always be effective. Third, the level/dimension view can be reused differently according to a WoT app settings, or even between several WoT apps. We illustrate the latter advantage in the section below with two use cases that rely on different models, and one use case that uses different combinations of levels/dimensions from the same model.

3.2. Illustration with different use-cases

We illustrate our meta-model with two use-cases that use specific context models. The first one is temperature regulation that needs to adapt to the user presence and settings. Its context model involves four dimensions that contains geolocation and network information, as well as time, actuator states, and user home preferences as shown in Fig. 3. Depending on the user settings, the application can rely different combinations of levels and dimensions to enable context-awareness. Typical users would rely on a model that includes both home and enterprise settings (plain squares in Fig. 3); children and elderly people would require different levels and dimensions (dashed squares in Fig. 3).

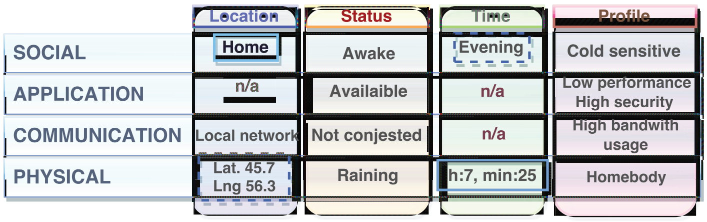

Figure 3: An example of Multi-level context model

The second use-case concerns agriculture. It involves drones that scatter bugs on plantations to protect them from threatening insects, an automatic watering system, and robots that pull off weeds from plantations. Each of them have their own context model, to provide the whole system with safe operation. According to the type of devices, level and dimension combinations to describe the context models can also differ. For example, drones robots only require a day/night granularity whereas the watering system requires hourly time slots. As well, the watering system do not use location information due to its immobility.

4. Evaluation

We build on the methodology proposed in Gómez-Pérez (1998) to evaluate our meta-model according to the following steps: (S1) Purpose and scope, (S2) Intended uses, (S3) Intended users, (S4) Requirements, (S5) Competency Questions (CQs), and (S6) Validation of CQs, as shown in Fig. 4. We refer to the metrics proposed in Hlomani and Stacey (2014) in (S6).

(S1)	The scope of our work includes smart home, smart farms… Our purpose is to provide context-awareness with reusable and relevant models.
(S2)	Any WoT scenario (see Section 3.2).
(S3)	WoT apps developers.
(S4)	Context information coverage (Location, Time, User Preferences…).
(S5)	(CQ1) Does the model cover required context information?
	(CQ2) Does the DL language allow for complete and sound results in a finite time?
	(CQ3) Does the DL language provide the logical constructs required by the reasoner?
	(CQ4) Are the number of levels sufficient to describe a WoT app context ?
	(CQ5) Are the levels redundant or overlapping?
(S6)	(CQ1) The meta-model allows any dimension to be created for complete coverage.
	(CQ2) The DL used (OWL) provides 3 profiles (EL, QL, RL) that are able to answer any reasoning problem (conjunctive query answering, class expression subsumption...) in a finite time.
	(CQ3) OWL provides expressive relationships (object, datatype properties) and concepts (classes, individuals, data values) allowing the reasoner to correctly answer queries.
	(CQ4) Levels are based both on related work and a typical WoT app architecture, thus covering the needed context information.
	(CQ5) Our levels do not overlap by design.

Figure 4: Evaluation of our meta-model.

5. Conclusion and perspectives

In this paper, we build a meta-model that combines levels and dimensions to help WoT apps identify, organize and reason about context information. Our meta-model aims at enhancing the reusability of reasoning mechanisms across application domains while leaving flexibility for developers to design their application-specific context models.

As future work, we aim at optimizing the reasoning process for WoT apps to handle fast-paced data streams as context sources, as well as to provide dynamic reconfiguration and adaptation for their components.

Acknowledgement. This work is supported by the French ANR (Agence Nationale de la Recherche) under the grant number <ANR-13-INFR-012>.

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Towards Perceived Service Interaction Productivity: A Proposed Conceptual Model

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Abstract

Understanding how to enhance service productivity is vital for advancing the service field and fostering economic growth. However, the concept of service productivity itself poses severe operational challenges as it is unclear how to operationalize inputs and outputs in a service setting. Despite this fuzziness, existing models often conceptualize service productivity based on formal productivtiy functions. Moreover, they neglect productivity related interactions within the overall service network as they either exclusively focus on the perspective of the service provider or just consider dyadic interactions (i.e. provider-customer). In order to overcome these limitations and provide operationally relevant insights for enhancing service productivity, this short paper proposes an early version of a conceptual model coined "perceived service interaction productivity". Inspired by practical challenges of managing a multi-sided service platform for e-mobility, this paper represents work in progress and shall provide a foundation for future research.

1 The Challenge of Enhancing Service Productivity

Recently, enhancing service productivity was identified as one of the top three research priorities in order to advance the service field (Ostrom, Parasuraman, Bowen, Patricio, & Voss, 2015). However, the concept of productivity itself, which is often understood as the ratio of output to the input required to produce it (Johnston & Jones, 2004; Tangen, 2005), poses severe challenges in a service context. Amongst others, it is unclear how to operationalize inputs and outputs

(Grönroos & Ojasalo, 2004; Yalley & Sekhon, 2014).[1] This study is inspired by the challenge to drive productivity in the context of the newly established, web-based platform eMobilisten.[2] Sponsored by the German Federal Ministry of Education and Research, the goal of eMobilisten is to foster long-term acceptance of e-mobility in society. For this purpose, eMobilisten offers distinct services for both organizations (e.g. online broadcasting of innovation challenges to benefit from external ideas) and the public (e.g. interactive community platform with online tutorials to learn about e-mobility). For effective and efficient service provision, the providers of eMobilisten are heavily dependent on the participation of various external actors (e.g. companies with innovation needs and community members as co-producers of knowledge and solutions). The goal of this study is to develop a first conceptual model, which shall inspire future empirical research and guide the design of scientifically sound and practice-oriented methods for enhancing the productivity in the context of multi-sided service settings such as eMobilisten. Next, a short overview of existing conceptual approaches for managing service productivity is presented. After this, based on identified challenges, a new conceptual model is introduced. Finally, a short discussion and an outlook for future research are presented.

2 Conceptual Foundations of Service Productivity

Throughout the last decades, scholars of different fields have explored the topic of service productivity (Lehmann, 2015).[3] In the context of business administration, Bartsch, Demmelmaier and Meyer (2011) identify four conceptual approaches for operationally managing service productivity. Initially, proponents of the *(1) industrial productivity approach* try to adapt existing concepts of industrial

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[1] As discussed by Tangen (2005), the term productivity was used over two centuries ago in the context of agriculture. Since then multiple verbal as well as mathematical definitions for explanation and calculation have been elaborated.

[2] www.emobilisten.de

[3] In an extensive literature review, Lehmann (2015) identified eight scholary perspectives on service productivity: *(1) macroeconomic*, *(2) public management*, *(3) strategic, (4) organizational*, *(5) customer*, *(6) technological*, *(7) operations management* and *(8) operations research* perspective). This paper focuses on a business context, thus it does not consider the macroecnomic or public management perspective on service productivity.

production to enhance productivity in a service context (e.g. Carlborg, Kindström, & Kowalkowski, 2013; Levitt, 1972; Murphy, 1999; Staats, Brunner, & Upton, 2011). In contrast, proponents of the *(2) service production approach* stress the particularities of the service delivery processes and aim to formalize specific drivers of service productivity. In this context, it is highlighted that productivity can be considered at different process stages (e.g. Corsten, 1994; Jones, 1988; Sigala, Jones, Lockwood, & Airey, 2005). Next, contributions falling under the *(3) customer integration approach* consider the management of customer involvement throughout service delivery as a key issue for service productivity. In doing so, it is emphasized that customers have their individual productivity perspective which may be different from the provider's one (e.g. Anitsal & Schumann, 2007; Johnston & Jones, 2004; Parasuraman, 2002; Weijters, Rangarajan, Falk, & Schillewaert, 2007). Finally, contributions from the *(4) service marketing approach* dismiss the constant quality assumption postulated in the industrial productivity approach and stress the interdependence of service productivity and quality (e.g. Chase & Haynes, 2000; Grönroos & Ojasalo, 2004; Rust & Huang, 2012; Vuorinen, Järvinen, & Lehtinen, 1998). A key contribution of this stream is the service productivity model of Grönroos and Ojasalo (2004) which different authors recognize as the most encompassing conceptual model of service productivity (Bartsch et al., 2011; Becker, Beverungen, Knackstedt, Rauer, & Sigge, 2014). Grönroos & Ojasalo (2004) formalize service productivity as a function of internal efficiency, external efficiency and capacity efficiency. However, the authors admit that it is unclear how to actually measure these efficiencies. As a remedy they suggest that productivity measures should be based on the ratio of revenues from a given service divided by the cost of producing this service.

Notwithstanding the theoretical contributions of existing conceptual approaches, from a managerial perspective, they pose severe challenges. First, it is argued that they are unsuited to measure the productivity of services which are based on interactive inputs and qualitative outputs such as knowledge and information (Biege, Lay, Zanker, & Schmall, 2013). Moreover, existing models do not take into consideration that service processes often consist of interactions among multiple entities besides the formal service provider and the customer (Sampson, 2012). Finally, they neglect the importance of an entity's individual service objectives, expectations and learning for effectiveness and efficiency considerations.[4]

Next, a new model addressing these issues is introduced. As mentioned before, it is inspired by practical challenges of managing eMobilisten. However, the model will be described on a general level in order to demonstrate a broader range of possible applications.

3 A Model of Perceived Service Interaction Productivity (PSIP-Model)

The proposed model is inspired by an operational view of services as presented by the Unified Services Theory (Sampson & Froehle, 2006) and the related Process Chain Network framework (Sampson, 2012). Following this perspective, services can be understood as special types of production processes that are defined by extensive provider-customer interactions (Fließ & Kleinaltenkamp, 2004; Sampson & Froehle, 2006). As presented in Figure 1, at minimum, a service process integrates activities and/or resources of two entities: one formal provider and one customer (in the figure their interaction is presented by the solid line). However, various additional entities such as other customers or network partners may be involved at certain stages of the service process as well (Alter, 2012; Maglio, Vargo, Caswell, & Spohrer, 2009; Sampson, 2012). These network partners may be interacting with the service provider and/or with one or more customers (indicated by the dashed lines). Each of these process entities has certain objectives and expectations why it takes part in the service process. For some entities the process may meet specific needs (e.g. a company receiving user feedback for an innovation challenge), whereas other entities may receive a generic resource (i.e. a service provider receiving money for carrying out certain process activities) that can be used to engage in other service processes in the future (Sampson, 2012; Vargo & Lusch, 2004, 2008).

[4] A short overview of existing approaches and their managerial implications is portrayed in the attachment.

For fulfilling these objectives, entities engage in direct interactions (i.e. person to person) and/or surrogate interactions (i.e. where one entity interacts with non-human resources of another entity such as technology or information) (Sampson, 2012). Moreover, service processes are initiated and terminated by stages of independent processing. Furthermore, the degree of control of the entity under consideration can be depicted. It is the highest when an entity engages in independent processing as the respective entity is only working on its own resources. On the contrary, direct interactions are characterized by the lowest level of control. For example, there are various aspects of a personal interaction that cannot be controlled by management such as the mood of the customer or the level of sympathy between customers and front-line employees (Sampson, 2012).

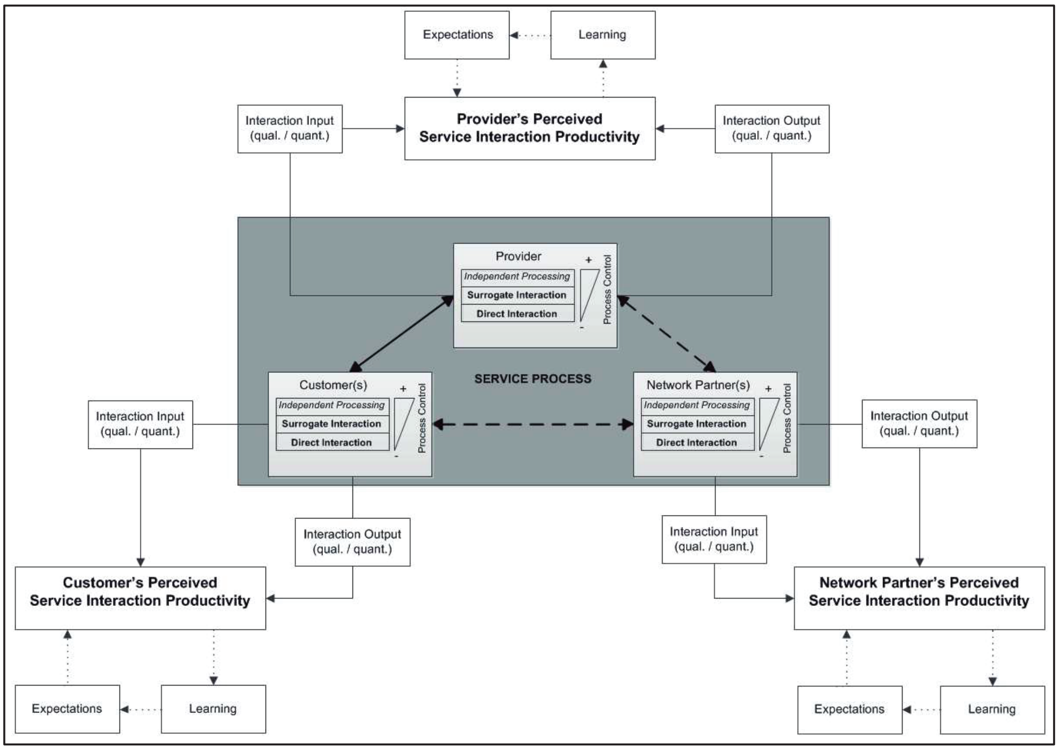

Figure 1
A conceptual model of perceived service interaction productivity (PSIP-Model).
Source: Own illustration. Service process depicted based on Sampson (2012).

Throughout the service process, each of the process entities provides certain qualitative and/or quantitative inputs and receives certain qualitative and/or quantitative outputs (Vuorinen et al., 1998). Particularly qualitative service outputs are subject to individual assessments (Frey, Bayon, & Totzek, 2013; Grönroos, 1984; Zeithaml, Berry, & Parasuraman, 1993). Additionally, expectations may influence role behavior and satisfaction (Oliver, 1980; Solomon, Surprenant, Czepiel, & Gutman, 1985). Thus, the perceived productivity of interactions is far from being objective and stable. In fact, it is of dynamic nature and dependent on the expectations of the process entity under consideration. Furthermore, productivity perceptions are based on a mutual learning experience among the entities involved. Over time, entities can familiarize with each other and the service process which may lead to a better awareness about what to expect and how to interact in order to improve outcomes (Grönroos & Ojasalo, 2004).

All in all, perceived service interaction productivity shall be conceptualized as an entity's individually perceived efficiency and effectiveness of interaction stages making up the total service process. In doing so, it is in line with the general trend to dismiss service productivtiy as a mere efficiency concept (Maroto-Sánchez, 2012). Also, in line with ideas of the proponents of the customer integration approach, productivity can be considered from different entities' points of view.

4 Discussion & Future Research

As mentioned before, this paper presents an early version of a conceptual model for service interaction productivity. In contrast to previous conceptual approaches of service productivity, it highlights the importance of looking beyond a singular (i.e. provider) or dyadic (i.e. provider-customer) perspective and takes the larger service network into account. Moreover, it stresses the idiosyncrasy of productivity assessments and the importance of expectation and interaction management. From a provider's point of view, it is essential to gain in-depth understanding concerning interaction demands and develop measurable productivity objectives that balance and orchestrate the individually perceived productivities of all interaction partners involved.

A potential starting point for developing indicators for measuring the subjective effectiveness of service interactions is provided by literature from the field of organizational psychology (Pritchard, Harrell, DiazGranados, & Guzman, 2008;

Pritchard, Weaver, & Ashwood, 2012). Future work should analyze how such measures could be developed taking the perspective of external interaction partners into account. In order to enhance efficiency, the application of lean principles throughout the different interaction stages could be a promising endeavor. In doing so, actions that are not perceived as valuable by the respective interaction partners may be reduced (Carlborg et al., 2013; Staats et al., 2011; Staats & Upton, 2011).

In the future, in-depth empirical insights are required in order to explore perceived service interaction productivity. For this, case study research will be conducted to evaluate if empirical observations are in line with the model's claims (Yin, 2009). As a pilot case, *JOSEPHS®-the Service Manufactory* will be analyzed. This case is chosen as it represents a highly interactive, multi-sided service setting which is likely to yield rich data. After this, eMobilisten and other cases from different fields will be analyzed in order to repeatedly (dis-)confirm and extend previous findings (Eisenhardt & Graebner, 2007).

Moreover, service scholars and practitioners should evaluate if the proposed model is (1) exhaustive, (2) understandable and (3) does not have unnecessary categories (Gregor, 2006). Based on these insights, the model will be adapted accordingly. By doing so, it shall present a theoretically sound foundation for conducting action design research (Sein, Henfridsson, Rossi, & Lindgren, 2011) in order to elaborate a practice-oriented method to enhance perceived service interaction productivity.

Acknowledgements

We gratefully acknowledge support by the German Federal Ministry of Education and Research (project: CODIFeY-Community-basierte Dienstleistungsinnovation für e-Mobility; FKZ 01FE14002).

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Attachment: Table 1

	Conceptual Approach				
	Industrial productivity	**Service production**	**Customer integration**	**Service marketing**	**Network interaction**
Main rationale	Managing service productivity with the help of "lessons learned" from industry.	Managing service productivity based on a detailed analysis of the service delivery process.	For managing service productivity it is critical to consider both, provider and customer productivity.	For managing service productivity, the quality dimension needs to be considered.	For managing productivity it is important to consider an entity's individually perceived efficiency and effectiveness of multientity interactions.
Productivity perspective	Service provider (total productivity)	Service provider (total productivity)	Service provider & customer (individual productivities)	Service provider & customer (total productivity)	Service network entities (individual productivities)
Key managerial implications for productivity management	Factory-like thinking is beneficial in a service setting. Management should invest in standardization, technology, automation etc..	Productivity should be analyzed and enhanced at different, service specific stages (e.g. capacity management and customer integration).	Management should look beyond internally-focused productivity measures. Positive changes in provider's productivity may have negative results for customer's productivity. Enable customers to improve their individual service productivity.	Management should seek an optimal balance between quantitative and qualitative inputs and outputs. Customers need to be enabled to improve general service productivity.	Key levers for productivity management include an entity's goals, expectations, perceptions, activities and processes throughout different interaction stages. Measurement of inputs / outputs needs to be based on contextual factors (e.g. interaction goals). Management should strive to enhance interaction partners' perceived service productivity.
Exemplary contributions	• Levitt (1972) • Murphy (1999) • Staats, Brunner, & Upton (2011).	• Jones (1988) • Corsten (1994) •	• Fitzsimmons (1985) • Parasuraman (2002) • Johnston & Jones (2004) • Anitsal & Schumann, (2007).	• Vuorinen, Järvinen, & Lehtinen, (1998). • Grönroos & Ojasalo (2004).	• *This paper*

KIT Scientific Working Papers
ISSN 2194-1629