Information Systems Success Awareness for Professional Long Tail Communities of Practice

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Abstract

Facilitated by modern networked ICT, people around the world organize in self-sustaining *communities of practice (CoP)* across professional domains and organizational boundaries. Communities thereby pursue the main goal to learn how to do better. With today's trend for mass individualization, we find a vast number and diversity of small professional niche communities in the long tail, apart from few large communities in the mainstream of the Web.

As prerequisite for sustained success, communities must constantly stay aware of quality and impact of their *community information systems (CIS)*. With fast-paced emergent technological and social progress, communities must develop agency to decide *which tools* best support them and *why*. While data-driven enterprises spend considerable technical and human resources in sophisticated *business intelligence and analytics (BI&A)* solutions for such decisions, communities face a real challenge, given their inherent resource scarcity. In meritocratic communities, a shared notion of CIS success must be negotiated from multiple specific, sometimes conflicting and idiosyncratic stakeholder perceptions of CIS success existing in a community. Standard positivist BI&A approaches with myopic focus on financial outcomes lack support for such inherently anti-positivist negotiation processes. Communities require respective support for CIS success awareness in terms of methodology, formalization, and technical infrastructure.

As solution to this problem, this dissertation presents MobSOS, a framework for CIS success awareness, tailored to the ontological properties of professional long tail CoP. From a methodological point of view, MobSOS extends a community-oriented design science research methodology by an explicit notion for CIS success modeling as essential part of evaluation. CIS success models play the central role of *fluid digital media* operationalizing negotiation. From a technical point of view, MobSOS pursues an integrative approach to extend contemporary Web and P2P-based CIS platforms by CIS success awareness with the help of a CIS success modeling toolkit. Based on a comprehensive formalization framework, MobSOS supports operations such as monitoring, assessing, exploring, modeling, measuring, visualizing, validating, sharing, and negotiating different stakeholder notions of CIS success in a community-wide discourse.

In the context of several national and international research projects, we successfully applied MobSOS in communities with varying scopes in domains such as health care, multimedia management, and technology-enhanced learning. Typical advanced CIS success models include few, yet highly relevant and effective success factors. They are well-balanced combinations of universal vs. community-tailored success factors and metrics. In particular, we note that CIS success models with full coverage for both *quality* and *impact* and focused scope are more useful than models with myopic single-dimension focus and a vague scope. Awareness on CIS quality and impact brings communities agency in form of a better informed decision on CIS tool selection, use or active development. We could demonstrate that CIS success models contributed to determine ideal software configurations, to estimate development efforts, to identify and eliminate bottlenecks, to elicit hidden requirements, or to judge concrete impact on the community. MobSOS also proved as effective learning analytics framework to identify learning patterns, to detect usage anomalies, or to measure learning progress. Our technical evaluations finally show, that MobSOS is an effective, performant, and low-cost open-source framework for CIS success awareness.

Kurzfassung

Mithilfe moderner vernetzter Informationstechnologie organisieren sich Menschen weltweit über professionelle Domänen und organisationale Grenzen hinaus in selbst erhaltenden *Communities of Practice (CoP)*. Im Zusammenhang mit dem aktuellen Trend zur Massenindividualisierung finden wir abseits weniger großer Mainstream-Communities eine unermessliche Anzahl und Vielfalt kleiner, professioneller Nischen-Communities. Diese müssen sich als Voraussetzung für nachhaltigen Erfolg ständig über Qualität und Wirkung ihrer *Community-Informationssysteme (CIS)* bewusst sein. Mit schnell voranschreitendem und emergentem technologischem und sozialem Fortschritt müssen Communities eine Fähigkeit zur Entscheidung entwickeln, *welche Werkzeuge* sie am wirkungsvollsten unterstützen und *warum*. Während heutige datengesteuerte Unternehmen zur Erlangung dieser Fähigkeit beträchtliche Ressourcen in Form von Expertise und Infrastruktur in anspruchsvolle *Business Intelligence & Analytics (BI&A)* investieren, sind Communities durch inhärente Ressourcenknappheit eher benachteiligt. In meritokratischen Communities muss eine gemeinsame Auffassung von CIS Erfolg erst durch die Verhandlung der spezifischen, manchmal konfligierenden und idiosynkratischen Einzelauffassungen verschiedener Interessengruppen ermittelt werden. Herkömmlichen positivistischen BI&A Ansätzen mit kurzsichtigem Fokus auf Finanzergebnisse fehlt eine Unterstützung für inhärent anti-positivistische Verhandlungsprozesse. Communities benötigen daher geeignete Unterstützung eines CIS Erfolgsbewusstseins in Bezug auf Methodik, Formalisierung, und technischer Infrastruktur. Als Beitrag zur Lösung dieses Problems präsentiert diese Dissertation MobSOS, ein Rahmenwerk für CIS Erfolgsbewusstsein, zugeschnitten auf die ontologischen Gegebenheiten professioneller Long Tail CoP. Aus methodischer Sicht erweitert MobSOS eine communityorientierte Design Research-Methodik um eine explizite Auffassung von CIS Erfolgsmodellierung als essentiellen Teil der CIS Evaluierung. CIS Erfolgsmodelle spielen dabei die zentrale Rolle *fluider digitaler Medien* zur Operationalisierung konkreter Verhandlungen. Aus technischer Sicht verfolgt MobSOS einen integrativen Ansatz zur Erweiterung heutiger Web- oder P2P-basierter CIS Plattformen um ein Erfolgsbewusstsein mithilfe einer Werkzeugsammlung zur CIS Erfolgsmodellierung. Basierend auf einem umfassenden Formalisierungsrahmenwerk unterstützt MobSOS Operationen wie Monitoring, Bewertung, Erkundung, Modellierung, Messung, Visualisierung, Validierung, Verbreitung und Verhandlung unterschiedlicher Auffassungen von CIS Erfolg verschiedener Interessengruppen in einem communityweiten Diskurs. Im Kontext mehrerer nationaler und internationaler Projekte konnten wir MobSOS erfolgreich in Communities in den Bereichen Gesundheit, Multimedia und technologiegestütztes Lernen einsetzen. Typische fortgeschrittene CIS Erfolgsmodelle beinhalten nur wenige, dafür relevante und effektive Erfolgsfaktoren. Sie stellen ausgewogene Kombinationen aus universellen sowie auf die Community zugeschnittenen Erfolgsfaktoren dar. Insbesondere sind CIS Erfolgsmodelle mit voller Abdeckung für *Qualität* und *Wirkung* und scharf eingegrenztem Spielraum deutlich brauchbarer als solche mit eindimensionaler Abdeckung und einem vagen Spielraum. Ein Bewusstsein über CIS Qualität und Wirkung verleiht Communities eine Handlungsfähigkeit im Sinne von informierten Entscheidungen über die Auswahl, Nutzung und Weiterentwicklung von CIS Artefakten. Wir konnten zeigen, dass CIS Erfolgsmodelle zur Findung idealer Softwarekonfiguration, zur Einschätzung von Aufwand, zur Identifizierung von Engpässen, zur Anforderungserhebung oder zur Bewertung konkreter Auswirkungen beitragen können. Unsere technischen Auswertungen zeigen, dass MobSOS ein effektives, performantes und kostengünstiges Open-Source Rahmenwerk für CIS Erfolgsbewusstsein ist.

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Dominik Renzel

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Chapter 1

Introduction

In contemporary modern societies, we find *mass individualization* as undeniable trend, that is increasingly becoming reality at a massive world-wide scale with the help of networked *Information & Communication Technology* (*ICT*). In his influential book from 2006 [Ande06], Chris Anderson took up on Clay Shirkey's earlier observations that marketplaces selling virtual goods over the internet increasingly made profits with a large variety of niche products instead of a few best-sellers. The authors describe a transitional shift from the mainstream, i.e. the head of the power law-governed demand curve, to a plethora of niches in the curve's so-called *long tail*. This trend is continuously growing stronger with today's major online retailers such as Amazon or Alibaba or crowdsourcing platforms such as Kickstarter or Indiegogo. In a study on Amazon book sales data, Brynjolfsson et al. found that niche books accounted for 36% of Amazon's sales with a five-fold increase from 2000 to 2008 [BHSm10], thus clearly showing that this trend is here to stay.

The major contribution of the Web, and in particular the Social Web 2.0 is thereby to facilitate the formation and support of a plethora of different communities as organizations of people with common interests, practices, needs, goals, etc. Data-driven enterprises of today increasingly compete in [Dave06, CDHs10] and benefit [BHKi11] from *Business Intelligence and Analytics* (*BI&A*) [CDNa11] and in particular Web Analytics [Kaus10] techniques to reveal and analyze these communities. The goal is thereby to gain deep understanding of the communities' inner workings and ultimately to open them up as new niche marketing opportunities. According to Klamma [Klam10], in 2010, 95% of all World Wide Web users were organized in long tail communities with similar interests and practices, with [BHSm10] suggesting an even higher percentage today. Due to its sheer endless number of rather small and highly diverse communities, the long tail is thus not only an interesting and highly relevant target for marketing, but also for interdisciplinary research of sociologists, economists, physicists, computer scientists, etc.

In the context of our research group, we are mainly focused on *professional long tail communities of practice* as a very specific, yet frequently occurring subclass of long tail communities. According to Wenger's definition, a *Community of Practice* (*CoP*) is a *"group of people who share a concern or a passion for something they do and learn how to do it better as they interact regularly."* [Weng98]. These communities tailor and constantly adapt combinations of digital media to community information systems for supporting and sustaining their communication and collaboration practice.

1.1 Problem Description

As part of their central goal of learning how to do it better, communities require an ongoing measurement and awareness of their own successes and failures. Wenger et al. provide evidence for this essential requirement from several professional community contexts such as car manufacturers, insurance companies and consulting agencies [Weng98, WDSn02]. Such awareness is essential for a self-sustainable overall community life cycle. Communities must constantly create new and measurably relevant *values* and *impacts* for their members to justify and secure their continued existence [WDSn02]. In their endeavor for success in terms of sustaining, renewing and optimizing their practice, professional communities require support for reflection, custom-tailored to their specific goals, practices, needs and differing notions of community success over time. These values also include community tools that undergo constant scrutiny and development to match the ever-changing and emergent practice of communities.

In the *Information System* (*IS*) domain, we particularly find evidence for the importance of IS success measurement as means to prove IT *payoff* as one of the most identity-giving concepts in IS research until today [BeZm03]. In particular, we find a decade-long strand of information systems success research [DeMc92, GSCh08, DMSe14] until today, providing additional evidence for the importance of measurement and awareness. In the same vein, this thesis argues that communities must also constantly assess and measure quality and impact of their community information system and its individual components to gain awareness about their quality and impact for the community. Communities must be able to decide *which tools* best support their practice and – more importantly – *why*. Only with such an ideally close to real-time awareness, communities can achieve informed guidance of their further action. In the context of our own case studies, we found additional evidence for the need to prove payoff in healthcare contexts, in which communities must prove the quality and impact of digital media-based therapy tools to receive sustained funding from public insurance (cf. Section 6.1).

Success awareness for information systems used in community contexts is not directly transferable from standard BI&A approaches used in entrepreneurial contexts. Typical Web analytics success measures like "eyeball pairs", click counts, or conversion rates [Pete04, Pete06, Kaus10] are too simplistic to capture the complex and diverse notions of success from the perspectives of community end-users. From a research perspective, we find fundamental differences between research on enterprise and community information systems success in terms of ontology and epistemology, as we will argue in more detail in this thesis. While the mainstream notion of enterprise information systems success targets universally valid standard models mostly boiling down to financial figures [Bryn93, BBL*96, GSCh08] *(positivist)*, we argue that community information systems success depends on complex combinations of universal and very community-specific factors *(anti-positivist)*. While enterprise hierarchies are relatively stable over time, communities typically exhibit informal and highly dynamic power structures, governed by forms of democracy, meritocracy and expertocracy [Kim00]. Open Source Software communities like Apache [Fiel00] are concrete examples for such forms of governance [Scac01, EKJA14]. While a common notion on information system success in enterprise contexts is imposed from higher-level management, communities must negotiate a common notion of community information system success on eye level. While data-driven enterprises can spend considerable resources in technical infrastructure and qualified software development and analytics staff, self-sustained communities are inherently resource-scarce.

We thus consider establishing community information system success awareness as a research problem on its own. Communities first need respective methodologies to gain success awareness, matching their inherent properties. These methodologies must be integratable into regular community practice and adaptable to the particular community ontology. Communities furthermore need effective and intuitive formalizations that serve as digital media for negotiating a shared notion of information system success in a community. These formalizations in turn serve as prerequisite to a range of services related to success awareness in terms of analysis or visualizations of certain success aspects. Finally, formalizations and services for community information systems success awareness must be seamlessly integrateable into arbitrary existing community infrastructures.

1.2 Research Questions

In the light of these fundamental requirements on establishing a sense of information systems success awareness in professional long tail communities of practice, this dissertation addresses the following three research questions:

Research Question RQ1: How can professional long tail communities of practice achieve a shared sense of *Community Information System* (*CIS*) success awareness with the help of a media-supported and negotiation-based methodology? How can they benefit from this awareness in the context of their existing CIS design and use processes?

Research Question RQ2: What formalisms should communities use to model community information systems success? How can communities formalize the assessment, negotiation, and validation of different notions of CIS success?

Research Question RQ3: How should technical infrastructures for community information systems be designed to achieve integrated support for community information systems success awareness? What tools are necessary to achieve such awareness?

1.3 Example Scenario

For illustrational purposes, the following simplified scenario describes a concrete example of *how* the approach in this thesis should ideally help a community to gain CIS success awareness and *for what benefits*. The scenario is thereby a simplified description of a real-life situation we faced in one of the case studies presented towards the end of this document.

Consider a therapy support group (*community*) of people suffering from reading and writing disabilities due to brain injuries. The conversations and read/write training units during therapy sessions (*practice*) help patients to evade their social isolation and to regain their lost skills (*goals*). However, therapy sessions with qualified therapists are too seldom due to reduced coverage from public health insurance. The community therefore decides to try a regular, no-cost version of a text-based chat (*tool*) from a commercial service provider to stay in contact and to train conversation skills, apart from regular therapy hours. Using this chat tool principally seems to work well in terms of reducing isolation (*tool impact*), but at the same time raises usability issues (*tool quality*). Due to its overwhelmingly complex user interface (*low quality*), patients frequently report frustration (*negative impact*) and state the need for a much more simple tool that better supports their training efforts (*requirement*). The engaged therapist staff develops the idea of requesting funding to develop an own tool with specialized support for people with reading and writing disabilities. Initial research funding is granted, but sustained funding for maintenance, operation, and further development from public health insurance requires evidence *that* the tool provably helps patients at a reduced therapy budget – in other words: the tool pays off – and *why* the tool is helpful or not, i.e. what factors are most relevant for its success or failure. The community decides to take this exercise not only due to the expectancy of receiving sustained funding, but also as valuable means for *self-reflection* to learn how to do better for their own good (*benefits*). With only limited resources in terms of qualified research and development staff, time, and funding, the community decides to apply the free open-source MobSOS framework for CIS success awareness to develop a commonly agreed and valid *success model* for their chat tool. At first, different therapists and patients have different opinions of what factors are most important for the success of the chat tool in their particular context. In the background, the framework collects usage data of the chat tool, allowing to measure generic system quality aspects such as software stability (*success factor*) with failure rates (*success metric*) or community and tool-specific factors such as improvements in communication speed with increased number of words per message. In order to measure the general acceptance of the chat tool and other very subjective factors such as perceived ease of use or perceived helpfulness, community therapists use MobSOS to organize small personalized surveys, injected into regular tool use in an unobtrusive manner. After a certain evaluation period and with sufficient evaluation data at hand, the community uses MobSOS to statistically determine the relevance of individual factors and the validity of individual models. Backed by a certain quantifiable statistical evidence, negotiations in few expert panel sessions lead the community to successfully formulate a commonly agreed notion of success for their chat tool. The community has thus gained a sense of tool success awareness and is able to draw beneficial conclusions, e.g. to guide further development of the chat tool or to justify funding. After a longer period of operation, patients in the community identify a new and much more appealing tool recently emerged on the market. Repeated measurements and assessments of this new tool with slight adaptations of the existing success model for chat tools finally justify the community's abandonment of the old chat tool in favor of the new one.

1.4 Research Methods

Following the common definition of a research paradigm, the choice of research methods for this thesis was mainly determined by its given research *ontology* and *epistemology*. As we will discuss in much more detail in the following chapter, community information systems, i.e. communities, digital media technologies, and the complex interplay between them, are socio-technical systems, inherently characterized by structuration and emergence phenomena [Orli92, Orli10] and several different life cycles [WDSn02, IrLe09] induced by the social and technical facets of our ontology. To account for such an anti-positivist ontology, our epistemology mainly bases on the design science research approach borrowed from the IS research discipline [HMPR04] – *to gain knowledge from the active design and evaluation of artifacts*. Artifacts are thereby not restricted to software products, but also include mathematical formalisms, methodology elements, evaluation products providing empirical evidence, etc. Given the continuous mutual influence of people and technologies, we chose an inherently repetitive and cyclic research process, in compliance with Hevner's three intertwined cycles of relevance, development & evaluation, and rigor [Hevn07]. Given that any design activity must be justified by a concrete need, the first step in each iteration consisted of a literature study, assessment of the current state-of-the-art to identify concrete functional and non-functional requirements. In particular state-of-the-art assessment serves to identify potential unique selling points of the new design artifact in comparison to existing solutions. While literature study, state-of-the-art assessment, and development and evaluation are rather standard elements of every research process, our approach partially included, but mainly developed elements custom-tailored to conducting research with long tail communities, especially with respect to evaluation. As more concrete methodological basis tailored to software engineering in communities of practice, we both employed and actively extended the *Architecture for Transcription, Localization, and Addressing Systems* (*ATLAS*) framework [JaKl08, Klam10]. Our research process thus welcomes frequent interactions with community members in order to elicit concrete functional and non-functional requirements for the respective design artifacts or to evaluate existing prototypes from a community point of view. For example, we augmented the initial literature study and assessment with a social requirements engineering approach [KJHR11, LCRK12, ReKl14], accompanied by Requirements Bazaar [RBKJ13, RKJa15a] as dedicated support tool. Most importantly, the outcomes of this dissertation contribute to a community-oriented IS evaluation methodology. This fact has important implications for the design and evaluation activities in our research process in terms of two complementary levels. Design activities in this work mostly involve two different levels: 1) *the design of a CIS artifact to be evaluated with certain MobSOS components* unless it already existed and 2) *the design of MobSOS components*. In the same manner, evaluation activities in this work involve two different levels: 1) *the evaluation of a CIS artifact with the help of MobSOS components* and 2) *the evaluation of MobSOS components*. This distinction between two different levels of design and evaluation is reflected in the case studies of this work, chosen as appropriate evaluation format in design science research. The quantitative and qualitative evaluation of concrete CIS tools with MobSOS still yields interesting implications for MobSOS itself, but is of rather secondary importance for this work. The main purpose of evaluation for this work is however the evaluation of MobSOS components.

1.5 Thesis Contributions

We have packaged all individual contributions of this work under the overarching *Mobile Community Information System Oracle for Success* (*MobSOS*)[1] framework for community information systems success awareness in professional long tail communities of practice. All MobSOS components are organized around our research questions. The MobSOS Methodology is a methodological extension of the overarching ATLAS methodology for reflective community information systems

[1]This acronym was inspired by the ancient seer *Mopsos* (gr. $\mu\acute{o}\psi o\varsigma$), known from greek mythology. Mopsos is told to be founder of the oracle of Apollon in Klaros. Mopsos was prophet among the Argonauts, i.e. the group of heroes who conducted the maritime expedition to Colchis for the purpose of fetching the golden fleece. Mopsos outperformed several famous other seers, e.g. Kalchas and Amphilochos.

engineering [Klam10]. As such, it directly contributes to RQ1. Our methodological extension thereby integrates the concept of community information system success awareness into an overall Design Science Research approach. Central part of this methodological extension is the active negotiation of a shared community information systems success awareness with the help of fluid, dynamic success models as part of ongoing system evaluation.

MobSOS CIS Success Modeling contributes an extensive formalization of community information system success. As such, it mainly contributes to RQ2, but also includes minor contributions to RQ1, as formalizations are part of the methodology. Success models are conceptualized as fluid digital media, resulting from a human-machine transcription process, and based on quantitative objective observation data and qualitative/subjective survey data. Our contributions thereby include several modeling guidelines. For frequent repetitions of success model validation, we elaborated a combination of light-weight expert panel and regression techniques.

The MobSOS Community Information Systems Success-Aware Infrastructure contributes an abstract notion of a generalized community information system infrastructure with built-in support for success awareness. As such, it contributes to RQ3. We realized this support with the MobSOS tool kit, consisting of several awareness-related services, i.e. data collection, survey management, data analysis and visualization for exploratory and confirmatory purposes, and success modeling.

1.6 Thesis Overview

The rest of this dissertation is organized as follows.

In Chapter 2, we introduce the research contexts of professional long tail communities of practice. In this chapter, we discuss principal ontology and epistemology of this context, define basic terminology, provide an overview on relevant related work and state-of-the-art, and identify the research gaps motivating this work.

In Chapter 3, we present the MobSOS Methodology. We first localize our extension in the overarching ATLAS methodology and then successively zoom into the ATLAS process up to community information systems success modeling as community-wide media transcription.

In Chapter 4, we present the formal approach to MobSOS community information systems success modeling and validation. We thereby describe community information system success models as fluid media for negotiating success, powered by a combination of observation and survey data.

In Chapter 5, we present the abstract MobSOS success-aware community information system architecture, including the MobSOS toolkit and its components MobSOS Monitoring Pipeline, MobSOS Surveys, MobSOS Query Visualization, and MobSOS Success Modeling.

In Chapter 6, we report evaluation results of the overall MobSOS approach and its components in the context of three case studies. In these case studies, we applied MobSOS in the context of an aphasia community and its custom chat tool, a cultural heritage preservation community using mobile multimedia management tools, and the larger technology-enhanced learning community and a management framework for building personal learning environments.

In Chapter 7, we conclude this dissertation with a final discussion of results and contributions, as well as a brief outlook to possible avenues for future work.

Chapter 2

Research Context

In the previous chapter, we motivated the overall thesis goal of bringing information systems success awareness to communities. In this chapter, we set the stage for our research towards this goal. First, we provide terminology definitions for the most important concepts and entities that run through this work like a golden thread. We thus strengthen the awareness for the deeper conceptual meanings behind sometimes inconspicuous technical terms. Second, we link the most important concepts to related academic work and industrial state of the art. The core of this work is of rather interdisciplinary character, located at the intersection of social science, information systems, and computer science. Our discussion thus spans over a set of distinct, yet conceptually overlapping research areas within these disciplines. Our aim is thereby to integrate concepts, theories, methodologies, and technical approaches into a coherent overall framework for success awareness in community information systems. Third, we derive the basic ontological and epistemological foundations from this framework. The clear understanding of research ontology and epistemology with respect to conducting research and development in communities serves as major prerequisite for a methodology of establishing success awareness. Fourth and most importantly, we extract relevant research challenges from existing literature and practice serving as motivation for this work.

In Sections 2.1 resp. 2.2, we develop the combined terms *Long Tail Community of Practice* resp. *Community Information System* as main ontological and epistemological foundations used throughout this work. In Section 2.3, we develop the term *Community Information System Success*, based on a literature study of traditional and modern information systems sucess research. In Section 2.4, we discuss the current state of the art in Web-based community information systems engineering and evaluation. In Section 2.5, we define the term *Community Information Systems Success Awareness* as an adaptation of Endsley's situational awareness theory [Ends95], adapted to communities of practice and community information systems. In Section 2.6 we finally summarize our observations and relate them to the contributions of this work.

2.1 Professional Long Tail Communities of Practice

Being situated in the area of advanced community information systems, the work in our group is focused on researching the design, use, and analysis of digital ICT in so-called *Professional Long Tail Communities of Practice*, a term combined from the social learning theory of CoP [BrDu91, LaWe91, Weng98, BrDu00, Weng00] and Anderson's long tail market theory [Ande06]. As a result of multiple cross-sectional ethnographical studies, different researchers [BrDu91, LaWe91, Weng98, BrDu00, Weng00] described communities of practice as a universal form of social learning found across all areas of human interaction. Such social learning occurs in co-located communities as parts of larger business organizations, either in emergent forms (e.g. insurance companies [Weng98]) or in institutionalized forms (e.g. car manufacturers [WDSn02]).

Without clear understanding of its profound definition, the term *"Community of Practice"* has often been confused with other forms of human organization, such as organizational units, work departments, regional neighborhood communities, communities of interest or product-centered online communities. Although Communities of Practice share certain aspects with these other forms, they are fundamentally different. For this work, we adopt Wenger's original definition of a CoP as a *"group of people who share a concern or a passion for something they do and learn how to do it better as they interact regularly."* [Weng98]. Communities of practice are characterized by a *joint enterprise*, *mutual engagement* and a *shared repertoire* of knowledge, symbols, social rules, jargon, and tools, etc. A later definition by Wenger et al. elaborates social community interaction as *learning together*, *building relationships*, and *developing a sense of belonging and mutual commitment* [WDSn02]. Most importantly, community participation takes place on a *regular basis* and is *voluntary*. However, in return for their volitional involvement, community members expect *value*. Communities must therefore continuously invest in value improvement and innovation as incentives for sustained member participation and attraction of newcomers. The original conception of CIS is not bound to the use of ICT. However, an increasingly pervasive presence of Web 2.0 social media technologies for communities [Weng09] foster the formation, communication, collaboration, and constant innovation in self-sustaining *virtual* communities [Kim00].

Community Learning In any CoP, social learning *"how to do it better"* is the central driver of community activity. This type of rather informal learning is different from institutionalized formal learning, as it is situated in actual practice, including the authentic social environment of the community. Community of practice learning is characterized by a dualism of *participation*, i.e. interaction with other community members in terms of communication, collaboration, and social negotiation and *reification*, i.e. the creation of *artifacts* reifying the given practice. These reifications not only include transcriptions of tacit knowledge, but also the development of novel digital media and tools for generating and disseminating knowledge in a community-specific manner.

Jarke & Klamma operationalize this dualism of participation and reification in their digital media-centric theory of learning in communities of practice [JaKl05, Klam10]. Based on the seminal SECI model [NoTa95] community member exchange knowledge in a cyclic process of socialization, externalization, combination, and internalization. This knowledge exchange is further operationalized with Jäger's theory of transcriptivity ("Transkriptivitätstheorie" [Jaeg02, JJKS08]) and its three basic operations of *transcription*, *addressing*, and *localization*. Transcriptivity theory thereby describes the transformation of making pre-medial, tacit representations of knowledge – the so-called *prescripts* – explicitly readable as *scripts*, i.e. representations of new semantical knowledge as with the help of employing a *transcript*, i.e. a means for this transformation. A simple example for such a transcription is to generate meeting minutes (script) by using a text-processor (transcript) to protocol (act of transcription) the main discussion points from the ongoing conversation (prescript). More generally, digital media technologies serve as transcripts to facilitate arbitrary intermedial discourses in communities by producing, negotiating and disseminating knowledge, e.g. by combining digital media artifacts such as text and videos (prescripts) documenting community knowledge on a Web page (script). By transcription, unreadable, pre-medial prescripts become readable scripts, addressed to certain target audiences (*addressing*). For example, meeting minutes might use a terminology that is only understandable for a certain circle of privy managers. In the current situation of information abundance, communities increasingly face over-addressing and thus must focus their attention to the community-specific reception of scripts that are of local importance for them (*localization*). For example, different stakeholders in a community might be able to access the same minutes documents, but only focus on those relevant for them and just extract the information from each minutes document that is relevant to them. The conceptual universality of transcriptivity theory allows to capture a wide spectrum of different knowledge acquisition tasks naturally occurring in communities. In the context of this work, we build on this media-centric learning theory to model the process of gaining success awareness about the digital media technologies developed and used in communities of practice (cf. Section 3.4).

The principle of *Legitimate Peripheral Participation* (*LPP*) [LaWe91] serves as basic foundation for all social learning processes in communities of practice. New members are welcomed and supported by the community to start with rather passive and uncritical participation in the periphery. From well-established communities of practice in the area of *Open Source Software* (*OSS*) development [Fiel99], we know that such a welcoming culture plays an important role in sustained community evolution [WDSn02]. It attracts newcomers with novel ideas, along with the motivation and capabilities to pursue these ideas. With active involvement and diverse kinds of contributions valuable for individual members and the whole community, newcomers can gradually proceed "inwards" by gaining proficiency, trust, and reputation. In the context of this work, the LPP principle also applies to community participation and contribution by researchers and designers. These groups often bring a combination of both development and analytical capabilities that are seldomly available, yet highly appreciated resources for communities.

Long Tail Communities The Web is a scale-free, fragmented network governed by power law distributions [Bara01]. 95% of its users are organized in rather small self-sustained communities in the distribution's long tail [Klam10, Ande06] in contrast to the distribution's head established by a well-connected corporate mainstream and its firm-sponsored virtual communities [PDSu13]. From a marketing perspective, Anderson's long tail economic theory [Ande06] became seminal, as it foresaw the cultural and economical shift from a relatively small number of mainstream products and markets in the head towards a huge number of niche markets in the long tail of the power law-governed demand distribution. In the past years, the most prominent manifestations of this theory have become successful worldwide reality with marketing platforms (e.g. Amazon[1], Alibaba[2]) or

[1] https://amazon.com
[2] http://alibaba.com

crowdfunding platforms (e.g. Kickstarter[3], Indiegogo[4]). Brynjolfsson et al.'s empirical studies on Amazon booksales from 2000-2008 showed that customer surplus generated by niche books grew more than fivefold in that period, that 36.7% of Amazon's 2008 book sales took place in niches [BHSm10], and that altogether the long tail is growing longer in its distribution. Although comparable empirical research is not available for the long tail of online communities of practice, we strongly believe in similar growth effects.

Community Heterogeneity Long tail communities of practice are characterized by an inherently high degree of specialization and resulting *idiosyncrasy*. Especially in the long tail, no two communities are the same. As such, communities bear interesting opportunities for interdisciplinary research, design, and development in highly creative, epistemic constellations [AmRo08]. In particular with respect to needs for idiosyncratic solutions and their potential for cross-community or societal adoption, communities of practice are suitable research contexts for studies on exaptations, extensions, and innovations of digital media technologies [GrHe13, RKJa15a]. While academic researchers join communities to advance knowledge, professional developers join to innovate and co-create new digital media technology artifacts. In particular in the design-focused areas of computer science and IS, researchers are trained to combine both roles [HMPR04, VaKu04].

In addition to the high heterogeneity *between* different communities, we even find heterogeneity *within* communities. This internal heterogeneity stems from different stakeholder roles, levels of participation, individual or role-specific goals and conceptions of successful goal achievement, and different needs for improvement and innovation. Orthogonal to domain-specific stakeholder roles,

[3]https://kickstarter.com
[4]https://indiegogo.com

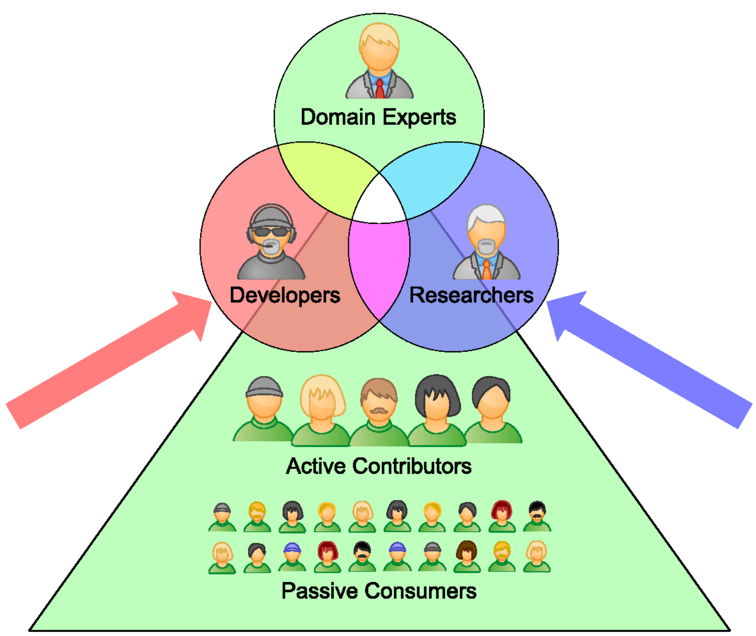

Figure 2.1: Archetypical Pyramid of Innovation-Driven Communities of Practice

we especially emphasize the roles of software developers and researchers. By contributing their expertise to design and evaluation of innovative community-tailored digital media artifacts, they can quickly advance from peripheral participation to expert ranks. In Figure 2.1 we summarize the most focal overlapping member roles as a conceptual archetype of the professional long tail communities of practice we consider in our research, not only for this work.

Community Governance In contrast to comparably static, hierarchical and formal power structures found in organizations and companies, geographically distributed virtual communities of practice are characterized by open, informal, shared, dynamic, and trust-based social structures. Such structures are often governed by certain combinations of democracy, expertocracy and meritocracy [Kim00]. We find strong acceptance for such shared power structures in OSS communities [Scac01, EKJA14] such as the Apache Foundation [Fiel00]. This observation is in particular important for community participation of open source developers and researchers, as they contribute their expertise in development and analysis to the design and evaluation of new digital media technologies, according to the needs and in close collaboration with community members.

However, despite their initial openness and leap of *trust*, communities of practice must and do cultivate a reasonably critical stance of *distrust* towards newcomers and their contributions. We agree with Gans' *Trust-Confidence-Distrust* (*TCD*) model [Gans08] in that distrust is healthy for communities. A reasonable amount of distrust helps them to stay focused on particular goals and to differentiate true intentions for sustained and engaged commitment from false intentions of temporary participation, as these might exploit or even damage the community's reputation. In a similar vein, communities constantly assess their *confidence* towards the situated use of digital media technologies in terms of quality and impact as necessary prerequisite to decide technology adoption, development, replacement, or abandonment. Such confidence assessment requires appropriate analytical capabilities from community members. Confidence assessment furthermore requires appropriate evaluation methodologies and technical support as part of community information system infrastructure. However, most of these prerequisites are not fulfilled for communities of practice, thus rendering a clear research gap [PDMc12].

Community Participation & Contribution Communities of practice range from small and intimate communities with less than 15 members over medium fluid and differentiated communities with 15-50 members up to larger communities of 50-150 or more members [WDSn02]. While smaller communities usually face strong and intimate collaboration, larger communities exhibit a wider spectrum from novice to expert participation. In larger communities we find the *"90-9-1"* rule of participation inequality [Niel06] generally found in digital social media. With approximately 90% of all community members, the majority of mostly novice community members participates rather passively as knowledge and service consumers with only few active contributions. A smaller fraction of about 9% contributes more actively to the overall community learning process. These active members use, evaluate, and express needs with regard to the digital media technologies appropriated or developed for their specific community context. They actively test and provide feedback on new technologies and contribute smaller knowledge artifacts to the community's shared repertoire. The smallest fraction of about 1% usually established by community experts additionally marks responsible for the most important and influential contributions towards a common benefit. Especially in geographically distributed epistemic communities depending on networked digital media technology and constant self-innovation [AmRo08], contributions not seldom include active research, design and development to support or even enhance current community practices. As such, the participation of academic researchers and professional software developers can be understood as highly appreciated reinforcement to the usually very limited and scarce development and analysis resources available in long tail communities. Most research of this work was in fact situated in such communities.

Community Life Cycles In addition to their multi-faceted heterogeneity, long tail communities are highly dynamic in several ways. They hardly ever start out of the blue, but rather emerge from foundational ideas and expertise gathered in prior community contexts. Communities are subject to multiple individual and community-related life cycles [LaWe91, Kim00, WDSn02, IrLe09], and continuously co-evolve and emerge in socio-material practice [OrRo91, Orli10] of human interaction with digital media technologies.

For individual community membership, legitimate peripheral participation [LaWe91] imposes an individual membership life cycle [Kim00]. Kim's life cycle thereby consists of five phases combined with member roles: *peripheral/visitor*, *inbound/novice*, *insider/regular*, *boundary/leader*, and *outbound/elder*. During the sequential transition through these phases, members are driven by different goals, motivated by their expectations for value, realizations of own ideas, and their changing roles in the community. While a novice pursues to quickly learn jargon and principal basics of his community, the very same person might later develop to a leader with the goal to sustain his community. In the same manner, quality and impact of community artifacts might be conceived differently. A novice might perceive severe issues with an overwhelmingly complex community tool, while an expert might appreciate its extensive feature set. As a sum of all individual membership life cycle instantiations, a community is subject to fluctuation, as new peripheral members join and outbound members leave. Apart from individual memberships, communities as a whole are also subject to *community life cycles*. Such life cycles are independently described for communities of practice [WDSn02] and online communities [IrLe09]. Wenger et al. describe five life cycle phases of *potential*, *coalescing*, *maturing*, *stewardship*, and *transformation*. Iriberri & Leroy [IrLe09] present a model of five phases of *inception*, *creation*, *growth*, *maturity*, and *death* with majorly corresponding meanings. In Figure 2.2, we juxtapose these two community life cycle models and show their substantial conceptual overlaps. Wenger et al. contribute different levels of energy and visibility as well as developmental tensions experienced in different phases. Iriberri & Leroy contribute an explicit process model with development foci characterizing the phases. However, given the strong idiosyncrasy in long tail communities, we usually find strong differences between concrete community life cycle instances with respect to community-specific practices, goal settings, and perceptions of success. Every community follows its own rythm [Weng98, WDSn02].

Another source of dynamicity in long tail communities of practice stems from the structuration-theoretical, inseparable *duality of agency and structure* [Gidd84]. The same duality also holds for the active human use and development of digital information technology [OrRo91, DePo94]. As communities continuously appropriate digital media technologies for their purposes, these technologies create change in members' agency to learning how to do it better. This change in turn triggers structural changes in terms of developing even more sophisticated technologies. Not seldom, a community's appropriation of digital media technologies is different from the designer's original intentions [BoRo05]. In Section 6.1, we find an example for this phenomenon in connection with the development of a chat tool for language-impaired persons. In such highly dynamic and evolutionary socio-material practice [Orli10], change is often rather *emergent* than planned. Under this

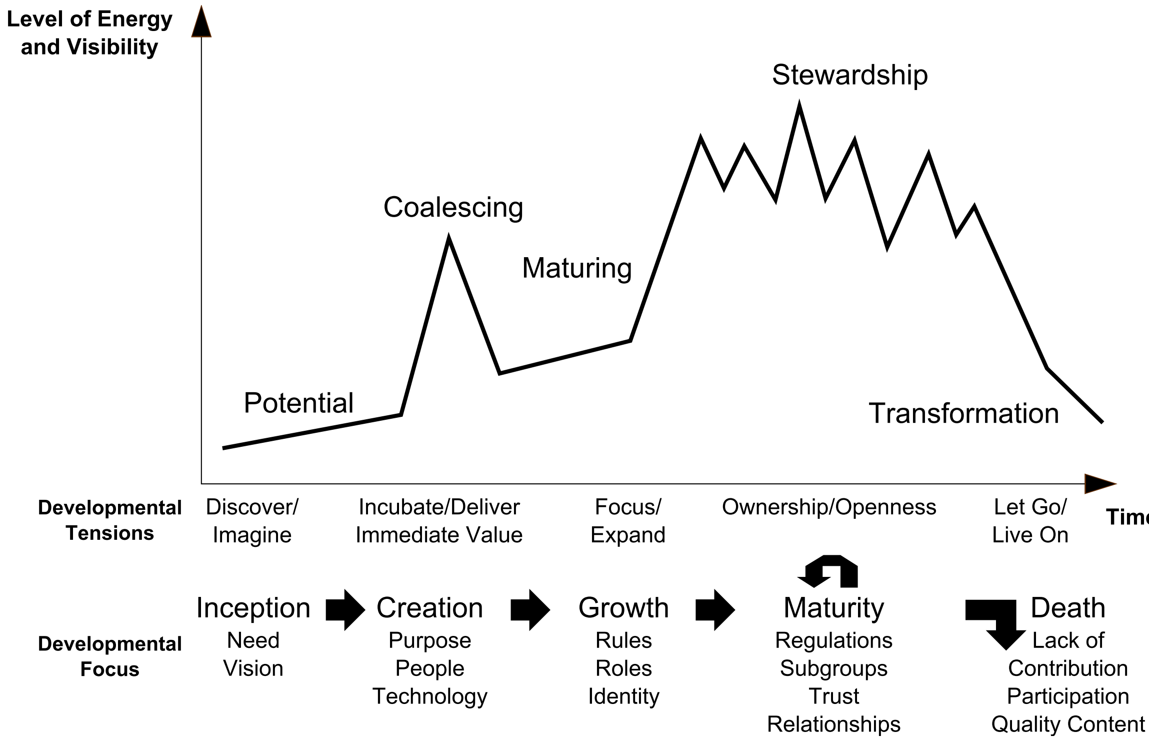

Figure 2.2: Community Life Cycles – Visibility and Process [WDSn02, IrLe09]

assumption of emergent change, communities must continuously trace and evaluate their practice from both process and product perspectives, in particular with respect to the use and development of digital information technology for value creation.

In close relation to the goal of this work, the original works on communities of practice already discuss the measurement of value of a community's knowledge system. Measurement thereby includes a backwards-directed reflection of past community impact and the assessment of the current status. In order to *learn how to do it better* [Weng98], *"communities need measures to know how they are doing to guide ongoing efforts[...]"* [WDSn02]. Several authors have suggested such measures in the form of community success factors for different community types [BFS*06], different stakeholders [LSKr06] and for different community life cycle phases [IrLe09]. In particular for virtual communities of practice, knowing how they are doing includes an *ongoing* awareness on quality and impact of the used digital media technologies.

Community of Practice Research Ontology & Epistemology From the above discussion we conclude two major properties of professional long tail communities of practice: *heterogeneity* up to idiosyncrasy and *dynamicity* in terms of different intertwined life cycles and emergent socio-material practices as effects of structuration theory. Especially the focus on heterogeneous communities bearing a multitude of different and changing stakeholder conceptions of individual and community success is a strong indicator against a positivist research ontology [OrBa91]. The central social learning goal of *how to do it better* common among all communities of practice entails the need for an ongoing critical evaluation and reflection of existing community practice from different stakeholder perspectives. In particular in connection with the participation of researchers and developers in highly creative and epistemic virtual communities of practice [AmRo08], a substantial part of knowledge creation is related to the design and evaluation of new digital media artifacts [HMPR04, VaKu04, SHP*11]. This observation largely complies with the epistemology of a critical research paradigm [OrBa91]. As such, it is surprising that most related research on community success pursues a positivist epistemology of synthesizing and quantifying general universally valid success factors. We rather argue for a critical research epistemology, where a coherently agreed awareness of overall community success can only emerge from a *negotiation* of different competing contradictory conceptions of success from different stakeholder perspectives. The use of quantitative statistical methods from the positivist toolkit can contribute to more objective, evidence-informed negotiations among competing stakeholders.

2.2 Community Information Systems

Communities actively shape the digital media technologies they use, while at the same time these technologies shape them. Until now we mainly focused on the social perspective of our research ontology and epistemology. In this section, we explicate this inseparably connected technical perspective of community information systems.

A classical definition by Alter states an information system as *"combination of work practices, information, people, and information and communication technologies organized to accomplish goals in an organization"* [Alte92]. This inseparable connection between people and digital media technology is a main focus in information systems research. According to Lee, *"research in the information systems field examines more than just the technological system, or just the social system, or even the two side by side; in addition, it investigates the phenomena that emerge when the two interact"* [Lee01]. Until today, IS research seeks *"to advance knowledge about the effective and efficient utilization of information technology by individuals, groups, organizations, society, and nations for the improvement of economic and social welfare"* [Agar11].

Information systems process data into relevant forms of information for end-users to make decisions or take action. End-users may be using the information to make a decision to improve an organization or to take action to positively impact society [PDMc12]. Although these comparably generic definitions still hold valid until today, concrete information systems have undergone a tremendously fast technological evolution with deep ramifications into social life, increasingly blurring the boundaries between professional and private. While first generations of information systems were mainly siloed installations of mainframe and terminal solutions confined to single companies, the rise and public availability of increasingly usable and affordable global networking platform technologies such as the Internet, the Web [Bern89], the Web 2.0 [Orei07, OrBa09], and mobile cloud computing [KRKC10] not only paved the way for organizational networks and the addition of bottom-up knowledge management to top-down business processes [JaKl08]. These technologies also opened new opportunities for the organic formation of self-sustained online communities, distributed across organizational boundaries, including the long tail communities of practice in the focus of this work.

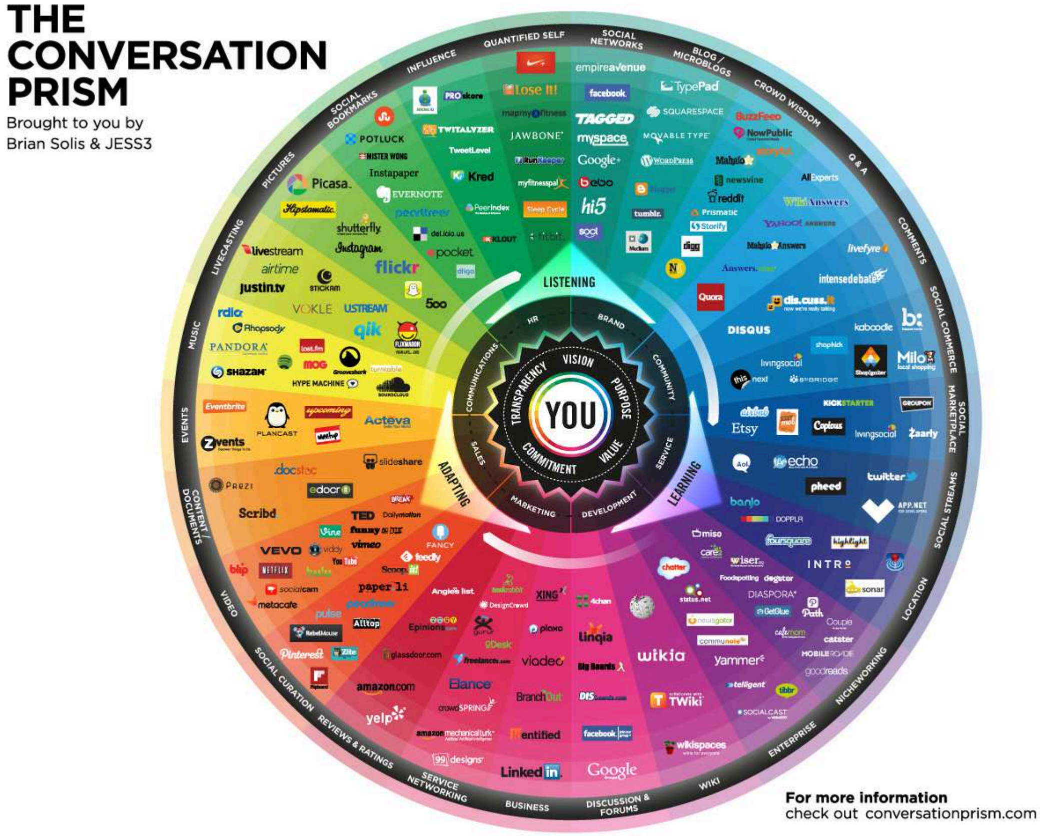

Figure 2.3: Solis' Conversation Prism of Social Media [Soli13]

Web-Based Social Media Today, professional online communities have a large and quickly growing ecosystem of social media [KaHa10] at their disposal. Contemporary social media usually follow established design principles [Fiel00] in order to enable interoperability [PZLe08] with other social media. This interoperability is an essential prerequisite to many different forms of choreographed and orchestrated mashups [YBS*07, BDSh08, SMW*12] fostering serendipitous reuse and recombination [Visn08]. Hence, community information systems are orchestrated ensembles of digital media artifacts [OrIa01, SHP*11] rather than monoliths.

Most prominently, social networking sites [BoEl07] act as anchor media. They allow communities to model social relationships, to communicate and share different kinds of multimedia content, and to integrate with a large number of other mainstream digital media. Figure 2.3 shows version 4.0 of Solis' conversation prism [Soli13] as a result of his ongoing studies in digital ethnography, tracking and ordering the most dominant social media by their appropriation in worldwide use. Interestingly, Solis' prism includes a *nicheworking* facet, reflecting the demand for social media tailored to the needs of niche communities in the Web's long tail (cf. Section 2.2). Although the few nicheworking media listed in this category create a distorted impression on the sheer endless number of niches in the long tail, they indicate a growing mainstream awareness for long tail demands.

Reflective Information Systems Organizational information systems use is often mandated by political and inert corporate strategy. In contrast, the informal power structures, dynamicity and inherent emergence in communities of practice call for an ongoing critical reflection and awareness on quality and impact of the used digital media constellations. Several authors therefore emphasize the importance of technical and methodological support for ongoing reflection in and on technology-mediated action [Scho83]. Klamma defines a community information system as reflective information system, using a variety of Internet engineering technologies to support communities of practice, thereby depending on a complex interplay of informal and evolving community structures, evolving technology and the mostly hidden rules of network structures. Klamma particularly introduces the essential requirement for reflective support in community information systems such that *"communities [can] measure, analyze, and simulate the interplay of structure and agency [...]"* to achieve awareness [Klam10]. This requirement not only holds for technical instantiations of reflective community information systems [JaKl08], but also for respective community information systems engineering methodologies. Based on critical and constructivist research paradigms as well as Schön's reflective practice, Mathiassen emphasizes the need for reflective information systems design [Math98]. This reflective aspect of information systems is especially important in the context of this work, as reflection on information systems success in terms of a situated notion on quality and impact is prerequisite to gaining success awareness.

P2P-Based Social Media In recent years, social media, in particular *Online Social Networks* (*OSN*) are increasingly criticized for their lack of end-user privacy, data protection, and control over own data. A recent trend therefore argues for the revival of *Peer-to-Peer* (*P2P*) technologies [RoDr10], as their conceptual networked architecture is closer to the actual nature of communication and collaboration in online communities [BuDa09]. Information exchange happens in a decentralized, self-organizing and secure end-to-end fashion without the reliance on intermediaries in the form of cloud service providers. The organic growth of such decentralized P2P networks rather contributes to network resilience regarding faults and attacks. Data royalty is no more monopolized on the side of central service providers, but under truly distributed control of end-user communities in multiple administrative domains. Recently, this revival of the P2P concept has gained traction among researchers and millions of practitioners in areas such as file sharing and distribution (e.g. bitTorrent), media streaming, telephony (e.g. Skype), volunteer computing (e.g. SETI@home) [RoDr10] and online social networks [BSVD09, BBS*09, CMSt09, AiRu10, NJP*12]. We furthermore see great prospect for further uptake of the P2P computing paradigm with influential Web technologies such as Web-RTC or XMPP [Sain11a], in federating cloud computing infrastructures [KKN*15], and in Internet of Things scenarios [AIMo10, SGR+14]. As such, P2P technologies bear interesting avenues for future research on community information systems.

As a conclusion for this section, we define a CIS as second ontological and epistemological pillar of this work. A CIS is a reflective information system that supports professional online communities of practice in the long tail by employing tailored combinations of Web or P2P-based social media. Any CIS constantly evolves from emergent change as a result of the dualism of social agency and technical structure.

2.3 Community Information Systems Success

With a clear conceptual understanding of the basic ontological and epistemological foundations of communities of practice and contemporary community information systems, this section develops an understanding of community information systems success as the focal construct of this work. Our understanding thereby builds upon several seminal contributions on IS success from several decades of information systems research, combined with related work on the success of online communities. In a critical discussion, we transfer pivotal findings from organizational information systems contexts and online communities to community information systems. This discussion reveals a paradigmatic conflict of the mainly positivist tradition in classical information systems research and the fundamental requirements for an anti-positivist, i.e. interpretive and critical paradigm necessary for researching community information systems success [StSt06]. Furthermore, this discussion serves as motivational basis for our anti-positivist methodology on the community-wide achievement of an awareness for community information systems success, yet borrowing from the positivist's method toolkit (cf. Chapter 3).

2.3.1 Information Systems Success

Since the early 1960s, many independent efforts in the IS discipline were concerned with measuring the effectiveness or the *success* of particular *Management Information System* (*MIS*) in professional organizations. Main purpose for measurement was to justify extant investments in information systems infrastructure and personnel. Some of the most highly influential instruments were designed to assess individual aspects of information systems effectiveness such as technology acceptance [Davi89] or user information satisfaction [BaPe83, IOBa83, DoTo88]. Most of this early research followed a traditional positivist paradigm adopted from social science research that majorly shaped the early days of the IS discipline [OrBa91, PDMc12].

With their I/S success model [DeMc92] DeLone & McLean started a long-standing research debate on IS success until today [GSCh08, DMSe14]. This debate develops along the radical innovation and evolution of information systems in several eras from siloed mainframe solutions until today's social media-driven information systems [PDMc12]. In the following sections, we trace relevant and seminal contributions from information systems success research and explicitly relate the most essential findings on IS success to our ontological and epistemological foundations of communities of practice and community information systems.

2.3.2 The I/S Success Model

After a large number of influential works on individual measurement instruments on information systems success (e.g. user information satisfaction (UIS) [BaPe83], end-user computing satisfaction (EUCS) [DoTo88]), Delone and McLean [DeMc92] published a large-scale metastudy on IS success, resulting in their seminal I/S success model. From more than 180 conceptual and empirical studies on IS success over the previous decades, they extracted over 100 success factors and grouped them in the six dimensions *System Quality*, i.e. the technical quality of the information system, *Information Quality*, i.e. the quality of the information conveyed to its users, *Use*, i.e.

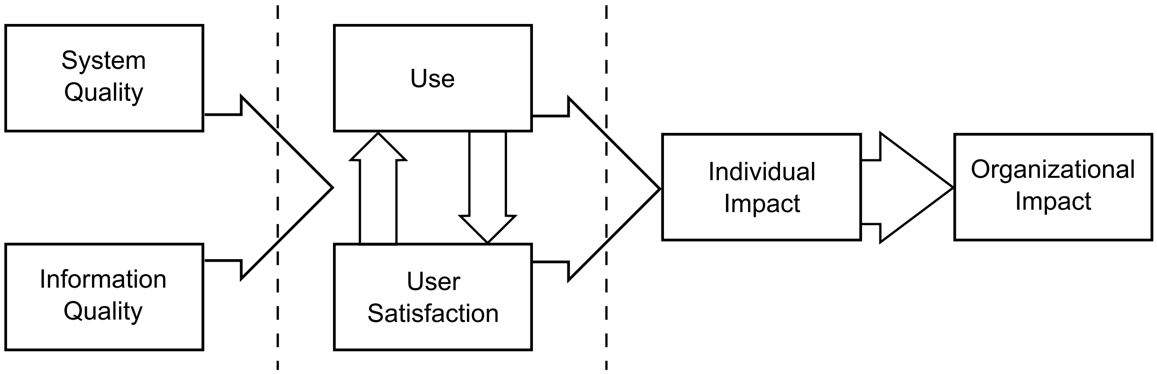

Figure 2.4: The I/S Success Model [DeMc92]

the actual use of the information system, *User Satisfaction*, i.e. the satisfaction of users with the functionality of the information system, *Individual Impact*, i.e. the impact for the individual user of the information system and *Organizational Impact*, i.e. the impacts for the whole organization employing the information system. DeLone and McLean hypothesized a set of causal resp. processual relations between these dimensions and summarized their findings in a nomothetical network of the different success dimensions (cf. Figure 2.4). System and information quality are conceived as the antecedents to actual use and user satisfaction with the system, which in turn are antecedents of individual impacts and finally impacts for the whole organization. DeLone & McLean thus conceive IS success as an inherently complex construct, determined by a vast array of possible *success factors*. These factors are in turn measured by an even larger set of related *success measures*. Independent empirical studies in subsequent years were concerned with the validation of the individual paths in DeLone & McLean's hypothetical model, resulting in critical discussions and later reconceptualizations. In parallel, several highly influential measurement instruments (e.g. usability [Broo96, Kira96], task-technology fit [GoTh95, Good98], user experience [LHSc08]) were added to the ongoing discourse. Interestingly, many of these seminal works exhibit conceptual overlaps with the I/S model, however without any explicit notion of it.

Several authors criticized the unclear process/causal semantics of the inter-dimensional paths of the model [BBL*96, Sedd97]. Despite considerable empirical research, results on the relationships among constructs related to IS success and its determinants are often inconsistent [GSCh08]. These interdimensional relationships are under constant debate until today [DMSe14]. Seddon & Kiev [SeKi94] initiated a discussion on the *Use* dimension, as system use is rather antecedent and/or consequence, but not constituting factor of IS success. Only voluntary use could serve as proxy for overall IS success, directly contradicting the predominant mandatory use of organizational management information systems, stipulated by executive managers. Mandatory IS use in professional organizational contexts raised a discussion on differentiating between *use* and *intent to use* [DeMc03]. Several authors [SSPB99, JiKl99, RLWe02, BuSt06] strengthen the notion that IS success is highly context-dependent on the system scope under consideration and the respective stakeholder perspective, incl. respective task and goal specificities. While technologies may appear to have objective forms and functions at one point in time, their percepts vary by different stakeholders and contexts of use, and over time [Orli92]. Other authors criticized a myopic focus on financial factors and argued for opening towards non-financial factors [Bryn93, BBL*96, KaNo96, JoHu01]. Such factors

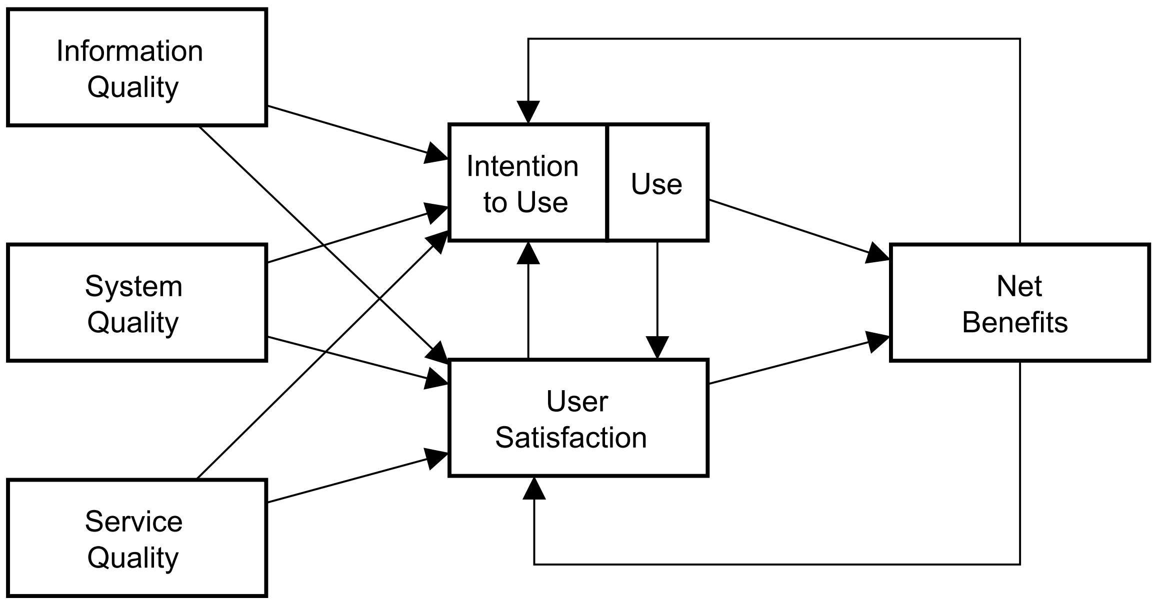

Figure 2.5: The Updated I/S Success Model [DeMc03]

should focus on intangible social benefits such as trust or reputation. Myers et al. [MKPr97] identified a lack of recognition with respect to other impact types beyond individual and organizational, i.e. intercultural work group [Ishm98], inter-organizational, or even societal impacts [Sedd97]. Pitt et al. [PWKa95] identified service quality [PBZe88, PBZe91, PBZe93] as missing with the upcoming notion of end-user computing.

DeLone & McLean later updated their initial model, thus taking into account interim critical discussions. Despite all criticism, the updated model (cf. Figure 2.5) continued to include the use dimension, yet in combination with *intention to use* as accompanying construct. Delone & McLean justified this continuation with the evolution to more open and end-user oriented information systems. These systems include voluntary use by customers and much more sophisticated technical means to empirically *"[...] consider the nature, extent, quality, and appropriateness of the system use"* [DeMc03]. Especially declining use is an indicator that anticipated benefits were not realized. The updated model included a new service quality dimension, justified by the work on Paramasuran et al.'s seminal SERVQUAL instrument [PBZe88, PBZe91, PBZe93]. Finally, the authors merged the impact dimensions of the original model into one *net benefits* dimension. This new dimension served as overarching construct summarizing all impact types [MKPr97] (e.g. impact on individuals, work groups, inter-organizational networks or society) for the sake of parsimony.

In subsequent publications, Delone and McLean together with other authors continuously discussed their model [PDMc08, PeMc09]. They particularly highlight its high level of validity and its impressive uptake across disciplines [DeMc03, DMSe14]. However, even until today, the inter-dimensional path structure of both the original and the updated model is frequently questioned among IS success researchers [GSCh08, TSMB14]. In fact, apart from a plethora of empirical studies (detailed overviews available from [DeMc03, DMSe14]) examining individual structural paths of the model, only few researchers empirically validated the complete model with strong limitations on representativeness [RLWe02]. Observing the many adaptations of DeLone & McLean's model to problem settings outside the school of traditional information systems research, the interest in the I/S success model rather focuses on applied IS success measurement. These works largely take for granted the structural relationships in the model's nomothetical network.

2.3.3 IS Success Evaluation as a Process

The many different criticisms and adaptations of the I/S success model are partially attributable to milestones in technology evolution. For that reason alone, the predominant positivist stance towards a static and universal IS success model seems inappropriate in the case of communities. As information systems themselves, information systems success is rather a dynamic, context and stakeholder-dependent construct calling for ongoing reflection and learning in feedback loops [Sedd97]. This ongoing reflection on IS success should also include aspects of ongoing IS development and deployment [BBL*96, Saar96]. *"Unless individuals and the organization can learn from experience and develop better systems and recognise better information quality, then it is unlikely that the measurement of outcome will serve any useful purpose"* [BBL*96].

However, IS success measurement should not exclusively focus on IS development [RoVe08] in terms of cost/benefit analysis and simple questions such as *"Does the system work?"*. They should rather maintain a wholistic view, including intangible social aspects of IS success [JoHu01], asking questions such as *"Is it used successfully?"* or *"Does it deliver value?"* [SmHi98]. End-user participation in IS evaluation is recommended, as it leads to better and more useful systems [SJCh06]. Doherty et al. [DAPe11] thus argue that assessment should rather focus on the operational phase of IS use with strong orientation to *end-user benefits*. An ongoing awareness on multiple divergent public perspectives on IS success allows an active discourse and negotiation process on further improvement in response. Jones & Hughes argue that *"[...] evaluation is not an event, based upon grand design, rather it is a process, based upon experiential and subjective judgement"* [JoHu01]. IS evaluation is considered as an interpretive, complex, multi-faceted, difficult and inherently social process situated in practice and development [JoHu01, StSt06]. Stakeholder perspectives on IS success may vary strongly in their narratives. Not seldom, we find evidence for extreme cases, where one stakeholder group conceives a system as success, while others see it as complete failure [BaMi08, CKAb14]. This complex social process notion is particularly important for transferring IS success to a notion of community information systems success in the context of dynamic and heterogeneous communities.

Several reconceptualizations of the I/S success model address this process notion. Ballantine et al.'s 3-D model emphasizes the process perspective of information systems design [BBL*96], proposing an inverse reading direction of the causal paths in the structural model. Anticipated impact thus guides requirements for quality. Saarinen's SOS model is designed as IS success measurement instrument, taking into account the development process separate from the use process [Saar96]. Seddon's respecification and extension of the I/S success model integrates a process cycle of observation, measurement, and feedback into an overarching cycle of voluntary IS use [Sedd97]. As more recent reconceptualization, we highlight Gable et al.'s *IS-Impact model* [GSCh08], as it plays a major role in the context of this work. Gable et al. define IS-Impact as *"a measure at a point in*

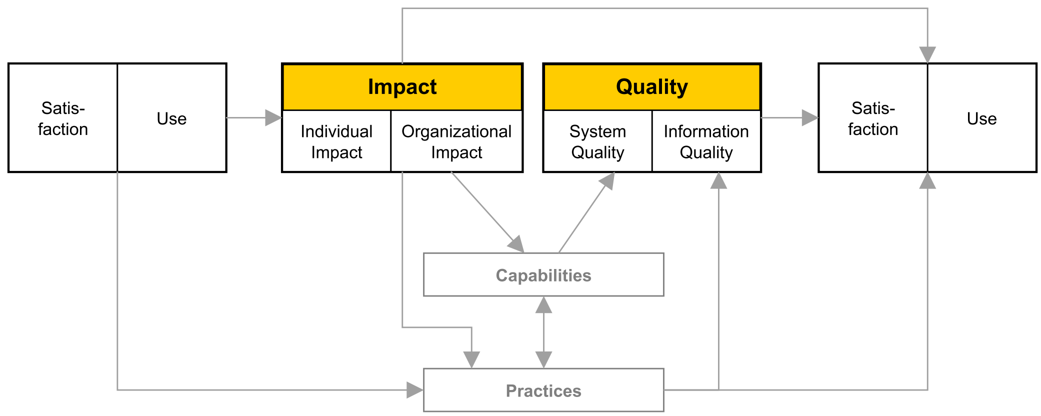

Figure 2.6: The IS-Impact Model (adapted from [GSCh08])

time, of the stream of net benefits from the IS, to date and anticipated, as perceived by all key-user-groups" [GSCh08]. The model is thus understood as holistic index representing the stream of net benefits. The impact half measures net benefits to date, while the quality half forms our best proxy to predict probable future impacts, based on actual quality.

Figure 2.6 depicts the overall IS-Impact model, highlighting the measurement model and showing the structural model in the background. The model thus divides DeLone & McLean's I/S success model into a measurement model of *forward-directed quality* and *backward-directed impact*. It furthermore integrates success modeling into an overall IS life cycle [GSCh08], adapted from Benbasat & Zmud's IS nomological network (IS-Net) [BeZm03]. Use and user satisfaction are explicitly excluded from the measurement model and are rather conceived as both antecedent and consequence of IS success in a loop fashion. Specific capabilities and practices co-develop with system use and the awareness on IS success. Another fundamental finding in Gable et al.'s work is the conceptualization of an IS success measurement model as *formative index* [DiWi01, DiSi06, JMPo03, PSRa07], i.e. perceiving IS success indicators as defining characteristics of IS success. We explicitly take up this property for the formalization of community success models in Chapter 4.

Interestingly, all of the above works emphasize IS success measurement as a reflective process. However, they assume that the set of constructs and inter-construct relationships remains stable across different kinds of organizations, systems, and users [SJCh06] and over time. This assumption is increasingly questionable with our ontology of communities of practice and community information systems. Governed by structuration theory, our ontology calls for more fluid models, adapting to emergent change in an ongoing process of community IS success evaluation.

2.3.4 Design Science Research & IS Success

With an inclusive stance towards IS design and development, IS success measurement processes must necessarily be integrated into overarching design and development methodologies with a focus on the actual *Information Technology* (*IT*) artifacts. Several seminal publications from the information systems discipline mandate for theorizing on the IT artifacts themselves [OrIa01], for being open to interpretive and critical research paradigms [OrBa91], and for a refocussing on the central concepts researched in the information systems discipline. Benbasat & Zmud summarized these findings in their IS nomological network describing the core focus of the IS discipline [BeZm03]. Nunamaker et al. [NCPu91] described an influential multi-methodological research approach, including five steps of *theory building* (conceptual frameworks, mathematical models), *systems development* (prototyping, product development, technology transfer), *experimentation* (simulation, field experiments, laboratory experiments), and *observation* (case studies, surveys, field studies).

Based on these fundamental findings, Hevner et al.'s design science-oriented research approach in information systems [HMPR04, VaKu04] added a critical paradigm of science on the artificial [Simo96] to the predominant positivist perspective. Epistemologically, knowledge and understanding of a problem domain and its solution are achieved in the building and application of a designed artifact [HMPR04]. Design research conceives artifact design as a wicked problem [RiWe84], characterized by a) unstable requirements and constraints based upon ill-defined environmental contexts, b) complex interactions among subcomponents of the problem and its solution, c) inherent flexibility to change design processes as well as design artifacts, (d) a critical dependence upon human cognitive abilities (e.g. creativity) to produce effective solutions, and e) a critical dependence upon human social abilities (e.g., teamwork) to produce effective solutions.

Compliant with [BeZm03, OrIa01], the IT artifact is of central concern. Artifacts are thereby conceived as components of information systems infrastructures, inseparable from the people and the social contexts they are used in. Figure 2.7 illustrates the resulting artifact-centered framework for design science research. Most importantly, the framework emphasizes its focus on *relevance*, *rigor*, and a *build-evaluation* loop, reflected in the notion of three interlinked cycles [Hevn07]. The relevance of a design problem is grounded in concrete business needs originating in specific IS environments. IS success-related factors of the designed artifact such as quality, efficacy, and utility

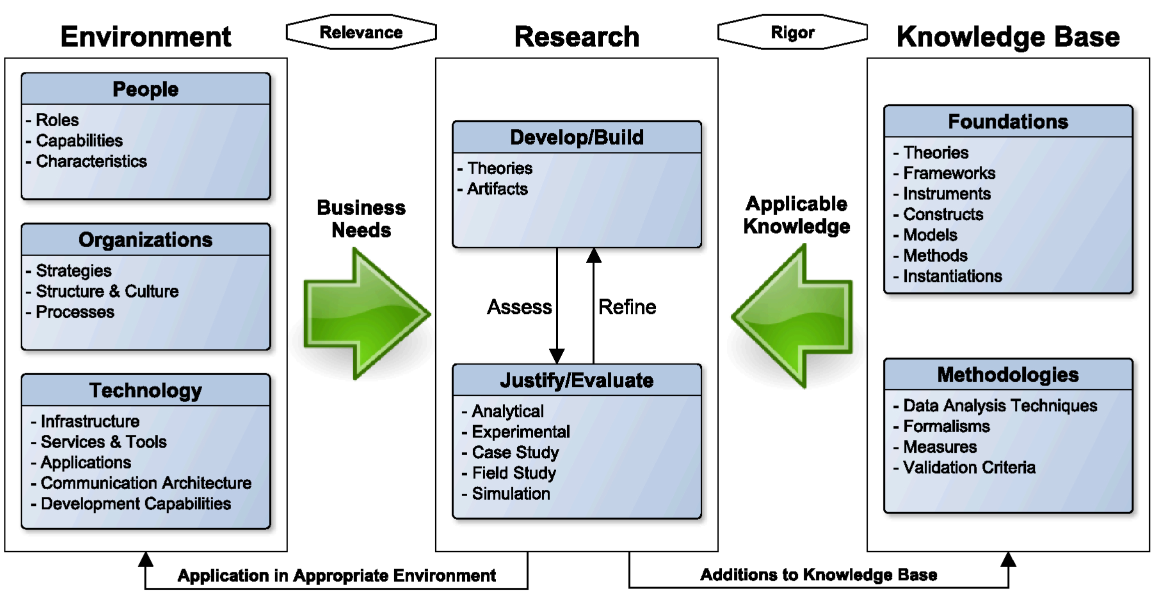

Figure 2.7: The DSR Research Framework (adapted from [HMPR04])

must be rigorously demonstrated via well-executed evaluation methods as part of the build/evaluate loop and integrated in the overall technical infrastructure of an IS. Scientific rigor is achieved by drawing upon a body of applicable knowledge in the form of established theoretical foundations and methodologies for both design and evaluation.

Recent seminal contributions in *Design Science Research* (*DSR*) include a dedicated research process model [PTRC07] and a line of research combining DSR with action research in the sense of small, but frequent interventions and a more formative, fast-paced and fine-granular evaluation of intervention-related impacts [SHP*11]. IS evaluation should not be a separate effort after completed design, but should rather be stronger entangled with emergent design and practice. The researcher's role should furthermore change to a more participative rather than observant stance. With respect to evaluation, we argue that IS success research and DSR research are directly complementing each other. DSR thereby provides a scientific framework and process models for IS design with an emphasis on evaluation. The models and related modeling, analysis, and validation techniques from IS success research contribute the theoretical and methodological underpinnings for IS evaluation in design research. IS success research outcomes can thus be considered as part of the DSR knowledge base. However, in the literature we find only few explicit connections between DSR and IS success research. In this work, we intend to strengthen these interconnections in the context of evaluating community information systems.

Particularly for communities of practice and community information systems, Klamma's ATLAS research framework [Klam10] has a conception of community information systems engineering and analysis, similar to DSR. Although measurement and analysis are explicitly mentioned as generic tasks, ATLAS still lacks a rigor cycle in the DSR sense, as it misses a specific focus on CIS evaluation, incl. CIS success modeling, measurement, analysis, and validation. In the context of this work, we address this research gap by contributing both methodological and technical support for CIS evaluation within the ATLAS framework (cf. Chapter 3).

2.3.5 Recent Challenges in IS Success Research

Over the years, the predominant positivist approach of information systems evaluation emerged into hybrid forms of quantitative/objective and qualitative/subjective evaluation [PDMc12]. This shift raised new research challenges. An increasing focus in current information systems concentrates on the design and measurement of massive large-scale information systems. These systems serve diverse populations for a wide range of purposes based on customer and social value, in particular with respect to virtual communities [PDMc12]. IS success should rather be measured by shared social value of the outcomes, perceived differently by different stakeholders at different moments in time. New measurement systems are required to capture and adapt to different perceptions and to react to changes in real-time. Research should accept that the measurement of IS success is a moving target and an inherently social process [JoHu01]. However, existing IS measurement instruments and technology are neither adaptive nor real-time enabled at the moment. Cecez-Kecmanovic et al. [CKAb14] propose a performative perspective of IS success measurement. Success and failure are *performed* and thus determined by different socio-material practices. These practices involve different notions of assessment agency among actors in an IS actor network of developers, users, technologies, media artefacts, etc. Success measurement is often neglected [GDWi05] due to its additional costs and difficulty [JoBe01]. Future research should thus contribute to lowering these costs by improving on simplicity and flexibility, while making research more innovative, realistic, impactful, and accessible to practice [TSMB14]. Models and processes should be simple and parsimonious, yet adaptable, and transferable to real-life practice. However, organizations still must decide what particular measures should be used to evaluate their specific information systems from relevant stakeholder perspectives.

DeLone et al. discuss another set of themes for future work in IS success research [DMSe14] along Cameron & Whetten's five fundamental questions of *"What System?"*, addressing system scope of evaluation, *"Who?"*, addressing evaluation stakeholders, *"Why?"*, addressing evaluation purpose, *"When"*, addressing evaluation timing, and *"How?"*, addressing evaluation processes as well as models, factors, and metrics. Isolating and identifying the system scope for IS evaluation remains a difficult, yet indispensable task for achieving meaningful results. Burton-Jones & Straub argue to select rich measures approriate to a correctly identified respective system scope, thus avoiding the frequent mistake of selecting too lean "omnibus" measures [BuSt06].

Regarding previous arguments for adaptiveness to different stakeholder perspectives, IS evaluation can only be considered complete, if all stakeholders are canvassed for their partially overlapping, partially disparate and conflicting perceptions of success. Furthermore, IS evaluation should allow to identify, differentiate, and address characteristics of different relevant respondents [StSt06]. Too often, evaluations collect irrelevant responses, thus skewing and biasing towards unperceivably invalid analysis results. A typical example is unknowingly collecting evaluation responses from end-users that never used the IS under scrutiny. IS success measurement systems thus require support for a more precise targeting of relevant respondents. In between the extremes of the individual and the organization as a whole, DeLone et al. furthermore identify groups and collectives across the boundaries of organizations, thus implicitly addressing the communities of practice being the focus of this work.

McLean et al. [DMSe14] propose different weightings according to stakeholder expertise in any of the respective success model's constructs. For example, feedback on technical system quality stated by a professional developer should intuitively be expected more qualified than feedback stated by an end-user without technical background. In the same vein, feedback on community impact stated by an experienced elder member should be expected more qualified than feedback stated by a novice member in the community's periphery. Although this notion seems intuitively reasonable, empirical tests of its validity still remain an open research challenge. In our work with communities, expert panels in fact proved as invaluable instrument for collaboratively finding a valid common notion of CIS success. However, perceptions of less-experienced end-users must not be suppressed from the very beginning. It is thus important to enable communities to become and stay aware of such discrepancies regarding CIS success perceptions in a community-wide discourse, that is not restricted to secluded expert circles.

Regarding the purpose of evaluation, IS success measurement should be designed for answering backwards-looking questions such as *"Has the IS had an impact?"*(and which impact), as well as forward-looking questions such as *"Is the IS worth keeping?"*, *"Does the IS need changing?"* or *"What future impacts will the IS deliver?"* [DMSe14]. Evaluation should act as a feedback function assisting organizational learning. Evaluation results should foster a deeper understanding of the interaction between technology and the underlying process, culture, and politics. Regarding the timing of evaluation, studies should be longitudinal, tracking observations and perceptions of IS success over the life cycle of the respective IS and its social surrounding. Rather than simply taking a cross-sectional snapshot of information systems success, IS success research should focus on the development of success narratives [TSMB14]. Benefits inherently take time to become visible. Measures of IS quality and impact take time to evolve throughout different IS life cycle phases.

Regarding measurement constructs, future research still requires a shift from myopic financial perspectives to more holistic views, emphasizing intangible social benefits of IS use in particular contexts. At the same time, researchers should minimize the issues resulting from surrogate, self-reported measures and seek for more objective measures to supplement or even replace perceptual measures. Until today, particular IS use-related measures are notoriously understudied [PDMc08], yet important indicators of systems success [DeKo03, BuSt06, BuGr13]. Petter et al. therefore argue for a toolbox concept collecting sets of measures that can be used to evaluate the success of the system in situated practice [PDMc12]. With IS success factors existing in continua of objective/rational vs. subjective/political [CKAb14] dimensions, some success factors are universal and objectively measurable, while particularly context-specific factors are subjective and sometimes idiosyncratic. Thus, human participation, cognition, and judgement will inherently have to remain integral parts of IS evaluation.

As further future research challenge, DeLone et al. address the ongoing need to study the changing nature of relationships between the constructs of IS success models, i.e. dimensions, factors, and measures. However, for this work, we adopt the widely accepted consensus on the validity of the individual dimensions of the I/S success model [DeMc92]. As in [GSCh08], we largely ignore the interdimensional path structure of the I/S success model. Instead, we focus our attention to adaptive and dynamic measurement models that merely consider the dimensions of the original model as universal structural template for changing constellations of factors and measures.

Burton-Jones further urges to conduct blue oceans research, i.e. extending conceptualizations of IS success beyond incremental refinements of the I/S success model [TSMB14] in specific contexts. The increasing diffusion of information systems beyond organizational contexts (cf. communities of practice) can be seen as an explicit key driver for such new IS success research. IS success measurement should change the focus from organizational performance to lived experiences of digital mediation and connected end-user needs in an increasingly ubiquitous computing environment like we have it today [Yoo10]. Research should open to new factors and metrics of quality and impact suited for these contemporary IS contexts. Apart from subjective perceptual measures from solely survey based assessment methodologies, researchers should develop multi-method methodologies including multiple qualitative and quantitative data sources for both objective and subjective factors. Future IS research should aim for a better understanding of context in IS success, tracing the history and politics behind success measures and capturing the different interpretations of IS success.

Conclusively, we find that a major part of recently formulated research challenges is very much in line with the ontology, epistemology and the goals of this work, i.e. to research new critical methdologies, processes and technical infrastructure for bringing community context-dependent success awareness to community information systems for long tail communities of practice. In the context of this work, we independently faced many of the research challenges originally formulated for organizational IS in long tail community information systems.

2.4 State of the Art

While the previous sections mainly reflect related academic work relevant in the context of this work, this section presents areas of current industrial state of the art relevant for this work. The first two sections concretize the practical manifestations of the DSR build/evaluate cycle (cf. Section 2.3.4) in today's practice of professional software engineering and data-driven enterprise. In particular, we point to the many different uses of data-driven analytics in enterprises that are also relevant for this work and hint to the scarce availability of readily processed analytics products for end-user communities, that motivated this work. In Section 2.4.1, we shed light on current agile software engineering methodologies such as Scrum and DevOps with focus on development process and end-user-oriented analytics. In Section 2.4.2, we discuss current concepts and technologies for data-driven enterprise IS evaluation approaches with BI&A and Web Analytics and their potential transfer to communities. In Section 2.4.3, we introduce a set of testbeds developed in the course of this work to evaluate the MobSOS approach. These testbeds allow us to evaluate concrete prototypes of CIS artifacts on the one hand and MobSOS itself on the other. The particular technical setups thereby help research the real-life situation of communities creating their CIS by combining multiple independent digital media services from independent providers. In contrast to real-life deployments with evaluation data collection distributed across independent service providers, these testbeds allow us to gain access to all collected evaluation data.

2.4.1 CIS Engineering in Practice - Agile DevOps Web Development

Contemporary development methodologies for Web-based social media are increasingly agile, moving forward in short iteration cycles (e.g. sprints in Scrum [Schw04]). Software development is no more siloed in organizational departments, but growing to more open collaboration and communication across organizational and individual boundaries with the use of Web-based, publicly accessible software engineering and communication tools for issue tracking (e.g. Atlassian JIRA, Apache Bugzilla), continuous integration (e.g. Jenkins, Travis), cloud deployment (e.g. AWS, Google Cloud Platform), revision-controlled source code management (e.g. GitHub, SourceForge) to name a few. With an awareness for the value of end-user participation [HiKr03, Hipp05] in open innovation processes [Ches03], additional social requirements engineering [KJHR11, LCRK12] methodologies and tools [RBKJ13] are increasingly becoming part of development infrastructures. Social media thereby serve as platform for such end-user participation in design and development processes, starting in early design phases. Most of these software engineering tools offer specific development process analytics support to reflect the outcomes of single agile iterations or the process as a whole. Such development process metrics provide valuable insights into overall IS success for multiple stakeholder groups. For example, developers can better control and manage their work, while end-users receive information on development liveness and progress, e.g. to decide for or against continued use [Hirs70].

Distributed open *Application Programming Interfaces* (*API*) and open source end-user development frameworks furthermore foster the formation of vivid and innovative ecosystems of open-source application development projects around social media services. Most social media are deliberately released perpetual beta. They start with a prototype realizing core functionality and then gradually improve in short agile development iterations.

Along with social media services, providers increasingly offer additional personal end-user analytics in freemium models. Lightweight analytics are available free of charge. Detailed analytics are offered as paid professional services with additional options, e.g. to export analytics data for further personal analysis. Each social medium thereby defines its own specific analytics model. For example, end-users of the popular slideshare service[5] receive basic access frequency statistics on their slide decks. On researchgate[6], researchers receive citation analysis metrics for their own publications. These person-related analytics can however be considered as mere by-product of a more comprehensive company-owned business analytics strategy (cf. Section 2.4.2). For reasons of data protection, companies argue to only grant access to highly aggregated and anonymized data. End-users usually neither have access to the data collected about them, nor do they have an influence on particular metrics computations and presentations. The importance and relevance of individual metrics included in these provided analytics is majorly decided on service provider side, and these metrics often do not match community requirements.

With the current DevOps methodology [Louk12, Huet12], development and operations teams grow closer together. Increased mutual awareness and communication are the key drivers facilitated with the aforementioned software engineering tools. The typical DevOps process is a cyclic 5-phase process of collaboration between development and operations, as depicted in the inner circle of Figure 2.8. The upper *feedback - develop - test* semicircle describes the contribution of developers, while the lower *deploy - monitor* semi-circle describes contributions by operations. An important task in DevOps is to guarantee largely automizable interfaces between development and operations to reduce friction. Development products should be handed over to operations in a directly deployable form. In the same vein, feedback collected or derived from monitoring efforts should be handed over to development in a directly actionable form.

[5]http://www.slideshare.net
[6]https://www.researchgate.net

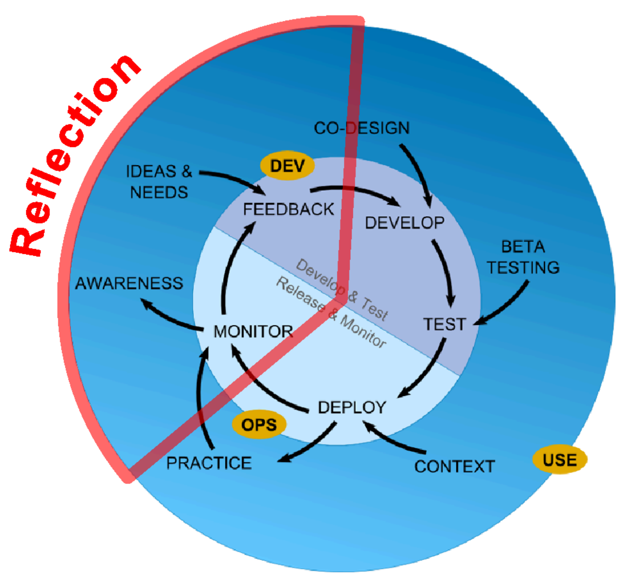

Figure 2.8: Reflection in the ACIS DevOpsUse Cycle

As more and more Web development takes place in publicly accessible OSS development environments fostering wide end-user participation, the influence of different types of end-user contributions on the DevOps cycle is no longer ignorable. End-users state feedback, ideas, needs, or contribute concrete co-designed artifacts as input for development. During test phases, end-users participate in beta-testing programs. Quality assurance thereby profits from collecting experiences and learning from deployments in many different community contexts. Publicly accessible results from monitoring include mostly system quality-oriented metrics such as uptime or response time, computed from monitored end-user interaction in concrete community practices. We therefore extended the *DevOps* cycle by an additional surrounding *Use* cycle [KKN*15]. With the resulting new *DevOpsUse* cycle, we explicate the different forms and contributions of end-user participation throughout all phases of the DevOps process.

The highlighted sector in Figure 2.8 is particularly relevant for this work, as it represents reflection-related activity. Taken together, the automatic collection of monitoring data and end-user feedback allow for a certain awareness on software product quality and impact. Reflection is thereby part of a continuous feedback loop, inline with structuration theory. Experience from practice provides data for creating awareness, awareness helps to guide further development, and so on.

Most importantly, all stakeholders contribute to and profit from the predefined analytics provided by the different engineering tools used throughout the process. However, today's rather static DevOps analytics support on development process and system quality metrics inherently lacks the flexibility to enable stakeholder and community dependent, dynamic, and holistic views on CIS success measurement as part of a community's reflective practice.

2.4.2 CIS Evaluation in Practice - Business Intelligence & Analytics

Today's IS practitioners widely agree, that credible success measurement is key to demonstrating the value of information systems. Interestingly, we find many of the findings of IS success research (cf. Section 2.3.1) amalgamated in international standards and organizational practice. For example from a software engineering perspective, the ISO 9246 and 25000 standards families define modeling and measurement procedures as well as batteries of concrete metrics to measure a wide range of software quality factors. We also still find continued use of a number of dated, yet established measurement instruments such as the *Technology Acceptance Model (TAM)* [Davi89], the *Software Usability Measurement Inventory (SUMI)* [Kira96], the System *Usability Scale (SUS)* [Broo96], or *SERVQUAL* [PBZe93] in industrial practice.

However, facing everyday organizational challenges, IS evaluation is often neglected [GDWi05] due to its additional costs, inherent difficulty [JoBe01] and long delays to observable impacts [MKRo00]. At best, only 20% of a system's value are created during system *development*, while 80% of its value are realized during system *use* [MKRo00]. In a largely customer-focused era of social media-based information systems, the key to understanding information systems success is to widely include end-user point of views into measurement. However, despite today's digital social media-based information systems technology and their sheer endless possibilities to capture and discuss public perspectives, companies have tended to largely ignore these perspectives for a long time. For today's enterprises, the ignorance of public valuation is known to result in a harmful lack of knowledge whether their products or services are indeed successful [PDMc12]. Data-driven businesses thus widely incorporate end-user participation and feedback from multiple social media channels (e.g. Twitter, Facebook, Pinterest) in Web analytics [Pete04, Jans09, Kaus07, Kaus10], in particular social media analytics [Evan12] efforts as part of their overall business intelligence and analytics strategies [CCSt12]. Brynjolfsson et al. found that firms emphasizing data-driven decision benefit with 5-6% higher output and productivity, 6% greater profitability and with 50% higher market value from IT [BHKi11]. With a growing competition on analytics [Dave06], companies employ increasingly advanced real-time analytics methodologies and technologies to achieve situational awareness as a form of competitive advantage [CDHs10]. Situational awareness enables different organizational stakeholders to directly reflect current success and translate analysis results to concrete business action.

Contemporary IS usually collect different kinds of operational data, e.g. service usage, search engine logs or social media streams, as basis for their business analysis. Additionally, they seek to explicitly assess the quality of their products and services, e.g. with the help of online feedback forms. With the proliferation of reviews, ratings, recommendations and other forms of expression in social media, online feedback has turned into virtual currency for businesses in marketing, managing reputation, and identifying future opportunities. However, to achieve a comprehensive situational awareness, businesses require analytics support in the form of appropriate technical infrastructure and qualified staff capable of handling an increasingly growing and complex ecosystem of analytics technology. Still, the operationalization of IS success measurement over a multitude of business-relevant data streams remains a challenge. The goal is to achieve awareness by reasonably aggregating collected data to actionable *Key Performance Indicator* (*KPI*), i.e. metrics designed to directly translate to action.

Given the growing number of increasingly heterogeneous long tail businesses, the provision of a universally valid success model matching the expectations of all stakeholders across businesses at all times is utopian. KPI portfolios must rather be tailored to the information needs of specific organizations and stakeholders. These portfolios are elaborate and constantly adapted combinations of established generic metrics valid across a wide range of contexts [Pete06], and context-tailored, sometimes even idiosyncratic metrics. Only after an organization has clearly defined its objectives and established its KPI portfolios, more advanced analysis becomes a lucrative initiative [Pete06].

In general, this work adopts several concepts of state-of-the-art BI&A and Web analytics for community information systems of long tail communities. In particular, we adopt the notion of actionable KPI as the pendants to relevant CIS success factors, as well as latest technical advances in automized social media data collection and analysis.

One of the biggest opportunities and at the same time challenges is the transfer from resource-rich, formal, and highly structured organizational contexts to resource-scarce, informal and loosely structured long tail communities of practice. This transfer entails a power shift, bringing data ownership and royalty from organizational data silos, back to end-user communities as the real producers and thus owners of the data collected in analytics efforts. The growing acceptance and awareness for data-driven analytics and their benefits recently find wide public resonance, e.g. in the quantified self movement, thus hinting to a growing willingness for public involvement into self-reflective analytical tasks such as CIS success measurement. Only in 2012, Davenport & Patil announced the job of a data scientist as the sexiest job of the 21st century [DaPa12].

2.4.3 CIS Research & Development Testbeds

Given the conceptual nature of contemporary CIS as custom evolving combinations of social media from different providers, empirical research on CIS in naturalistic settings is inherently difficult. Researchers usually face strong limitations in gaining access to internal digital media enterprise data sets for reasons of protecting customer data or avoiding to reveal critical intellectual property to competitors.

Instead, our research on whole CIS constellations in both contemporary Web-based CIS infrastructures must rely upon appropriate test beds. These testbeds integrate with respective contemporary infrastructure paradigms and development methodologies. They thus allow for CIS design, deployment, use and analysis in naturalistic settings with sophisticated and comprehensive control over CIS data sets not only for researchers, but also for developers, end-users and other stakeholders. Such testbed infrastructures particularly allow for the free experimentation with new digital media as means for fostering innovative research on CIS.

The contributions of this work have largely been developed, tested, and later integrated in several such CIS testbeds. In the following subsections, we present the three state-of-the-art CIS testbeds co-developed in the course of this work to research CIS success: the lightweight application server LAS for Web-based CIS, the las2peer framework for P2P-based CIS, and ROLE Sandbox for Web-based CIS in form of widget-based responsive open *Personal Learning Environment* (*PLE*).

Web-Based CIS Testbed: Lightweight Application Server

The *Lightweight Application Server* (*LAS*) is a lightweight CIS testbed platform, based on the concepts of *service oriented architecture (SOA)* and Web-based application servers [SKJR06]. LAS serves as platform to research, develop, and host innovative social media services tailored to the specific needs of professional long tail communities of practice, as conceptualized in Klamma's ATLAS approach [Klam10].

Figure 2.9 provides an overview of the basic LAS architecture. The LAS Java API allows arbitrary server extensions by connectors, components and services, the three basic LAS element types. *LAS services* define the actual functionality of LAS exposed to clients via remote method invocation over one of the available connectors. *LAS connectors* realize remote client communication with services over a range of application protocols such as the *Hypertext Transfer Protocol* (*HTTP*) [SKJR06], and the *Extensible Messaging and Presence Protocol* (*XMPP*) [ReKl09]. *LAS components* encapsulate common functionality shared by services or other components, e.g. database access. *LAS security objects* encapsulate fine-grained access control to protected user data with the help of the *access control list (ACL)* construct. A set of *core services* realizes user, community, object, and data protection management as well as the dynamic runtime management of LAS elements (i.e. services, components, connectors). As such, LAS is a flexible testbed for quick reconfigurations of community information systems and their use from arbitrary desktop and mobile devices.

In [Renz08, RKSp08], we extended LAS by capabilities to monitor CIS use, to collect feedback on CIS success in mobile online surveys, and to derive basal measurement models for CIS success with a slightly modified variant of DeLone & McLean's I/S success model. Since its launch in 2008 until today, developers created 30 digital media services used by more than 200

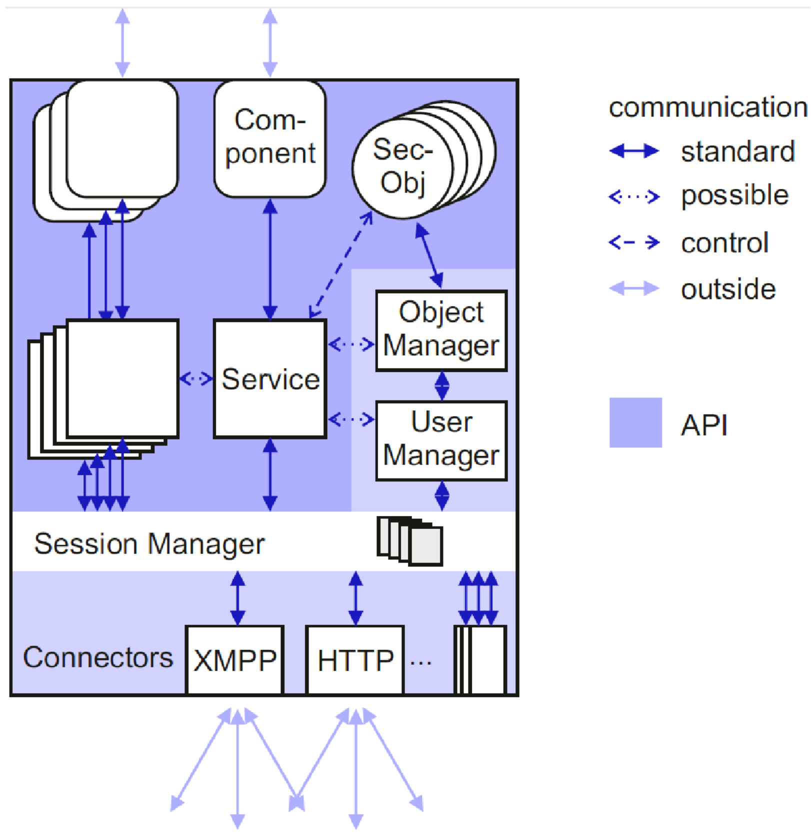

Figure 2.9: The Basic LAS Architecture

users, organized in more than 15 different communities. Still, the most popular services provide rich community-aware media annotation facilities with the MPEG-7 standard [SKJR06, SaSm01, MSSi02], e.g. community-aware semantic multimedia tagging [KSRe07], virtual non-linear storytelling [CSKR07, CKJa11], or semantic video annotation [NiKl14]. Meanwhile, MobSOS recorded logs on more than eight million interactions and survey responses, thus yielding extensive longitudinal data for tracing CIS use and supporting data-driven evaluation. In Section 6.2, we use this testbed constellation for the evaluation of several mobile multimedia applications.

P2P-Based CIS Testbed: las2peer

With las2peer, we contributed a further development of LAS towards a comprehensive testbed for P2P-based CIS in a diploma thesis guided in this work by the author [Jans13]. Recent works on decentralized *Online Social Networks (OSN)* are realistic in their estimation that major parts of societies will not change their habits and switch from a Web service-based to a P2P solution [AiRu10, BuDa09]. This observation is directly transferable to social media-based CIS. In order to achieve wide acceptance, distributed CIS must therefore combine Web and P2P paradigms in a reasonable and intuitive manner. The las2peer infrastructure is designed to natively enable such combinations. From a P2P perspective, las2peer is a network of *nodes* connected via *message ex-*

change and a *common data storage* (cf. Figure 2.10). las2peer therefore relies upon well-researched P2P technologies such as Pastry [RoDr01] and Scribe [CDKR02]. With las2peer, community members host their own nodes, where each of these nodes hosts a LAS core. Nodes can host an arbitrary number of *agents* as active participants in the network as well as services and community data. The resulting las2peer networks realize a truly distributed, yet secure and privacy-aware community information system infrastructure. Each agent is uniquely identified with a numeric identifier and furthermore holds an encryption key pair for securing all possible operation primitives such as sending and receiving *messages* as well as reading and writing data *envelopes* from the P2P network's shared storage, as indicated in Figure 2.11. las2peer agents unify both *human* and *non-human actors*, following one of the main principles of *Actor-Network Theory* (*ANT*) [LaHa99]. Human agents include individuals and groups serving as primitives for modeling complex community structures. As for non-human agents, *services* play a central role of providing communities with tools for collaboration and communication.

From a Web service perspective, any las2peer network can be seen as one virtual service platform. Any agent within the network can transparently access all services hosted within the network with-

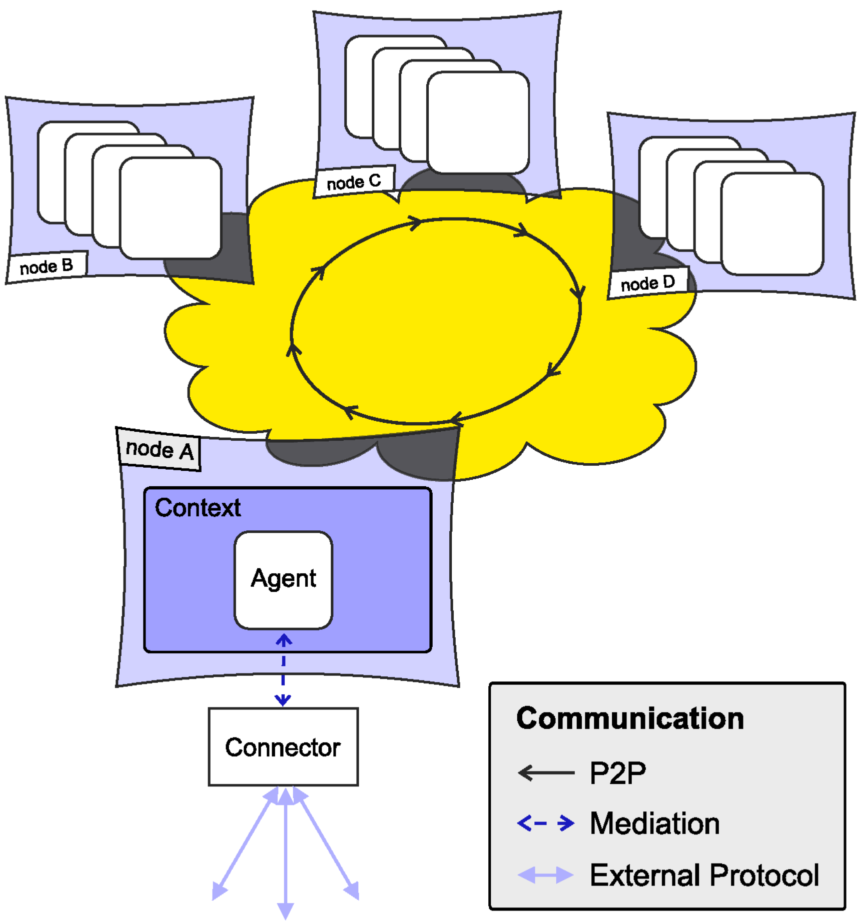

Figure 2.10: The las2peer Network Infrastructure

out knowing where they physically reside. The las2peer *connector* concept furthermore allows to instrument any node as access point for outside applications to communicate with the P2P network and its agents, in particular its services. External communication is thereby realized via mediation. Conceptually, a connector takes the role of a mediator acting on behalf of an external participant. Each las2peer node can be instrumented with an arbitrary number of connectors, usually realizing external communication with P2P agents over standard Web application and communication protocols. las2peer connectors thus function as bridge between Web service and P2P paradigms.

Unlike most existing realizations of P2P-based OSN, las2peer includes a complete Open-Source development framework. This framework fosters arbitrary extensions and re-combinations of any of its abstract or derived concepts, such as nodes, agents, messages, envelopes, agents, and connectors. With its development framework, las2peer serves as comprehensive and highly secure community engine with capabilities beyond the fixed standard toolkits of OSN as we know them today. As such, las2peer serves the major requirements towards a testbed of truly dencentralized next generation P2P-based CIS . In the context of this work, we extended las2peer with MobSOS, thus initiating research into novel infrastructures and approaches transferring CIS success data collection and measurement to the specificities of P2P computing [Jans13, DKK*13, Lang13].

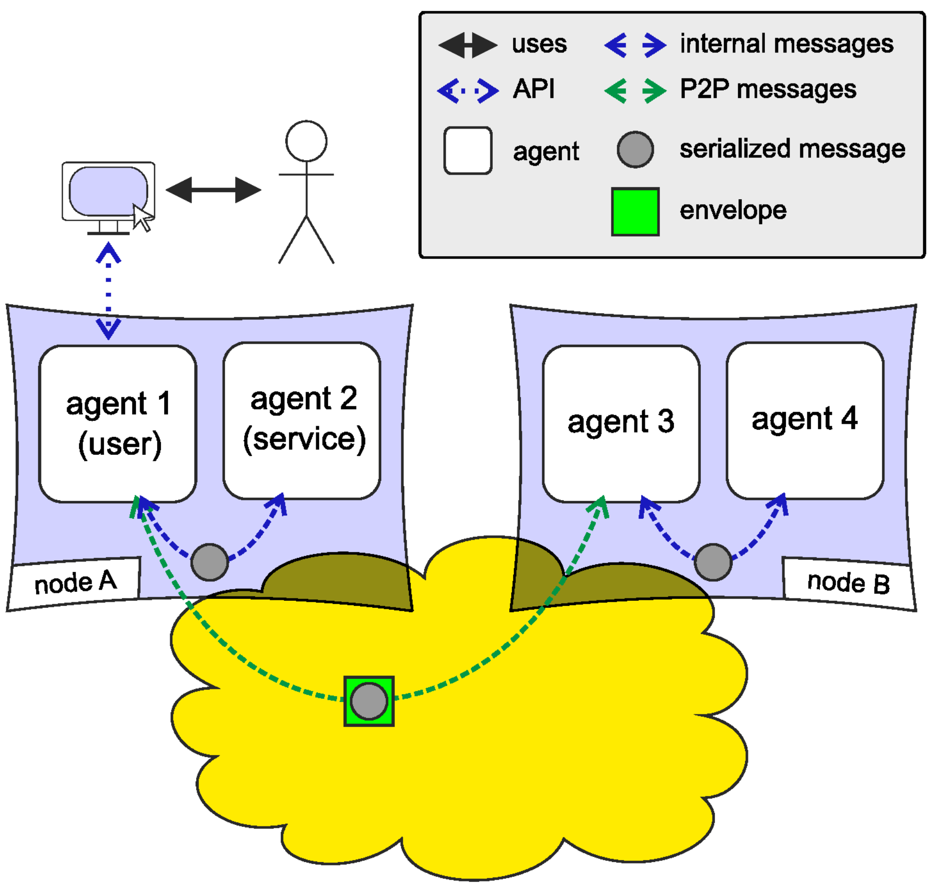

Figure 2.11: Agent Communication in las2peer

Widget-based CIS Testbed: ROLE Sandbox

The ROLE Sandbox is a Web-based *Software as a Service* (*SaaS*) deployment of the ROLE SDK, including a management platform for widget-based PLE [SMW*12] and rich developer support. From an end-user perspective, the central concept of the platform is a *space*, serving as context for community collaboration. A space thereby serves as container context for *widgets*, i.e. small learning tools usually realizing a responsive Web *User Interface* (*UI*) front-end to one or more micro services [LeFo14]. Such widgets thus serve as minimalistic frontends to social media supporting universal community activities such as content search, collaborative editing, or communication, but also very specific activities such as function plotting in math learning communities, or vocabulary training in foreign language learning communities.

The ROLE Sandbox is furthermore surrounded by a small ecosystem of related services [IPN*13], as indicated in Figure 2.12. End-users select widgets or complete widget bundles from a widget store [DDFa12] and combine them in spaces. Users thus build environments custom-tailored to specific learning activities. Recommendation services allow for personalized recommendations of widgets and bundles as well as people, content, and other resources. Both widgets and users in the same space can programmatically interact with each other, thus enabling a seamless orchestration of CIS tools and real-time communication and collaboration among end-users. Spaces can be pre-configured and shared with others, thus allowing rich re-use across communities. For cases where necessary CIS tools do not exist, the ROLE ecosystem includes Requirements Bazaar [KJHR11, RBKJ13], a social media platform for the negotiation of community requirements.

In the context of this work, we furthermore augmented the ROLE Sandbox with MobSOS components for the purpose of enabling learning analytics [ReKl13] and testing the outcomes of this work. While primarily being deployed as a sandbox for widget development, the openness of the ROLE sandbox attracted several thousand users worldwide. As such, ROLE Sandbox has become another valuable testbed continuously producing data for studying long tail learner communities in a naturalistic setting [RKKN15]. In a case study discussed later in Section 6.3, we discuss ROLE Sandbox in more detail.

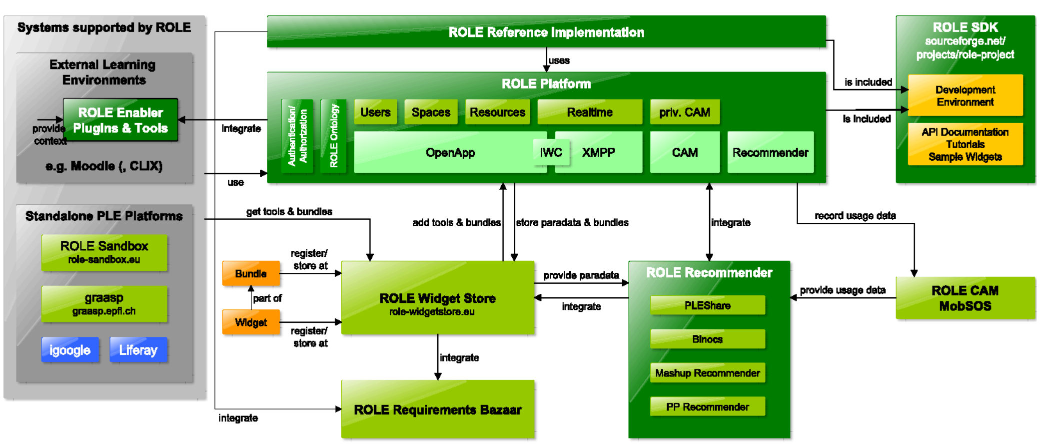

Figure 2.12: Overview of the ROLE SDK Service Ecosystem [IPN*13]

2.5 Community Information Systems Success Awareness

In their pursuit to learn how to do it better, community members intuitively reflect their individual and overall community success, based on both prior experience and the current situation. Reflective monitoring, i.e. the ability to monitor own actions in specific contexts, is an essential characteristic of a community's agency to self-sustain or to develop further. Through action, communities produce and progressively shape CIS structures. Through reflexive monitoring and rationalization, they transform them. To act, community members must be motivated, knowledgeable, and able to rationalize their action, and thus must reflectively monitor the action. Reflective action necessarily requires an awareness on past and present status, including quality and impact of the used CIS and its social media components. With a comprehensive understanding of our basic ontological and epistemological pillars of long tail communities of practice and community information systems as well as recent developments in IS and online community success research, we finally proceed to conceptualize *community information systems success awareness* as focal concept of this work.

For explanatory purposes, we employ an adaptation of Endsley's situational awareness [Ends95] theory to frame the achievement of CIS success awareness in a continuous CIS design and development process (cf. Figure 2.13). First step to achieving CIS success awareness is the *perception* of individual relevant CIS success factors and dynamics of relevant elements in the current CIS context. This perception is augmented with prior success impressions, socio-technical evolution of the system and shared community history. Second step is the *comprehension* of the current situation. The reasonable combination of individual relevant success factors to full models thus provides a wholistic picture of the environment. Third step is the *projection* of future status, e.g. in form of ideas or plans for improvements or innovation. With awareness for CIS success, community members develop agency [Hews10] for the collaborative negotiation, decision, and realization of

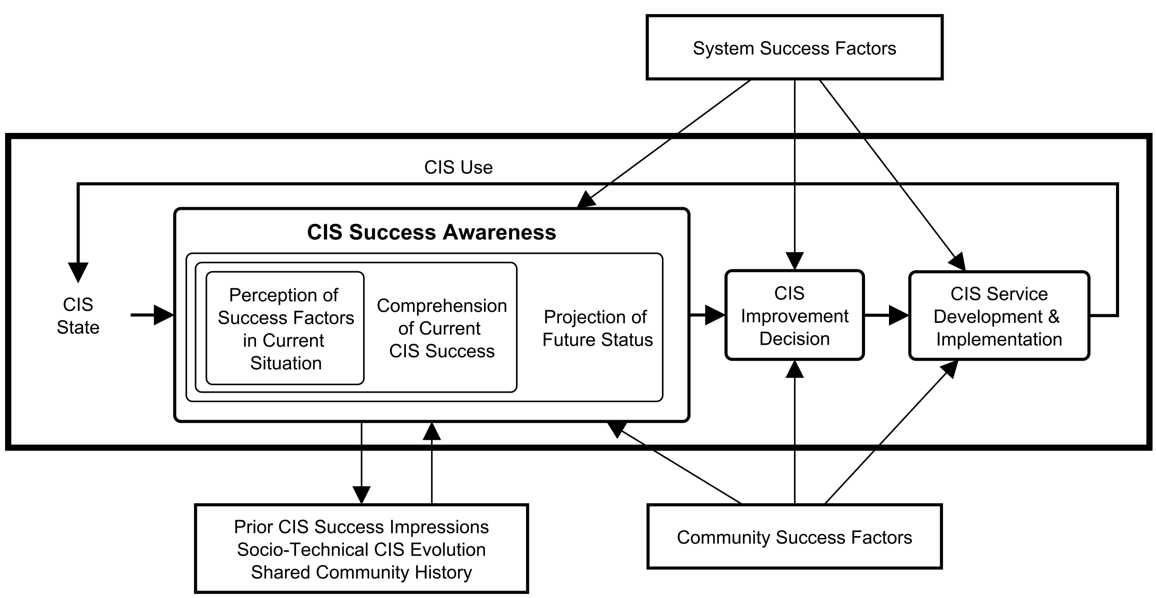

Figure 2.13: The CIS Success Awareness Concept (based on [Ends95])

relevant CIS improvements. CIS success metrics and respective visualizations can thereby serve as valuable nudges [ThSu08, Suns12] guiding further community action, very much in the sense of actionable KPI in business analytics.

Inline with our understanding of emergent socio-technical evolution, once improvements are completed, concrete CIS use generates new situations, and with them the demand to repeatedly update current situational awareness on CIS success among members. In turn, multiple changing perceptions of *individual CIS success awareness* among different groups of stakeholders must be negotiated in an ongoing social process to reach an ideally consensual *community-wide CIS success awareness*. Recent BI&A literature identifies the achievement of company-wide live, real-time situational awareness as highest form of competitive advantage achievable among data-driven businesses[CDHs10]. Dourish & Bellotti define group awareness as understanding for the activities of others, that provides a frame for own activities [DoBe92]. Gutwin & Greenberg add that group awareness is *"the upto-the-minute knowledge of other people's activities that is required for an individual to coordinate and complete their part of a group task"* [GuGr95]. Awareness serves the reduction of uncertainty and enables spontaneous coordination. In particular with respect to the pervasive social media landscape of today [ZSA*11], community awareness should provide adequate contextual information for the current situation of its members and enable members to reach a common understanding [KGKl04] on the success of the tools used. This knowledge in turn serves as an agreed roadmap for improvement and innovation.

Conclusively, we define *CIS success awareness* as an ongoing, holistic, ideally real-time awareness for CIS success, in turn fostering agency in deciding and realizing community improvements and innovation. A community-wide CIS success awareness can only be achieved in an ongoing social process of negotiating individual member perceptions of CIS success awareness.

However, one of the main research gaps driving this work is the lack of assessment agency usually found in communities of practice. Hints to this lack are clearly recognizable from recent challenges in IS success research and in contemporary BI&A practice. In contrast to large-scale data-driven corporations, communities often lack resources for dedicated business analytics staff units and infrastructure, as well as methodological and technical support for achieving agency in assessing, measuring, validating, and negotiating CIS success as prerequisite to achieving and benefiting from CIS success awareness.

2.6 Discussion

In this chapter, we first developed a basic ontology and epistemology established by the properties of long tail communities of practice and community information systems. Second, we developed terminology definitions for CIS success and CIS success awareness as the most focal concepts in this work. Third, we conducted a literature study in IS to support our term definitions, to critically discuss existing related work and to identify research gaps. Fourth, we provided an overview of the state-of-the-art in contemporary Web engineering and analytics. We thereby identified established concepts and research gaps from worldwide IS practice, related to our research problem of bringing CIS success awareness to long tail communities of practice. Figure 2.14 provides a high-level summary on the findings from this chapter in a CIS success-aware design science research framework used for this work.

The *environment* block represents the ontological and epistemological foundations for this work in form of communities of practice and their individual members resp. social media based reflective community information systems (cf. Sections 2.1 resp. 2.2). The inherent heterogeneity and dynamicity of communities of practice and the emergent socio-technical evolution of community information systems thereby suggest an overall critical and thus anti-positivist research paradigm.

The *research* block indicates the inseparable cyclic relation between CIS development and evaluation. Without CIS development, evaluation lacks purpose. In CIS development without evaluation, decisions for further improvement largely base on uninformed gut feeling rather than on comprehensively informed CIS success awareness. Based on this observation, CIS success measurement - as part of CIS evaluation and prerequisite for CIS success awareness - can only exist embedded in an ongoing CIS design process. This perspective largely guided the development of our comprehensive CIS design and evaluation methodology (cf. Chapter 3).

The *knowledge* block establishes comprehensive understanding of CIS success and related concepts from IS success research. Starting from rather positivist conceptions of universal and static IS success models, the IS research discipline moved on to a process-oriented critical conception of IS success, acknowledging stakeholder-relevant views and ongoing emergent development of inherently socio-technical IS. Meanwhile, IS evaluation is considered as an inherently complex, multi-faceted, difficult and social process, situated in practice across the boundaries of organizations, deliberately including end-user perspectives.

As such, contemporary views on IS success are inline with the inner workings of contemporary long tail communities and their specific CIS. The discussed results from IS research thus qualify as candidates for a transfer to our conception of CIS success. However, a direct transfer from organizational contexts to inherently different long tail community contexts is not trivial per se and must be tested and proven. Thus, the contributions of this work towards CIS success awareness must rather be considered as basic research in a largely uncharted territory of long tail communi-

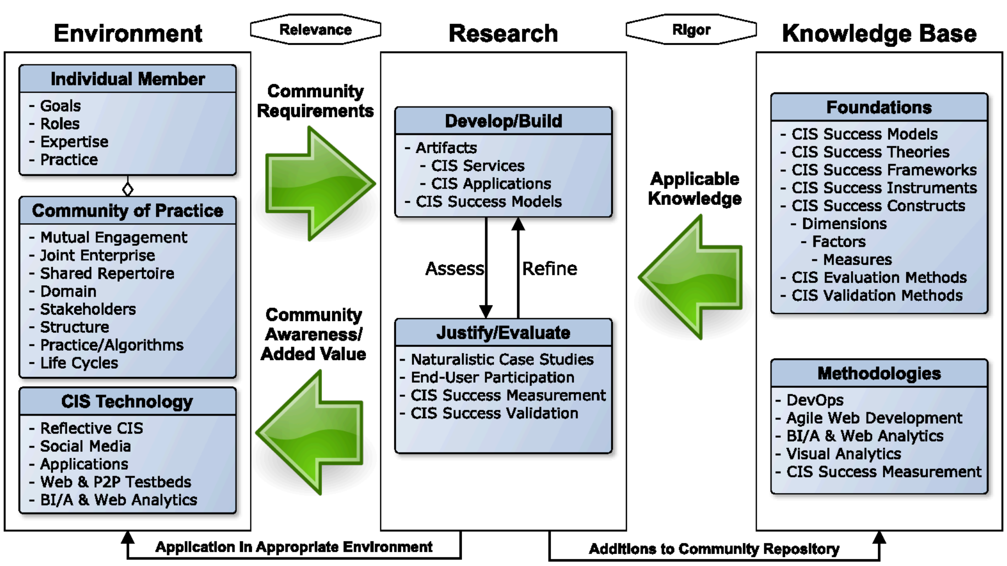

Figure 2.14: Community-Oriented Design Science Research Framework [RKJa15b]

ties. We thereby target recent research challenges in IS success research with respect to reflective, adaptive methodologies and technologies for more modern CIS evaluation accompanying design processes. Even until today, we find countless scientific publications claiming to contribute universal extensions or reconceptualizations of influential IS success models [GSCh08, DeMc92]. In fact, the majority of these works rather presents very context-specific adaptations of the respective parsimonious original model to contemporary technology developments and specific, sometimes idiosyncratic application contexts. Hence, the claim of this work cannot be to collect and compile an exemptive list of CIS success factors in a universally valid model, as this model would never be able to capture community specificities. Research across communities rather needs to be sensitivized to the large differences between long tail communities and the need to tailor models to diverse combinations of factors and metrics rather than some assumed uniformity across all contexts. We therefore emphasize even more than for information systems in organizational contexts, that CIS success is a highly context-dependent, dynamic, and emergent construct.

The claim of this work is rather to develop a coherent theoretical, methodological, and technical framework for CIS evaluation in long tail community contexts. This framework should provide the most general set of variables acknowledged as valid as a kind of template, from which concrete CIS success models can be instantiated as micro-theories in very specific community contexts. From the outcomes of IS research until today, the most general variables for such a framework adoptable in this work are the measurement metamodel of dimensions, factors, and measures as well as the subset of the dimensions of the original I/S success model, amalgamated in the IS-Impact measurement model [GSCh08]. Only if CIS success models originate from a coherent overall framework, we can cumulate knowledge that might eventually lead to universal knowledge on CIS success in the long run. To that regard, this work provides initial evidence for the viability of this approach in a few more or less longitudinal case studies in different communities using specific CIS (cf. Chapter 6). However, only with a larger and more representative set of samples from multiple communities, we may be able to prove commonalities across individual or community-specific conceptions of CIS success. These commonalities might serve as the basis to build up a catalogue of universal CIS success metrics valid across communities and artifacts and through time.

The contributions of Chapter 3 address the methodological gap by embedding CIS evaluation into a community-oriented design science research process. The goal is to achieve and profit from a community-wide awareness of CIS success, achieved in an ongoing social negotiation process of individual member perceptions of CIS success. These contributions thereby largely address RQ1, i.e. how to achieve and benefit from CIS success awareness. The contributions of Chapter 4 largely draw upon results from IS success research to encapsulate the complex concept of CIS success into a dedicated formal and operational representation. Success models thereby serve as appropriate media for measuring, modeling, validating as well as communicating and negotiating the different notions of CIS success in a community. These contributions address RQ2, i.e. how to assess, model, and validate CIS success. The contributions of Chapter 5 address the technological gap by conceptualizing an overarching CIS success-aware technical infrastructure and a comprehensive digital media tool kit for CIS evaluation around the formal representation of CIS success models. The realizations of this infrastructure and tool kit are compliant with today's social media landscape (cf. Section 2.2) and related state-of-the-art Web development methodologies, analytics, and CIS testbeds (cf. Section 2.4). These contributions address RQ3, i.e. how to design CIS technical infrastructures with integrated tool support for CIS success awareness.

Chapter 3

MobSOS Methodology

In the context of our ontological and epistemological preconsiderations of the previous chapters we argued that the reflection and guidance of community-specific learning processes including design and use of digital media artefacts requires a certain community-wide awareness of CIS success. In absence of targeted support, communities can at most develop a vague and basal precursor of such a common CIS success awareness in the course of informal, yet media-supported discourses. These discourses are characterized by different, partially overlapping, partially controversial, and subjective political perceptions on CIS success of individuals or stakeholder groups in a community [CKAb14]. In the sense of shared knowledge acquisition, all of these different perceptions on CIS success must become negotiated in an ongoing discourse to come to a common sense of CIS success awareness. This discourse should ideally help guide a community's constant adaptation to emergent changes towards directions beneficial for the community's goal achievement. Without appropriate methodological and technical support for the ongoing assessment, measurement, negotiation, and validation of both individual perceptions and their combinations towards community-wide CIS success awareness, this ongoing discourse is merely based on unfounded experiences, claims, assumptions, etc. This uncertainty poses risks of misdirection for the community learning process, in particular for the misguided commitment of efforts in community-oriented CIS design and development.

This chapter is therefore dedicated to research question RQ1 (cf. Section 1.2), how long tail communities of practice can achieve a shared sense of CIS success awareness with the help of a targeted, media-supported and discourse-based evaluation methodology and benefit from this awareness in the context of their existing CIS design and use. The resulting MobSOS evaluation methodology thereby bases on the existing ATLAS methodology [Klam10] and its underlying media-centric theory of learning in communities [JaKl05, JJKS08] (cf. community learning, Section 2.1). As part of the MobSOS evaluation methodology, CIS success models are created, combined, and continuously refined with the help of a community-tailored CIS success modeling method based on prior IS success research [DeMc92, GSCh08]. These models serve as fluid digital media for a continuous capturing, measurement, validation, and presentation for the ultimate purpose of negotiating CIS success in real-time. Machine-supported data collection and analysis, powering the measurement and validation of CIS success, is accomplished with methods from Web Analytics and online survey research. The goal is thereby to relieve communities from onerous, yet automizable evaluation tasks, e.g. data collection and extensive computations. Communities should have their hands free to focus on the essential human tasks towards reaching CIS success awareness and thus towards a better guidance of their learning process, in particular wrt. CIS design and development.

The rest of this chapter is organized as follows. We first localize our methodology on a high-level perspective of the overall ATLAS research methodology. We then successively proceed with stepwise zooming into increasingly detailed elaborations of the particular subprocesses, methods, mutual influences, and collaborations among different groups of community stakeholders. In Section 3.1, we describe the conceptual localization of the MobSOS evaluation methodology into the overarching ATLAS research methodology. In Section 3.2, we analyze existing evaluation approaches from different domains and derive key requirements for the MobSOS methodology. In Section 3.3 we contribute a cyclic process model for our MobSOS methodology, integrating individual process cycles of design, evaluation, and CIS success modeling. In Section 3.4 we introduce CIS success modeling as a special application of the ATLAS media-centric theory of learning. We thus explain the collaboration process towards CIS success awareness among all different stakeholders. In Section 3.5, we provide communities with a detailed flow chart and a set of guidelines for the CIS success modeling process. In Section 3.6 we conclude this chapter with a critical discussion of strengths, weaknesses, opportunities and threats of our methodology with respect to potential benefits, efforts, and adoption in long tail communities of practice.

3.1 Localization of CIS Evaluation in ATLAS

As a research methodology particularly tailored to participative and reflective CIS design in CoP, the ATLAS methodology is a suitable overarching framework for the MobSOS evaluation methodology developed in this work. Figure 3.1 provides a high-level view, including both procedural and architectural elements. From a procedural perspective, the most important notion is that ATLAS is *cyclic*. It thus reflects the mutually influencing interplay between social community practice and the digital media technologies supporting practice. Based on a continuous assessment of relevant community needs for digital media technologies in community-specific IS, developers, researchers and end-users cooperatively engage in two separate cyclic processes, i.e. *CIS development* and *CIS analysis, measurement, and simulation*. Together, these processes support community evolution. From an architectural perspective, both processes operate on shared *repositories* and *middlewares*. Repositories serve as storage locations for a potentially wide range of (meta)data artifacts. Following the operational media theory of *transcriptivity* [JaKl05], we conceive these artifacts as digital traces of community interaction with the CIS. Middleware thereby hosts the digital media establishing community-specific CIS functionality for the production of traces. A separate set of media-centric *self-monitoring tools* supports arbitrary forms of community reflection on these traces. The ATLAS methodology intentionally stays on a conceptually high level to serve as a generic framework, capturing all particular processes, methods, and architectural components that establish a CIS in its entirety. In the following, we conceptually embed our methodology for CIS success awareness into the ATLAS methodology. According to our previous definition (cf. Section2.5), CIS success awareness can only be reached as a result of contextualized CIS evaluation. Conceptually, evaluation is located in the *analysis, measurement, and simulation* cycle of the ATLAS methodology. A rather abstract, tacit form of CIS success awareness shapes in community members as a result

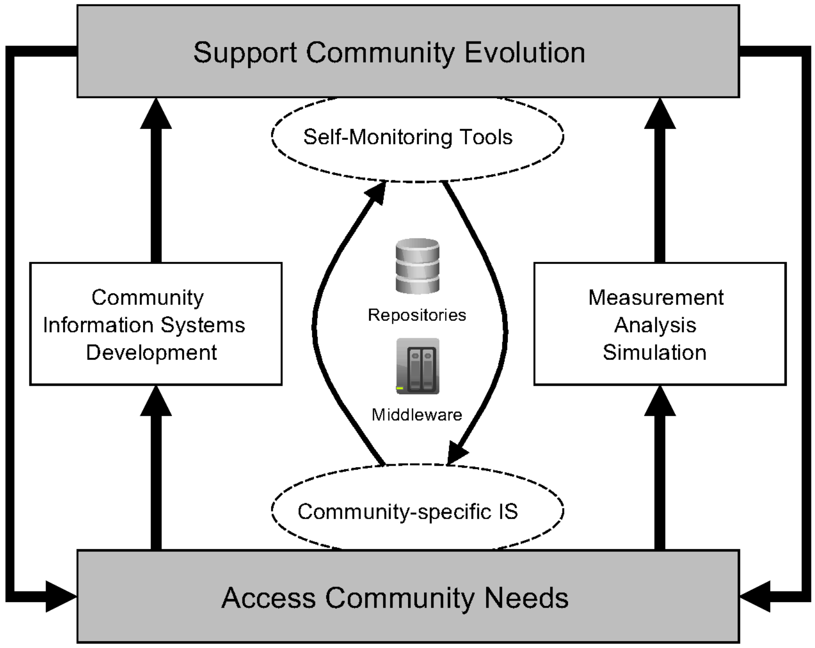

Figure 3.1: The ATLAS Research Methodology (adapted from [Klam10]

of exploring, what dimensions and factors are relevant and how they can be measured. This tacit knowledge must first be externalized and combined in a reified form to become addressable in a community-wide discourse towards more concrete and refined notions of CIS success. Within the ATLAS framework, such *reification* is achieved by so-called *transcription* into externalized media artefacts. Building on prior research on IS success (cf. Section 2.3.1), we reify CIS success in contextualized formal *CIS success models*. These models serve as fluid digital media for structuring, measurement, validation, and ongoing discourse as reflective and collaborative community process accompanying regular practice. Through transcriptions by community members, a-priori CIS success models become addressable and localized part of the community's shared repository for as basis for further continuous discussion, refinement and adaptation over time.

For such continuous CIS success modeling, including data collection, measurement and validation, communities require dedicated tool support. Such support must provide tools for the exploration of potentially relevant success factors and proxy measures, for formal model validation, and for the generation of human-readable representations, e.g. in the form of reports, dashboards or other visual analytics products. These tools conceptually belong to the self-monitoring tools of the ATLAS methodology. They should be understood as generic, community-independent tools, that however serve for a community-wide collaboration on context-specific CIS success models. In Chapter 5, we concretize such a service toolkit as part of the ATLAS self-monitoring toolkit and as basis for a CIS success-aware community infrastructure.

As a result of conceptually locating the contributions of this work in the ATLAS methodology, we conclude that a) most importantly, CIS success awareness is achieved bv evaluation locateable in the analysis, measurement and simulation cycle, that b) CIS success models are reified externalizations of context-specific notions of CIS success in the form of fluid digital media artifacts, locateable in the community's shared repository, and that c) CIS success modeling requires a set of supportive methods and tools locateable in the self-monitoring tool kit of the ATLAS methodology. In the following section, we first focus our attention to evaluation as essential activity accompanying design practice. This discussion serves as preparation towards developing our MobSOS evaluation methodology for the achievement of and benefit from CIS success awareness (cf. RQ1).

3.2 Key Aspects of CIS Evaluation

ATLAS does not explicitly recognize CIS evaluation as important part of its measurement, analysis and simulation cycle. A major contribution of this work is thus to explicate the important role of CIS evaluation and support its operationalization. Although not explicitly mentioned in the ATLAS methodology, this work understands evaluation as important, yet missing part of its measurement, analysis and simulation cycle. Evaluation is widely acknowledged as essential activity for quality assurance and process improvements in the context of academic and industrial development practice. Based on our ontological preconsiderations with respect to participative, collaborative, and highly agile forms of design and development of custom-tailored CIS digital media artefacts, communities require an appropriate evaluation methodology. Such a methodology must be able to keep pace with agile design processes and allow for multiple, possibly conflicting notions of stakeholder-specific and community-wide practices and goals. In this section, we perform a cross-domain analysis on evaluation and extract a set of key aspects relevant for CIS evaluation.

3.2.1 Cross-Cutting Objective-Based Evaluation

In IS design science research (cf. Section 2.3.4; [HMPR04, VaKu04]), scientific evaluation of a designed artifact against measurable objectives contributes to the development cycle, interleaved with other cycles for relevance and rigor [Hevn07]. The relevance cycle contributes the particular objectives relevant to achieve in the design product. The rigor cycle draws upon the DSR knowledge base and its formal methods, theories, models to foster rigorous evaluation. Peffers et al. [PTRC07] synthesize a design research process model from common process elements found across IS, engineering, and computer science disciplines. In an otherwise linear sequence reflecting a research plan towards scientific publication, evaluation is the only element in this process allowing for feedback loops to other process elements. Sein et al. [SHP*11] extend the pure design research approach with aspects of action research, including interventions based on in-process evaluations. Wieringa & Moralı [WiMo12] describe a combination of design and action research, where iterated evaluations become increasingly realistic in multiple engineering cycles of building, evaluating, and refining a technical artifact. Earlier iterations take place under idealistic, highly controlled lab conditions. Later iterations deliberately advance to much more complex and realistic conditions. In the course of this evolution, evaluation objectives change over time.

In the literature, we find independent occurrences of such evolution patterns across disciplines. In the systems engineering discipline [Sage92], we find evidence for objective, metrics-based system analysis of both engineering processes and products as evaluation concept. Systems analysis is conceived as *cross-cutting* process element. It is a distinct effort, however with mutual influences to all other process elements [Leon01, NASA13]. In [DOE02] we find a sequential stage-gate process model, where each stage transition requires in-stage assessment of process and product quality. External end-users are usually not involved in such system-focused evaluations.

BI&A, in particular Web Analytics [Pete04, Kaus10] (cf. Section 2.4.2 for a more detailed discussion) recently find wide adoption in data-driven enterprises [CDNa11, CCSt12]. Such analytics rely upon continuous evaluation of customer experience and opinion (e.g. A/B testing, online polling, focus groups). In particular ICT industries conceive continuous evaluation as essential activity accompanying innovative product and service development. The emphasis is on short cycles resulting from agile development methodologies (e.g. XP [BeAn05], Scrum [TaNo86, Schw04], DevOps [Huet12, Louk12]).

The common notion in all of these perspectives is that evaluation is a separate, however cross-cutting activity that involves comparisons of product or process properties against sets of goal criteria or metrics formulated with respect to goal objectives. However, we also find differences across evaluation approaches in terms of when and for what purpose evaluation efforts are undertaken.

3.2.2 Summative, Formative & Developmental Evaluation

Education science literature [Cron63, Scri67] provides a seminal classification in *formative* and *summative* evaluation perspectives. This classificication is valid until today and has since then been transferred to many non-educational backgrounds. The summative perspective focuses on final outcomes *after* completion of a process. In contrast, the formative perspective focuses on *in-process* evaluation with the goal to inject action research-inspired in-situ *interventions*, targeting more immediate action towards defined objectives. Both perspectives have in common that evaluation objectives and methodologies largely remain stable throughout the process. Academic researchers tend to prefer summative evaluation for obvious reasons. First, conclusive evaluation results are indispensable elements of scientific publication. They validate the respective research claims. In a widely agreed structure of research publications across disciplines, researchers define an evaluation methodology in the context of a research plan *before* a research project begins. In contrast, research results are traditionally achieved at the end of a research project and thus discussed towards the end of a publication. This type of evaluation is compliant with the summative perspective.

Modern agile design and development processes build upon more responsive in-process evaluation in addition to the summative perspective. Until recently, formative evaluation was much more work-intensive due to excessive and invasive efforts related to data collection and multi-method analysis. With the availability of modern technology and concepts such as Web Analytics, previously excessive formative evaluation efforts are now largely automated and thus less obtrusive to regular community practice. Machine-captured traces of fine-grained user interactions with Web-based media technology have become tractable for formative evaluation with advanced data mining and visual analytics methods [ThCo05, FWSN08]. The claim of formative evaluation to derive targeted interventions is largely congruent with the claim for *metrics actionability* [Pete04, Kaus10] in Web Analytics. We find clear trends towards combinations of cross-cutting formative and summative evaluation with emphasis on the formative perspective. This combination is the current standard in BI&A and Web Analytics and in the closely related learning analytics discipline [LoSi11, Ferg12, Klam13, Pard14].

Table 3.1: Summative, Formative & Developmental Evaluation

	Summative Evaluation	**Formative Evaluation**	**Developmental Evaluation**
Timing	post-process	in-process	in-process
Objectives	stable	stable	emergent, fluid
Processes & Methods	stable sequential	stable (+ interv.) iterative	emergent, fluid cyclic
Appropriate Phase [PrBe12]	mature established predictable	improving enhancing standardizing	exploring creating emerging
Systems Engineering	**×**	—	—
IS Design Research	**×**	×	—
Agile Development	×	**×**	—
Web Analytics	×	**×**	—
Learning Analytics	×	**×**	×
CIS Design in CoP	×	**×**	**×**

However, summative and formative evaluation have certain shortcomings with respect to their application in communities of practice. Most importantly, they lack flexibility with respect to unanticipated emergent phenomena occuring throughout a continuous evaluation process (cf. [SHP*11]). In both summative and formative perspectives, evaluation design, objectives, etc. must be well-defined in advance. Evaluations should take place under strictly controlled conditions. Apparently, these forms of evaluation are of limited benefit in realistic, highly emergent, and agile community contexts, where objectives are subject to unanticipated change.

Acknowledging these shortcomings of the predominant classification in summative and formative evaluation, we recently face the rise of new evaluation perspectives with a better match to the emergent nature of social innovation as we find it long tail community contexts. Patton's *developmental evaluation* [Patt11] provides an approach from social innovation, where *"[...] goals are emergent and changing rather than predetermined and fixed, time periods are fluid and forward-looking rather than artificially imposed by external deadlines, and the purposes are innovation, change, and learning rather than external accountability (summative evaluation) or getting ready for external accountability (formative evaluation)"*[Patt11]. Gopalakrishnan and Preskill recently coined the term *next-generation evaluation* as a combination of developmental evaluation, shared measurement and big data analytics technologies characterized by shorter development and evaluation cycles with more real-time feedback, shared responsibility for digital data collection, and the use of data as part of ongoing practice [GPLu13].

Modern agile development methodologies reflect this focus on emergent change and participation of multiple stakeholder groups in their Agile Manifesto [BBB*01]. They thus pledge to principles such as *"Individuals and interactions over processes and tools"*, *"Customer collaboration over contract negotiation"* and - most importantly - *"Responding to change over following a plan"*. Developmental next-generation evaluation does however not postulate the complete abandonment of formative and summative perspectives. The practical reality in long tail communities shows that community practice is not at all times subject to constant change (in contrast to industrial software development practice). We also find phases of relative stability and convergence wrt. CIS artifact use and design, justifying the application of established summative and formative evaluation methods [PrBe12]. With the involvement of researchers and their professional duty to publish the results of properly planned research projects, the summative perspective deserves appropriate reflection in our evaluation methodology. Community evaluation experts should thus consider the three perspectives of summative, formative, and developmental evaluation as tool kit to select from, depending on the particular evaluation context and purpose [PrBe12].

Table 3.1 summarizes the above discussion. It provides a brief overview of the most important distinguishing properties of the different evaluation perspectives and occurrences in different disciplines. At the same time, the table provides an overview of which perspectives we aimed to support with our methodology. We argue that an evaluation methodology for long tail communities of practice should support formative and summative evaluation perspectives for phases of relative stability, but emphasize the need for more participatory, agile, and data-driven evaluation approaches for emergent innovation, as we frequently face it in such contexts.

3.2.3 From CIS Evaluation Objectives to CIS Success Models

In the context of IS design science research, Peffers et al. state that *"[evaluation] involves comparing the objectives of a solution to actual observed results from use of the artifact"* by creating *"[...] knowledge of relevant metrics and analysis techniques [...]"* [PTRC07] as part of the IS design science research rigor cycle [HMPR04, Hevn07]. Mostly in summative and formative perspectives, evaluation involves comparisons of product or process properties against sets of predefined and explicitly stated *criteria*, whose accomplishments result in *success* or *failure*. In communities of practice governed by constant emergence, innovation, and exploration, the anticipation of such criteria is inherently difficult. In absence of such stable success criteria, it is thus even more important to focus evaluation on success *factors*. These factors strongly correlate with overall success in retrospection, but with a forward-looking purpose of learning how to do better [Weng98]. As such, CIS success factors rather relate to the question *why* and *to what extent* a CIS is successful or not. Unlike criteria, success factors are not a-priori human-defined, but rather abstract constructs immanent in the CIS . Important evaluation-related tasks are thus to identify and collect CIS success factors, to bundle them, to determine how these immanent constructs can be measured with the help of directly accessible proxy constructs, and finally, based on measurements, to decide their relevance and strength of influence for overall CIS success.

The decade-long research on IS success (cf. Section 2.3.1) has established *modeling* (cf. [DeMc92, BBL*96, DeMc03, GSCh08]) as a method to capture the different dimensions, factors, and measures of IS success in nomothetical networks. These networks serve as formal *structural* and *measurement* models fostering the analysis of the complex interplay between constructs with statistical techniques. In this work, we adopt this tradition by introducing CIS success modeling as essential community activity towards CIS success awareness.

With only few exceptions until today, IS researchers mainly follow a positivist school [OrBa91] with the goal to develop universally applicable models of IS success. As matter of validation, they study the correlational and causal relationships between the individual constructs in the structural model. In the presence of emergence phenomena and structuration effects situated in very specific community contexts, the methodology developed in this work must rather base on a strictly anti-positivist ontology. Community objectives, and with them the notions of CIS success, are subject to transformation and fluctuation throughout the whole community life cycle and its individual member life cycles. We thus rather perceive CIS success as dynamic, fluid and highly context-specific construct, and the same perception holds for CIS success models. Different individual or stakeholder perspectives towards CIS success are often governed by subjective or political aspects, possibly leading to partial or even complete disagreement [BaMi08, CKAb14]. The existence of multiple competing CIS success models even within the same community context is a logical consequence and an important finding of this work. CIS success models thus cannot be conceived as universal laws, carved in stone. They must rather be conceived as media, capturing different notions and facilitating an informed discourse towards a commonly agreed notion of CIS success. Such models should serve the purpose of guiding a community's learning process in a beneficial direction. Ideally, such a partially subjective discourse is underpinned with objective measurements, validations, and recombinations of individual notions on CIS success as more rigorous basis for argumentation. From an epistemological perspective, the positivist method tool kit widely used in IS success research offers a set of methods allowing for the formalization and formal validation of CIS success models based on prior measurements, but following an antipositivist ontology. We present a more formal CIS success modeling approach as further contribution of this work in Chapter 4.

From the above discussion we conclude, that CIS success modeling must be an ongoing collaborative activity as essential means to achieve CIS success awareness for the different notions across stakeholders and throughout a community's life cycle. CIS success modeling and the resulting CIS success models can be considered as more formal and rigorous means to produce CIS success awareness. The benefits of this approach are *self-reflection agency* and *informed guidance* of the design and evaluation processes of community-tailored digital media technology in a CIS . The claim of this work is to enable communities in capturing, negotiating, and thus shaping their situated notions of CIS success in a structured, measurable and validateable way with the help of CIS success models.

3.2.4 Data Collection & Analysis Methods

A prerequisite to all measurements efforts in the context of evaluation is the selection of appropriate *data sampling methods* guaranteeing the availability of basic evaluation data, and the selection of appropriate *data analysis methods* to make sense of this evaluation data. Particular ontological and epistemological preconsiderations specific to the particular research problem provide guidance for this selection from a plethora of different methods with individual strengths and weaknesses. In this section, we shortly discuss the selection of such methods with particular respect to gaining CIS success awareness in professional long tail communities of practice in connection with the highly participatory design, measurement, analysis and simulation described in the ATLAS methodology.

From an ontological point of view, several factors specific to long tail communities impose restrictive constraints for the selection of data collection and analysis methods. First, communities of practice face an imbalance between few researchers, developers and community experts on the one side and a potentially large number of end-users on the other. While the former group usually brings the expertise and willingness to act as evaluators, the latter group usually takes the role of the evaluation subject. Both groups can only spend small portions of their limited time on evaluation tasks. Second, community members are often spatially distributed. Large parts of their communication and collaboration is thus facilitated by digital media as part of their networked CIS technical infrastructure. Physical meetings are seldom due to excessive traveling and accommodation costs. Third, the constant change in the community induced by emergence phenomena and structuration effects requires evaluation to be an ongoing or at least repetitive activity. Fourth, even within communities, we find a high diversity of stakeholder groups with different notions on CIS success.

Many traditional data collection and analysis methods conceptually violate one or more of the above constraints and thus disqualify for an application in long tail community practice. Direct observation methods requiring the physical co-presence of a professional evaluator are practically infeasible, simply due to resource scarcity. Qualitative research methods such as interviews and focus groups can theoretically be conducted in recordable online video conferences, but require time-intensive interactions between evaluators and subjects, and even more time-intensive post-processing tasks for evaluators such as transcription, coding, etc. With limited resources and the requirement for repeated iterations of such tasks, these methods become practically intractable.

Communities thus need data collection and analysis methods immune to or even benefitting from the above constraints. Since most of the community's communication and collaboration takes place via Web-based CIS infrastructures, recent research in the areas of Learning Analytics, Web Analytics, and Developmental/Next-Generation Evaluation suggests to base data collection and analysis on machine-supported semi-automatic or even fully automated methods. The idea is to offload expensive and ongoing evaluation tasks such as data collection and statistical analysis to the CIS infrastructure and at the same time to strengthen support for tasks in which humans perform better than machines with the introduction of appropriate digital media tools.

In the context of this work, we adopt this notion for the selection of data collection and analysis methods powering CIS success modeling, measurement, and validation. In particular, we focus our attention to *real-time usage data monitoring* and *online surveying* as two inexpensive, well-established and complementary data collection methods. In Section 4.4, we discuss this combination in more detail with respect to expected efforts for different stakeholder groups, among them developers, who need to instrument CIS tools to produce usage and survey data. We argue that with this combination, communities collect sufficiently expressive data to capture and measure both qualitative and quantitative as well as subjective and objective aspects of CIS success. With usage data monitoring, we capture highly objective and context-enriched digital traces of community interaction with the digital media in their CIS. Usage data monitoring thus supports a very detailed real-time community observation and the derivation of actionable CIS success metrics in the spirit of Web Analytics (cf. Section 2.4.2). With online surveying, we additionally capture CIS success-related feedback from communities, thus enabling the measurement of those mostly subjective aspects of CIS success that are neither explicitly nor implicitly extractable from usage data. Based on the observation that the measurement of individual CIS success factors with online surveying is more resource intensive than usage data-based measurements, we formulate the placative principle *"observe, where possible, survey, where inevitable"* as important guiding principle for modeling CIS success.

3.3 CIS Success-Aware Design & Evaluation Process

Based on the conclusions on key evaluation aspects in CIS drawn in the previous section and the ontological foundations discussed in Chapter 2, we now present a CIS success awareness-driven design and evaluation process model. This model constitutes the next zoom level into the ATLAS research methodology from a process perspective. In this perspective, we position our MobSOS evaluation methodology for the creation of CIS success awareness in relation to the design and development process of the overarching ATLAS methodology and discuss the complex interplay of the cyclic processes. Figure 3.2 provides a schematic overview of this process model.

The main elements are two separate cyclic processes for *design* (outer blue) and *evaluation* (inner red), inspired by the design cycle in IS design science research [HMPR04, Hevn07]. Both of these cyclic processes are situated in a *long tail community context* (grey), that is also shown as cyclic process. The cyclicity of the community context thereby reflects the constant need for adaptation to any kind of emergent changes, induced by the practical incarnations and effects of structuration theory. These changes not only include particular adaptations within the boundaries of predefined design and evaluation processes, but also include adaptations of the processes themselves in the

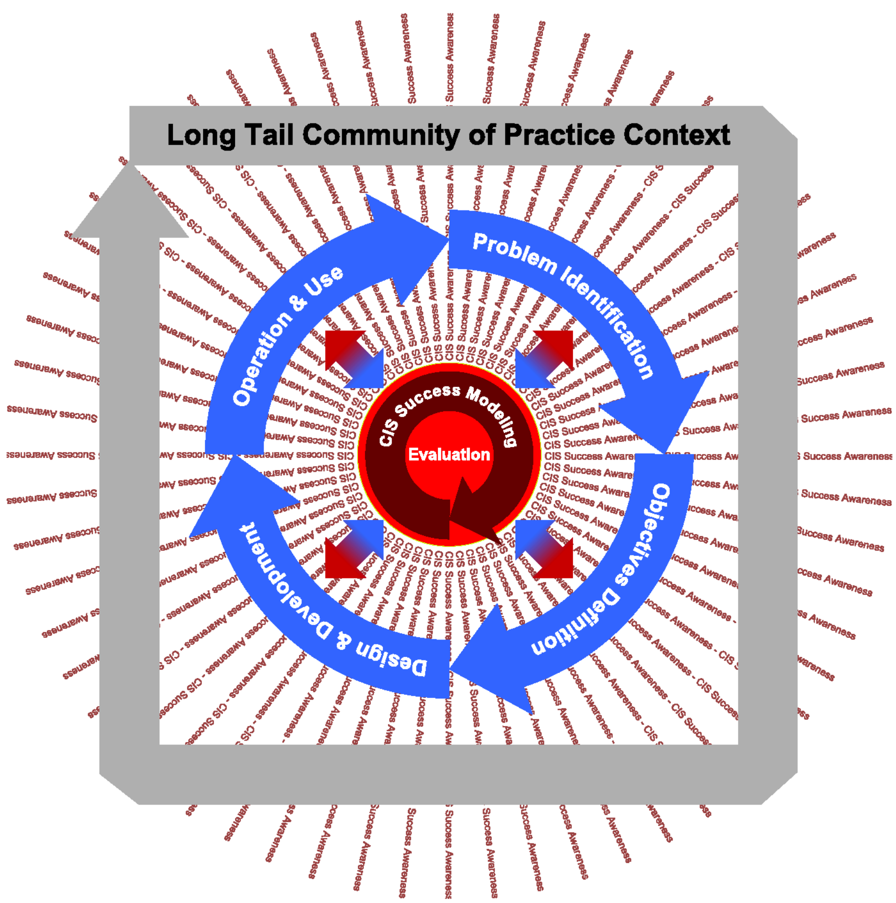

Figure 3.2: The MobSOS CIS Success-Aware Design & Evaluation Process Model

most extreme case [KJHR11]. We consequently argue inline with the ATLAS-compliant notion, that also processes themselves can be subject to change. However, they usually follow a standard pattern of established phases. The cyclicity of the design and evaluation processes reflect the constant reiteration of distinct process phases with mutual influences, expressed with the bi-directional red-blue arrows. Inline with the ATLAS methodology, both cycles are principally characterized by a participative approach, i.e. all community members collaborate in design and evaluation. However, given their particular professional expertise, the few available developers and designers in a community usually lead the design process. In the same manner, the few researchers and experts in a community usually lead the evaluation process. The collaboration between designers, researchers, and experts on the one side, and end-users on the other is usually subject to Nielsen's participation inequality rule [Niel06]. In the following subsections, we discuss the individual parts of the model in Figure 3.2 as well as their mutual influences in more detail.

3.3.1 CIS Design Process

The subdivision of the design process in established standard phases is a result of our synthesis of Peffers et al.'s design science research process model [PTRC07] with elements from modern agile development methodologies such as DevOps [Huet12, Louk12]. We thus reflect that operation and use are closely connected to development activities. In the same sense as in agile development methodologies, iterations of this cycle are short and frequent. In the *problem identification* phase, the community faces a concrete problem, motivating the design of a new artifact, e.g. a new digital medium or the extension of an existing medium by a new feature. In the *objectives definition* phase, the community collaboratively defines and negotiates the particular objectives to be reached by the new artifact, usually in the form of functional and non-functional requirements. In the *design & development* phase, developers start with designs of early non-functional prototypes (e.g. paper prototypes). In constant interaction with end-users, they develop and refine these initial design prototypes to functional digital media products. In the *operations & use* phase, prototypes or products are then deployed and used to support and enhance community practice in natural rather than laboratory settings. Resulting from the structuration-theoretical dualism of social interaction with technology [Orli92, Orli10], new problems are identified, thus initiating new design cycle iterations.

In agreement with Peffers et al. [PTRC07], we find different possible entry point scenarios in community practice. The development of a completely new digital medium as well as large extensions of an existing digital medium usually starts in the problem definition phase. Rather small extensions of an existing digital medium start in the objectives definition phase. Another frequent case occurring in communities is the appropriation of externally designed digital media and their explorative integration into the CIS technical infrastructure. The entry point in this case is the operation and use phase. For example, a community might have used a regular Web server for their Web presence, but now considers to manage contents with the much easier to use WordPress *Content Management System* (*CMS*)[1]. In frequent cases, communities however find that the inital appropriation results in forced and increasingly inconvenient exaptation. With design and evaluation resources available, communities then proceed to the problem definition phase for further development towards more convenient appropriation or the replacement with a new digital medium.

[1] https://wordpress.org

3.3.2 CIS Evaluation Process

Resulting from our previous discussions on summative, formative, and developmental evaluation (cf. Section 3.2.2) and evaluation as cross-cutting activity (cf. Section 3.2.1), we conceive evaluation as a parallel process with strong influences on the design process. Most important part in the evaluation cycle is the process of CIS success modeling, measurement and validation. *CIS success modeling* consists in the establishment of a model structure as well as the population of this structure with CIS success factors and measurement methods in the form of computation rules deriving CIS success metrics from input data. *CIS success measurement* consists in the formal execution of measurement methods defined in a CIS success model, thus populating the model with measurement data. *CIS success model validation* consists in the application of formal validation techniques to guarantee for different forms of model validity [SBGe04]. Most importantly, model validation allows to formally determine the relevance of particular CIS success factors as well as the measurement power of individual CIS success metrics. Low factor relevance hints to the reduction of a model, thus contributing to Occam's notion of parsimony [BuSt06]. We describe this formalization of CIS success models and their validation in more detail in Chapter 4.

Given emergence and structuration effects, we conceptualize CIS success as a *fluid* construct. CIS success models must thus be understood as fluid media creating CIS success awareness. Obviously, any creation or adaptation of CIS success models requires validation prior to concrete measurements. CIS success measurements can only be considered fully credible, if the respective model can be considered valid. Even without the change of model structure and measurement methods, the underlying data set is subject to change between measurements. While a CIS might work stable today and thus produces no error messages, it might become unstable tomorrow and flood the data set with error messages. Every CIS measurement should thus be followed by model validation. With multiple measurements and model changes possible within short time, model validation must thus be both simple, quick, and scalable. Ideally, CIS success modeling, measurement, and validation activities contribute to a convergent notion of CIS success awareness with high validity. However, emergent changes must be expected at any time. Obviously, CIS success modeling and its results are inherently pivotal to the achievement of CIS success awareness. Indicated by rays emanating from this process in Figure 3.2, CIS success awareness not only influences the community design process, but also the general community learning and adaptation process, perceptible within and even across the boundaries of the community context. This process is also governed by the practical consequences of structuration theory. Both individual as well as community-wide notions of CIS success – and with them CIS success awareness – are subject to constant change, thus requiring repeated CIS success model adaptations, measurements and revalidations. As CIS success modeling, measurement, and validation are the core contributions of this work, we describe the respective process in more detail in Section 3.4.

3.3.3 Mutual Process Influences

Regarding the mutual influences between the processes, we generally observe the following recurring pattern. The design process produces empirical data serving as input for evaluation. The evaluation processes this empirical data to community-specific knowledge becoming part of a community's shared repertoire and serving as further guidance for the design process and beyond. In particular, the streams of empirical data collected from the *objectives definition* resp. *operation and use* phases serve as essential input for CIS success modeling resp. CIS success measurement and validation. As discussed in Section 3.2.4, the predominantly developmental forms of evaluation reasonable in communities of practice are driven by data collection and analysis methods from Web Analytics to online surveying. In the context of this work, we argue that complementary combinations from context-enriched usage data and online survey feedback data already suffice for the derivation of measurable and validateable CIS success models. These forms of data collection and analysis are locateable in the operation and use phase of agile development processes. However, other forms of analysis such as *Social Network Analysis* (*SNA*) [WaFa94] applied to the digital media artifacts are expected to widen the scope to further interesting aspects of CIS success. Many of these analysis methods find application in the context of the measurement, analysis & simulation cycle of the ATLAS methodology, but are out of scope for this work. In the objectives definition phase, the exploration and negotiation of non-functional requirements in the context of a *Social Requirements Engineering* (*SRE*) approach [LCRK12] can be conceived as early precursors to CIS success factors. Individual CIS success factors with anticipated, yet unvalidated relevance can already be collected and structured in a-priori CIS success models, even before measurement and validation become possible with the availability of concrete empirical usage and feedback data. The formal and technical details of CIS success modeling, measurement, and validation are discussed in the next chapters.

3.3.4 Applicability of CIS Modeling, Measurement & Validation

Most importantly, we differentiate between two phases allowing for different operations from CIS success modeling, measurement, and validation. In both phases, we find different forms of CIS success awareness. This differentiation in two phases bases on the availability of a *materialized* form of the digital media artifact to be designed and evaluated. These two phases thus largely relate to the different phases of design and evaluation, as indicated in Figure 3.3.

The first phase is characterized by the absence of a materialized design artifact. It spans over the initial *Problem Identification*, *Requirements Engineering*, and *Design & Development* phases of the design process as well as over the initial *Planning* and *Data Collection* phases of the evaluation process. In this phase, the community can already achieve a first, however yet uncertain precursor of CIS success awareness. In this early stage, communities gain first intuitions of possible success

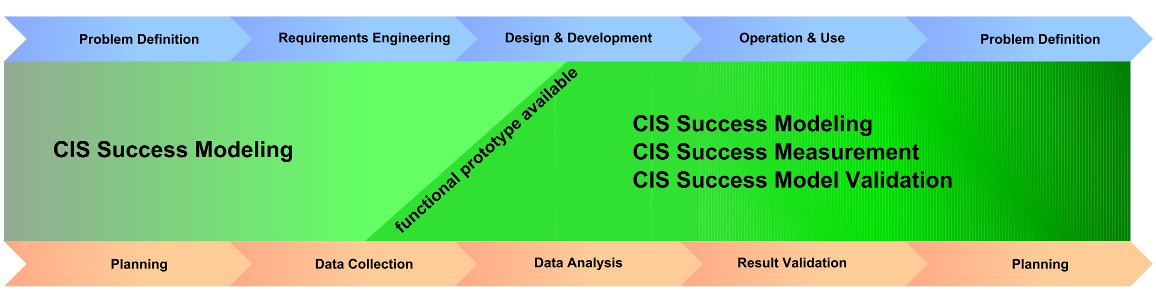

Figure 3.3: CIS Success Modeling in Relation to Design & Evaluation

factors. These impressions might be vague and imperfect. Yet, they still foster the active discussion on CIS success among community members. CIS success measurement and model validation are inherently impossible without concrete measurement data in the form of usage data or online feedback on the design artifact. However, the community can already make use of existing media data resulting from the requirements engineering process to inform CIS success modeling. In the second phase, characterized by the availability of a materialized design artifact, CIS success modeling, measurement and model validation become possible. Data collection in the form of online feedback assessment already allows measurement and model validation for early non-functional prototypes (e.g. paper prototypes) of the digital media artifact to be designed. With the deployment of a functional prototype into the CIS infrastructure, measurement and model validation can be based on usage data and online feedback for all further iterations of the design and evaluation cycles. Only then, our methodology can unfold its full function spectrum.

3.3.5 Benefits from CIS Success Awareness

In the previous sections we repeatedly stated the beneficial role of an adaptive CIS success awareness for the design process in terms of better informed guidance. In this section, we explain this beneficial relationship, based on an interpretation of Simon's seminal notion of design as a search process for an optimal solution to a problem [Simo96] and the related generate/test cycle. Figure 3.4 provides a graphical representation for our explanation.

While the x-axis denotes progressing time, the y-axis denotes the distance of the design process from a theoretically perfect design solution for a community-specific problem. Inline with the inherent structuration effects in communities, we denoted two emergent changes taking place at different timepoints. The two dashed graphs describe the theoretical extremes of design processes.

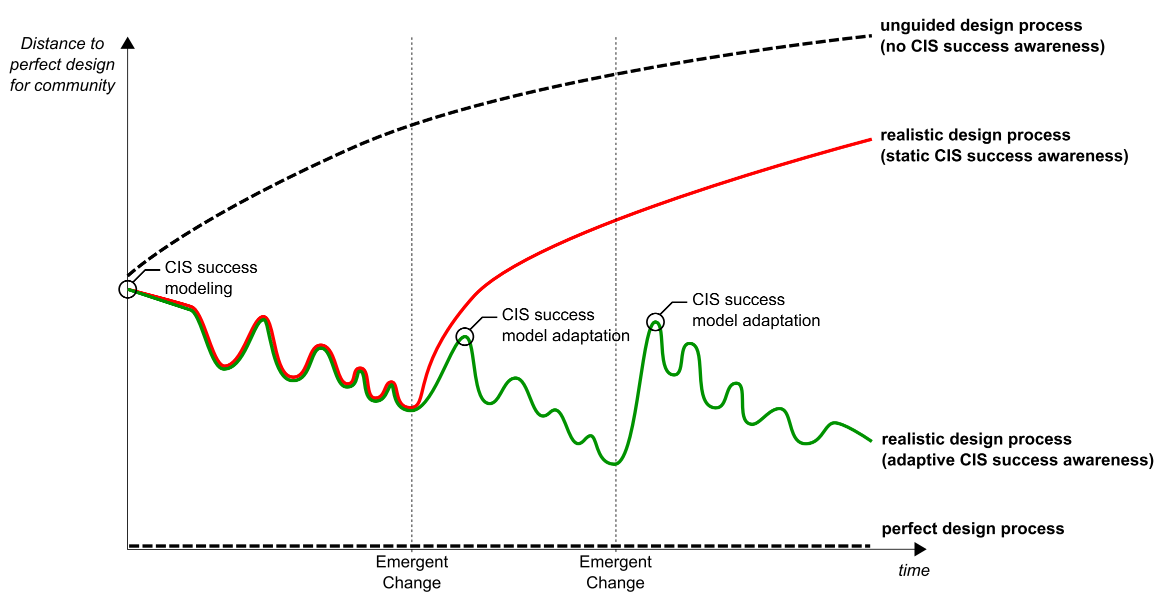

Figure 3.4: Adaptive CIS Success Awareness for the CIS Design Process

The lower dashed graph thereby represents a perfect design process, based on a perfect sense of CIS success awareness. The upper dashed graph represents an imperfect design process that is completely unaware of CIS success. The red and green graphs represent a rather realistic design process with access to an initial CIS success model including methods for ongoing measurement and validation. For these design processes, the current success of the design solution is measurable at all times. Depending on measurement results, the design can then be adapted towards improvements on those highly relevant CIS success factors, whose measurement values scored low, thus bringing the design solution closer to an anticipated perfect solution. As such, any form of CIS success awareness resulting from a valid CIS success model provides beneficial guidance of the design process, but only as long as the CIS success model stays valid. The red graph describes a design progress, following a static assumption on CIS success awareness. The green graph describes the same design process, but supporting ongoing adaptations of the underlying CIS success model (cf. developmental evaluation methodology). While the progress of both lines is initially congruent, the benefit from ongoing model adaptations becomes visible with the first emergent change, assuming that the notion of a perfect design solution has changed and with it the CIS success factors relevant in this perfect solution. The initial CIS success model is likely to lose its validity to properly measure CIS success. Only with model adaptation towards new design objectives, the process can benefit from CIS success awareness as guidance (green graph), while no adaptations effectively render the design process unguided (red graph). It should be noted that the above considerations are of rather theoretical nature. Yet, they provide an intuitive explanation of the beneficial role of ongoing adaptive CIS success awareness throughout the CIS design process. More concrete benefits are answers to questions like *"Is the community moving in the right direction with this tool?"* or *"Is financial support for sustained use or even further development qualitatively and quantitatively justifiable?"* Another concrete benefit of this approach is self-reflection agency of the design and evaluation processes taking place within communities.

3.4 CIS Success Modeling, Measurement, & Validation

In this section, we provide the last zoom level into the ATLAS methodology to concretize the complex interplay between design, evaluation, and CIS success modeling, measurement, and validation from Figure 3.2. In particular, we describe the collaborative process of CIS success modeling, measurement, and validation as a special instance of the foundational ATLAS media-centric theory of learning in communities of practice [JaKl05, Klam10]. In this theory, community-specific knowledge is produced in the form of *digital media artifacts* as combinations of existing digital media artifacts in a community's shared repository. These new media result from transcription, localization, and addressing operations [JaKl05], embedded in a cyclic process of socialization, externalization, combination, and internalization [NoTa95].

Figure 3.5 shows our adaptation of Klamma's foundational theory explaining the collaborative process of CIS success modeling, measurement, and validation. In repeated iterations of the cycle, communities successively achieve different forms of CIS success awareness by creating, adapting, recombining, analyzing, and negotiating CIS success models collaboratively. The ATLAS theory thereby provides a suitable framework for explaining the collaboration among the different groups

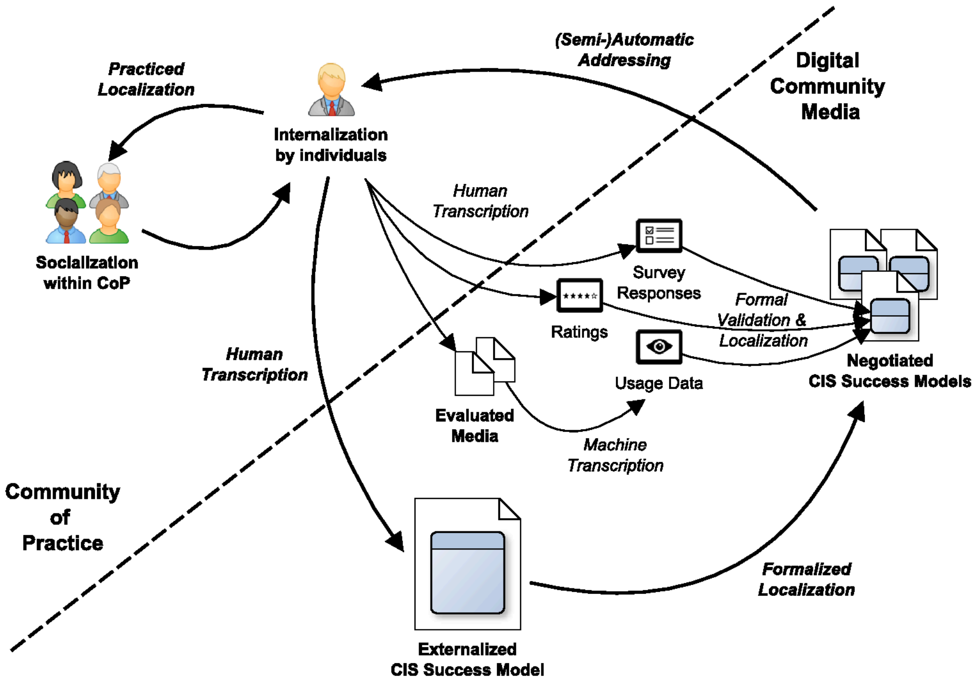

Figure 3.5: CIS Success Modeling as Media Transcription [Klam10]

of stakeholders. In analogy to the two applicability phases of CIS success modeling (cf. Section 3.3.4),we describe two different modes of operation. In absence of a materialized form of a digital medium, communities can already start a premedial discourse on individual early notions of CIS success, however with only vague and unfounded forms of CIS success awareness as the result. In presence of a materialized digital medium to evaluate, CIS success modeling, measurement, and validation become applicable, thus leading to a more tangible form of CIS success awareness, supported by CIS success models as addressable and localized scripts transcribed generated from online feedback and usage data.

For illustrational purposes, we describe the whole process by choosing a scenario for the initial design and development of a new digital medium. For a complete walk through, we assume that a community as a whole has identified a problem (cf. problem identification, Figure 3.2). The community plans to solve this problem with a new digital medium that does not yet exist, but should be developed, evaluated, and constantly refined in a cooperative and CIS success-aware manner. We furthermore assume that the community includes members with expertise for software development and systematic evaluation and that the community as a whole is willing to contribute to design, evaluation, and the achievement of a joint CIS success awareness. From practical experience gained during multiple collaborations with long tail communities we know, that usually developers or researchers with computer science background bring expertise in software development. In the same vein, researchers bring evaluation expertise, and core community experts bring the deep domain knowledge, enabling them to further interpret and combine individual community-specific notions of CIS success. Last but not least, we assume that the CIS infrastructure includes means for usage data and feedback data collection as well as digital tools allowing to capture CIS success models as digital media artifacts and supporting CIS success modeling, measurement and validation operations. In the course of this work, we present an initial set of such data collection means and support tools in Chapter 5.

In presence of a concrete identified problem, the typical start towards the design of a new digital medium consists in the elicitation and negotiation of early-phase requirements. This social collaborative task involves all community stakeholders, i.e. end-users, experts, researchers and developers (cf. objectives definition, Figure 3.2). A small group of developers usually faces a large number of requirements from end-users. Due to limited development resources, the few developers need effective and efficient means to manage and prioritize requirements. For each requirement they must estimate feasibility and development efforts and compare these against an estimated expected impact for the community. End-users need effective and efficient means to first externalize requirements and then collaboratively vote for or against their importance. Based on the results of such voting processes, developers commit their limited resources to those requirements found highly relevant by the whole community. In the context of our work, we researched and supported such processes with Requirements Bazaar [RBKJ13, ReKl14, RKJa15a], a browser-based social media platform for SRE [KJHR11, LCRK12], involving the reification of community requirements as digital media artifacts.

At this point, the MobSOS process of CIS success modeling, measurement and validation starts as media centric learning process. Based on prior requirements elicitation and negotiation processes, individual community members independently begin to internalize possibly relevant CIS success factors as more or less direct results from anticipative reflections on non-functional requirements with respect to quality, impact and satisfaction of the yet unavailable digital medium. As in [Klam10], these internalized, tacit, premedial precursors of CIS success factors are subject to discussion among community members, not necessarily involving questions of measurability, but questions of anticipated relevance. This discourse might result in *consensus* providing clear guidance for the further design process in the ideal case. Even more likely, communities face discrepancies across different perceptions of CIS success. According to Engeström, these *contradictions* reveal hidden conflicts and disturbances that often hint to innovative ways to resolve the conflict [Enge01]. In repeated *practiced localization* of such communication, previously internalized individual notions of CIS success are either informally discussed as part of *socialization within the CoP* or externalized by human transcription in the form of multiple a-priori CIS success models.

This human transcription consists in rather informal descriptions of CIS success models. Possible media for externalization in this stage are blogs, collaborative documents, etc. Alternatively, CIS success factors can be discussed in the context of the original requirements, e.g. with Requirements Bazaar. It should be noted that in this early stage there exists no materialized form of the digital medium to be evaluated by end-users. Thus, a-priori models can already consist of potentially relevant factors, and in the best case anticipated, however yet untested measurement methods. In the absence of usage and feedback data, both formal CIS success measurement and validation are impossible. However, as a result of formalized localization of these a-priori models, communities can apply expert panel techniques such as Q-sorting [MoBe91] or Lawshe's approach [Laws75] for an initial selection and sorting of potentially relevant CIS success factors (cf. Section 4.5.1). Discussants collaboratively develop certain precursors of CIS success awareness with these early forms of CIS success models with medial representations. This early form of CIS success awareness yet involves a high degree of uncertainty resulting from the inherent inability to conduct CIS success measurements in the absence of a concrete design outcome. With the availability of early materialized forms of the digital medium (e.g. paper prototypes), evaluation can start with the collection and analysis of survey data, thus drastically lowering uncertainty. Survey research thereby involves moderate planning efforts for researchers with evaluation expertise. They must plan surveys and externalize specially designed questionnaire forms, localized and addressed to the community with the intention to measure CIS success. Ideally, these questionnaire forms reuse established survey instruments. However, in particular in long tail community contexts with idiosyncratic notions of community-specific CIS success factors, established instruments do not exist and must thus be designed first. End users must furthermore respond to surveys by completing questionnaire forms addressed to them as means of human transcription.

In Chapter 5, we provide advanced CIS tools for the design and conduction and response to CIS success-related online surveys. A lightweight form of survey-based CIS success measurement widely applied on the Web consists in the simple collection of ratings on overall success. This form of CIS success measurement should be included in every CIS success model, as it is the basis for formal CIS success model validation (e.g. regression; cf. Chapter 4). With the availability of a fully functional prototype integrated into a CIS success-aware infrastructure, usage data collection becomes viable. While end-users use the new digital medium, the infrastructure observes this use and produces usage data as means of machine transcription. In this stage, CIS success models include CIS success factors, well-defined measures and computation rules deriving metrics from usage, survey, and rating data, real-time measurement data and validation results as well as means for presentation, e.g. in the form of dashboards or reports, localized and addressed to the community. With the availability of fully functional CIS success models represented by digital media and with full support for measurement and validation, communities can achieve formally valid forms of CIS success awareness in a continuously adaptive manner by reiterating the cyclic process.

Inline with the terminology of transcriptivity theory, usage data, feedback data, and survey responses are scripts, i.e. results of different transcriptions. Respective logging mechanisms serve as transcripts for documenting the premedial use of the CIS and its digital tools to addressable and localizable usage data logs. Respective online survey services serve as transcripts for collecting the premedial, tacit valuations of end-users with respect to certain success factors of the used CIS tools into addressable survey response data, localized for a certain evaluation context. At the same time, these scripts serve as prescripts that become transcribed to new scripts in a community's shared repertoire in the form of evaluation products such as data visualizations, dashboards, etc. The CIS success models and their data filtering and transformation rules thus serve as the transcripts facilitating transcription, addressing and localization. In the next chapters, we provide techniques and tools for the exploration, creation and validation of CIS success models as digital media artifacts.

3.5 CIS Success Modeling Guidelines

As a final contribution of this chapter, we provide a detailed flow chart of the overall process of CIS success modeling, measurement, and validation, providing an overview of pivotal decision points and actions to be taken (cf. Figure 3.6). This flow chart serves as guideline for CIS evaluation in communities using the MobSOS approach. Furthermore, we provide five guidelines for the selection of CIS success factors and CIS metrics from [RKJa15a].

Guideline 1: Think Community The selection of CIS success factors should be driven by community goals. Concrete measures should be actionable towards the goals and objectives of communities, as widely required in practical Web Analytics [Kaus10, Pete04, Pete06]. In particular, awareness for these measures should help inform all stages of the CIS design process.

Guideline 2: Balance Parsimony & Completeness In general, communities should try to achieve a balance between parsimony and completeness [BuSt06] with regard to CIS success model complexity. This principle should already apply during the exploration of potentially relevant CIS success factors and measures. On the one hand, CIS success models should make best efforts to explore a wide variety of factors and metrics. On the other hand, CIS success models should be kept as compact as possible. In most cases, only few CIS success factors are most relevant, and CIS design should be able to focus on exactly these most relevant factors. In short: CIS success modeling should follow the principle of Occam's razor.

Guideline 3: Avoid Obtrusiveness The principle *"observe where possible, survey only if inevitable"* should be applied to avoid unnecessary invasiveness and obtrusiveness to community practice. Usage data collection and surveys should not substantially interfere with actual CIS use. However, users should be informed about data collection procedures for transparency reasons. Whenever possible, success measures should be derived from actual usage data to reduce efforts in survey planning and participation. Preference towards usage data-derived measures is also motivated by their objectiveness. We recommend to monitor all user interaction with the CIS on the level of standard application protocols used to access CIS services.

We agree with [DeKo03] that such low-level protocol data is probably the most objective data available. Collecting such data at the collective level of a CoP results in valuable information, not only on overall CIS performance, but also on the interdependencies occurring among users. Such data might appear to capture more information than needed, but can turn out to be valuable in the case of developing new success measures requiring data that would otherwise not be available. Communities should consider such historical information as part of their shared repertoire. However, success measures of inherently subjective nature still must be assessed with the help of surveys.

Guideline 4: Prefer Established Constructs For the selection of relevant measures, we confirm the recommendations of [GSCh08]. Any CIS success model should make use of established and rigorously validated factors and measures, where possible. However, in many cases the specificity of individual communities requires the differential application and combination of new and old factors and measures [SHWS02]. Sometimes communities will even need to create and validate completely new, proprietary measures. This necessity should not be seen as detrimental to model quality [BGSt01]. However, this should not be understood as invitation to omit validation.

Guideline 5: Prefer Face Validity Any CIS success model should undergo rigorous validation using formal statistical analysis techniques, if possible. Such formal validation helps to automatically reveal irrelevant CIS success factors or CIS success metrics with low measurement power. However, especially in the case of small communities, a low number of data samples can effectively render the application of formal validation ineffective or impossible. Ultimately, a high level of face and content validity is the most desirable property of any CIS success model. We discuss model validation in much more detail in Section 4.5.

3.6 Discussion

In this chapter, we have presented the MobSOS evaluation methodology as an embedded extension of the ATLAS methodology. After a coarse localization of our contributions in the overall ATLAS methodology, we first extracted key aspects of CIS evaluation from the literature and - based on this discussion - derived a first notion of CIS success modeling as central method to achieve CIS success awareness. Based on the extracted key aspects, we then presented an inherently cyclic CIS success-aware design and evaluation process accompanied by the MobSOS-specific CIS success modeling, measurement, and validation process for creating CIS success awareness and discussed mutual influences and benefits. We finally described CIS success modeling, measurement, and validation as continuous application of the ATLAS media-centric theory of learning in communities of practice. With this theory, we explained the ongoing discourse processes towards a common and ever changing sense of CIS success awareness already starting in early phases of CIS design. The discourses manifest in the evolution of CIS success models as fluid media under constant adaptation.

The mere existence of our methodology does however not guarantee its adoption in all communities. First of all, communities are only likely to adopt a CIS success awareness-driven design and evaluation methodology, if the benefits resulting from CIS success awareness sufficiently outweigh the efforts and risks in achieving such awareness for both community and research practice. Clearly, communities must be willing to make up-front investments. They must accept an initial period of efforts potentially outweighing benefits. Concrete processes and methods must first be developed, implemented and established in a *community culture* embracing CIS success awareness and thus largely reducing efforts and increasing benefits.

Furthermore, the adoption of such a methodology is a matter of *trust*. Researchers and developers bring the capabilities to establish evaluation processes and provide training. However, they depend on the trust of influential core members of the community capable of creating a benevolent or hostile political stance towards evaluation as obtrusive and disruptive change. Fortunately, a widespread spectrum of industrial and research practice building upon modern data-driven approaches has proven that such mid to long-term efforts pay off significantly. They currently find increasing adoption across many different domains [CDNa11, CCSt12]. Furthermore, the initialization periods towards an accepted evaluation culture can be expected to fall much shorter in long tail community contexts, due to their usually small size and higher flexibility. Last, but not least, an established methdological culture for continuous evaluation and reflection of CIS success must never be understood as convergent. In the same sense as digital media technologies and the related notions of CIS success will change across stakeholders and over time, methodologies themselves will be subject to ongoing change and adaptation [KJHR11]. In the following chapters we present the necessary formalisms, tools, and algorithms supporting the methodology developed in this chapter.

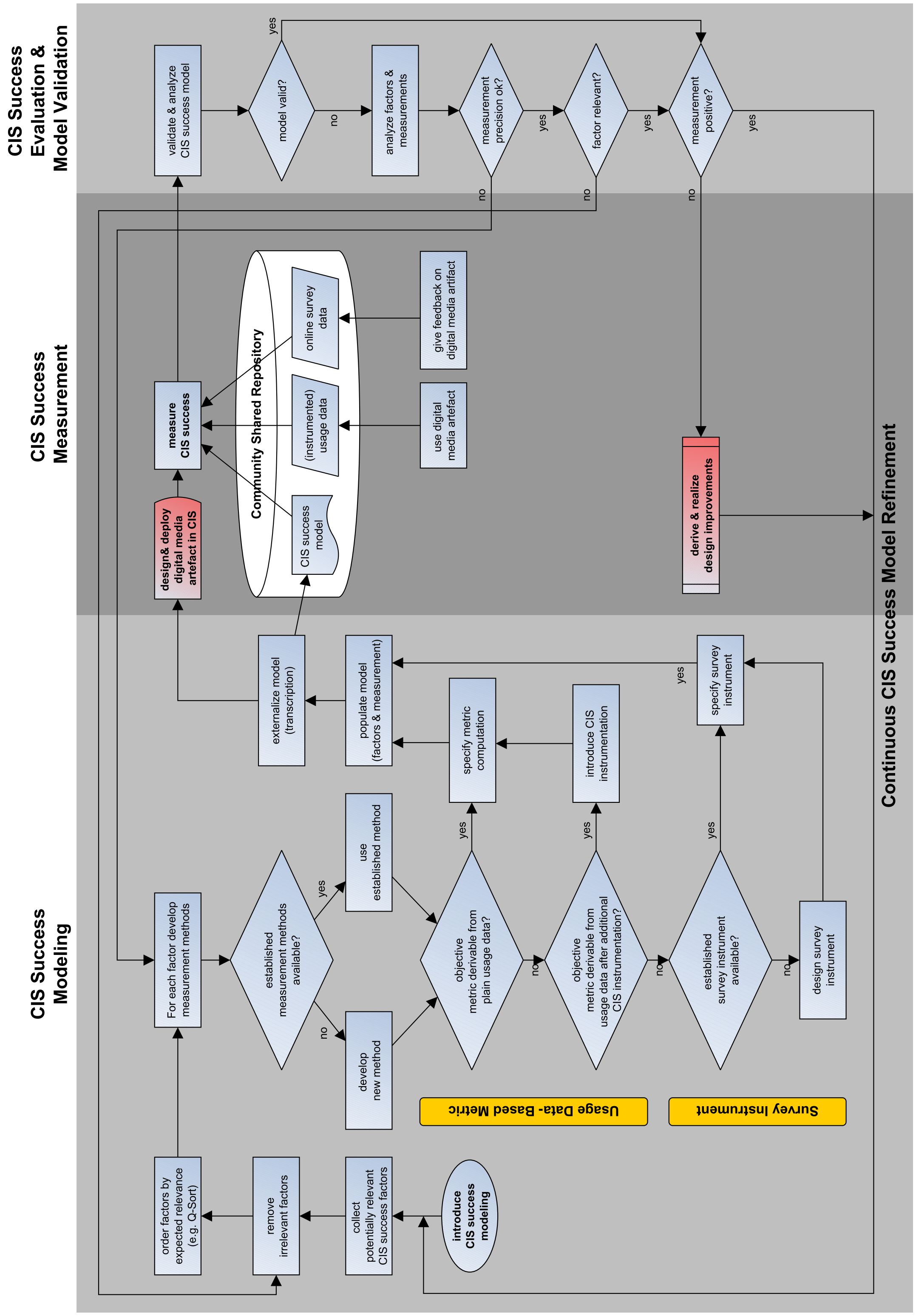

Figure 3.6: Flow of CIS Success Modeling, Measurement, and Model Validation

Chapter 4

MobSOS CIS Success Modeling

In the previous chapter, we presented CIS success models as fluid media for negotiating a common awareness of CIS success in a community. Given the inherent properties (diversity, dynamicity) and phenomena (life cycles, emergence, innovation, socio-technicality) usually found in such contexts, our research builds upon the notion of multiple dynamic and context-dependent CIS success models. We thus clearly argue against the existence of a single universal CIS success model. In contrast to one-off research efforts towards success models typically found in research literature, we conceive the active exploration, creation, validation, and continuous refinements of CIS success models as integral community activity, fostering awareness, reflection and learning about the essential factors and measures of CIS success as part of the overall process of *"learning how to get better"* [Weng98].

A fundamental prerequisite to achieve technical support for such activity is a comprehensive formalization framework for modeling CIS success, integrated into a community's shared repertoire. Such a framework must include basic data collection, the exploration of candidate CIS factors and metrics, their (re-)combination in formal models of CIS success, and the formal validation of such models. The CIS success models produced with this formal framework thus serve as the fluid media for CIS success awareness we conceptualized in the context of the ATLAS transcriptivity theory in the previous chapter. However, our fundamentally different notion of CIS success modeling as repetitive and ongoing activity embedded in community practice has several implications for such a formalization framework, as we will discuss in this chapter in detail.

As such, the contents of this chapter mainly contribute to answer research question RQ2 (cf. Section 1.2), i.e. how to formally assess, model, and validate CIS success, including formal basic data modeling, integration of low-level basic data sources to higher-level CIS success models, and their validation. Indirectly, this chapter also contributes to answering research question RQ3, i.e. how to design CIS technical infrastructures with integrated tool support for CIS success awareness, as it lays the foundations for CIS success modeling, exploration, and awareness tools. CIS success model validation also contributes to research question RQ1, i.e. how to achieve and benefit from CIS success awareness in ongoing community design practice, as it defines a set of heuristics for model refinement and operationalization in the context of our CIS success-aware design science research methodology (cf. Chapter 3).

In Section 4.1 we contribute a list of requirements for a CIS success formalization framework, guiding the design and implementation in our MobSOS framework. In Section 4.2 we contribute the MobSOS structural model template for CIS success, based on influential works from IS success research. In Section 4.4, we justify and provide detailed descriptions on the individual basic data sources we implemented for our formalization framework. In Section 4.3 we then present the integration of basic data sources to formal CIS success metrics and their composition to complete CIS success measurement models. In Section 4.5, we present a combination of expert panel and regression techniques to validate CIS success models. In Section 4.6, we conclude this chapter with a short summary of contributions and discuss limitations and avenues for possible future work.

4.1 Requirements

The design of our formal framework for the assessment, modeling, and validation of CIS success was guided by a set of requirements. These requirements result from literature research, from general observations of researching CIS success in long tail community contexts with our methodology (cf. Chapter 3), and from considerations on concrete technical implementations (cf. Chapter 5). In particular, the requirements we collected in the following paragraphs are necessary prerequisites for creating concrete support of CIS success modeling and awareness in the sense of ATLAS media-transcription theory (cf. Section 3.4).

With MobSOS being a data-driven approach, many of the most fundamental requirements already apply to the selection and design of basic data sources. Given the dynamicity and diversity of long tail CoP contexts, the design of basic data sources is particularly challenging due to the emergent character of CIS success. Most importantly, the emergent nature of hypotheses on CIS success (i.e. candidate CIS success metrics) requires a reasonable *trade-off between universality and specificity* for the employed basic data sources. Data sources must allow for the widest possible inclusion of potentially relevant aspects of CIS success for a multitude of communities and CIS artifacts emerging over time. At the same time, basic data sources must allow to capture community-specific phenomena. In presence of emergent structuration effects, no community can anticipate all aspects that will ever become relevant for CIS success over its life cycle. In the same sense, no community can anticipate what data would be necessary to measure such unanticipated success factors. We thus introduced the requirement for data source *extensibility*. Basic data models and sampling methods should include sufficiently flexible *extension mechanisms*, that allow for explicit augmentation by missing highly context-specific details.

The inherently cyclic nature of our methodology (cf. Chapter 3) induces frequent and short iterations of repeated CIS success modeling and validation activities as part of media transcription. Hence, techniques chosen for these tasks should be *light-weight* and highly *automated*. This requirement should apply throughout the whole formalization framework, from basic data collection to formal validation. By design, data sampling methods should avoid a high demand for active evaluation efforts by community members, e.g. responses to lengthy surveys. Instead, automated data collection techniques should replace manual efforts. This requirement relates to our guiding principle *"observe where possible, survey only if inevitable"* (cf. Section 3.5).

Probably one of the most challenging and at the same time most essential requirements to modeling CIS success is the *choice of accessible data sources and sampling methods*. The challenge is thereby directly related to the ontology of communities and their CIS as combinations of tools from an ecosystem of independent providers (cf. Chapter 2.2). Service providers will neither grant communities access to their own data (as)sets nor will they allow communities to instrument their software products with extensive measurement facilities. In cases where CIS artifacts are co-developed with communities, this challenge is less severe, since the community is in full control over its code, its deployments, and its data assets. However, our approach to CIS success modeling should apply the same data sources and sampling methods for all cases. We thus require *provider-independent* data models and sampling approaches. For this work, we combined approaches from *Web Analytics* for the collection and analysis of *usage data* [Pete04, CrPo09, Kaus10] with traditional research approaches building on *survey data*, as it is widely used in IS research and practice [Gabl94, PiKr93], in particular for survey instruments focused on IS success [Davi89, VeDa00, LHSc08, GSCh08].

The joint use of multiple basic data sources serving as inputs to CIS success models requires a coherent *data integration* [Lenz02] concept. This requirement is closely related to the application of the media-centric ATLAS transcriptivity theory to CIS success modeling, as introduced in Section 3.4. Only with a coherent data integration concept, communities can seamlessly aggregate and recombine basic usage and survey data to complete success models in the sense of machine transcription and formalized localization, as indicated in Figure 3.5 (p. 54). This data integration concept must be reflected in the underlying data models, sampling methods, and model validation techniques. Speaking in terms of data integration, every CIS success model should conceptually define a mapping from the basic data sources to a global schema representing the success model, thus pursuing a *global-as-view (GAV)* approach [Lenz02]. However, given that CIS success models are dynamic constructs, mappings should be *flexible* and *modular* to allow for repeated model adaptation and recombination in the sense of transcriptivity theory. Such flexibility includes a conceptual decoupling of CIS success metrics from CIS success models to allow for their reuse and recombination. Support for such modular mappings is realizable with a set of pivotal attributes that allow for data integration via *attribute correspondence*.

With regard to the addressing of CIS success models in the sense of ATLAS theory, data sampling procedures must guarantee for *consistent and unique addressing of the involved pivotal entities* (e.g. user, community, CIS artifact). Such addressing is realized with the help of *standard global-scope identifier schemes* and *standardized encodings of contextual information*, e.g. *Request for Comments* (*RFC*) 3339 [KlNe02] for time. Apart from data integration, such schemes allow for efficient data *filtering*. In our research ontology (cf. Chapter 2), any CIS success model is only valid within given contextual constraints, most importantly for given CIS artifacts and communities. Hence, success models should be enabled to filter for data exclusively produced in these contexts. Usually, identifier schemes for pivotal entities are already integral part of professional CIS platform design and should thus be reused by the related sampling methods where possible. A prominent example is the realization of user identifier schemes with *Single Sign-On* (*SSO*) mechanisms such as OpenID Connect [SBJ*14].

To prepare for the seamless exploration, analysis, and validation of CIS success metrics and models, e.g. with data mining software, a comprehensive formal data model and its related data sampling methods should be furthermore designed towards the production of directly importable and processable *data formats*. In particular for the validation of CIS success models, the relational model is well-suited for a direct application of formal validation techniques with scientific data mining tool suites (e.g. R, KNIME, RapidMiner), as these usually provide support for tabular formats.

The selection of CIS success model validation techniques must be guided by several considerations. First, the principal *measurement perspective* of the model (formative vs. reflective [JMPo03]) must be decided before any validation is considered. Misspecification of the measurement model poses risks towards strong bias and negative impacts on validation [JMPo03, DiSi06]. Second, appropriate *types of validity* relevant for CIS success must be selected (cf. [Stra89] for a comprehensive taxonomy of validity types and [SBGe04] for recommendations on related validation techniques). With respect to CIS success models, we are mainly interested in *content validity* and *construct validity*. In particular, we are interested in *predictive validity* with respect to the operationalization of CIS success models. Communities should receive CIS success awareness with support to determine which factors are most relevant and how changes in the respective metrics are expected to influence overall CIS success. Third, the selection of validation techniques should favor effective, yet lightweight approaches. This requirement is motivated by the agile and cyclic nature of our MobSOS methodology (cf. Chapter 3). The research cycle of exploration, validation, and refinement implies the need for frequent repetitions of model validation. Last, but not least, a formalization framework for CIS success models should be designed for *scalability*. Scalability thereby not only refers to a technology-oriented perspective in terms of data storage, indexing, and query processing performance, but also to a social-oriented perspective in terms of efforts and resources required to be spent by community members in the context of evaluation.

4.2 Conceptual Modeling of CIS Success

Based on our literature study on IS success in Section 2.3.1, an important preconsideration on modeling CIS success is an overarching *modeling concept*. To that regard, Gable et al.'s work on the IS-Impact model [GSCh08] provided many key aspects for formal CIS success modeling in long tail community contexts, as we conceptualized it as part of our contribution of a CIS success formalization framework. The IS-Impact model basically is a reconceptualization of DeLone and McLean's I/S Success model [DeMc92]. Most importantly, the IS-Impact model deliberately omits the structural model due to a lack of convincing empirical validity for its causal/process paths reported in literature. We agree with this notion for pragmatic reasons. Our primary interest focuses on the factors that influence CIS success and their *measurement model*. The structural model in our conception rather serves the simple purpose of grouping and structuring CIS success factors and metrics in dimensions for improved understandability of the whole CIS success model.

The IS-Impact structural model groups the six I/S success model dimensions into three dimensions of *quality*, *impact*, and *use/satisfaction*. We adopt this grouping as a generic structural template valid for all custom-tailored CIS success models to be created with our MobSOS approach. The IS-Impact measurement model however excludes *satisfaction*, as most satisfaction measures are already covered in impact and quality metrics and *use*, as it is mostly seen as antecedent or consequence of IS impact. We conceive use as both antecedent and consequence of CIS success. As such, use still contributes valuable information on CIS success and should thus not be abandoned from success models. In fact, the most essential notion of success in today's social media landscape bases on very simple use metrics, most prominently *"eyeballs"*. In our framework, we however allow more complex metrics to cover arbitrary usage patterns. We also retain the satisfaction dimension, as it enables us to measure and differentiate satisfaction both quantitatively and qualitatively on community-specific features of CIS artifacts. Similar to Gable et al. [GSCh08] we capture overall satisfaction in terms of impact and quality as an overall criterion measure for CIS success. However, our validation goal is different. In contrast to Gable et al., our approach targets the creation, refinement, negotiation, and repeated validation of frequently adapted *fluid custom CIS success models*. We argue that a single one-size-fits-all model is impossible to achieve, given the high degree of diversity among different long tail communities. Thus, validation in our approach rather aims at gaining insights on the importance of specific measures in specific community contexts, for specific CIS artifacts, at specific points in time, and given other contextual constraints.

We conceive CIS success as a *dynamic construct*, measured as snapshots of current system quality and retrospective system impacts, influenced by and influencing capabilities and practices of system users [GSCh08]. CIS success is subject to community life cycles and a socio-technical systems perspective (cf. Section 2.3.3). Most importantly, Gable et al. classify IS success as an inherently multi-dimensional *formative* construct, following the seven criteria of Jarvis et al. [JMPo03]. This notion is not different for our conception of CIS success. CIS success metrics are viewed as *defining characteristics* of CIS success. Changes in CIS success metrics are expected to cause changes in overall CIS success. Changes in overall CIS success are not expected to cause changes in CIS success metrics. Finally, CIS success metrics do not necessarily share a common theme.

Based on the above discussion, our general conception of a CIS success model follows the structural template of a multi-dimensional formative index as depicted in Figure 4.1. In particular, we anticipate the existence of multiple instances of this structural template for different community contexts, different CIS artifacts, different points in time, and different community domain-dependent constraints. The structural template includes *CIS Success* as the dependent variable, assessed by a criterion measure. The existence of such a criterion measure fosters the application of regression techniques for validation purposes (cf. Section 4.5). CIS success is further modeled with the five different dimensions *System Quality*, *Information Quality*, *User Satisfaction*, *Individual Impact* and *Community Impact*, grouped as in [GSCh08].

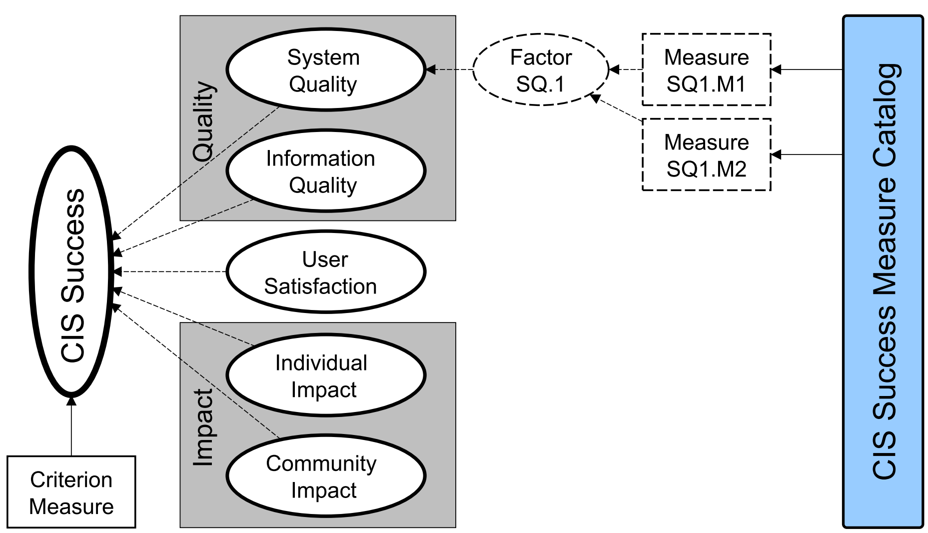

Figure 4.1: Structural Template for CIS Success Models

In turn, each *dimension* is established by a set of *factors*, and each factor is described by a set of *measures*. Both factors and measures are not fixed part of the template, as indicated by their dashed outlines. For each CIS success model instance, they are dynamically added to the model's structural template, thus addressing our requirement for modularity and flexibility.

Following the observation of universal measures or at least measures commonly applicable in multiple contexts, we introduced the concept of *CIS Success Measure Catalogs* for improved measure reusability. Implicitly, this concept requires that formalizations of CIS success measures are parameterizable by contextual constraints for their re-use across different contexts. The respective measurement model to such structural models of CIS success is simply defined as the set of all measures and the overall criterion measure. In the following section, we present our formal framework for CIS success models from a pure measurement perspective.

4.3 Formal CIS Success Measurement Models

In further response to the requirements from Section 4.1, we conceptualize a framework for the construction of formal CIS success measurement models, as depicted in Figure 4.2. Main constituents of this framework are a set of *basic data sources*, serving as the common basis for the construction of an arbitrary number of *CIS success models*. Each CIS success model is thereby defined in the context of a given *community*, a given *CIS artifact*, and a given set of *context constraints*, includ-

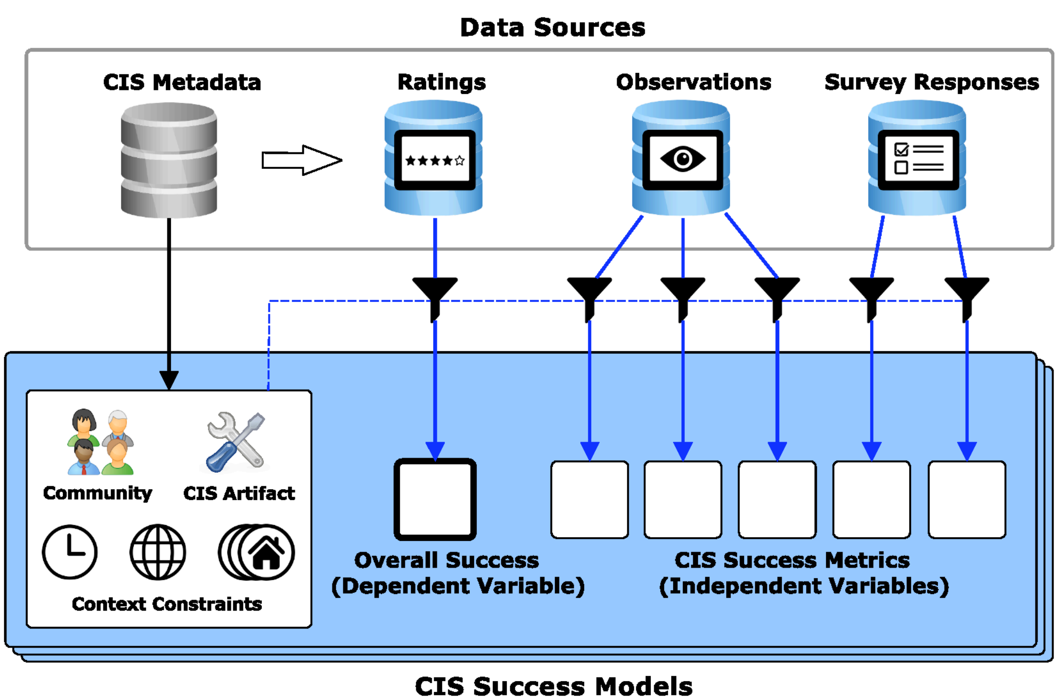

Figure 4.2: Formal CIS Success Measurement Model Construction Framework

ing temporal, spatial and other domain-specific constraints. These pivotal parameters describe the particular CIS evaluation context, i.e. who did what in which community context using which CIS artifact, when, where, and under which other context conditions (cf. [CaWh83]). For each CIS success model, these pivotal parameters fundamentally guide the computation of a set of *CIS success metrics*. Parameters thereby serve as filters on the basic data sources to restrict model computations to relevant data only, as indicated by the funnel symbols in Figure 4.2.

CIS metadata play the essential role of providing unique identities for pivotal entities such as users, communities, CIS artifacts, etc. As such, they guarantee for a seamless data integration by attribute correspondence. Both data sources and models build upon the same metadata provided by CIS core services, e.g. user & community management and authentication & authorization.

In the following, we present our contribution of a comprehensive formalization of CIS success models in terms of an integrated view on the different MobSOS basic data sources. For our formalization, we employ concepts and notations from data integration theory [Lenz02] and extended relational algebra [Codd90, ElNa00], given its procedural character and closeness to *Relational Database Management System* (*RDBMS*).

$$M = (c, \alpha, C_\kappa, m_1, \ldots, m_n, m_\Omega, \pi) \tag{4.1}$$

Formally, we define a CIS success model as in Equation 4.1. A model M is defined for a *community* c, a CIS *artifact* α, and additional *contextual constraints* C_κ. These constraints may for example express that a particular success model should only take into account use and feedback from a certain country, a closed time window, or for very specific functionalities of the artifact. Technically, C_κ is formulated as conditional statement over context attributes defined for the basic data sources. The following elements $m_1, \ldots, m_n$ represent the CIS success metrics of the model, expressed as *parameterized queries* to the basic observation and survey data sources. A more detailed discussion of these data sources is provided later in Section 4.4. The concept of parameterized queries allows for the re-use of individual CIS success metrics across different models and thus allows their collection in separate catalogues. m_Ω represents the dependent variable for *overall success*, expressed as a parameterized query to the basic data source for overall success rating data. A function π finally defines a mapping, that assigns the individual CIS success metrics to the respective factors and dimensions of the intended structural model.

Each parameterized query $m \in \{m_1, \ldots, m_n\}$ computes a view $\Delta_m(M)$, yielding data for an individual CIS success metric. Equation 4.2 describes the generic scheme for computing such views in extended relational algebra. In principle, this equation provides a procedural view on CIS success metrics computation transferable to RDBMS.

$$\Delta_m(M) = \gamma_{u,\theta_m}(\sigma_{C_M}(R)), R \in \mathcal{S}_o \cup \mathcal{S}_s \tag{4.2}$$

Starting point for each computation is the selection of a relation R from either one of the basic MobSOS data sources for observation data and for survey data, i.e. $R \in \mathcal{S}_o \cup \mathcal{S}_s$. The selection operator σ filters the respective data set for only those tuples relevant for the CIS success model M, given by the conditional C_M. Hence, the parameterization of each query mainly depends on context constraints formulated for a particular model M. These constraints restrict metrics computations to only those data relevant for the particular model. The aggregation operator γ finally computes a value for the given success metric m for each user u with the help of a special function θ_m over a subset of the attributes in $\sigma_{C_M}(\Delta)$. This function θ_m is characteristic for the particular metric computation. Equation 4.3 shows the similar scheme for computing the relation $\Delta_{m_\Omega}(M)$. The computation function θ_Ω is comparably simple in contrast to the possibly complex functions definable for θ_m. Usually, we consider only the latest CIS success rating for a particular user without any further transformations.

$$\Delta_{m_\Omega}(M) = \gamma_{u,\theta_\Omega}(\sigma_{C_M}(R_\Omega)), R_\Omega \in \mathcal{S}_\Omega \tag{4.3}$$

The most frequent use case of the above formalizations is the evaluation of CIS success for a single CIS artifact in one dedicated community context. In this case, the conditional C_M usually follows the form $\alpha = \alpha_M \wedge c = c_M \wedge C_\kappa$. However, referring to the support for different CIS resp. community types and scopes, C_M can be formulated differently, e.g. for certain stakeholder groups instead of the whole community resp. services or application portfolios instead of a single application.

With a full outer join over all individual views Δ_{m_i}, we can compute the data set Δ_M for CIS success model M, as explained by Equation 4.4. The resulting view can be understood as a set of tuples containing data for the dependent variable CIS success and all independent CIS success metrics per user. The view Δ_M is directly suited for further analysis, most importantly validation.

$$\Delta_M = \Delta_{m_\Omega}(M) ⟗_u (\Delta_{m_1}(M) ⟗_u \cdots ⟗_u \Delta_{m_n}(M)) \tag{4.4}$$

4.4 Basic Data Sources & Sampling Methods

As described in the previous section, another contribution of this work is the explicit selection of three fundamental basic data sources, i.e. observation data, survey data and overall CIS success rating data. Our selection was mainly guided by literature research and the requirements formulated in Section 4.1. With observation data we introduced a basic data source allowing the application of Web analytics [CrPo09, Kaus10] and data mining [FPSm96], in particular Web usage mining [SCDT00] to CIS usage data. With survey response data we introduced a basic data source traditionally used in IS research [PiKr93] and in particular recommended for mixed-method case study research on IS success [Gabl94]. With overall CIS success rating data, we introduced a special kind of survey data source commonly used for the overall evaluation of contemporary social media, e.g. with five-star ratings or up-downvoting [ZMLM11]. Before we present each of these three basic data sources in more detail, we start with a comparative discussion on obtrusiveness, justifying the later selection of data modeling aspects and related sampling techniques. Table 4.1 summarizes the results of our comparative survey.

In the context of CIS success research in long tail communities, we observe differences in the obtrusiveness of particular data sampling techniques from multiple stakeholder perspectives, i.e. end-users, developers, and researchers. While *observation* in terms of automated usage data collection is inherently effortless for end-users and researchers, it can become effortsome for developers. Required efforts thereby depend on the used observation technique (cf. [SCDT00, CrPo09, Kaus10])

Table 4.1: Obtrusiveness Analysis for MobSOS Data Sampling Methods

	End-User	Developer	Researcher
Observation	none	low-high	low
Surveying	medium-high	low	high
Rating	low	low	low

and the level of additional CIS artifact instrumentation necessary to collect relevant data. We thus chose automated server-side logging [SCDT00] of standard application protocol data as main data sampling technique. We furthermore apply a combination of data cleaning and context data enrichment operations known from *Extract, Transform, Load* (*ETL*) processes in data warehousing [JLVV00] and low-effort CIS artifact instrumentation [SCDT00]. With this combination, we achieve a highly unobtrusive and universally applicable data sampling technique for observing CIS use. In Section 4.4.1, we discuss observation data in more detail from a *data modeling* perspective. In Section 5.2, we provide details on our observation *data sampling* approach with the help of MobSOS monitoring pipelines.

Surveying is connected with low efforts for developers, but can become effortsome for both end-users and researchers. Researchers must dedicate efforts to the organization and conduct of surveys. End-users must spend efforts for the submission of survey response data, depending on the complexity of the used survey instruments. In the worst case, both researchers and end-users suffer from unnecessary efforts as a result of unmatched *response relevance* [PiKr93, StSt06, DMSe14]. Researchers have to carefully select end-users *relevant* for their surveys. Intuitively, an end-user's response to a survey can only be considered as relevant, if that end-user was exposed to the CIS artifact under scrutiny. Without control for relevance, end-users without such prior exposure still receive invitations to survey, spend unnecessary efforts to submit irrelevant responses, and thus introduce unwanted bias. With the availability of observation data, such response relevance problems can be solved automatically. We provide concept and implementation of such an approach later in Section 5.3.2.

Obviously, online surveying is only one among many possible techniques for sampling subjective qualitative data that is neither explicitly nor implicitly contained in observation data. Typical techniques such as focus groups and interviews are widely used in both research and industry practice. However, these techniques require the co-presence of evaluators and subjects. Given our ontology of highly distributed online communities, these techniques are practically unfeasible due to excessive traveling costs to achieve such co-presence. For most long tail communities it is common to never meet in person in their whole life cycle. Instead, they use digital communication media to achieve virtual co-presence. As such, online focus groups and interviews are theoretically possible, but still require effort-intensive and bias-prone postprocessing tasks such as transcription and coding. Last, but not least, any form of direct interaction between subjects and an evaluator is subject to the Hawthorne-bias [RoDi39]. In contrast, online surveys can be conducted asynchronously, require less efforts, yield direct and unbiased results, and are familiar to most end-users.

In the special surveying case of rating the overall success of a CIS artifact, the efforts for both researchers and end-users are low given the low complexity of the task. However, the response relevance argument becomes even more important, since low efforts on both sides cause a higher risk for biased data. In Section 4.4.2, we discuss survey data from a data modeling perspective, including survey management aspects.

Resulting from the above considerations, we conceive observation and surveying as two complementary data sampling techniques establishing the core principle *"observe where possible, survey only if inevitable"* with the overall goal to reduce obtrusiveness (cf. Section 3.5). While observation is preferable due to its inherent unobtrusiveness, surveys complement observation-based metrics with assessments on subjective or otherwise practically inaccessible CIS success aspects. Although certain CIS success aspects might be derivable with sophisticated data mining [FPSm96] techniques, communities usually lack the competence for their application. In such cases, surveying replaces the objective results achieved with data mining with biased perceptions reported in survey responses. Although being more imprecise and biased, surveys at least make the underlying constructs *accessible* for CIS success exploration and modeling. Surveying becomes even more unavoidable since frequently occurring cases of subjective CIS success aspects are inherently not derivable from observation data.

From a data integration perspective, the construction of formal CIS success models implies certain requirements to the individual data sources. One of the most important design contributions of the MobSOS approach is the integration of data sources from the very beginning. In particular, all basic data sources and related sampling methods must comply with the same identifier and description schemes for pivotal entities and context parameters used in formal descriptions of CIS success models. This contribution allows for convenient merging of data items from the same entities across data sets and thus renders costly schema matching operations obsolete. Each basic data source schema must thus include respective attributes, and the related data sampling method must rely upon the same CIS metadata to guarantee direct attribute correspondence. We reflect this essential requirement in a *kernel attribute set* K to be included in each basic data source by design (cf. Equation 4.5). Each basic data source must include a *user identifier* u, a *community identifier* c, a *CIS artifact identifier* α, and a set κ of *universal context attributes* such as time and place.

$$K = \{u, c, \alpha, \kappa\} \tag{4.5}$$

As most contemporary standard CIS platforms include core services providing metadata on pivotal entities and context parameters, we recommend the use of such metadata where possible. Most importantly, such core services inherently define global identifier schemes for pivotal entities such as users and CIS artifacts as part of their authentication and authorization schemes (e.g. OpenID Connect [SBJ*14]). We particularly recommend widely accepted global universal concepts for pivotal entity addressing such as *Uniform Resource Identifiers* (*URI*) [BFMa98], *Universally Unique IDentifiers* (*UUID*) [LMSa05] or *Jabber Identifiers* (*JID*) [Sain11b]. However, even until today we observe, that most central identity provisioning systems do not directly reflect communities as pivotal entities. We thus introduced communities and related identifier schemes as part of the CIS's core services in our LAS testbed [SKJR06] (cf. Section 2.4.3). For the description of non-entity contextual parameters, we recommend the use of standard and globally valid description schemes (e.g. [KlNe02] for temporal constraints). In the course of this work, context attributes include *physical*, *technical* and *social aspects*. Context attributes are sometimes highly community-specific.

They can significantly influence differences in perceptions of quality and impact across different communities. As an example for differences in social context, a chat tool with extensive features for group communication might be attributed with high quality by most people, but not communities of speech-impaired people (cf. Section 6.1). As an example for differences in technical context, a multimedia management tool designed for areas with a performant mobile or WiFi infrastructure might not show its full power for cultural heritage documentation fieldwork in rural areas of Afghanistan without any internet connection. Due to the absence of standardized identifier or description schemes for such cases, we justify the use of proprietary schemes. However, universal global standard identifier and description schemes are preferable in general, since they even allow relating pivotal entities across different CIS. As such, the use of context attributes serves as necessary prerequisite for fostering cross-community analysis of CIS success.

In the following sections, we concretize our realization of observation data, survey data and overall CIS success rating data in more detail. We thereby put particular focus on our further contribution of data model design and provision with respect to the MobSOS formal CIS success modeling framework. For all data sources we contribute a comprehensive concept for the provision of *relational data representations*, including pivotal entities and context attributes for attribute correspondence. Given their support in a wide spectrum of tools and development environments required to model, measure, analyze, validate, and present CIS success to communities (cf. Chapter 5), relational representations cater for the highest possible degree of data interoperability. Most importantly, relational data representations find wide operational support in databases and statistical analysis suites required for practical CIS success modeling and validation tasks. This contribution is not trivial, since in many cases basic data sources do not natively exist in a conceptually relational representation and thus require respective transformations. This holds in particular true for standard application protocol data.

4.4.1 Observation Data

Observation data captures the interactions between different classes of actors in a CIS, i.e. users and CIS artifacts in the form of services, applications, autonomous software agents, etc., enriched with contextual information. With an ongoing collection of historical and recent observation data in their shared repertoires, communities receive rich opportunities to derive CIS success metrics across all different dimensions of CIS success. Most apparently, protocol log data fosters the derivation of CIS success metrics in the system quality dimension. Logs usually capture technical attributes such as response times or error rates, along with technical context attributes on CIS artifacts. Due to its inherent objectiveness and unobtrusiveness due to automatic collection, this work considers context-enriched observation data as the most important basic data source. Accordingly, we consider standard application protocol logging as the primary observation data sampling technique. For a comprehensive formalization framework, we design observation data sources following the relational model.

For this work, we contribute designs and implementations of data models and sampling methods for three major open standard application protocols. These protocols cover the major classes of protocol families frequently employed in contemporary CIS. The HTTP protocol [FiRe14a, FiRe14b] covers any form of hypermedia interaction. HTTP protocol log data particularly captures the interaction with different classes of Web services, most importantly RESTful Web services. The

XMPP [Sain11a] protocol covers any form of federated real-time communication and collaboration within and even across communities. The Pastry protocol serves as representative for a whole class of different protocols for arbitrary agent interaction in P2P networks from media streaming and file sharing to online social networking [BuDa09, BBS*09, BSVD09, CMSt09, AiRu10, NJP*12]. The automated collection of observation data on the level of such standard application protocols results in inherently generic interaction descriptions in terms of common protocol operations with predefined standard syntax [FiRe14a, Sain11a] and semantics [Fiel00, FiRe14b, Sain11a]. The mapping of specific interaction syntax and semantics to common protocol syntax and semantics is integral part of CIS service and application development.

Generic protocol syntax and semantics usually include the notion of different *modes of interaction* between different actors as well as different *interaction patterns*. Regarding modes of interaction, *user-to-artifact* interaction is the most apparent and at the same time most important mode, as it directly captures the interaction between end-users and CIS artifacts. *User-to-user* interaction captures social interactions between CIS users, mediated by the CIS artifacts under scrutiny. *Artifact-to-artifact* interaction captures the interactions between individual CIS artifacts. Although this dimension does not involve any human actors, the derivation of additional CIS success metrics is theoretically possible and appropriate. Across paradigms such as *Service-Oriented Architecture* (*SOA*), *Representational State Transfer* (*REST*) [Fiel00] and microservices [LeFo14], we find the recurring pattern of service composition and orchestration. In order to function as integrated CIS, the individual component CIS artifacts must communicate with each other. However, the consideration of this interaction mode is beyond the scope of this work. Apart from the different modes of interaction between different actors, we find different classes of *interaction patterns*, reflected in application protocols and bringing implications for the design of our basic data sources. In this work, we focus on three patterns reflected in the selected protocols: *request-response*, *push-pull*, and *publish-subscribe* [BiJo87, EFGK03].

Finally, all protocols we considered include open standard concepts for *entity addressing* and *protocol extensions*. However, across protocols, these concepts differ in terms of complexity and expressiveness. Again, these differences have implications for modeling protocol log data with a relational model. Table 4.2 shows a comparison of the selected major application protocols with respect to modes of interaction, interaction patterns, extension mechanisms, and entity addressing.

$$o = (u, c, \alpha, \kappa, p, I, \kappa_I) \tag{4.6}$$

Table 4.2: Major Application Protocols – Properties For Observation Data Collection

Protocol	Interactions	Interaction Patterns	Extension Mechanisms	Entity Addressing
HTTP	User-to-Service Service-to-Service	Request-Response	Headers	URI [BFMa98]
XMPP	User-to-Service User-to-User Service-to-Service	Server-side Push Request-Response Publish-Subscribe	XMPP Extension Protocols (XEP)	JID [Sain11b]
Pastry (P2P)	Agent-to-Agent	Server-Side Push Request-Response Publish-Subscribe	Agent/Message Extensions	UUID [LMSa05]

Based on the above considerations, we formalize observation data as an abstract set of tuples o of the form shown in Equation 4.6. The attributes u, c, α and κ comply to the set K of kernel attributes included in every basic data source for reasons of later data integration by attribute correspondence. The specific elements added for describing observations of CIS interaction consist of a peer p potentially interacting with u, an embedded tuple I of attributes describing the interaction and κ_I a tuple describing additional context parameters connected to the interaction (e.g. user agent, device type, additional context attributes resulting from CIS artifact instrumentation). Given a relational schema for observation data for a given protocol $\mathcal{S}_o = \{R_{o_1}, \ldots, R_{o_n}, R'_o\}$, the tuples above can be understood as view R'_o virtually unifying all the relations modeling the respective observation data model. In our practical implementation for MobSOS, we realized these virtual views for the convenient access to all relevant attributes from a single table. In the following paragraphs, we present formal observation data models for these protocols.

Observing REST/HTTP-Based CIS Interaction

Originally designed for the access to static hypermedia, HTTP is nowadays the global standard for accessing arbitrary Web services and applications. The success of previous generations of SOAP-based services and of the current generation of RESTful microservices [Fiel00, RiRu07, LeFo14] is mainly attributable to the existence of this universal protocol.

The main protocol core [FiRe14a] defines syntax and routing of user interactions with a CIS and its services following a request-response pattern. Entity addressing in HTTP employs the URI concept with given syntax `scheme://authority/path?query`. Interactions between users and CIS artifacts are described by request-response pairs. In particular for addressing entities of the kernel attribute set K, we employ the concept of authorization tokens managed by central identity management systems such as OpenID Connect [SBJ*14]. Auth tokens implicitly include globally valid identifiers for users and CIS artifacts. Requests are essentially formulated with the help of a *URI* describing a target resource, a *method* from a fixed vocabulary with well-defined semantics (GET, PUT, POST, DELETE, OPTIONS, etc.), and a *Multipurpose Internet Mail Extension* (*MIME*) [Resn08] *type* describing the media type of the request data payload. Web services hierarchically group a set of *URI patterns* they provide as their functionality with *URI templates* under a common endpoint URI. With URI templates, individual URIs can be matched to respective services. Responses are described by a *response status* from a fixed system of classes of numeric identifiers with predefined semantics expressing success or failure (e.g. 4xx for client errors, 404 for resource not found) and a MIME type describing the media type of the response data payload. Although the HTTP protocol is stateless by definition, many Web services artificially introduce a session construct to group individual interactions to single sessions of CIS interaction. We thus include this construct in our conceptual model, but only use it, if the underlying CIS uses sessions.

With HTTP observation data, we essentially collect request-response pairs in the scope of a community's set of employed Web services, enriched with context data. In order to provide observation data in a relational format, we developed a relational schema $\mathcal{S}_o$, depicted as *Entity-Relationship Diagram* (*ERD*) in Figure 4.3. The simple and flat structure of HTTP request-response data enables a relatively simple mapping to a relational log model. Several context enrichments are already available from standard header fields (e.g. user agent, referrer) without further efforts. Custom context extensions can be transferred along with regular requests in the form of custom header

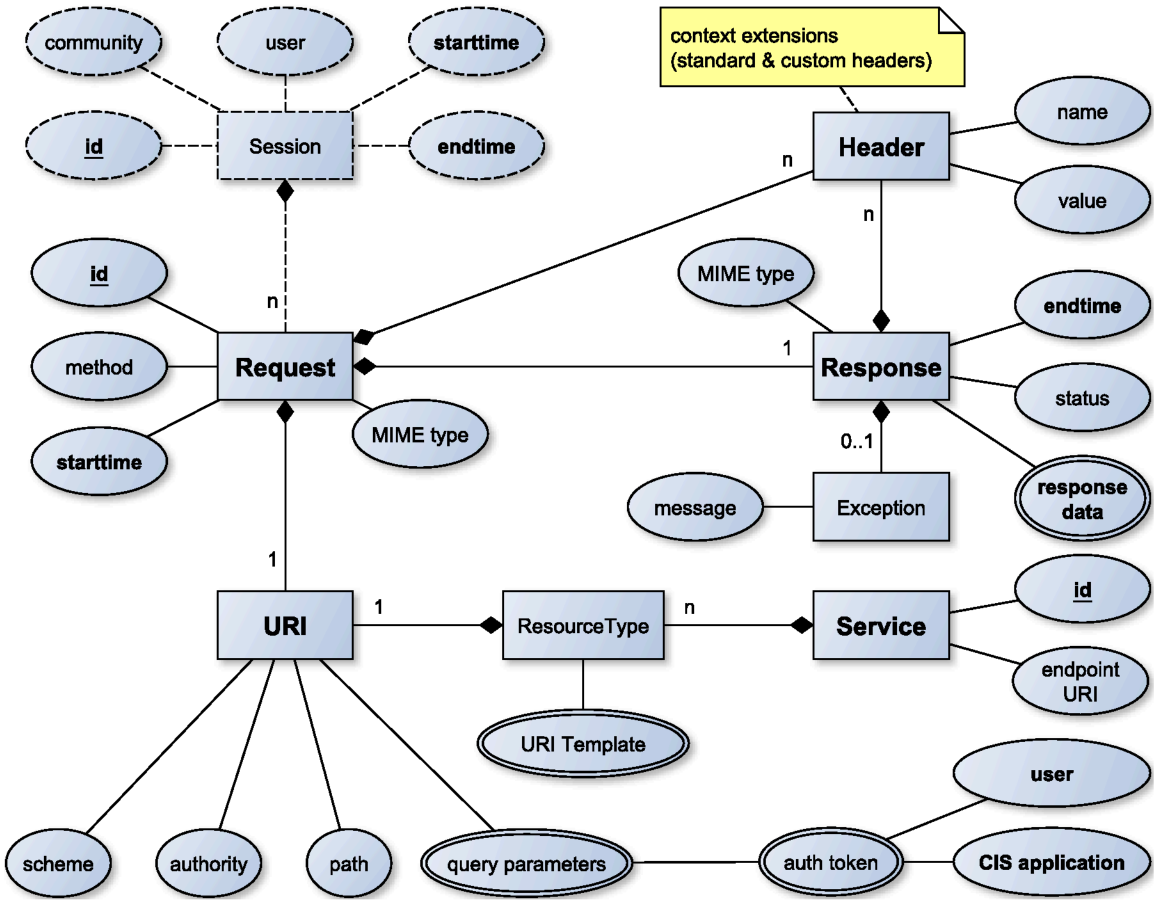

Figure 4.3: ERD for Observation Data of CIS Interaction Over HTTP

fields. Our model practically extends and enriches standardized tabular HTTP access log data formats such as the *common log file format*[1] and *extended log file format*[2] used in standard servers such as nginx[3] or Apache HTTPD[4]. Elaborate instantiations of our HTTP observation data model include context extensions for social, physical, and technical aspects, applied in case studies in the context of digital cultural heritage management communities using mobile multimedia annotation tools ([RKSp08, ReKl09]; cf. Section 6.2) and in the context of online learner communities using widget-based personal learning environments([RKKN15]; cf. Section 6.3).

Observing XMPP-Based CIS Interaction

Originally designed as an Instant Messaging protocol, XMPP is nowadays a general-purpose open standard protocol for real-time communication and collaboration applications [HoWa10, SGR+14]

[1] http://www.w3.org/Daemon/User/Config/Logging.html#common-logfile-format
[2] http://www.w3.org/TR/WD-logfile.html
[3] http://nginx.org
[4] http://httpd.apache.org

applied in community contexts. Its core [Sain11a] defines a message format and routing concept used to transport semi-structured *Extensible Markup Language* (*XML*) messages called *stanzas* between arbitrarily definable entities in real-time. For entity addressing, XMPP uses the JID concept [Sain11b]. A JID describes an abstract entity as a node at a given domain using a specific resource and follows the syntax `node@domain/resource`. The domain part thereby describes an XMPP server (e.g. the home server of a community), possibly federated with other XMPP servers. With this federation concept, XMPP enables *server-to-server* communication between communities. JIDs thus serve as global universal entity addressing scheme for users (e.g. `user@community`), but also for other entities such as services, chat-rooms, publish-subscribe channels, or autonomous software agents, including context information. The three different stanza types *message*, *presence*, and *IQ* (for information query) reflect three different interaction patterns possible in XMPP, i.e. *push-pull*, *publish-subscribe*, and *request-response* respectively. While message and presence stanzas are transmitted in a fire-and-forget fashion, IQ stanzas entail a response in all cases. All stanza types can result in success or error, expressed with standardized *status coding* schemes. *Rosters* allow individual users to manage lists of trusted other entities. XMPP thus directly supports the construction of social networks. XMPP directly inherits its powerful extension concept from XML. *XMPP Extension Protocols* (*XEP*) are defined as extensions to the core stanza types and belonging to XEP-specific namespaces. The XMPP Standards Foundation maintains an ever-growing list of standard XEPs. Typical examples are multi-user chatrooms or even lately *Internet of Things* (*IoT*) applications. Although the generic XML extension mechanism

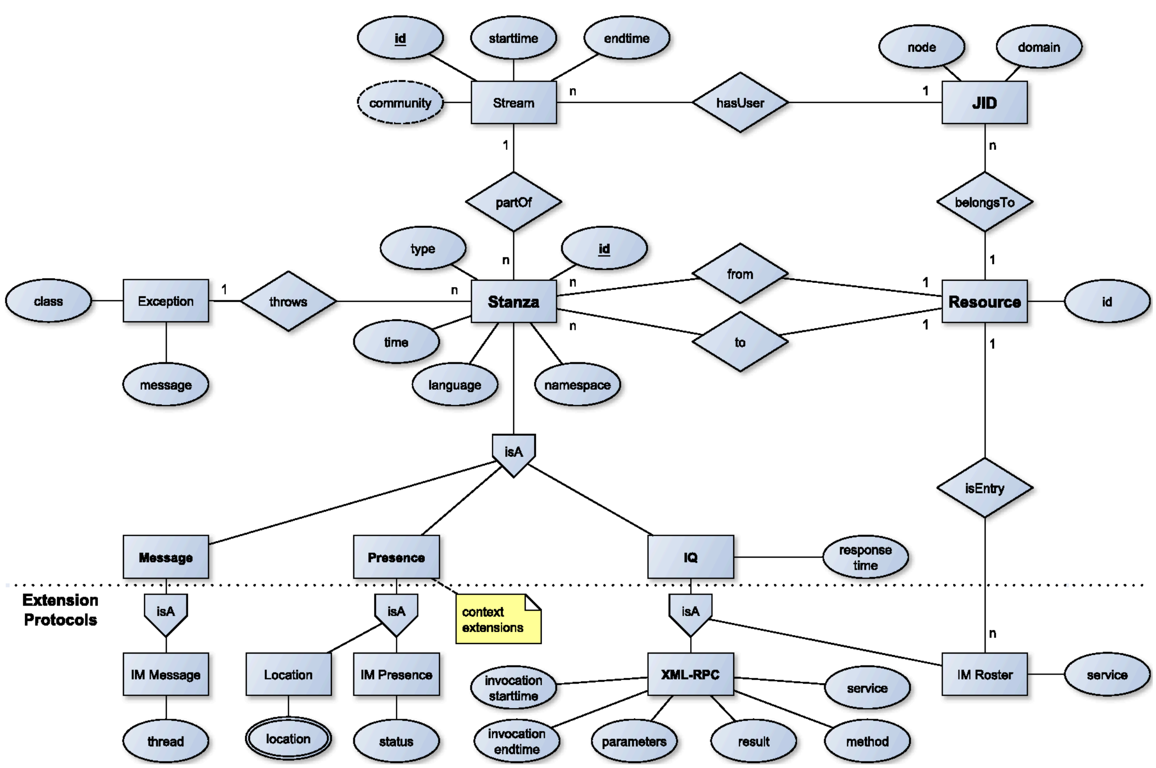

Figure 4.4: ERD for Observation Data of CIS Interaction Over XMPP

fosters the creation of arbitrary proprietary protocol extensions, most applications build upon the protocol core or its standard extensions.

With XMPP observation data, we essentially collect stanzas in the scope of a community's XMPP server, i.e. local members of the same community and outgoing/incoming stanzas to/from other servers. In order to provide observation data in a relational format, we developed an XML-to-relational mapping (cf. [BFMe05]), resulting in a schema $\mathcal{S}_o$ depicted as ERD in Figure 4.4. XMPP extension protocols are realized with the *isA* construct, resulting in additional tables describing the extension-specific attributes. Unlike headers for HTTP, XMPP protocol extensions automatically entail modest additional data modeling efforts. Since most community tools for real-time communication and collaboration rely upon the protocol core and a few essential protocol extensions, additional data modeling efforts are however seldomly required. In general, presence stanzas are best suited for transferring rich context data such as location, online status, mood, live sensor data, etc. in real-time. The model shown in Figure 4.4 already includes Jabber-RPC [Adam11] as an IQ-based extension to access Web services via XMPP. As such, this extension allows to transparently perform user-to-user and user-to-service communication over the same protocol instead of using separate protocols [Schl09]. XMPP thus facilitates the collection of user-to-user and user-to-service interactions even across communities, following all three interaction patterns of push-pull, request-response, and publish-subscribe. Elaborate instantiations of our XMPP observation data model include Multi-User Chat [Sain12] as another extension protocol used for our case study on a chat tool for aphasia communities ([Grun10, RKJa15b]; cf. Section 6.1).

Observing P2P-Based CIS Interaction

Last but not least, we cover the class of P2P-based CIS on the example of a Pastry-based [RoDr01] protocol we realized for our P2P community platform las2peer (cf. Section 2.4.3). The core of this protocol (cf. Figure 4.4.1) defines a simple messaging scheme between different classes of *agents* located on distinct *nodes* in a P2P overlay network. Different *message* types are achieved with a combination of *event* descriptors, augmented with additional *remarks*. The event descriptors thereby realize an *extensible message categorization* scheme. The remarks field allows for arbitrary additional message fields, e.g. to encode additional context enrichments. The protocol furthermore allows to model arbitrary agents as extensions of the abstract agent by subclassing. With this concept, the las2peer protocol allows to model arbitrary agent-to-agent interactions. Currently available agent types allow to model users, services, and communities as collections of arbitrary agents. A special class of *monitoring agents* is responsible for the collection of observation data in such P2P networks. A special class of *mediators* mediates service invocations, encoded as special type of event with respective remarks fields capturing user-to-service interaction.

With P2P observation, we essentially capture messages transmitted between arbitrary agents located at specific nodes [Lang13]. As such, this protocol offers more openness and flexibility than HTTP and XMPP. However, although there are no restrictions on the number of event types and remarks fields, the structure and set of fields should not differ among messages of the same event category for later data aggregations towards CIS success models. For instantiations of this data model, we thus designed a set of de-facto standard fields with predefined remarks field structure and contents.

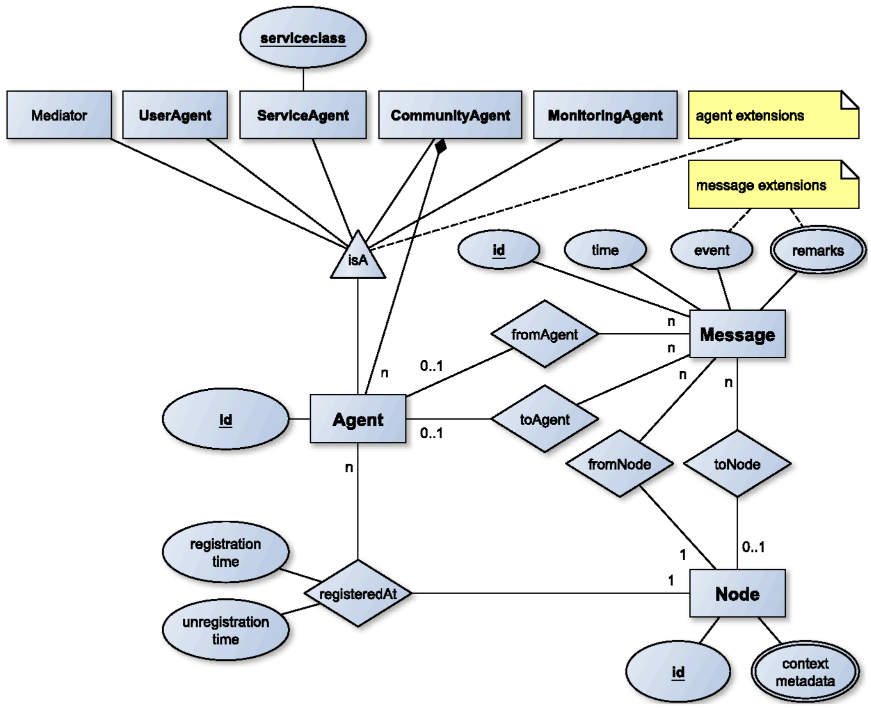

Figure 4.5: ERD for Observation Data of CIS Interaction Over Pastry (P2P)

4.4.2 Survey Data

With survey data we capture both survey management and survey response data. For the later derivation of CIS success metrics, only response data is relevant. However, survey management data can serve as contextual enrichment of survey response data. Surveying also inherently fulfills the requirements for genericity and extensibility, as it only defines the conceptual frame for collecting end-user responses on CIS success with the help of survey instruments, such as five-star ratings or questionnaires. Rating the overall success of a CIS artifact is conceived as a special case, where the questionnaire simply consists in a single ordinal-scale item. Compliant with guideline 5 from Section 3.5, we explicitly support the use of non-standardized items in order to reflect and emphasize important community-specific idiosyncrasies [BFS*06] commonly found in the long tail. We thus provide an *open survey data model* for the collection of arbitrary survey responses, however focused on the collection of CIS success-related community feedback. Figure 4.6 depicts the conceptual data model for survey management and collection as ERD. The model includes three central entities, i.e. *surveys*, *questionnaires*, and *responses*. A *questionnaire* is described by basic metadata such as name, description, owner and organization of conduct including a logo, and - most essentially - a *questionnaire form*. Any questionnaire can be reused in an arbitrary number of surveys. Surveys serve as management contexts for the collection of responses.

Likewise, a *survey* is described by basic metadata, survey context with optional start and end-times, a surveyed CIS artifact given with a respective universal global identifier, and a reference to a predefined questionnaire. Surveys can furthermore be triggered by conditional event triggers. The trigger entity thus reflects the concept of *triggered micro-surveys*, an advanced survey administration tech-

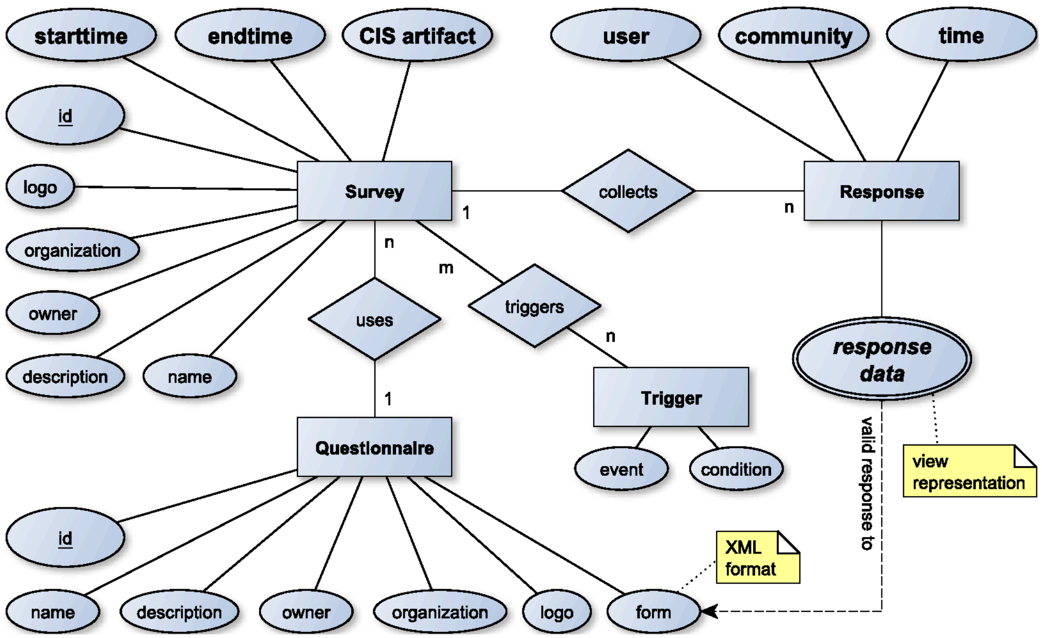

Figure 4.6: Entity Relationship Diagram for Survey Management & Response Data

nique, addressing response relevance [PiKr93, StSt06]. In Section 5.3.2, we present a technical concept and realization of such triggered micro-surveys in more detail.

Survey responses are collected in the context of a survey. A survey response is described by an optional global universal identifier of the survey participant matching the respective observation data model, the time of submitting the response, an optional community context, and a completed questionnaire form. In Section 5.3.2, we present the MobSOS open XML Schema for describing questionnaire forms and responses and show how these forms can be adapted to communities and individual members. Collected survey responses allow for convenient XML-to-relational mappings. Survey response data thus becomes available in relational views. These views cater for the integration with observation data and for the further derivation of CIS success metrics as part of complete CIS success models. Entries in these relational views are tuples s of the form described in Equation 4.7.

$$s = (u, c, \alpha, \kappa, \rho_1, \ldots, \rho_n) \tag{4.7}$$

The attributes u, c, α and κ comply to the set K of kernel attributes included in every basic data source for reasons of later data integration by attribute correspondence. The specific elements added for describing survey responses to the n individual items of a survey measuring CIS success consist of a set of responses $\rho_1, \ldots, \rho_n$. In order to allow access to survey response data for CIS success modeling, we thus define a virtual schema $\mathcal{S}_s$ consisting of the response views for all surveys $s_1, \ldots, s_m$ managed by the CIS , i.e. $\mathcal{S}_s = \{V_{s_1}, \ldots, V_{s_m}\}$.

4.4.3 CIS Success Rating Data

With CIS success rating data, we collect overall ratings on CIS success for given CIS artifacts in given community contexts. Although the collection of such data is a special form of surveying, we deliberately separate this data source from survey data for various reasons. First, end-users should be empowered to submit overall rating feedback, independent from their willingness to participate in surveys. Second, end-users are familiar with standard representations and assessment techniques such as five-star ratings or up/downvoting [ZMLM11]. Third, this separation addresses the requirements for CIS success model modularity and flexibility.

$$\omega = (u, c, \alpha, \kappa, \rho_\Omega, \mathcal{F}_\Omega) \tag{4.8}$$

Formally, we model individual entries ω in the overall CIS success rating data source as depicted in Equation 4.8. The attributes u, c, α and κ comply to the set K of kernel attributes included in every basic data source for reasons of later data integration by attribute correspondence. The specific elements added for describing overall CIS success consist of an ordinal-scale rating ρ_Ω and an optional feedback comment $\mathcal{F}_\Omega$ for collecting additional qualitative information, e.g. sentiments, requirements or justifications of the ratings. In order to allow access to overall CIS success rating data for CIS success modeling, we thus define a virtual schema $\mathcal{S}_\Omega$ consisting of a single relation R_Ω, i.e. $\mathcal{S}_\Omega = \{R_\Omega\}$.

4.5 CIS Success Model Validation

In principle, each version of every CIS success model created with the formal CIS success modeling approach described in Section 4.2 requires *validation*. Only a valid model allows useful conclusions for a community. Model validity is thereby understood as the degree to which the model and its indicators indeed measure overall success. We thus designed the formal representation of a CIS success model M and the computations of the resulting data set $\Delta(M)$ for a seamless and direct application in a combination of different validation techniques. We thereby borrow from a comprehensive set of validity types and corresponding validation techniques [SBGe04] supporting the rigorous scrutiny of CIS success models.

In contrast to positivist practice working towards fixed universal models, we use validation in the sense of a critical paradigm. We conceptualize CIS success models as *fluid working hypotheses* under ongoing repeated scrutiny and constant evolution. As already stated in our requirements for formal validation, our approach requires a careful selection of validity types and corresponding validation techniques. For this work, we particularly emphasize a combination of *content validity* and *predictive validity* as major notion of success model validity. These validity types are supported by a set of comparably light-weight validation techniques suitable for frequent agile iterations. Starting point for model validation is an a-priori candidate CIS success model with a potentially large set of candidate success metrics. The used validation techniques thereby not only help to assess different validity types. They also include means to *reduce candidate models* to their essence, i.e. the most relevant factors for CIS success, and to *interpret results* for continuous model adaptation or operationalization in community practice. We thus contribute our selection of techniques that cater for a community's agency to stay aware of the most essential CIS success factors and to act accordingly. In the following sections, we present our notion of CIS success model validity as a combination of *content validity* assessed with the help of *expert panel techniques* and *predictive validity* assessed with the help of *regression techniques*.

4.5.1 Content Validity & Expert Panel Techniques

As discussed in Section 3.4, expert panel techniques play a central role for the validation of fluid CIS success models, as they are already applicable for the most vague precursors of full CIS success awareness without concrete measurements. Expert panel techniques make effective use of an important, yet inherently available resource at the core of any community of practice: expertise.

In order to sustain their communities, experts at the core often hold certain management functions. They continuously engage in decisions on which levers to pull for the highest impacts towards community improvements. Such discussions inherently relate to possibly different individual perceptions of CIS success that must be resolved to a commonly agreed community awareness on CIS success with the help of active negotiation.

Several authors in IS literature propose expert panel techniques as less rigorous alternatives to model validation in cases where more formal validation techniques are not applicable due to a lack of representative data [BGSt01, PSRa07]. This perspective is highly related to a researcher's need to present empirical evidence in publications. In this work, we pursue a more community-centered perspective on the combination of expert panels and more rigorous statistical techniques. Even without precise statistical measurement, expert panels are already effective in negotiating early conceptions of CIS success constructs in the sense of *content validity* [SBGe04], most importantly face validity. Statistical measurement and the assessment of CIS success model quality with statistical tools such as regression analysis are effective means to assess CIS success models for their quantifiable predictive validity. With sufficient representative community observation and survey response data available in the community's shared repertoire, these techniques additionally cater for quantitative empirical evidence.

The basic target of expert panel techniques is to determine collaboratively for a given candidate CIS success model, which of the candidate success metrics and factors are most relevant for overall success and which are not. As such, expert panel techniques not only serve the purpose of model validation, but also use insights from the validation process to guide further practice. In particular, we propose approaches proven to work well for such CIS success model validation in expert panels.

With a candidate model at hand, Lawshe's approach [Laws75] tests for a common expert judgement on the importance of individual dimensions, factors, and metrics for the whole CIS success model. More precisely, this technique involves community experts by asking them to rate the importance of a success construct on a 3-item ordinal scale (*not necessary; useful, but not essential; essential*). A construct only remains part of the model, if more than 50% of the experts rated it as essential. As such, Lawshe's approach belongs into the class of purely confirmatory validation approaches.

Moore & Benbasat [MoBe91] propose a special form of Q-sorting with open categories. As such, this approach is suited for both confirmatory and explorative validation. With a given candidate success model at hand, experts independently assign CIS success factors and metrics to values on a two-ended ordinal scale (e.g. from *totally irrelevant* to *highly relevant*), according to their personal opinion. The active assignment to these levels of relevance in direct collaboration with other experts constitutes the core of this method. Preferably, the group of experts includes representatives from the widest possible range of stakeholder groups, e.g. domain experts, researchers, and developers. The openness of Moore & Benbasat's approach furthermore caters for explorative validation. In this open variant, experts may add previously unreflected, but potentially relevant other success constructs to the model in the process. Individual sortings from multiple experts finally allow a commonly agreed relevance ranking for success constructs in the model.

Lawshe's and Moore & Benbasat's approaches thereby formalize and quantify the negotiation processes naturally taking place among experts to determine a commonly agreed CIS success awareness. Especially for experts with a research background, these techniques provide the formal and quantifiable empirical evidence required for successful scientific publication. With a critical mass of representative observation and survey data from end-users, the additional consideration of regression techniques allows for additional statistical rigor and thus more precise CIS success models.

4.5.2 Predictive Validity & Multiple Regression Analysis

As a very pragmatic, yet formal statistical type of validity, predictive validity is expressed as the degree to which a given set of success metrics explains overall success [SBGe04]. Undeniably, predictive validity is a concept from the positivist toolkit. In the light of the strictly anti-positivist, critical paradigm of this work (cf. Section 2.1), long-term prediction of CIS success is not achievable by definition. With the given ontology, CIS success models are expected to change as result of emergent structuration effects. However, measurement of predictive validity still allows formal statistical statements on how well an a-priori model under scrutiny fits the current reality and which factors are currently most relevant. This *short-term prediction* allows to guide community improvements in the right directions of the most relevant success factors. We furthermore adopt this notion of predictive validity because of its quantifiability with a set of formal statistical measures derivable from model data. According to its definition, a CIS success model is valid, if a significant amount of variance in the dependent variable, i.e. overall CIS success, is produced by the independent variables of the model, i.e. the success metrics, and not by other unknown sources of variance. This fundamental observation lays the foundation for assessing predictive validity with the help of regression analysis techniques, as recommended by several researchers [SBGe04, GSCh08].

As stated earlier in this chapter, we agree with Gable et al.'s [GSCh08] analysis of IS success as an inherently multi-dimensional *formative* construct. Diamantopoulos & Winklhofer [DiWi01] present a framework for the construction of multi-dimensional formative indices, including recommendations for formal, however comparably light-weight validation techniques of the measurement model (i.e. multiple regression), reliable statistics (i.e. *Analysis of Variance* (*ANOVA*), model fit, coefficients, significance) and rather intuitive interpretations. In contrast, Petter et al. [PSRa07] describe a set of rather heavy-weight approaches based on *Structural Equation Modeling* (*SEM*) [UlBe12]. SEM is particularly recommended for the analysis of path relations between constructs. However, as stated before, we explicitly ignore these path relations. We thus prefer regression analysis for its lightness, its intuitive interpretation, and its wide support in statistical software suites. Regression analysis is particularly well-suited for the analysis of relationships between a set of independent variables (i.e. CIS success metrics) $\mathcal{M}_1, ..., \mathcal{M}_n$ and one dependent variable (i.e. overall CIS

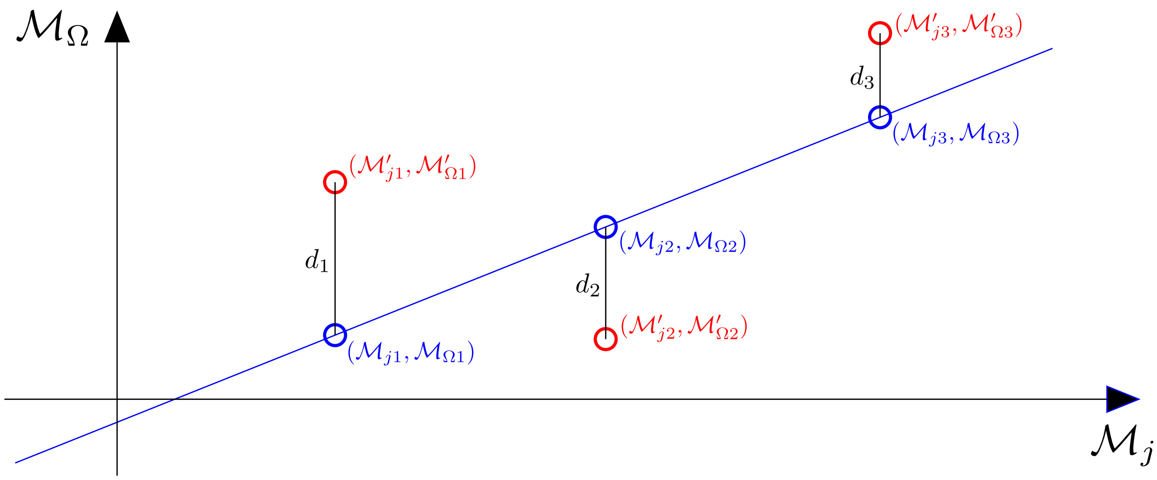

Figure 4.7: Scatterplot for Single Success Metric $\mathcal{M}_j$ incl. Regression Line

success) $\mathcal{M}_\Omega$. The data for each of these variables is produced by the views $\Delta_{m_1}(M)$ through $\Delta_{m_n}(M)$ and $\Delta_{m_\Omega}(M)$ respectively (cf. Section 4.3). In the following, we assume that the combined data set $\Delta(M)$ consists of independent data samples from k different users, collected with our combination of observation and survey techniques. We abbreviate the i-th entry as a tuple $(\mathcal{M}_{1i}, \ldots, \mathcal{M}_{ni})$.

$$\mathcal{M}_{\Omega i} = \alpha + \sum_{j=1}^{n} \beta_j \mathcal{M}_{ji} + \epsilon_i \quad i \in \{1, \ldots, k\} \tag{4.9}$$

The dependent variable for overall success $\mathcal{M}_\Omega$ is thereby considered as a linear combination of the independent variables for success metrics $\mathcal{M}_1, \ldots, \mathcal{M}_n$. α is a constant referred to as *intercept*. The *regression coefficients* β_j indicate the expected change in overall success, if metric $\mathcal{M}_j$ is changed by one unit, keeping the values of all the other independent variables constant. Since the model under consideration is a *probabilistic* model, an error ϵ_i is added. This error reflects possible uncontrolled influences of a) variables not included in the model, b) measurement error and c) inherently unpredictable elements of overall success. Since the real relationship existing among variables is not directly observable, it is impossible to determine the true regression coefficients β_j and errors ϵ_i. Instead, they are approximated with respective estimates $a, b_1, \ldots, b_n$, determined during regression analysis. Figure 4.7 depicts this relationship between predicted and actual data as a *scatter plot*. The goal in regression analysis is to determine the line graph described by Equation 4.9. However, there is only a limited set of real-world observations $i \in \{1, \ldots, k\}$ from which the best approximation can be derived. Therefore, the *residual error* $d_i = \mathcal{M}_{\Omega i} - \mathcal{M}'_{\Omega i}$ with $\mathcal{M}'_{\Omega i} = a + \sum_{j=1}^{n} b_j \mathcal{M}_{ji}$ is used as a proxy to the real error. Finding the best approximation for the real regression coefficients is then the solution of a minimization problem of the *sum of squared errors* $SSE = \sum_{i=1}^{n} d_i^2$ with least squares estimators.

$$Min_{a,b_1,\ldots,b_n} SSE \tag{4.10}$$

Regression analysis requires several prerequisites to be fulfilled. First, independent variables and errors must be uncorrelated. Second, the independent variables must not exhibit excessive multicollinearity, i.e. linear relationships among success metrics. Third, each error is a random variable with expectation equal to zero, i.e. $E(\epsilon) = 0$. Fourth, we find *homoskedacity*, i.e. errors have a constant variance σ^2. Finally, errors are distributed according to the standard normal distribution, i.e. $\epsilon \sim N[0, 1]$.

Besides the computation of intercepts and regression coefficients, regression analysis computes several statistics that allow for straight interpretations regarding the quality of success models as a whole as well as of individual factors and measures. These interpretations in turn allow for further operationalization in terms of model refinements or CIS artifact improvements. Typical statistics from ANOVA yield an overall p-value describing model significance. With a low p-value below one of the standard significance levels of $p < 0.05$ (significant) and $p < 0.01$ (highly significant), this statistic confirms the alternative hypothesis that overall CIS success is influenced by the model's success metrics, and is thus not a result of pure chance. Model *goodness-of-fit* statistics allow statements about the proportion of variance in overall success explained by the model's success metrics. For model fit analysis we prefer the *adjusted coefficient of determination* $\overline{R^2}$ over its regular pendant R^2. While R^2 is likely to increase with a growing number of variables added to the regression equation, such additions introduce a concrete risk of model overfitting. The *adjusted coefficient of determination* $\overline{R^2}$ therefore penalizes entering irrelevant variables into the regression equation by a decreasing factor. As such, $\overline{R^2}$ provides information directly applicable in model building and refinement.

In particular early a-priori versions of CIS success models resulting from metrics exploration tend to contain a high number of potential metric candidates, that possibly exhibit a high amount of mutual multicollinearity. We therefore pursue a special type of *stepwise regression* for CIS success models. Success metrics are successively added to the regression equation, if they significantly correlate with overall success and exhibit minimal multicollinearity to success metrics already entered into the equation. All other candidate success metrics are dropped from the model. With such a stepwise regression technique, we can effectively reduce CIS success models to only those success factors and metrics that significantly influence overall success.

Regression coefficients hint to respective effect strength of individual success metrics by their absolute values and effect directions with their sign. The significance values computed for each success metric in the model allow statements about their relevance. Thus, models with acceptable overall significance and model fit as well as statistically highly significant factors and metrics serve as valuable quantified guidance on potential community improvement. Intuitively, improvements on factors with respective high absolute regression coefficient values and high significance values are expected to have stronger effects than insignificant factors with regression coefficient values close to zero. If stepwise multiple regression analysis with a set of candidate metrics results in a model with poor goodness-of-fit and significance statistics, the community should continue its exploration for further, yet undiscovered factors and metrics. In Section 6.2 we describe a particular instantiation of our stepwise multiple linear regression approach in the context of a case study on a mobile multimedia management tool. The result is a very compact and highly relevant CIS success model.

4.5.3 Predictive Validity & Ordinal Logistic Regression

Although multiple regression fulfills our requirement for a light-weight statistical validation technique, one particular finding of this work is that our formalizations of CIS success models in practice often do not comply with the assumptions of multiple regression, i.e. scale levels, normality, homoskedascity, and linearity. Most importantly, multiple regression follows the assumption that the regressand is a *continuous* variable. Violations of the above assumptions result in large measurement error. MobSOS however assesses overall CIS success, i.e. the regressand, with discrete ordinal scales, e.g. 5-star ratings or dichotomous up/downvoting (cf. Section 4.4.3). Although a different design of a continuous ratio-scaled dependent variable would solve this problem, various success metrics functioning as regressors tend to violate other assumptions. Multiple regression follows the assumption that both regressand and regressors are normally distributed and homoskedastic.

During the course of this work, CIS success metrics with high face validity were often heteroskedastic and not normally distributed. Last, but not least, multiple regression assumes a linear relationship between regressor and regressand, which was also often not given with relevant CIS success metrics. The scatterplot in Figure 4.8 illustrates the mismatch of linear regression and typical success measurement data on the example of an independent success metric *"Average Request Processing Time"* in relation to the dependent variable *"Overall Success"*. The red line graph thereby represents the resulting intercept and regression coefficient from linear regression. The red line graph correctly captures the general trend that a higher average request processing time results in lower overall success. The green graph illustrates the much more precise results from ordinal logistic regression. The overall sum of residuals is much lower than for linear regression. However, the interpretation of the two graphs is fundamentally different, as we will discuss in more detail in this section.

To that regard, we found the recommendations in [DiWi01] misleading and thus investigated for better alternative regression techniques. Both visual inspection of Figure 4.8 and literature suggests that *ordinal logistic regression* [Agre02] is a better match for the given problem. The technique is an extension of regular logistic regression for dichotomous dependent variables to ordinal-scale

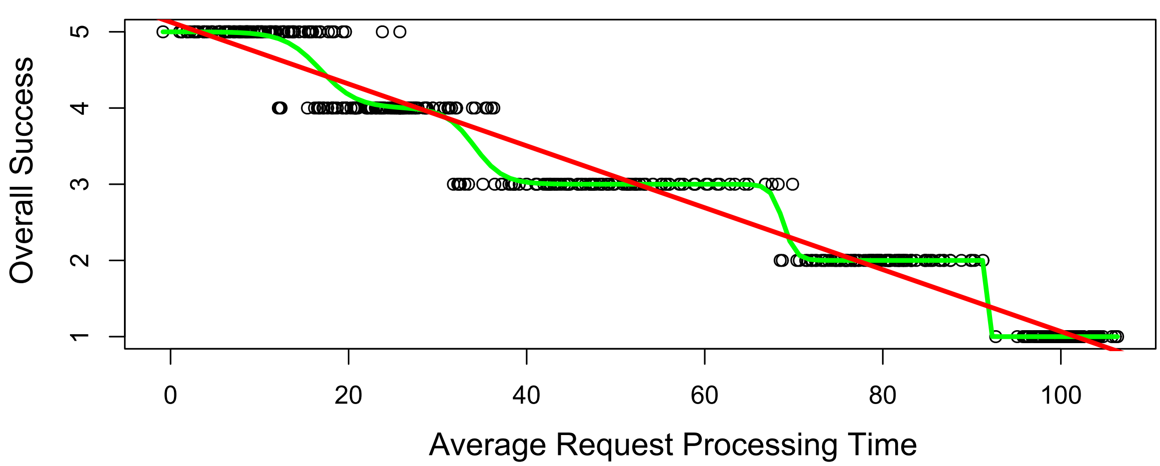

Figure 4.8: Linear vs. Ordinal Logistic Regression for CIS Success Measurement Data

dependent variables. Assumptions on linearity, normality, homoskedacity, and scale levels do not apply as constraints. However, as for multiple linear regression, multicollinearity between individual metrics must be avoided. As for multiple regression, the analysis statistics computed for the ordered logistic regression model support statements on predictive power as well as effect strength, significance and relevance as part of construct validity. However, the interpretation of analysis results is fundamentally different. The logistic regression model bases on *probabilities* and *odds* rather than on *concrete values* as in linear regression.

As further contribution of rather theoretical nature, we transfer our formalization of CIS success models from Section 4.2 to an ordinal logistic regression model. We thereby reuse the formal notation already introduced for multiple regression in Section 4.5.2, thus allowing for a more convenient comparison of the two regression techniques. Given a CIS success model M, let $\mathcal{M}_\Omega$ represent the dependent ordinal variable of overall CIS success on an L-point scale (e.g. $L = 5$ for a five-star rating) and $\mathcal{M}_j, j \in \{1, \ldots, n\}$ the individual success metrics, i.e. the independent variables of the model.

The general *cumulative logit model* [Agre02] for a CIS success model M is then described by a system of $L - 1$ equations - one for each scale level - of the form described in Equation 4.11. For each scale level, the logit is defined as the natural logarithm of the estimated *odds* ζ_l of overall CIS success being rated less or equal to l, i.e. $\zeta_l = \frac{p_l}{1-p_l} \quad (p_l = p(\mathcal{M}_\Omega \leq l))$. In analogy to multiple linear regression, α_l describes the *intercept* for each logit, and β_{lj} the *effects* of each success metric $\mathcal{M}_j$. In the more parsimonious *proportional odds model*, all logits have different intercepts, but share the same effects (cf. Equation 4.12). However, for this more simple model, the proportional odds assumption must be tested first, e.g. with a test of parallel lines [Harr01].

$$ln(\zeta_l) = \alpha_l + \sum_{j=1}^{n} \beta_{lj} \mathcal{M}_j \quad l \in \{1, \ldots, L-1\} \tag{4.11}$$

$$ln(\zeta_l) = \alpha_l + \sum_{j=1}^{n} \beta_j \mathcal{M}_j \quad l \in \{1, \ldots, L-1\} \tag{4.12}$$

Values for $\beta_1, \ldots, \beta_n$ allow statements on effect strength in terms of logarithmic odds ratios or directly as odds ratios, if exponentiated. e^{β_j} describes effect strength as an odds ratio, given a one-unit increase in the metric $\mathcal{M}_j$ with all other metrics constant. Additional statistics on p-values resp. confidence intervals computed for each effect value allow statements on statistical significance resp. relevance of the respective CIS success metric. Standard statistical significance levels are recommended, i.e. $p \leq 0.05$ for significant relationships and $p \leq 0.01$ for highly significant relationships. A standard relevance test for a given metric consists in a simple check on the 95% or even 99% confidence intervals of e^{β_j}. If the value of 1 is contained in this interval, i.e. the odds are even, then the CIS success metric $\mathcal{M}_j$ has no effect and can be removed from the model. In parallel to the R^2 coefficients of determination for linear regression, research literature provides a wide array of *pseudo-*R^2 statistics for measuring model goodness-of-fit, including adjusted versions (see [MiSc96, Mena00] for an overview). Although a scientific consensus on these pseudo-R^2 statistics could not yet be achieved, the semantics of Nagelkerke's (adjusted) R^2 [Nage91] are

Table 4.3: Regression-Based Heuristics for Model Refinement & Operationalization

Situation	**Action**
$R^2 < \tau$	explore for more relevant, yet independent metrics
$p_{e^{\beta_j}} > 0.05$	remove irrelevant metric $\mathcal{M}_j$ from model
$1 \in CI_{e^{\beta_j}}$	remove irrelevant metric $\mathcal{M}_j$ from model
$\lvert e^{\beta_j} \rvert \gg 1$	improve CIS artifact on metric $\mathcal{M}_j$

congruent with the semantics of the standard (adjusted) R^2 statistic for linear regression (cf. Section 4.5.2), measuring the percentage of variance explained by success metrics.

On a higher level of interpretation, we found that regression statistics enable heuristic strategies towards model *refinements* and *operationalization*. Model refinements target the exclusion of irrelevant and the inclusion of potentially relevant aspects of CIS success (cf. Section 3.4). Such refinements contribute to an increasingly reasonable balance between parsimony and completeness and drive the exploration and awareness for CIS success in a comprehensible manner. Operationalization enables communities to derive concrete activities [GSWo10]. Intuitively, significantly relevant, but low-scoring success metrics for a given factor indicate the urgent need to improve the CIS artifact with respect to this respective factor. Such operationalization relates to the essential requirement for *actionability*, widely found in Web analytics literature [Kaus10, Pete04]. Table 4.3 presents a set of heuristics for model refinements and operationalizations, based on regression outcome statistics. If model goodness-of-fit measured with a pseudo-R^2 statistic is below a given threshold τ, an unacceptably low percentage of model variance is explained by its metrics. As a consequence, the model is considered incomplete. Community analysts should explore additional metrics that are statistically independent from $\mathcal{M}_1, \ldots, \mathcal{M}_m$ to avoid multicollinearity. If the effect of a metric is statistically insignificant (i.e. $p > 0.05$) or the confidence interval of the odds includes 1, the success metric should be removed from the model. In the same manner as for multiple linear regression, effect strengths can be used to decide for improvements on the respective success metrics. If e^{β_j}, i.e. the odds of raising overall CIS success are significant, relevant, and greater than 1 resp. lower than -1, the model suggests to improve the CIS artifact under consideration on metric $\mathcal{M}_j$. The resulting rank order of odds enables communities to prioritize improvements on the CIS artifacts. Intuitively, improvements of metrics with higher significance and expected odds should in generally cater for larger impact.

Once the regression model for a CIS success model M is computed from a given data set, the model can be queried. For a more intuitive interpretation in terms of cumulative probabilities instead of odds, literature suggests the isolation of p_l. With Equation 4.13, we can directly compute the probability of CIS success being rated l or less for a set of given metrics values $\{\mathcal{M}'_1, \ldots, \mathcal{M}'_n\}$.

$$p_l = \frac{e^{\alpha_l + \sum_{j=1}^{n} \beta_j \mathcal{M}'_j}}{1 + e^{\alpha_l + \sum_{j=1}^{n} \beta_j \mathcal{M}'_j}} \tag{4.13}$$

Community analysts can query the model by entering different fictional metrics combinations and receive predicted effects in return. The usual procedure is to first choose the most significantly relevant metrics with the highest expected effect strength and then query the model in different possible ways. A typical question is: *"Assuming that the community improves success metric $\mathcal{M}_j$ to a certain value, what is the probability that overall success is rated k afterwards?"*. All of the above described ordinal logistic regression models (i.e. cumulative logit and proportional odds) including all discussed outcome statistics are supported by standard statistical software such as R [IhGe96] and thus allow for the development of CIS success model query tools.

4.6 Discussion

In this chapter, we presented a comprehensive formalization framework for CIS success modeling and validation. We thus contributed to a comprehensive answer towards research question *RQ2*. After a thorough discussion of concrete requirements, we contribute both a structural and a measurement model for CIS success, derived from seminal IS success research literature [DeMc92, GSCh08]. In particular, we model CIS success as multi-dimensional formative index. While the structural part of our CIS success models is mainly used for communication and presentation purposes, we focus on the measurement model. We then presented our formal concept of deriving measurement models of CIS success from a set of generic and at the same time extensible basic data sources, i.e. observation, survey, and overall CIS success rating data, following a formal data integration approach. In particular, we contribute a sophisticated formal data integration concept based on attribute correspondence of unique entity identifiers used across the different data sets. Most importantly, CIS success metrics are parameterized for a modular decoupling from concrete CIS success models, thus allowing their catalogization and re-use in different contexts. We then introduced each individual basic data source in detail. For each source, we contribute abstract formalizations of data views seamlessly connecting to subsequent model construction and validation. With observation data, we enable communities to capture CIS interactions among different agents (users, CIS artifacts, etc.) with the help of enhanced automatic standard protocol logging. With data model implementations for HTTP, XMPP, and P2P, we contribute to a wide coverage of different classes of CIS using these protocols. We thus find that these protocols fulfill our requirements for extensibility and a reasonable trade-off between universality and specificity. With survey data, we enable communities to capture those aspects of CIS success, which are neither implicitly nor explicitly contained in observation data. We clearly separate overall CIS success rating data from all other data sources to accomplish modularity and re-usability requirements.

For model validation, we recommended a combination of expert panel and regression techniques due to their suitability for repeated application in frequent model adaptation and refinement operations. Expert panel techniques thereby hold a baseline function applicable even in the earliest stages of CIS success awareness. Regression techniques function as additional source of statistically rigorous empirical evidence in presence of sufficient representative model data. We furthermore derived a set of heuristic strategies based on validation outcome statistics as means for model refinement and operationalization. Finally, we discussed ordinal logistic regression as improvement over linear regression with respect to precision and predictive power, yet with a completely different, but equally powerful interpretation in terms of odds and probabilities. This discussion is an important contribution to current discourses in IS success research, with SEM and linear regression being the predominant model validation techniques. All stages of our formalization framework build upon the relational model, thus achieving a seamless connection to statistical tools for validation and to the infrastructure and tools presented in the next chapter.

In our conceptualization of a formal CIS success measurement framework, we included observation and survey data as the two main basic data sources. However, user-generated content can be considered as another data source potentially powerful for the derivation of CIS success metrics, in particular with respect to the measurement of information quality and the extraction of sentiments on CIS artifact quality and impact. We deliberately considered the inclusion of respective user-generated content data sources as out of scope for this work for two reasons. First, we focus on the main hypothesis that CIS success is already largely measurable and explainable from observations of CIS interaction and from surveys on CIS success. Second, the fundamental requirement for a reasonable trade-off between universality and specificity is not fulfilled for user-generated content. Each specific data source reflecting user-generated content introduces different data structures and domain knowledge and thus requires the application of specific data analysis techniques. However, the derivation of CIS success factors from user-generated content, e.g. with sentiment analysis or social network analysis is a potential avenue for future work.

With regard to observation data, communities are subject to uncertainty with respect to particular high-level interactions (cf. I in Equation 4.6). This uncertainty results from a lack of compliance to standard protocol syntax and semantics. In an analysis of major public HTTP-based RESTful Web services and their adherence to REST design principles [Fiel00], we identified a dramatic lack of compliance to standard syntax and semantics [RSKl12]. For example, many RESTful service providers systematically model all interactions with resources by overloading the HTTP GET method, although conceptual semantics would have suggested PUT, POST or delete methods (e.g. `GET resource?op=delete` instead of `DELETE resource`). As practical reason for such deliberate ignorance of RESTful design principles, service providers argue with limited browser support for the full set of HTTP methods. Such design issues entail complications during the exploration, creation, and validation of observation data-based success metrics. In agreement with common guidelines for application design [Fiel00, RiRu07], we thus recommend strict compliance to standard protocol syntax and semantics during CIS service and application development.

During the exploration of new CIS success metrics, community analysts frequently experience the need for rather complex computations. In particular, database query statements to compute rather complex success metric values can easily become malicious. In many cases, such complex queries can be resolved to a function computing the combined result of multiple more simple benign queries. We present a first realization of using such functions for success modeling in Section 5.5. However, we confirm the common notion from Web Analytics practice that simple metrics are preferable due to their easy understandability and interpretation.

Chapter 5

MobSOS CIS Infrastructure

In this chapter, we present the MobSOS Infrastructure as a technical realization of a CIS infrastructure with integrated community support for CIS success awareness. This abstract generalized infrastructure is designed to operationalize the MobSOS methodology in arbitrary CIS installations. In particular, we describe the individual components of a MobSOS toolkit for CIS success awareness as part of the ATLAS self-monitoring toolkit (cf. Section 3.1; [Klam10]). It supports typical media transcription operations such as data collection, success metrics exploration, success modeling, and visual analytics. Together, these tools support the CIS success modeling process, based on the ATLAS theory of learning as media transcription (cf. Section 3.4). Implementations of these tools base on our formalizations of CIS success models (cf. Section 4.3) as fluid media for a collaborative negotiation of shared CIS success awareness. To cover a wide variety of existing CIS implementations, we designed the MobSOS CIS success awareness toolkit to seamlessly integrate with multiple architectural styles of CIS platforms. In this work, we mainly focus on distributed Web service infrastructures in the cloud as the current state-of-the-art. We additionally discuss the realization of CIS success awareness in P2P-based community infrastructures as trendsetting scalable and privacy-aware alternative to the cloud computing paradigm. This chapter thus presents contributions towards research question RQ3 (cf. Section 1.2), i.e. how to design CIS technical infrastructures with integrated tool support for CIS success awareness.

In Section 5.1, we begin with an abstract overview of typical CIS architectures and describe the conceptual integration of further components necessary to achieve CIS success awareness along with important non-functional requirements applying to such components and the architecture as a whole. In subsequent sections, we present all MobSOS components in more detail in connection to their particular tasks in the overall MobSOS methodology. In Section 5.2, we present MobSOS Monitoring Pipeline as main component for the automatic collection and enrichment of CIS usage data. In Section 5.3, we present MobSOS Surveys as advanced online service approach for the management and administration of online surveys as main component for the collection of CIS success-related survey response data from community members. In Section 5.4, we present MobSOS Query Visualization as an online visual analytics approach supporting the exploration and collection of CIS success factors and metrics towards the development of CIS success models. In Section 5.5, we finally present the MobSOS Success Modeling service for the creation and exchange of formal representations of CIS success models in the form of different evaluation products.

5.1 CIS Success-Aware Community Platform

Long tail communities typically employ ensemble combinations of different digital media in their practice. These media are technically realized as services and tools. As discussed earlier, contemporary CIS are thus conceived modular ensembles of artifacts in the form of distributed services, tools, and repositories, fusioned into one virtually integrated CIS. Users access this CIS with different devices, from desktop computers to sensor-equipped smart devices. In order to bring all these different backend and frontend components together into one CIS experience, communities require a modular, yet reasonably integrated CIS platform. In the next sections, we discuss an abstract CIS architecture incl. CIS success awareness extensions (cf. Section 5.1.1) and present a list of important non-functional requirements (cf. Section 5.1.2).

5.1.1 Abstract Architecture & CIS Success Awareness Extensions

The grey parts of Figure 5.1 show the archetypical high-level abstraction of a virtual modular CIS platform architecture. It should be noted that practical instances of this abstract CIS infrastructure might be distributed, e.g. to different data centers or to different P2P nodes.

As part of a community's shared repertoire, a *community repository* serves as collective and historic knowledge base containing all information relevant to the community. Effectively, such a repository is realized with a set of heterogeneous databases, ideally maintained under community control. A set of available *CIS services* provides support for actual community-specific practice, including the interaction with the community repository for persistent data storage and management purposes. Thereby, services establish the core business logic of the CIS available to its hosted communities. A small subset of *core services* are essential and sufficiently generic for re-use in multiple CIS ensemble contexts. Core services include authentication, authorization and community management for managing the access to both community repository contents and CIS service functionality within and across communities. Further examples for services sufficiently generic for application across different community contexts are chats, social media or multimedia sharing [SKJR06].

However, highly specialized communities often face needs for additional or adapted services custom-tailored to specific community practice. Thus, any CIS platform must support *extensibility*. We particularly achieve extensibility by arbitrary new community services with service development frameworks. These frameworks allow access, re-use, and combination of existing and new services to complete mash-up ensembles. Effectively, CIS service artifacts are Web services exposing their functionality in *application programming interfaces (APIs)* over standard protocols. To stay open for multiple - even proprietary - application protocols, CIS usually offer a *connector* concept and thereby support extensibility on the protocol level. Connectors are usually accompanied by *logging modules*, allowing to log protocol data for inspectional purposes. *CIS tools* serve as end-user frontends for communities and realize concrete applications with the help of CIS service ensembles [SHP*11]. Effectively, such tools are realized as desktop, mobile or browser applications interacting with the CIS platform backend and its services over one or more of its connectors.

To facilitate CIS success awareness for any concrete CIS following the above abstract architecture, MobSOS follows an *integrative* approach making use of existing concepts and frameworks instead

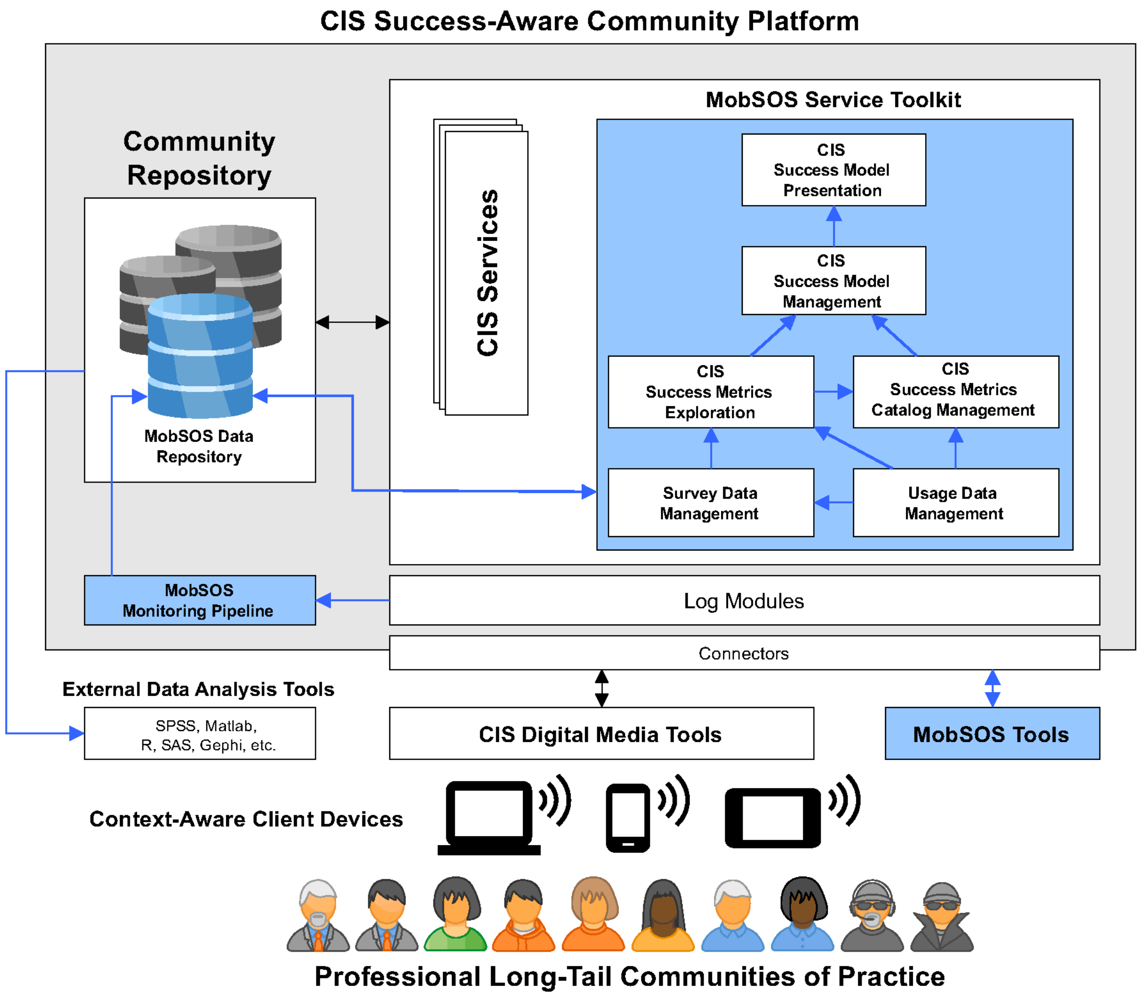

Figure 5.1: Abstract CIS Success-Aware Community Platform Architecture

of introducing complex extensions to the aforementioned overall abstract CIS platform architecture. The parts of Figure 5.1 highlighted in blue show the fundamental components to be added to any CIS to foster CIS success awareness. Logging modules provide input for MobSOS Monitoring Pipelines. A *MobSOS Service Toolkit* in connection with a set of *MobSOS Tools* supports the interaction with CIS sucess awareness extensions by community members.

Monitoring pipelines are designed for the automatic collection of CIS usage data (cf. Section 4.4.1). Usage data enables the context-aware observation of community interaction with the CIS and its services via CIS tools. Except for configuration and maintenance, community members never interact with logging modules and pipelines directly. MobSOS services establish the support for CIS success awareness in communities from a backend perspective. By adhering to the CIS's service extension framework, they seamlessly integrate with the overall set of CIS services as first-class citizens. The MobSOS service toolkit is designed to support communities in developing agency wrt. CIS success awareness. The design of this toolkit reflects the MobSOS methodology's process from survey management and data collection over CIS success factor and metric exploration, cataloging, CIS success modeling, to the presentation of evaluation products facilitating CIS success awareness. MobSOS tools establish the support for CIS success awareness in communities with a focus on end-user frontends. In the same manner as CIS tools are frontends to CIS service ensembles, MobSOS tools are frontends to MobSOS service ensembles. MobSOS tools are either realized as full-featured *stand-alone applications* or as *light-weight instrumentations* of CIS tools.

By design, basic usage and survey data as well as all higher level digital media artifacts such as CIS success models or visualizations are created by transcription (cf. Section 3.4). These artifacts are considered and handled as integral part of a community's shared knowledge. Consequently, all data collected, processed, and produced with the help of MobSOS components is stored in the MobSOS data repository as part of the community repository.

5.1.2 General Non-Functional Platform Requirements

Our concrete designs and technical implementations of this rather abstract architecture as well as the MobSOS components in concrete community contexts followed a central set of general non-functional requirements from the very beginning.

We guided the design of our abstract CIS success-aware architecture with the central requirement for *modularity*. In the same sense as all other components in our largely service-oriented architecture, we designed MobSOS as a tool kit of components for *seamless integration* with both basic infrastructure (e.g. authentication and group management services) and arbitrary service extensions. We thereby deliberately avoided tight coupling and the connected necessity to change any existing parts of a CIS infrastructure. Instead, we applied proven Web technologies and concepts to achieve integration by loose coupling. With our modular design involving a clear separation of concerns, we furthermore support the *scalability* of our approach. The growth and emergence of arbitrary concrete CIS in terms of new tools and services is thereby technically independent from and thus not limited by the MobSOS platform extensions. However, given the design of MobSOS services as regular CIS services like any other service on a community platform, we provide for a high degree of extensibility by new, yet unanticipated MobSOS tools by combining existing ones.

With respect to the ontology of our approach, in particular the inherent heterogeneity of CIS across different long tail communities, we planned for the highest possible degree of MobSOS reusability across communities and their concrete CIS implementations. We particularly addressed this requirement with an appropriate degree of *genericity* in all implementations of MobSOS components. This requirement becomes most apparent with our implementation of a rather generic visual analytics service (cf. Section 5.4) to explore for the widest possible range of CIS success metrics.

Last, but not least, in order to avoid unnecessary obtrusions of regular community practice and disruptions of CIS experience, we designed MobSOS components for appropriate performance and availability. We thereby paid special attention to allow for *real-time* behaviour, where necessary. Real-time capabilities are important prerequisite to achieving levels of awareness close to situational awareness [Ends95]. This requirement particularly applied to the collection of observation data in near real-time with our monitoring pipeline concept (cf. Section 5.2), which in turn allows for near real-time CIS success analytics. With respect to responsiveness of visual analytics tasks, real-time capabilities are also closely connected to scalability considerations with respect to the underlying analytics data storage and retrieval system. In particular, large amounts of analytics data continuously collected from the observation of CIS use can slow down respective analytics queries.

Over the whole course of this thesis work, we monitored these requirements and improved existing implementations. In particular our monitoring pipeline for the automatic collection of observation data is a result of experiences from multiple implementations and adaptations for different protocols in different community contexts. In the following sections, we discuss the individual components of the MobSOS tool kit realized in the context of this work in more detail. For each component, we list specific requirements, describe the concepts and realizations addressing these requirements, and present related MobSOS applications and CIS tool instrumentations with MobSOS.

5.2 MobSOS Monitoring Pipeline

While communities interact with the services and tools in their CIS, this interaction is usually logged on the level of the underlying application protocols. As discussed in Section 4.4.1, usage data logs foster the self-observation of community activity and the derivation of respective CIS success metrics with appropriate aggregations and transformations. However, further focused analysis requires the persistent storage of relevant and ideally context-enriched usage data in databases, along with contextual metadata supporting localization and addressing [JaKl05, Klam10]. MobSOS realizes this requirement with a pipeline concept.

The MobSOS Monitoring Pipeline [ReKl13] realizes the collection of observation data incl. its enrichment with contextual data. Its main functionality is comparable to extraction, transformation and loading process chains known from data warehousing approaches such as *OLAP (OnLine Analytical Processing* [JLVV00]. The basic idea is to intercept interactions between community members and CIS artifacts on the level of the underlying communication protocol and to collect transcripts about this interaction into the community's shared repository along with contextual information of technical, physical or social nature [ReKl09]. As such, the MobSOS Monitoring Pipeline [ReKl13] is one of the two main technical means supporting the first steps of the MobSOS methodology (cf. Chapter 3) in terms of context-enriched observation data collection.

5.2.1 Requirements

Most importantly, usage data collection must fulfill the requirements already formulated in Section 4.1. Given the inherent diversity of long tail communities, the collection of usage data must be sufficiently generic to allow a wide array of unanticipated viewing angles on data for the exploration of CIS success metrics. Existing public service solutions such as Piwik [1] or Google Analytics[2] usually restrict communities to analyzing Web site or product success in terms of established revenue-focused success metrics such as conversion, churn and retention rates [Pete04, Pete06, Kaus10]. With MobSOS Pipelines, we pursue a generic data collection approach prepared for unanticipated CIS success metrics. However, the dual requirement for *data relevance* must also be fulfilled to allow focused analysis. Thus data collection should only reflect those types of community interaction

[1] https://piwik.org
[2] https://analytics.google.com

that contribute relevant insights in later analyses. Irrelevant usage such as access to static website content or inline libraries should be filtered out.

Usage data collection techniques must *avoid the need for excessive instrumentation*, given the inherent scarcity of developer resources in long tail communities. Contemporary usage data monitoring and collection approaches [Kaus10, CrPo09] require such instrumentation in order to achieve more precise measurements for predefined metrics. This instrumentation also restricts further analysis to only those aspects of CIS use that were instrumented before. As such, the requirement to avoid excessive instrumentation is related to the genericity requirement stated earlier. Despite its genericity, protocol log data must sometimes be augmented with additional data sent by CIS tools or explicitly by community members that is not captured per-se. Standard application protocols therefore provide extension mechanisms (cf. Section 4.4.1). MobSOS uses these mechanisms as means for lightweight instrumentation, however with the clear intent to keep instrumentation as low as possible. Compliance with our conceptual *data integration* concept (cf. Section 4.3) is required to guarantee convenient joinability of the different data sets in later analysis steps.

In terms of performance, usage data collection must not interfere with regular CIS interaction. Current instrumentation approaches sometimes cause substantial overheads on the end-user side, thus slowing down regular CIS interaction. We consider such ineffectiveness as harmful invasion hampering regular community practice. If usage data collection blocks regular use of the system, then we risk bias in time-based measurements (e.g. service response time as success metric). MobSOS should thus avoid this substantial overhead. Usage data collection must guarantee scalability, in particular in terms of sufficient data throughput to cope with possibly high loads of community interaction with the CIS. This also holds for the further enrichment with context data related to usage data, as we will discuss in the next section. Due to the comparably small size of long tail communities, this requirement might seem irrelevant for CIS. To be realistic we must however consider CIS platforms as environments hosting large numbers of small communities.

Finally, any usage data collection approach must conceptually be applicable to different architectural styles. Given that CIS platforms usually include different architectural patterns, usage data collection approaches must conceptually follow a modular and architecture-agnostic design for efficient re-use in different technical deployments.

5.2.2 Concept & Realization

We realized all of the above requirements with the help of the structural design pattern of a *pipeline*, well-known from UNIX systems [GHJV95]. Figure 5.2 shows our conceptualization of such a pipeline as chain of processes, where the output of each process is the input of the next. The entry point to any MobSOS pipeline is a buffered *protocol log data source*. Raw log data d_0 is then piped through an arbitrary number of linked *elements*. The initial *pre-processing elements* realize non-idempotent data transformation functions P_x with $P_x(d_i) = d_{i+1}$, such as tokenization, filtering and anonymization. All subsequent elements are idempotent, i.e. $P_x(d_p) = d_p$. The first of these elements stores the pre-processed log data d_p to the MobSOS database.

Subsequent *enrichment elements* derive further context information from preprocessed data with the help of data enrichment functions E_y with $E_y(d_p) = e_y$ and persist the resulting data e_y in the MobSOS database, thereby guaranteeing referential integrity to the original pre-processed data d_p.

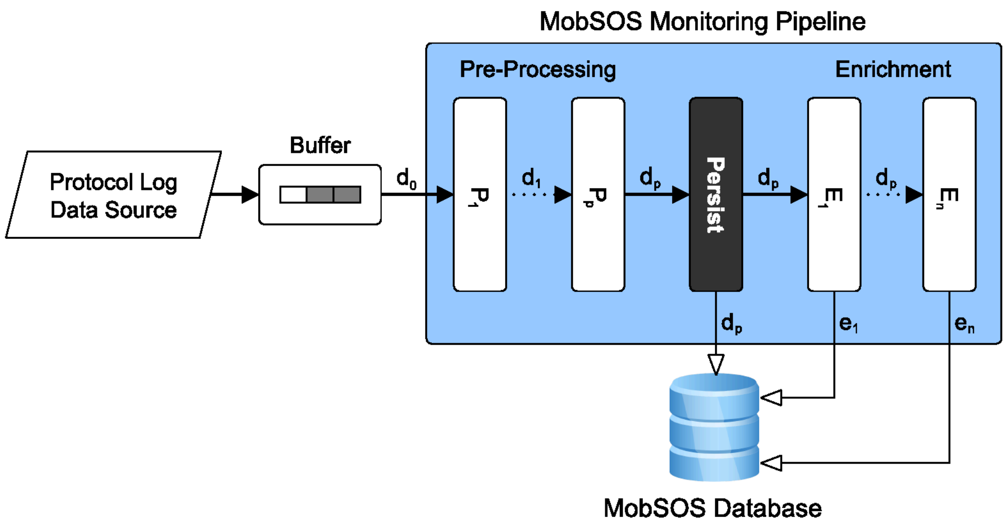

Figure 5.2: The MobSOS Monitoring Pipeline Concept

The underlying database engine can join pre-processed log data and enrichments in one usage data vector $\delta = (d_p, e_1, \ldots, e_n)$. In practice, we use an enrichment function for the derivation of user u and used artifact a from access tokens contained in the log data ($E_{auth}(d_p) = (u, a)$). Other examples are *geo-location*, i.e. deriving geospatial client location from IP addresses, or *interaction clustering*, i.e. assigning individual interactions to categories of interaction types. Given the buffer between data source and pipeline, we optimized pipeline throughput with the introduction of a pool of multiple reusable asynchronous *log entry workers* as performant solutions in producer-consumer scenarios [GHJV95]. Each worker acts as a consumer, repeatedly removing a single log data entry from the buffer, traversing it through all elements of the pipeline, and ultimately storing log and context information in the MobSOS database. As such, the MobSOS Monitoring Pipeline is a basic building block for collecting context-enriched usage data.

In cases of small-scale CIS deployments, piping a single log stream into a singleton instance of a monitoring pipeline is sufficient. In more distributed federated CIS scenarios, multiple log data streams must be collected and unified into a monitoring pipeline from different sources. Multiple patterns are possible for the realization of distributed protocol log data collection. In the context of several bachelor, master, and diploma theses guided in this work by the author, we realized log data collection modules with *reverse proxying* for Web-based CIS using HTTP [Renz08, Schl11] and XMPP [Schl09, Grun10] and with *publish-subscribe* patterns for P2P-based CIS [Jans13, Lang13].

With the *reverse proxy* pattern [Somm03] (cf. Figure 5.3, top), different *services* distributed across multiple *hosts* are transparently unified under one endpoint with the help of a reverse proxy configured to dispatch client interaction to respective CIS subsystems. Such scenarios effectively boil down to the centralized CIS approach with one singleton pipeline maintained at the reverse proxy level. This approach was found to be most convenient, as protocol log data collection happens at one place (i.e. the reverse proxy) for a potentially large number of proxied services. This approach is suitable for a large number of scenarios, where the major part of community interaction with the CIS happens as service interaction over the HTTP protocol.

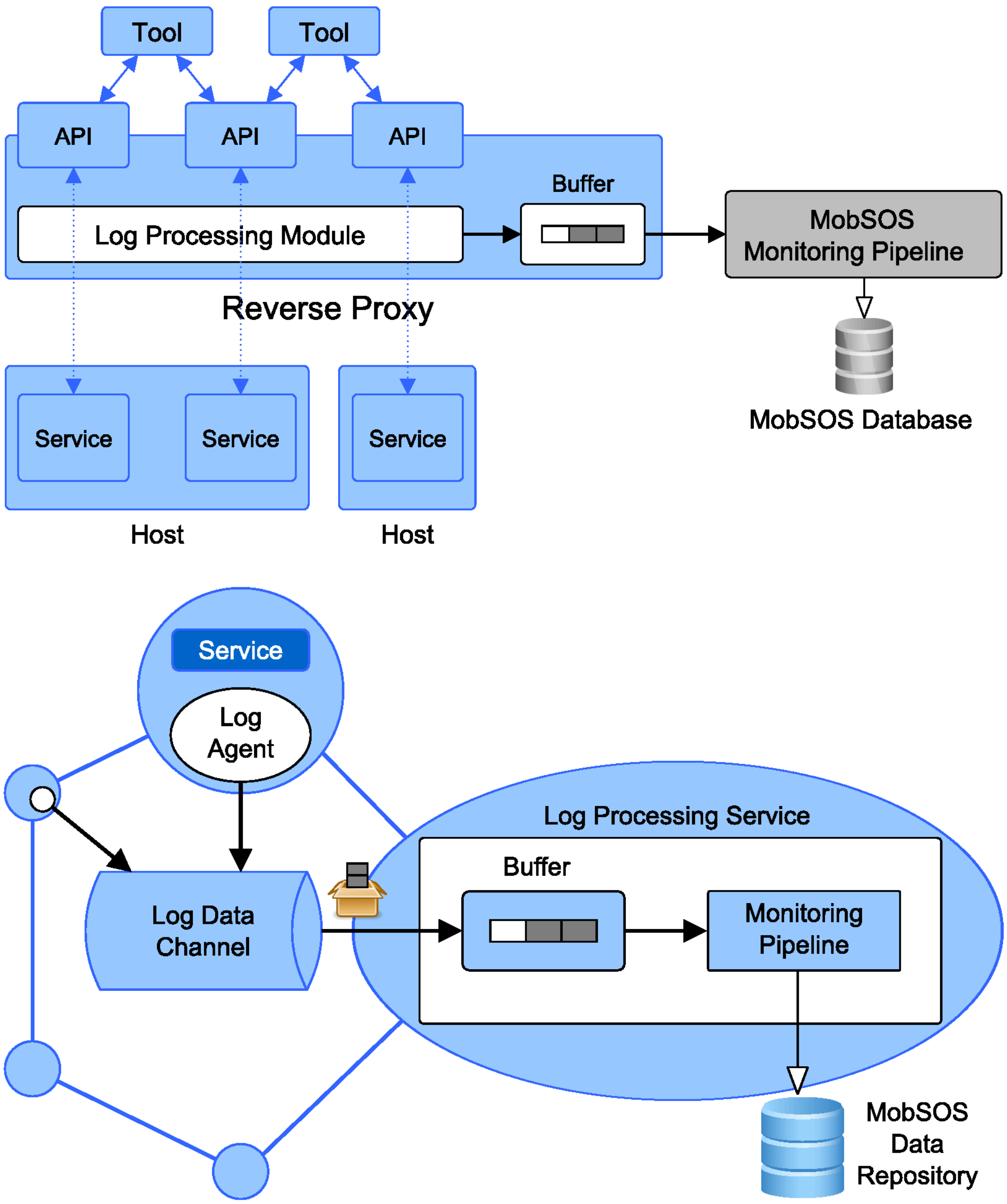

Figure 5.3: MobSOS Pipeline - Patterns for Log Data Collection

The *publish-subscribe* pattern [GHJV95] (cf. Figure 5.3, bottom) applies to distributed service provisioning network scenarios. In such scenarios, every node in a network potentially acts as host for multiple communities and services collaborating with each other. Community interaction with the CIS produces observation data as by-product of regular operation at each individual node. Each node willing to share log data therefore maintains a dedicated *log agent* collecting data in a local buffer. Once this local buffer reaches a threshold, the log agent packages the contents of the buffer and *publishes* the packet to a dedicated *log data channel*. A dedicated *log processing service* agent subscribes to the channel. Upon notification of incoming new packets the service agent takes care of unpackaging and pushing the data into the pipeline via a buffer.

CIS Tool Instrumentation

In general, the collection of usage data with MobSOS Monitoring Pipeline is designed for minimal invasiveness for end-users, researchers, and developers (cf. Table 4.1). Where possible, we introduced enrichment elements deriving contextual information from the available information contained in usage data. However, further CIS success analysis may require additional context information, that is not transferred with regular protocol data by default, but could be transferred with respective protocol extensions. We therefore pursue a lightweight client instrumentation approach that enables CIS tools to actively transfer additional data by exploiting the respective application protocol's extension mechanisms (e.g. extension headers for the HTTP protocol). With this instrumentation approach, developers can augment regular usage data with arbitrary extensions. These extensions can be explicitly prompted from the user, automatically generated by the CIS tool (e.g. specific high-level events) or retrieved from the CIS tool's surrounding environment (e.g. sensors on mobile devices). MobSOS uses this client instrumentation concept for the active transfer of user-prompted current community context c, which is not part of any standard application protocol at the moment. A further example is the retrieval of geo-location data from GPS sensors in mobile devices, which is much more precise than IP address-based geo-location services, realized as pipeline enrichment elements.

5.2.3 Discussion

Altogether, with the help of the MobSOS Monitoring Pipeline and respective lightweight CIS tool instrumentations, we achieve the full set of pivotal elements required for MobSOS observation data (cf. Section 4.4.1), including arbitrary extensions. In Section 6.3, we discuss the design of a MobSOS Monitoring Pipeline instance for observing end-user activity in a personal learning platform in more detail. In the context of this work, we have implemented monitoring support for several different protocols, among them open standard application protocols such as HTTP or XMPP, but also proprietary protocols used for the communication between nodes in P2P network substrates (e.g. Pastry [RoDr01]) as examples of truly distributed CIS architectures. Across protocols, we find that the derivation of operational interaction semantics from syntactical constructs is possible in principle. However, we also find that in particular operational semantics are often misinterpreted or abused by service providers for different, mostly technical reasons, thus leading to uncertainty by deviating from standard semantics in actual implementations [RSKl12]. For both reverse proxy and publish-subscribe approaches the pipeline itself is the main bottleneck through which all collected data must traverse. However, in all our case studies we experienced comparably low amounts and sizes of transmitted data buffer contents in typical long tail community contexts. These data volumes do not cause any significant congestion that would effectively render real-time data collection impracticable. In cases of congestion, multi-pipeline approaches distribute load, but also introduce new challenges such as the avoidance of duplicate entries or synchronization issues. In general, the pure use of protocol data for analytical purposes has often been criticized for several reasons. Among the main reasons are data impurity and lack of expressiveness. The Web Analytics domain recommends more recent approaches such as Web beacons or JavaScript tagging [CrPo09, Kaus10]. The learning analytics domain recommends the additional instrumentation of learning tools with data production frameworks [WNVD07], claiming to yield much cleaner and to-the-point data.

However, this work takes a sceptical stance towards such approaches, since they require additional design and development efforts with regard to instrumentation. In particular in long tail community contexts with their inherently strong asymmetry in terms of high numbers of end-users vs. scarce numbers of developers, the declared goal of MobSOS was to minimize additional development efforts, among them additional instrumentation for analytical data production. The choice of using standard protocol data serves this goal, since their collection is a by-product of regular CIS operation, normally used by system administrators for inspection purposes. Most standard application protocols allow for custom data extensions still allowing for additional instrumentation.

Furthermore, for most open standard protocols there exist developer APIs across programming languages. In contrast, higher-level data instrumentation APIs are usually not available in multiple programming languages. Effectively, the standard protocol logging approach developed in this work is much more lightweight and generic than other techniques. Together with the concept of data enrichment elements, the expressiveness of the collected data is optionally enhanceable with minimal effort for developers. In general, communities can only learn from their history, if it is recorded for later analysis. Such a history is recorded with the help of MobSOS Pipelines and considered as first-class citizen in a community's shared repertoire [Weng98].

5.3 MobSOS Surveys

Even though communities can already capture a major part of their CIS interaction, allowing for objective observation, subjective CIS success aspects can inherently not be derived and measured from usage data. MobSOS thus allows to capture additional aspects of CIS success not derivable from any observed CIS use with the help of its built-in online survey facilities. Perceived satisfaction or perceived benefits are typical examples of such subjective, immanent CIS success factors. Surveys thus constitute the second main pillar of data collection in MobSOS. In contrast to the indirect approach of deriving success metrics from observation data, surveys targeted at CIS artifact success allow for a comparably direct transfer of responses to success metrics.

In the IS discipline, survey research has a long tradition as valuable research tool for both quantitative and qualitative research [Krae91], especially in the domain of IS success research [Stra89]. For gathering subjective impressions of CIS success, survey research is well-suited for application in long tail communities (cf. Section 4.4). Survey research is however frequently criticized for its low response rates, weak linkages between units of analysis and respondents, and over-reliance on results, especially if applied as single method approach, where multi-method approaches are needed [PiKr93]. In this section, we discuss several technical approaches to overcome such problems particularly occurring in long tail community contexts.

Although a plethora of publicly available online survey services exist on the market, we identified a set of requirements for communities not fulfilled in public online services. We thus designed MobSOS Surveys as integrated component of the MobSOS toolkit, custom-tailored to the requirements for use in long tail community contexts. In addition to the collection of context-enriched observation data, the MobSOS toolkit includes service and tool support for managing and conducting online surveys focused to assessments of CIS success. We thereby include advanced schemes to make best use of MobSOS usage data to improve response relevance and timeliness.

5.3.1 Requirements

Data integration of survey data with usage and other data is among the most important requirements. In Section 4.3, we already discussed the importance of guaranteeing joinability of the different data sets included in the analysis of CIS success. Using an external online survey service urges communities to control for data integration themselves. MobSOS considers data integration as one of its main principles and thus takes this burden from communities.

As for usage data, *protected storage and access* to survey data is another requirement gaining importance and wide public attendance. Most online survey services pursue a cloud computing model, involving data storage in data centers of unknown location and underlying data protection legislation. We argue that such public cloud service provisioning models fundamentally violate requirements for protected storage and access. Effectively, service providers do not *own*, but *control* the data produced by the communities. Furthermore, service providers might cancel services, thus urging communities to migrate their survey data. Resulting issues regarding data ownership and privacy recently gain public attendance and skepticism against cloud-based service provision. MobSOS considers survey data as part of a community's shared repository. Data storage and access should be strictly limited to community members and controlled premises.

With the requirement for *response relevance* we refer to the intuition that a community member can only make *relevant* statements about a specific CIS artifact or feature in a given community context, if that person has used and evaluated it before. As a consequence, community members should only be included in respective success-related surveys, if the above condition is fulfilled. Access to the survey participant's usage data enables checking and enforcing response relevance. However, in presence of participation inequality [Niel06], it is reasonable to raise survey participation by loosening the above constraints, e.g. by allowing anonymous survey participation, which cannot be linked to any prior CIS artifact usage.

Response immediacy is another important requirement directly related to response relevance. Taking into account the inherent dynamicity and emergence of CIS success, communities should collect information on CIS success in a timely manner. Intuitively, the response to a success survey is most valuable, when assessed close to the timepoint when the artifact or feature under scrutiny was used. At the same time, community members should not be burdened with requests for survey participation too early and frequently. Access to the survey participant's usage data enables better-informed timing of survey administration. For example, community members should only be asked for survey participation on a given artifact, if they frequently used it. Response immediacy also requires targeted addressing of community members for the ongoing and repeated conduction of surveys. A central community repository of ongoing surveys, openly accessible to all members at all times, is a minimal support for such addressing. Response immediacy is only given with explicit intervention by researchers actively advertising surveys to knowingly relevant participants. To even increase response immediacy, community members should be able to directly participate from within the surveyed artifact. Ideally, survey participation is triggered automatically upon the occurrence of certain events such as repeated use of the surveyed artifact within a predefined open or closed survey period. Such integrated response collection is usually achieved with participation frontends integrated in a CIS tool's user interface and powered by a backend survey service API. Community members either receive navigation links to a survey participation frontend hosted by the service or implement their own participation frontends, powered by the service API.

Last, but not least, questionnaire form *re-use* and *customization* should be explicitly supported. This requirement is motivated by our guidelines from Section 3.5, where we recommend the re-use of validated survey instruments across different contexts. Technically, an *adaptive template* approach including *open description formats* for questionnaire forms helps realize this requirement.

5.3.2 Concept & Realization

Consistent with our CIS success-aware architecture in Figure 5.1, MobSOS Surveys consists of two parts, i.e. a *backend service* part for data management exposing its features over an API, and different integrated and stand-alone *frontend tools* serving as UI to the service over the API.

Most importantly, the underlying data model follows the formal data integration scheme described in Section 4.4.2. With this integration, survey administration and conduction play hand in hand with usage data collection and allow communities to analyze and use both data sets as one in real-time. Besides basic survey management, the service includes two advanced features enabled by this data integration and directly contributing to response relevance and immediacy: *adaptive survey forms* and *event-driven micro-surveys*.

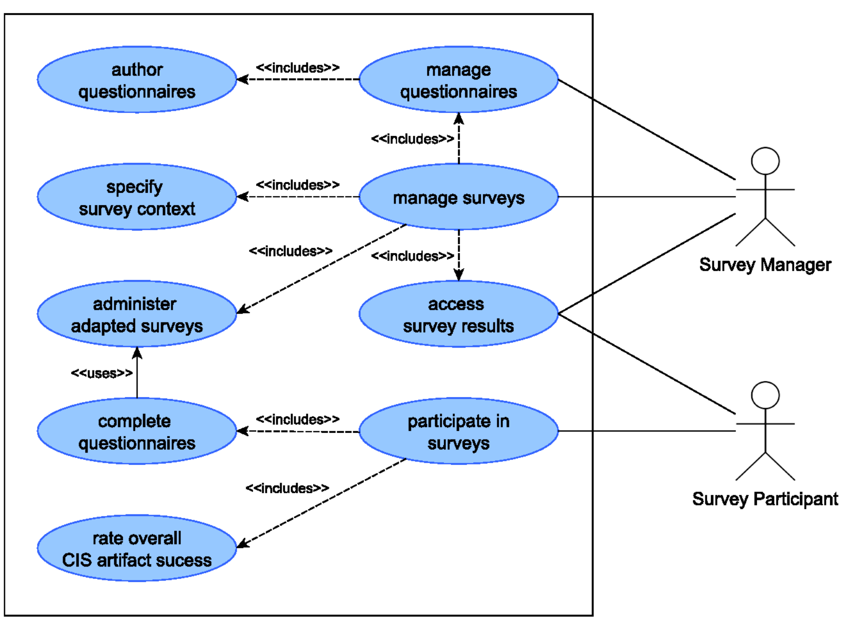

Figure 5.4: MobSOS Surveys - Use Cases

The basic functionality of MobSOS Surveys is explained in Figure 5.4 as UML use case diagram. The service supports both *survey managers* and *survey participants*. Survey managers are supported in designing and *managing questionnaires* re-usable in different survey contexts and in *managing surveys*, related to a CIS artifact in a given community context and to a given survey period. The role of a survey manager is mostly played by community experts initiating explicit evaluations of CIS artifacts. Figure 5.5 shows a browser-based frontend for survey management. Survey participants are supported in submitting survey responses via service-generated participation frontends, adapted to the respective participant and survey context. MobSOS Surveys furthermore provides simple export functionality for results (e.g. comma-separated vectors, boxplot visualizations). These export features are available to both survey managers and participants, thus following Wenger's philosophy of a shared repertoire including the community's history on assessments of CIS success. With particular respect to modeling CIS success and to producing evaluation products, the MobSOS Query Visualization (cf. Section 5.4) and MobSOS Success Modeling (cf. Section 5.5) services provide more sophisticated options for reusable data visualizations. In the following paragraphs, we discuss the more advanced features of MobSOS Surveys with particular respect to the requirements of response immediacy and relevance.

Adaptive Surveys

In order to support basic requirements for personalization, response relevance and immediacy in the collection of survey data, MobSOS Surveys realizes a built-in scheme for adapting questionnaire forms to their respective survey context. MobSOS Surveys allows the definition of standardized questionnaire *form templates* and *responses* with the help of a simple XML-based open markup language. Figure 5.6 shows an overview of the language schema.

For modeling questionnaire form templates, the main structuring elements are *pages*. A page can either present purely informational content (*InfoPage*) (e.g. for navigational hints) or ask for response (*QuestionPage*). Each page defines a name and contains a dedicated element for instructions. By design, each question page contains exactly one item from a list of predefined, designer-controllable item types. At the moment, MobSOS Surveys supports three different item types: *dichotomous* (e.g. yes/no questions), *scale* (e.g. Likert scales) or *open* (e.g. additional comments). While scale and dichotomous items are rather suited for quantitative feedback, free-text items add support for collecting qualitative feedback. Each question page allows to define generic item parameters such as identifiers for addressing or response optionality, as well as additional item type-dependent parameters such as scale ends and labels.

Questionnaire responses serve as simple containers for collecting answers to individual items. Each response document resp. each individual answer must directly relate with the questionnaire resp. questionnaire item it was submitted for. This relation is realized with foreign key dependencies, as indicated by the red dotted lines in Figure 5.6. Conceptually, this simple structure of questionnaire responses allows straight-forward mappings from XML to a relational table format for convenient storage, retrieval, and integration with other MobSOS data, in particular usage data. Altogether, our one-item-per-page design intends to keep questionnaire forms simple and compact and to control user experience on mobile devices. This design thus supports our CIS success modeling guidelines to balance parsimony and completeness (cf. Section 3.5). The extension by further item types (e.g. multiple-choice) is possible. However, by design the open questionnaire language should stay as

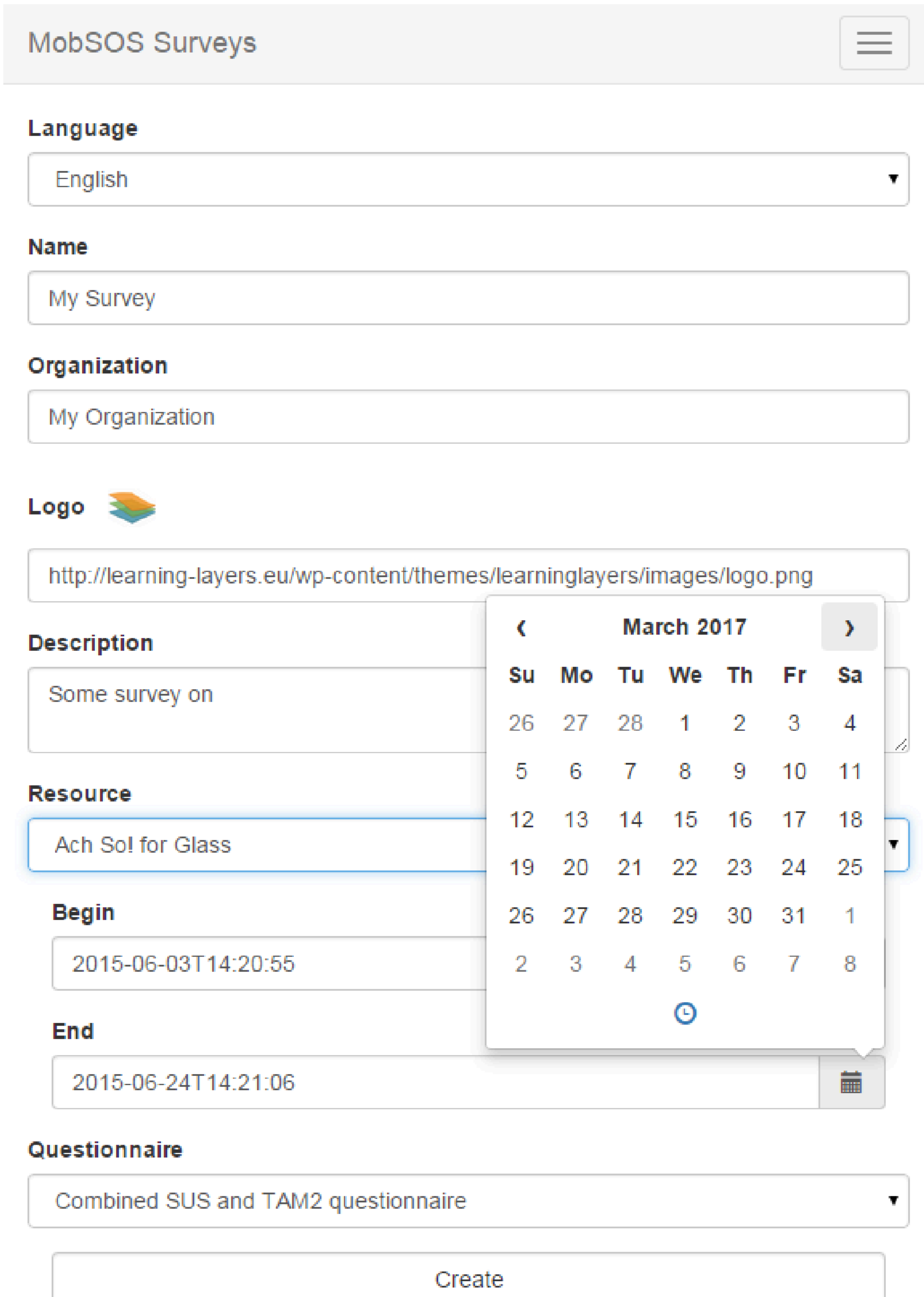

Figure 5.5: MobSOS Surveys - Browser-Based Survey Management Frontend

simple as possible and keep the one-item-per-page guideline. Presenting multiple items on one page leads to serious user experience issues on small displays.

We consider internationalization as standard, yet very important additional part of questionnaire form adaptation. We therefore make use of the built-in language attributes of the XML language. Community members can specify their preferred languages in the respective tool clients or in the language settings of their favorite Web browsers. The adaptation engine reflects these settings by returning a questionnaire form in the preferred language, if a respective localization is available.

The XML schema definition of the MobSOS Surveys open questionnaire markup language is available as part of the MobSOS Surveys Open Source repository. MobSOS Surveys includes built-in support for checking and enforcing validity resp. integrity of questionnaire form templates and responses with the help of XML schema validation and additional consistency checks to guarantee response validity. Besides the original XML representation, mappings to JSON are available for more convenient use of the MobSOS Surveys API in Web applications.

We furthermore extended MobSOS Surveys' questionnaire markup language with a predefined, yet extensible set of *placeholder variables* allowing personalized, context-dependent and usage data-aware instantiations of the questionnaire template. With such personalization and adaptation features we achieve better targeted addressing of community members on individual and community level. A core set of placeholder variables covers survey context and metadata on all involved entities (survey, community, surveyed CIS artifact), retrievable for any instance of the respective questionnaire form template independent from the particular survey participant. With another core set of *participant-dependent variables*, MobSOS Surveys enables dynamic in-survey access to person data (e.g. name, age) as well as a set of basic usage metrics derived from the survey participant's CIS usage data on the surveyed artifact (e.g. number of interactions or period of use). These

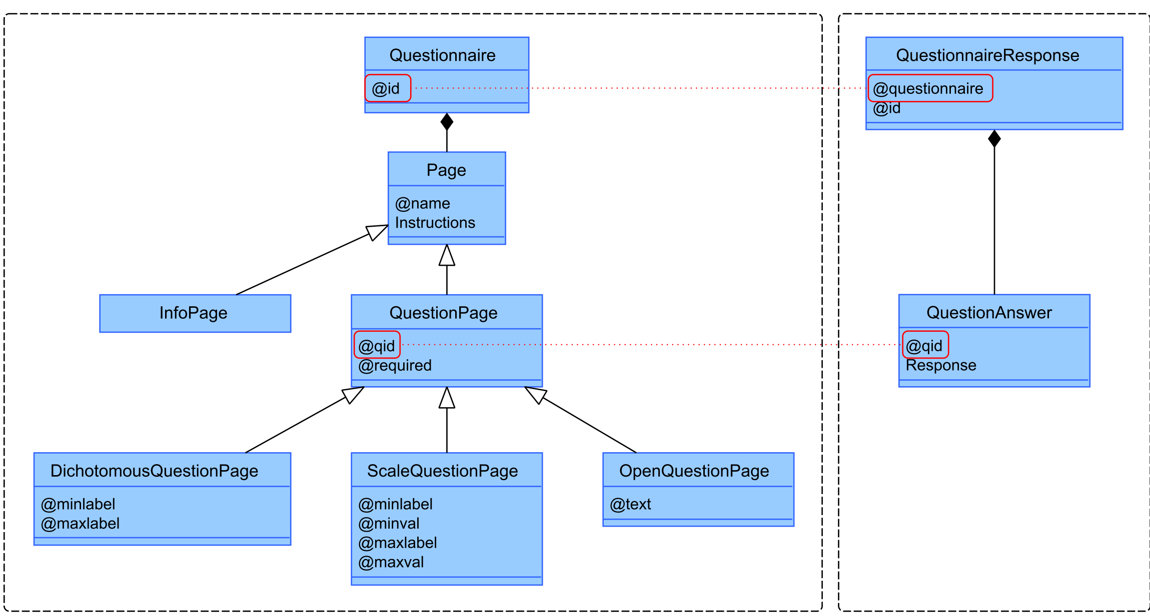

Figure 5.6: MobSOS Surveys - Open Questionnaire Markup Language Schema

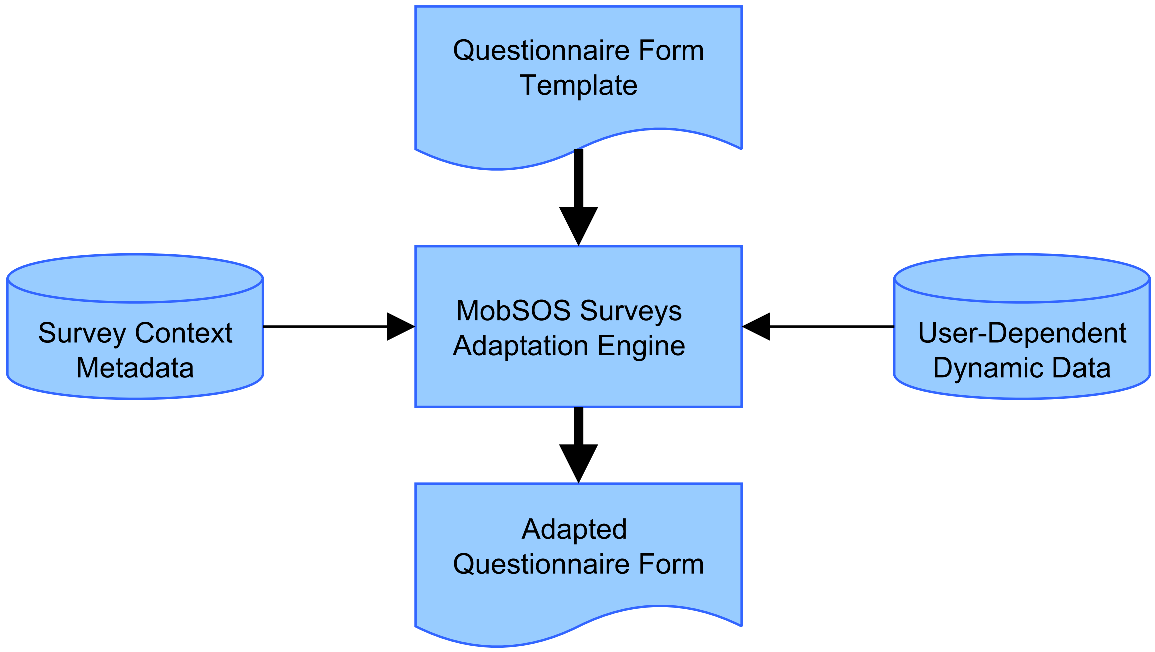

Figure 5.7: MobSOS Surveys - Adaptation Engine Concept

variables are only reasonable in questionnaire form instances administered to authenticated survey participants. Apart from the initial core set of variables, MobSOS Surveys supports the extension by custom variables tailored to specific community contexts and related CIS artifacts.

Figure 5.7 explains personalized questionnaire form generation by adaptation. Central part is a dynamic *adaptation engine* including an extensible set of replacement rules for placeholders. Main input to this engine is a questionnaire form template, including placeholders. The adaptation engine replaces variable keywords with access to survey context and user metadata as well as dynamic aggregations of context and user-dependent usage data. The result is an adapted questionnaire form, ready to be administered to the requesting survey participant.

Figure 5.8 gives a practical impression of our open questionnaire form template language and adaptation engine. The example presents a question item used in a custom survey instrument developed for an early case study on MPEG-7 multimedia description services in a cultural heritage community (cf. Section 6.2). The page defines a *mandatory* 11-notch *scale* item with values and labels of *0 (poor)* and *10 (high)* at its scale ends. An element for instructions contains a statement on the authenticated participant's media use, followed by the item's original question. The statement contains three variable keywords `SURVEY.RESOURCE`, `MEDIA.VIEWED`, and `MEDIA.FORMATS`, serving as placeholders for survey context information and simple usage data-driven overview metrics respectively. The right-hand side screenshot shows the result of MobSOS Surveys' adaptation process, rendered on an early J2ME-enabled mobile device, thus illustrating the strict display size limitations valid for many mobile devices.

Used in early MobSOS-powered assessments of CIS artifact success, this simple adaptation approach raised awareness for further discussion on improvements. In particular, survey participants

```
<qu:Page name="Multimedia_Quality_of_Service"
    xml:lang="en-US"
    qid="SQ.10.1"
    minval="0"
    maxval="10"
    minlabel="poor"
    maxlabel="high"
    required="true"
    xsi:type="qu:ScaleQuestionPageType">
  <qu:Instructions>
    During your evaluation of ${SURVEY.RESOURCE}
    you have accessed ${MEDIA.VIEWED} distinct
    media of ${MEDIA.FORMATS} formats. How is
    the quality of service regarding multimedia
    content access?
  </qu:Instructions>
</qu:Page>
```

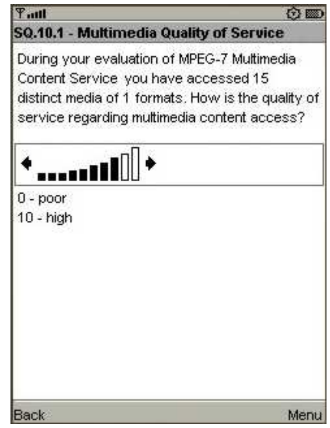

Figure 5.8: MobSOS Surveys – Scale-Type Question Page on Mobile Device

reported that the small overview hints on their own usage, powered by usage data-driven variables, made them curious on their own usage behaviour of the surveyed artifact. To that extent, usage data-driven variables and survey adaptation already contributed a sense of self-awareness on CIS artifact use. However, this simple adaptation approach did not yet include any means for data-driven *control* for survey participation or administration.

Triggered Micro-Surveys

Especially during the early exploration for candidate CIS success metrics, excessive length and unstructuredness of CIS success questionnaires is problematic [PiKr93]. Items often seem irrelevant for community members, since they refer to facets of the CIS artifact the participant never actively used. Response relevance [StSt06] has to be explicitly decided by survey participants, thus causing useless confusion and efforts during survey completion. To guarantee response immediacy, researchers must invest additional efforts in order to administer surveys with appropriate timing. We thus extended the aforementioned survey adaptation and personalization approach by an active component in the direction of *conditional/event-triggered micro-surveys*. The core idea of this approach is to automate survey administration with the help of *triggers*. Conceptually, a trigger is defined to fire on a specific *event* or *condition*, expected to occur in a given survey context particularly related to the use of the surveyed CIS artifact.

Real-time and historic MobSOS usage data thereby serve as data source to evaluate trigger events/conditions against. In particular, we defined two basic types of triggers: *event triggers* and *conditional triggers*. Combinations of these two basic types yield *conditional event triggers* as third possible trigger type. *Event triggers* fire based on single events reported by the surveyed CIS artifact. With this trigger type, certain user actions within a

$\langle trigger \rangle$ ::= $\langle questionnaire \rangle$, $\langle event \rangle$ | $\langle condition \rangle$.

$\langle event \rangle$ ::= $\langle identifier \rangle$.

$\langle condition \rangle$ ::= $\langle atomic\text{-}expr \rangle$ | $\langle binary\text{-}expr \rangle$ | $\langle not\text{-}expr \rangle$.

$\langle atomic\text{-}expr \rangle$ ::= $\langle var \rangle$, $\langle cop \rangle$, $\langle val \rangle$.

$\langle not\text{-}expr \rangle$ ::= '$\neg$' , $\langle condition \rangle$.

$\langle binary\text{-}expr \rangle$ :: $\langle condition \rangle$, '$\vee$' | '$\wedge$' , $\langle condition \rangle$.

$\langle cop \rangle$ ::= '=' | '$\neq$' | '>' | '<' | '$\geq$' | '$\leq$' .

Figure 5.9: EBNF Representation of MobSOS Surveys Trigger Language

Listing 5.1: Complex Conditional Event Trigger Example

```
<QuestionnaireTrigger id="7MAdPNjdex">
  <Questionnaire ref="L8WBIdNXXq" />
  <Event handle="mediumAnnotated"/>
  <Condition type="AndType">
    <Condition type="NotEqualsType">
      <Var>USER.CONTEXT.COUNTRY</Var>
      <Val>de</Val>
    </Condition>
    <Condition type="OrType">
      <Condition type="GreaterThanType">
        <Var>SURVEY.RESOURCE.USETIME</Var>
        <Val>5</Val>
      </Condition>
      <Condition type="GreaterThanType">
        <Var>SURVEY.RESOURCE.USEFREQ</Var>
        <Val>10</Val>
      </Condition>
    </Condition>
  </Condition>
</QuestionnaireTrigger>
```

CIS artifact can be linked to the administration of an adapted micro-survey in real-time. *Conditional triggers* fire upon the positive evaluation of aggregate conditions implicitly contained in real-time and historic context-enhanced MobSOS usage data. With this trigger type, complex conditions related to CIS artifact use in a given survey context can be linked to survey administration. *Conditional event triggers* are a combination of the two aforementioned trigger types. They fire when the surveyed CIS artifact reports a certain event under the specified context conditions. Trigger events resp. conditions should be designed to justify the administration of a very short questionnaire to the respective participant for which the trigger event occurred resp. condition holds, focused to specific related aspects of CIS artifact success. Examples of such aspects are specific artifact features, stakeholders, or other context attributes. Our triggered survey approach thus fosters the specification of context and event-based triggers in given survey contexts and to *evaluate* trigger expressions of the associated surveys and questionnaires respectively.

For specifying triggers, we designed a description format as supplement to the open questionnaire markup language defined earlier. Figure 5.9 presents the formal syntax of a trigger. Due to its partly recursive structure for trigger conditions, we present formal syntax in EBNF. A trigger is linked to a specific questionnaire form template and defined to fire on either the occurrence of an event or the fulfillment of a condition. An event trigger is sufficiently described by a simple identifier acting as *event handle*. A conditional trigger is described by a conditional expression. A conditional event trigger is described by an event handle, combined with an additional conditional expression. An atomic expression describes a comparison of a single variable's current value and a reference value with one of the available comparison operators $=$, $\neq$, $<$, $\leq$, $\geq$, $>$. Variables usable with this approach include current context information as well as the subset of those survey adaptation variables (cf. Section 5.3.2) compatible with the comparison operators. The description of more complex conditionals is supported with boolean operators $\wedge$,$\vee$, and $\neg$. Listing 5.1 presents an example description for a complex conditional event trigger. This trigger fires upon the reception of a *mediumAnnotated* event for those participants outside Germany, who either used the surveyed CIS artifact for more than five hours or more than ten times.

CIS Tool Instrumentation

The administration of triggered micro-surveys directly within CIS tools requires different means of client instrumentation. Such instrumentation in particular includes mechanisms for firing trigger events, for evaluating trigger conditionals, and for administering micro-surveys to community members, based upon these triggers. Firing events is achieved by wrapping individual key interactions of the CIS artifact with invocations of a special callback for asynchronous event handling, according to the observer pattern [GHJV95]. The parameters passed to the callback include information on the current context, the participant for which the event occurred and the respective event handler. The asynchronous reaction to such callbacks is mainly intended, though not limited, to the administration of event-related micro-surveys. The active evaluation of conditional expressions is realized as separate CIS tool thread repeating the evaluation of multiple trigger conditionals in regular time intervals. Upon the positive evaluation of a relevant conditional expression, the CIS tool instrumentation invokes a special callback function for conditional handling.

Algorithm 1 Recursive evaluation function for survey trigger conditionals

```
function EVAL(c)
    switch type(c) do
        case AndType return EVAL(c.e1) ∧ EVAL(c.e2)
        case OrType return EVAL(c.e1) ∨ EVAL(c.e2)
        case NotType return ¬ EVAL(c)
        case EqualsType return GET(c.var) == c.val
        case GreaterThanType return GET(c.var) > c.val
        case LessThanType return GET(c.var) < c.val
        ... other convenience comparison operators accordingly
end function
```

Algorithm 1 presents pseudo-code for the recursive evaluation function.

As for the CIS tool instrumentation for context-enriched usage data collection, the instrumentations discussed here must be reflected on the user interface level to make community members aware of surveys relevant for them. In particular, the callback functions resulting from the instrumentation for triggered micro-surveys must be connected to respective user interface elements for survey participation to achieve response relevance and immediacy.

5.3.3 Discussion

The concept of triggered micro-surveys was particularly designed to contribute to the requirements of response relevance and response immediacy. At the same time, it was designed to reduce efforts on both sides of the survey organizers and partipants, compliant with MobSOS' overall goal to reduce obtrusiveness of online evaluation activities.

In order to assess the preference of automatically triggered micro-survey administration in comparison over traditional administration of full survey instruments, we conducted an evaluation of our approach. For our study, we invited a small, but focused community of CIS artifact developers ($N = 15$) inherently interested in the success of their CIS artifacts and familiar with traditional online surveying methods. Participants were asked to try the triggered micro-survey approach in a realistic scenario and then report their preferences in a short two-item questionnaire on preference and usefulness of the approach. Although not representative, the results in Figure 5.10 indicate a clear preference for triggered micro-surveying over traditional surveying approaches.

As for triggered micro-surveys, we evaluated two different strategies for survey administration using our CIS instrumentation approach. The first strategy administers a micro-survey questionnaire form immediately upon catching the callback. This strategy fulfills the response immediacy requirement in its most literal sense, but at the same time obtrudes regular use of the CIS artifact by interrupting the regular application flow. The second

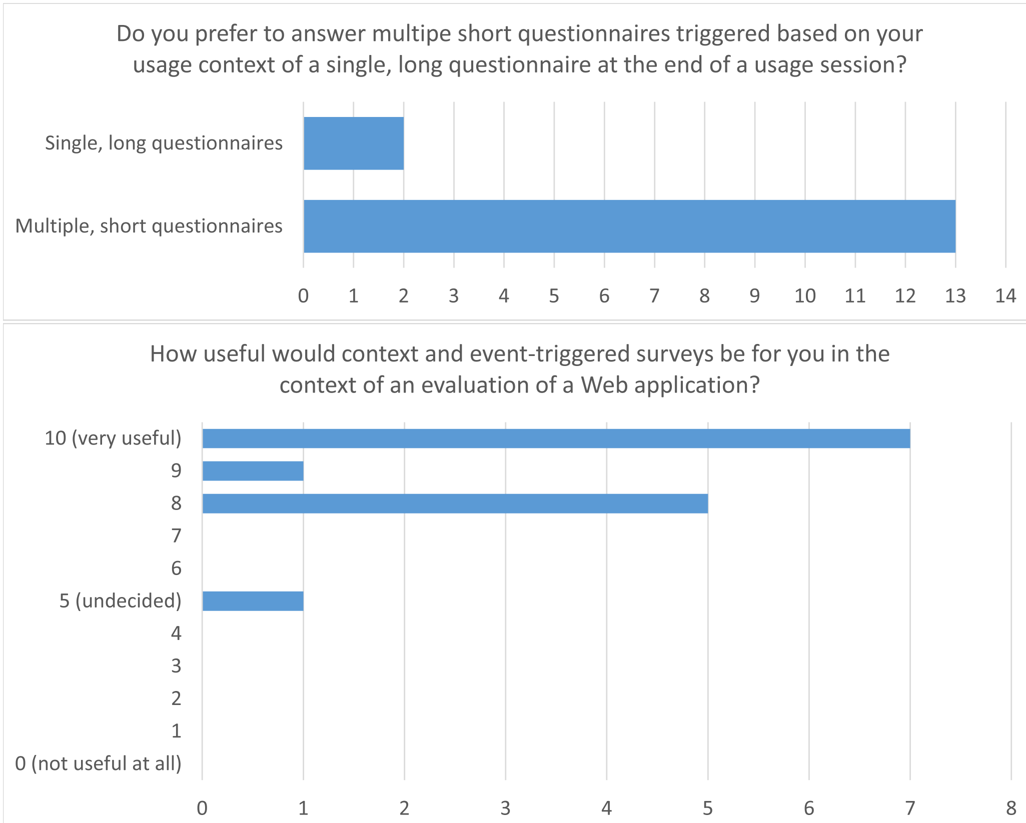

Figure 5.10: Preferred Questionnaire Length & Usefulness of Triggered Surveys

strategy flags the participant for later survey administration. We made good experiences with delayed survey administration at the start of the next session. While this strategy yields bearably less immediate response, it is dramatically less obtrusive. Although both strategies are possible in parallel, we recommend to minimize the burden on community members. Furthermore, community members must be enabled to opt-out of triggered surveys. If community members decline participation, they should not be bothered again with repeated invitations. Forcing users into survey participation can lead to heavily skewed results, ultimately leading to distorted CIS success assessments.

Although the overall design of MobSOS Surveys intends to solve some of the problems of survey research in naturalistic community contexts, the mere availability of advanced survey technology cannot be the only remedy. As discussed in the context of our methodology in Section 3.6, communities must develop a culture of continuous evaluation, including the active participation in surveys. Survey participants must be primed to the importance of their responses for their communities. As part of our community-oriented design science research approach [RKJa15b], researchers can serve as facilitators of such a culture with training and the credible demonstration of results to create awareness for CIS success aspects, that were otherwise impossible to capture.

5.4 MobSOS Query Visualization

In the previous sections, we discussed the collection of MobSOS usage and survey data in detail. With a growing amount of MobSOS data becoming available with continuous CIS artifact use and evaluation, communities need tools to analyze and create awareness for their inner workings, not only with respect to measurements of CIS success. Following the idea of making historical and real-time MobSOS data accessible as part of a community's shared repertoire [Weng98], this section presents *MobSOS Query Visualization (MobSOS QV)* as tool for data exploration, for creating community awareness, and for the development of CIS success measures as precursor to the creation of complete CIS success models.

We thus designed MobSOS QV as visual analytics [ThCo05] framework, conceptually integrated into the CIS success-aware infrastructure as part of the MobSOS toolkit (cf. Section 5.1.1). MobSOS QV is a generic solution to enable communities to continuously make sense of their data - not only collected with MobSOS Monitoring Pipeline (cf. Section 5.2) and MobSOS Surveys (cf. Section 5.3) - with the help of *query visualizations* embedded in *dashboards*. Technically, MobSOS QV is achieved as a synthesis of standard Web and database technologies. MobSOS QV consists of a Web service backend for the management of query visualizations and dashboards, as well as several frontend-side Web applications to author, publish, and interact with data visualization dashboards.

5.4.1 Requirements

In order to draw benefits of this collection wrt. CIS success modeling and awareness, communities must however be able to see, explore, understand, and reason about large amounts of MobSOS data at once [ThCo05]. They need to make sense of the data in their particular community contexts in terms of answering questions or discovering patterns of interest [HeSh12], not only to identify CIS success factors. The relatively new research area of visual analytics [ThCo05, HeSh12] provides powerful concepts enabling such sensemaking in an iterative, repetitive process of creating, exploring, and refining appropriate data visualizations. The development of CIS success models furthermore requires compact and efficient side-by-side visualizations of multiple measures at the same time. To that regard, *dashboards* have proven as viable approach to display multiple units of relevant information on a single screen [Few06]. The inherent stakeholder dependence and dynamicity of community-specific CIS success models furthermore requires dashboards to be *personalizable* and *configurable*. Data exploration on dashboards thus requires dynamic management facilities in terms of recombining, reorganizing, an reconfiguring visualization units on the dashboard canvas according to preference, importance, etc. In analogy to the concept of CIS success measure catalogues (cf. Section 4.2), communities should furthermore be enabled to *reuse* proven data visualizations from existing catalogues on the one hand and to *create* and *manage* custom visualizations for specific community purposes on the other.

A recent approach to address these requirements are componentized Web frontends, e.g. *widget-based* dashboards. A widget can be conceived as a small, self-contained, and interactive application with focused and sharply outlined purpose and functionality. In the context of this work, we mostly focus on interactive data visualization widgets for advanced exploratory analysis being central to visual analytics applications [ThCo05, FWSN08]. *Parameterization* is an important prerequisite to the interactiveness of data visualization widgets and whole dashboards, as it enables usual operations such as filtering, zooming and panning important for visual analytics [FWSN08]. This parameterization is closely related to the parameterized queries computing contextualized success metrics, as described in Section 4.3.

Last but not least, the presentation of such individual data visualizations or combinations thereof with the help of dashboards should be easily *accessible* and *embeddable* into a community's information infrastructure being part of the CIS without the need to install separate software on the side of community members. This requirement is analogous to the MobSOS Surveys requirement for embeddability of surveys into CIS artifacts to improve response immediacy (cf. Section 5.3).

As communities successively develop individual data visualizations and dashboards, they create new information artifacts as contributions to the development of CIS success models. In analogy to usage and survey data, these information artifacts represent data that belongs to a community's shared repertoire and should thus be maintained in community-controlled premises in contrast to the cloud approaches pursued by public analytics providers.

5.4.2 Concept & Realization

In this section, we first conceptualize query visualizations and dashboards in a bottom-up manner, including concepts for personalization, configuration, and parameterization. In particular, we discuss the relation of query visualization dashboards to CIS success models. We furthermore present the operationalization of these concepts with the help of a use case analysis for MobSOS QV.

A *query visualization* $Q = (q, v, m)$ is based on a given dataset d and defined by a *parameterized database query* q, a *configurable visualization* v, and accompanying *metadata* m. q is defined as a query statement formulated in a standard query language of d's underlying database management system (e.g. SQL [ISO11] for relational database management systems). Query statements can be further *parameterized* by the augmentation of q with placeholders for *filter variables*. Before a query statement is evaluated by the underlying database engine, all placeholders are replaced by the actual values of the respective filter variables, set by the community member. A *filter* is defined by an *identifier* unique over d and a special type of query statement defined in the context of d. A filter query thus yields a list of possible filter values.

With this decoupling from query visualizations, filters are reusable across different query visualizations. Filter values can thus be dynamically set in real-time to adapt multiple parameterized query visualizations on a dashboard at the same time. The filter concept thus allows to parameterize complete visualization dashboards. v is defined by a specific *visualization type* and related visualization *configuration parameters* to be set by the author of a query visualization at design time. Visualization types currently supported by MobSOS QV include *tables*, *pie charts*, *bar* and *line charts*, *radar charts*, *timelines* and *graphs*. Except for tables, each visualization type requires a specific structure for the query result returned after evaluation of q. In other words, q must *match* v to achieve a valid query visualization. If q does not match v, the user is warned with an appropriate error message. While some configuration parameters are valid across visualization types (e.g. width and height of the visualization canvas), each type can define its own set of configuration parameters. Finally, m annotates a query visualization with *title*, *description* and *author*.

Although the conceptualization of query visualizations is rather generic and applicable for a wide array of data sets and visualization tasks, this work understands them as important tool for communities to reflect, explore, and create CIS success models for improved awareness. Figure 5.11 explains the relation between CIS success models on the one side and individual query visualizations and dashboards on the other side. Query visualization widgets can be understood as direct visual representations of the metrics at the leaves of a CIS success model. A dashboard can be understood as structural arrangement of visualizations for all metrics in a given CIS success model.

It should be noted that CIS success models and query visualization dashboards are not isomorphic by definition. Only a subset of query visualizations is directly transferable to CIS success metrics. By that we mean those visualizations that directly map to quantitative numeric metrics in the sense of key performance indicators as they are known from Web Analytics [Pete04, Pete06, Kaus10], i.e. those visualizations expressing ratios, aver-

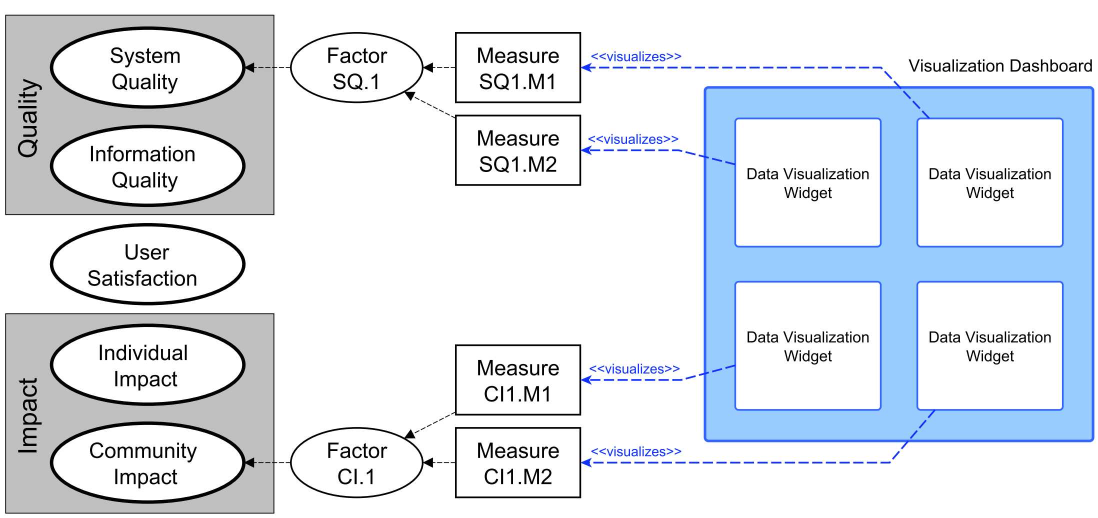

Figure 5.11: CIS Success Models & Query Visualization Dashboards

ages, and percentages. The query visualization concept was however deliberately designed generically to support the active exploration of CIS success metrics. Query visualization dashboards do not reflect the hierarchical dimension and factor substructure of CIS success models. We deliberately abstained from augmenting dashboards by visual subdivisions and annotations to avoid visual complexity harming the dashboard's usability.

Figure 5.12 presents the operationalization of MobSOS QV's query visualization concept in UML use case notation. We thereby differentiate three different actor groups in communities: *consumers*, *publishers*, and *authors*. By design, we anticipated the subset relation *authors* ⊂ *publishers* ⊂ *consumers*, reflecting Nielsen's participation inequality theory [Niel06], not only in terms of numbers, but also in terms of data analysis expertise found in communities. Thereby, authors constitute the expectedly smallest group of data analysis and visualization experts capable of authoring and refining query visualizations, including the management of data sets and filters. As such, they contribute the results of query visualization *authoring outcomes* to *visualization catalogues*. The next larger group draws upon these catalogues to design and configure visualizations or complete dashboards and to publish them in a community's information infrastructure to create awareness, not only for CIS success. Consumers constitute the expectedly largest group of community members accessing published visualizations and dashboards to consume and interact with them, possibly by controlling the aforementioned filters. In the following, we discuss the main constituents of MobSOS QV from the perspective of the actor groups in Figure 5.12.

Visualization Authoring

Query visualization authors (cf. Figure 5.12) play an important facilitator role in MobSOS, since they actively contribute to the exploration and confirmation of CIS success metrics and their management in catalogues. The role of these actors is best played by community members with background in professional data analysis. In practice however, most communities lack the resources to employ professionals and only command data analysis skills with adept proficiency. Professional data analysis tools (e.g. Excel, SPSS, SAS, R, KNIME or Rapidminer) tend to overwhelm data analysis adepts with their vast feature sets. According to our observations, the exploration of CIS success metrics only requires a small subset of these features, handleable with comparably low requirements to data processing knowledge. Such tools can furthermore cause high licensing and maintenance costs, usually exeeding community budgets. Their handling furthermore requires extensive training not available and affordable in most communities. Last, but not least, most professional data analysis tools are insufficiently integrated with CIS information infrastructures to directly present analysis results as means for creating awareness.

Communities rather require low-cost, easy-to-use zero-installation data exploration frontends with minimal training requirements, which are directly integrated with the CIS and allow for low-effort publications of data visualizations to community members. We thus prototyped and researched several variants of browser-based authoring environments for query visualizations. A first version was realized as a *widget bundle* consisting of three widgets: an *explorer/creator widget* for developing query visualizations, a *control center* widget for managing user-centered data sets and filters, and a *gadget creator* widget for exporting visualizations as ready-to-use widgets.

Figure 5.13 provides an overview of this authoring environment. Authoring a query visualization in this environment consists in *1) selecting a data set*, *2) formulating a possibly parameterized query statement on this data set*, *3) selecting and pre-configuring a visualization type*, *4) annotating the authored query visualization with metadata*, as indicated in the gadget creator widget in Figure 5.13, and finally *5) generating a file containing the code for the authored widget*. The produced code is thereby compliant with the OpenSocial Gadget specification and includes RESTful interactions with the MobSOS Query Visualization service in the backend to render query visualizations. Figure 5.14 shows an example of a dashboard arranging four query visualization widgets. We created this dashboard in the context of one of our MobSOS case studies in the ROLE project (cf. Section 6.3).

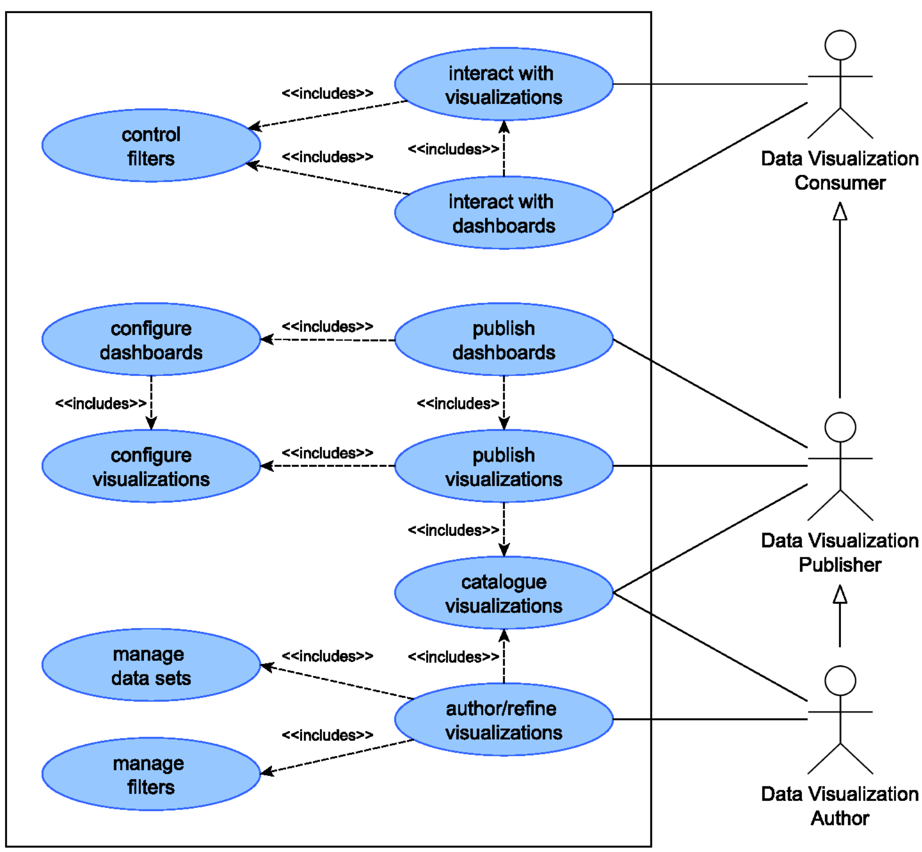

Figure 5.12: MobSOS QV – Actor Groups and Use Cases

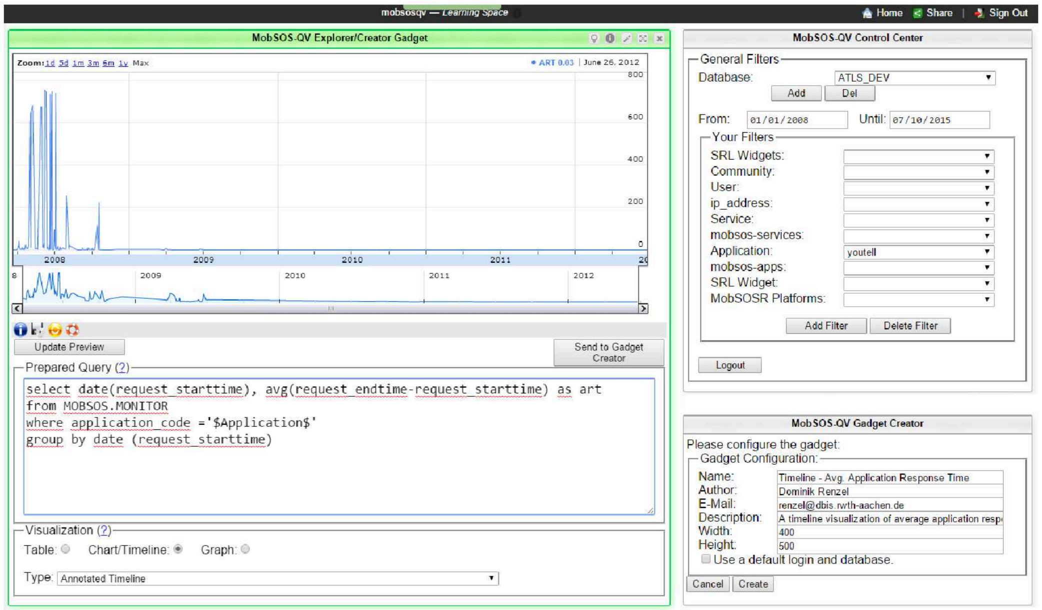

Figure 5.13: MobSOS QV – Authoring Widget Bundle

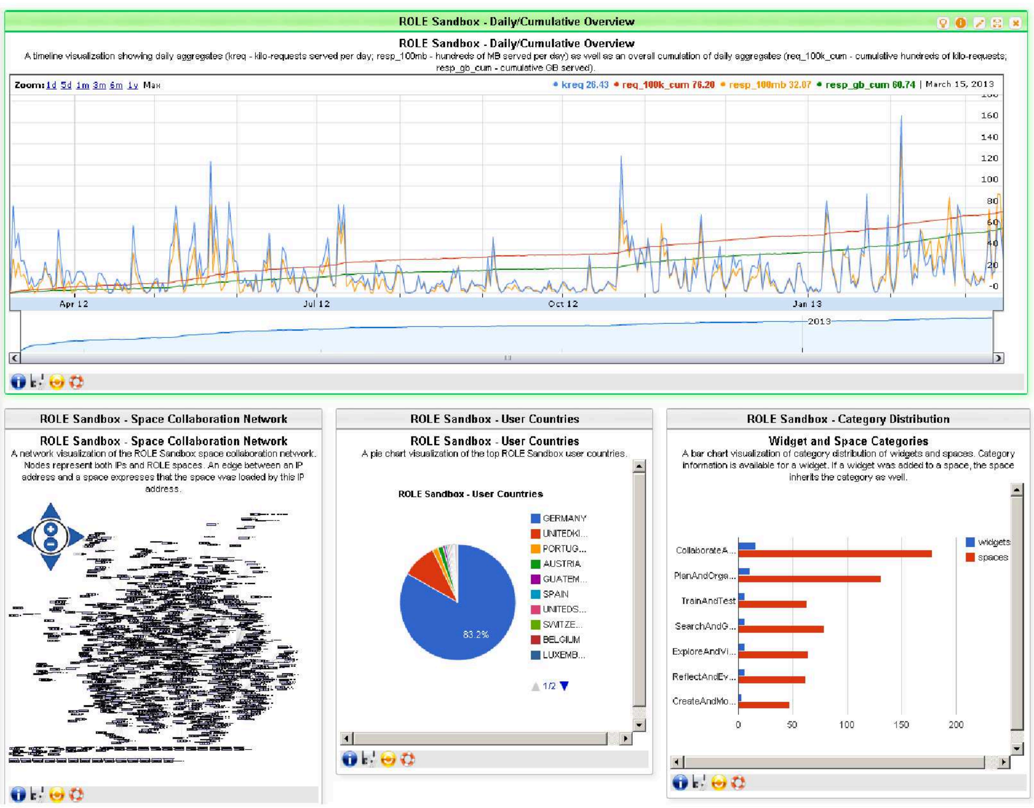

Figure 5.14: MobSOS QV – Widget Dashboard Example: ROLE Sandbox

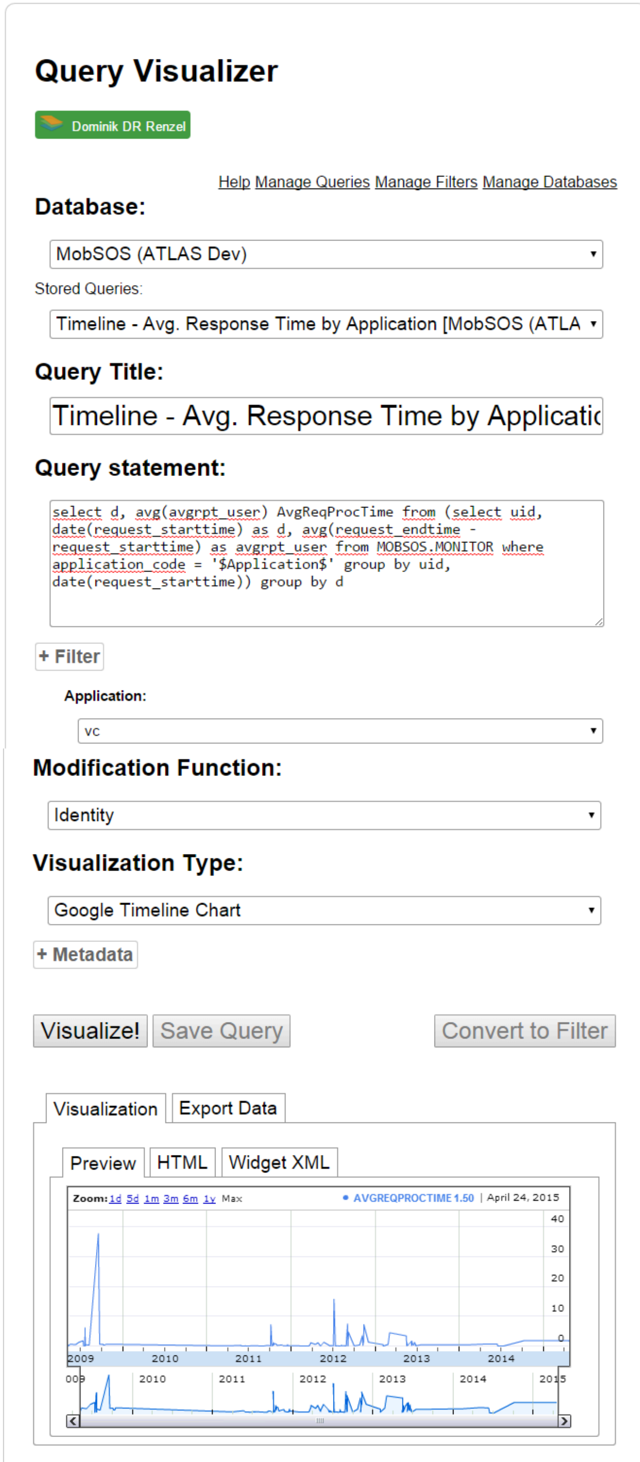

Figure 5.15: MobSOS QV – Stand-Alone Authoring with Rich Export & Embedding

Visualization Export & Embedding

With existing catalogues of query visualizations, community members playing the visualization publisher role require means of exporting and embedding query visualizations in a community's information infrastructure with the goal to enable interaction and to create awareness. While query visualization authoring support of our first prototype was well-accepted, we detected several major issues from the publisher perspective (including issues reported in [DEKl12]). First, query visualizations could only be exported as files. As such, re-use of query visualizations and building CIS success metrics catalogues posed serious usability issues. The limited widget export functionality was found too restrictive to embed query visualizations in a community's information infrastructure, more concretely in Web sites and content management systems. Publishers stated the need for better integrated management and browsing of visualizations. For better scaling of data visualizations, authors required convenience data transformation functions such as normalization and logarithmization. In collaboration with [DEKl12], we realized these missing requirements in a second prototype as stand-alone Web application decoupled from the previously used widget dashboard environment. The new prototype realizes different *embedding formats* of query visualizations for later embedding and their combination in query visualization dashboards. These embedding formats include readily usable Web code elements to be embedded in Websites. Therefore, the service relies upon standard Web technologies (HTML/CSS/JavaScript) as well as publicly available Web visualization frameworks such as Google's visualization API [3] for charts, yWorks' yFiles [4] for graphs or d3.js [5] for custom data visualizations. The service furthermore supports a rich set of result *export formats* for data (e.g. CSV, XML, JSON, HTML) or static images of the produced visualizations (e.g. PNG, JPG, SVG, PDF) for external processing and generation of evaluation products. Although the built-in visualization types have proven to cover many data visualization use cases, MobSOS QV is designed for extensibility, thus allowing to plug more visualization types in future. Figure 5.15 shows the frontend of the stand-alone authoring environment, including its rich export and embedding options.

Visualization Dashboard Design & Interaction

With particular respect to the design, configuration and publication of query visualizations on dashboards, we introduced several enhancements. In the context of the TEL-Map project, we researched and evaluated the design, configuration, and embedding of widget-based query visualization dashboards into a Drupal content management system. In the course of this integration, we further strengthened the accessibility and usability of the query visualization catalogue concept with the help of a *widget store*, directly integrated

[3] https://developers.google.com/chart
[4] https://www.yworks.com/yfiles
[5] http://d3js.org

in the browser-based dashboard environment. For improved visualization catalogue management and browsing, we extended visualization metadata by *categories* and *keywords*. Furthermore, we improved usability in terms of positioning and configuring visualizations on the dashboard canvas. We integrated the realization of this concept into the Learning Frontiers portal. This portal was part of the EU commission support action *TEL-Map*[6], analyzing the European *Technology-Enhanced Learning* (*TEL*) research project landscape and related research performance indicators.

Until now we mainly discussed visualization dashboards focused on CIS artifact success. However, arbitrary MobSOS data-based dashboards are possible with MobSOS QV. This openness is particularly helpful during success metrics exploration and construction.

5.4.3 Discussion

Directly inherited from the dynamicity of communities, the creation, publication, and interaction with query visualizations is inherently ongoing and cyclic. Accordingly, visualizations and dashboards should be continuously revised and refined, according to the community's changing reflections on CIS success and its relevant constituents. As such, the framework proved its usefulness in applications beyond the modeling of CIS success, e.g. showing the evolution of scientific [DCP*11, DEKl12] or open-source developer [HLKl14] communities. Especially timeline visualizations were found popular for tracing the development of individual metrics over time. Simple dashboards showing timeline visualizations of usage data-based metrics (e.g. number of requests, average response time, average error rate) helped communities to stay aware of CIS success for different purposes. Simple metrics around rising or falling CIS artifact use showed community activity and impact. The awareness of system quality metrics such as CIS artifact failure rates over time helped CIS artifact developers to identify and fix technical problems. Among all services deployed in our CIS infrastructure, query visualization ranked among the top three used services in terms of numbers of users and their sustained use of the service for different data sets. We thus conclude, that query visualization is indeed an important constituent of a CIS to explore CIS success factors and metrics and to create CIS success awareness. A more detailed evaluation of query visualization dashboards is presented in Section 6.3.5 in a technology-enhanced learning researcher community context [DEKl12].

5.5 MobSOS CIS Success Modeling & Reporting

In the previous section, we described MobSOS Query Visualization as means to explore and create continuous awareness for individual CIS success metrics. Only a subset of query visualizations directly map to and therefore qualify as CIS success metrics. To that

[6] http://www.telmap.org

extent, the exploration for relevant CIS success metrics produces useful by-products for creating different kinds of awareness, however not focused on CIS success. If we limit our considerations to the aforementioned subsets qualifying as metrics, we can amalgamate many of the concepts described so far to create technical means for formally describing and presenting CIS success models, either a-priori in explorative phases or completely validated in confirmative phases. MobSOS technically supports this notion with dedicated support in the form of the MobSOS Success Modeling service described in this section.

5.5.1 Requirements

Most importantly, the MobSOS Success Modeling service should allow communities to manage and present *formal representations of CIS success models* as hierarchical structures, including collections of relevant CIS success metrics at their leaves. Given the observation that certain CIS metrics are sufficiently generic and universally applicable in multiple CIS success models, the service should account for *CIS success metrics reusability*. Thereby, the query visualization catalogue concept is directly transferable to *CIS success metrics catalogues*.

Transitively, we find overlappings in CIS success models across stakeholders or whole ccmmunities as well as across CIS artifacts, in particular for the system quality dimension. Large portions of CIS success models are reusable in multiple community contexts, for multiple stakeholders, and for different artifacts. Communities therefore require intuitive *exchange formats* to avoid redundant CIS success modeling efforts. Following the same rationale, CIS success metrics catalogues should become exchangeable as well. Although metrics and model re-use is preferable, especially communities in the long tail experience cases of idiosynchrasy, where the exploration and construction of specific custom CIS success metrics becomes necessary.

Exploration should allow for the *rapid prototyping* of such custom metrics. In particular the formulation of single query statements for compound metrics can become a complex and time consuming task. Respective query statements usually involve mathematical functions, interwined with complex join operations and nested queries, thus obscuring the underlying calculation rules. Formalizations of compound metrics should rather focus on their calculation rules described by mathematical formulae, whose arguments represent the results of simple query statements. The evaluation of such formulae should be performed by the MobSOS Success Modeling service instead of the underlying database management system. While complex compound metrics are in some cases inevitable, simple metrics are preferable for reasons of understandability, explainability and interpretability. Given formal representations of CIS success models, the MobSOS Success Modeling service should support their *computation* and *presentation* based on the data in a community's shared repository (i.e. usage and survey data). As for all other MobSOS toolkit services, the MobSOS Success Modeling service raises requirements for protected data storage.

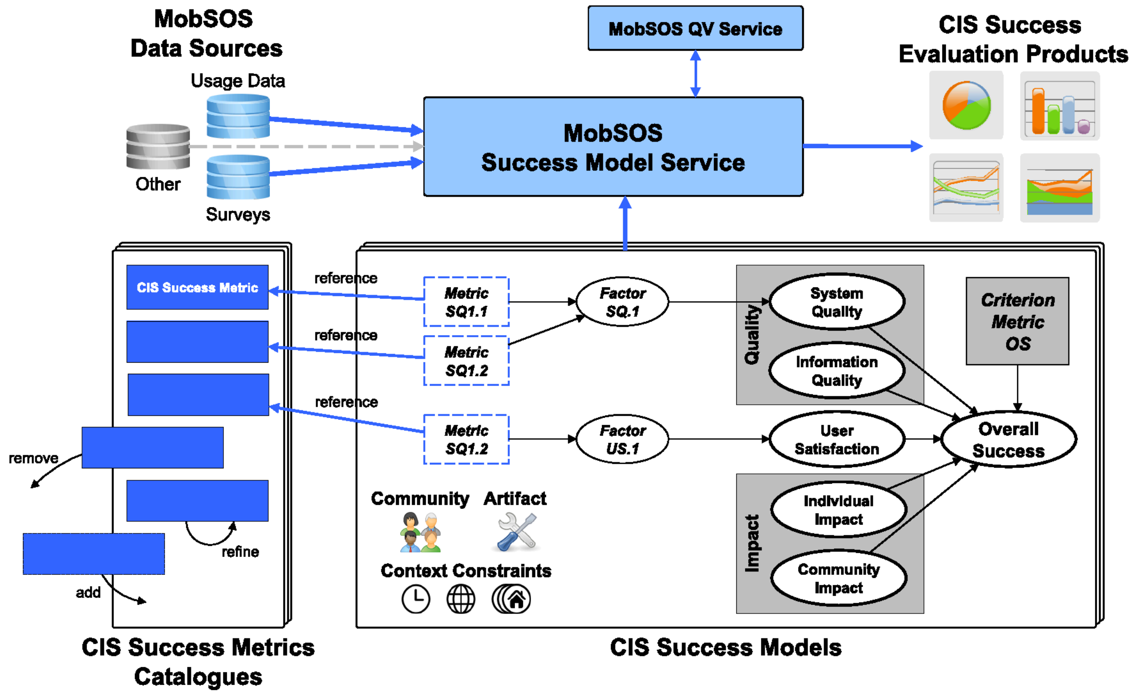

Figure 5.16: Concept for MobSOS CIS Success Modeling Service

5.5.2 Concept & Realization

Conceptually, the MobSOS Success Model service supports three main tasks: 1) *managing formal descriptions of CIS success metrics catalogues*, 2) *managing formal descriptions of CIS success models* and 3) *generating CIS success evaluation products*. The overall concept of CIS success modeling and reporting is sketched in Figure 5.16. Formal descriptions of CIS success models follow a template approach fostering model reuse in different community contexts and for different CIS artifacts. Conceptually, a formal description of a CIS success model starts with a structural template, as defined in Figure 4.1. The designer of a CIS success model then populates the template with factors relevant for the respective success dimensions. Factors are in turn populated by linking to factor-relevant metrics from the community's CIS metrics catalogues. Each entry in these catalogues defines metrics in terms of metadata, calculation rules, related database query statements, and optional visualization parameters. With this conceptual decoupling, individual CIS metrics can be re-used in multiple CIS success model templates, driven by the same catalogues without the need for explicit replication. With means of exchanging and sharing such formal descriptions between community stakeholders or even across communities, CIS success metrics catalogues and model templates can be reused in multiple community contexts and for multiple CIS artifacts. For an effective exchange and sharing of CIS success models and CIS metrics catalogues, we developed two respective interlinked XML formats.

```
<SuccessModel id="smid1"
  artifact="aid1"
  community="cid1"
  name="Chat Service Success Model"
  description="A success model for chat services.">

  <Dimension name="Individual Impact">
    <Factor name="Improved Communication">
      <Metric catref="mcat1" idref="mid1"/>
    </Factor>
  </Dimension>

</SuccessModel>
```

```
<MetricsCatalog id="mcat1"
  community="cid1"
  name="Aphasia Tool Metrics"
  description="...">

  <measure id="mid1"
    name="Message Length Increase"
    description="Increase in avg. words/message">

    <query name="avg_wpm_before">
      (query pre-test data)
    </query>

    <query name="avg_wpm_after">
      (query post-test data)
    </query>

    <presentation type="value">
      <operand name="avg_wpm_after" />
      <operator name="/" />
      <operand name="avg_wpm_before" />
    </presentation>
  </measure>

</MetricsCatalog>
```

Figure 5.17: MobSOS CIS Success Model & Metrics Catalogue Exchange Format

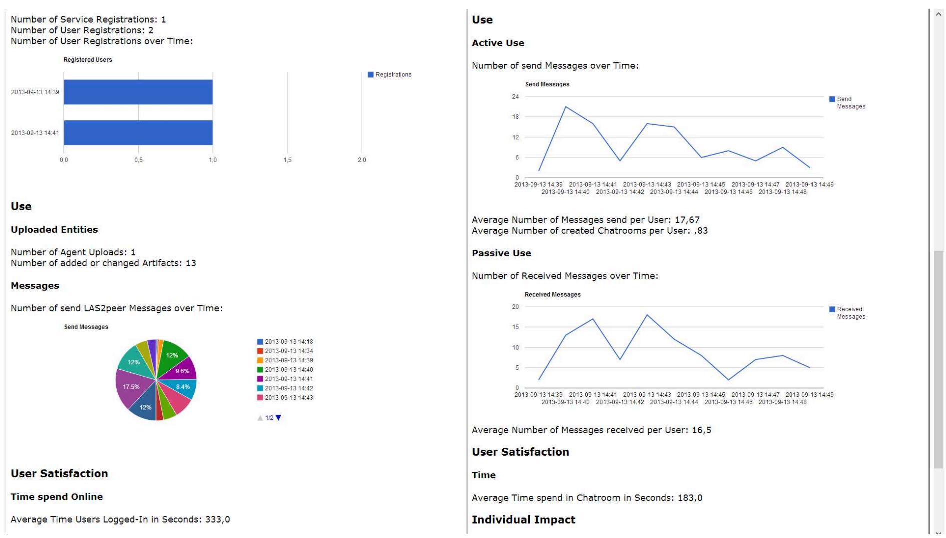

Figure 5.18: MobSOS Success Modeling - Example for Generated Evaluation Product

Excerpts of conceptual use of these XML formats are shown in Figure 5.17. Most importantly, metrics are defined in CIS metrics catalogues referable in CIS success models. As shown in the conceptual example, the definitions of queries were extended by additional means of further computation. This concept was introduced to allow explorers of CIS success metrics to combine a set of more simple to formulate database query statements as proof of concept prototypes to more complex single-query statements achieving the same result. Since the main purpose of these representations of CIS success models is awareness, each measure can be defined either as plain value or additionally include a visualization.

Taking a success model template, including references to metrics definitions from catalogues, the MobSOS Success Model service then executes respective database queries on the MobSOS data repositorys and performs respective computations, ultimately populating a success model with metrics values and rendering the results to evaluation products. For the rendering of optional visualizations in these evaluation products, the MobSOS Success Model service makes use of the MobSOS QV service described earlier in Section 5.4. In contrast to the query visualization dashboards mainly dedicated to CIS exploration, the evaluation products explicitly show the full structure of CIS success models with metrics at its leaves. With the help of a prototypic Web-frontend, success models for specific CIS artifacts in given community contexts can be selected and rendered as reports in regular Web browsers. An excerpt of such a Web-based report is shown in Figure 5.18.

5.5.3 Discussion

Following the overall MobSOS methodology, the use of the MobSOS Success Model service is appropriate at different phases with similar purposes, i.e. in the course of exploration and the creation of a-priori CIS success models and after the validation of CIS success models. The purpose is thereby to use the respective models for communicating and creating awareness for CIS success among community members. While MobSOS QV supports the unstructured collection and exploration of CIS success metrics, the MobSOS Success Modeling service's structured CIS success model templates help structure CIS success factors and metrics in a-priori models. Already during exploration, a community analyst should balance for parsimony and completeness (cf. Section 3.5; [BuSt06]) with the goal of compact a-priori CIS success models, however with a slight tendency towards completeness in terms of entering metrics seemingly relevant for further validation. In these phases, CIS success models tend to include comparably lean metrics, i.e. highly aggregated measures abstracting from entities such as individual users. These early a-priori success models should however be seen as interim results and thus be marked as such. For in-depth validation, lean metrics must be refined to richer metrics, requiring data aggregation on lower levels of individual community members, filtered by the specific community context and CIS artifact under consideration. Proper model validation still requires data analysts and sophisticated statistics tools enabling correlation/regression/factor analysis, including multicollinearity and goodness of fit tests, as suggested in Section 4.5.

The integration of sophisticated statistics libraries and tools into the MobSOS toolkit, probably accompanied by machine learning algorithms for semi-automatic selection of relevant success factors, was beyond the scope of this work. However, such integration is not impossible and thus stated as future work. For the moment, such analyses are performed by directly connecting statistics tools to the MobSOS data sets stored in the community's shared repository, as indicated in Figure 5.1. The confirmative part of validating CIS success models as formative indices includes further removal of redundant metrics towards ideally very compact, yet expressive CIS success models.

After validation, the MobSOS Success Modeling service is again used to refine a-priori versions and present complete formalizations of validated CIS success models as vehicles for CIS success awareness. It should however be noted that, given the cyclic character of the MobSOS methodology, any validated model can become invalid due to dynamicity and emergence effects found in long tail communities of practice. The representations of CIS success models produced by the MobSOS Success Modeling service will also create the awareness for factors potentially becoming invalid over time, since representations are derived from both historical and recent live data.

5.6 Conclusion

In this chapter, we presented the notion of a CIS success aware community platform infrastructure and the required services and tools create CIS success awareness with MobSOS. As such, this chapter presents the results of theory-informed engineering efforts as contributions towards answering research question RQ2 (cf. Section 1.2). The conceptual design of such a platform followed the MobSOS methodology for modeling CIS success with particular respect to our related CIS success modeling guidelines. The set of services and tools thereby provide long tail communities of practice with support for usage and survey data collection and management, the exploration for potentially relevant CIS success metrics and their management in catalogues, their combination in CIS success models, as well as the validation and presentation of CIS success models. For an integrated end-user experience responsive to CIS success awareness, we presented a light-weight CIS tool instrumentation concept bringing all MobSOS components and services together.

With particular respect to technical infrastructures for long tail communities of practice, we observed a fast-paced movement from community-maintained centralized service provisioning to highly distributed public cloud service provisioning. This switch provided great opportunities to communities in terms of cost savings and the quickly growing availability for whole service ecosystems at their hands. In particular social networking service platforms such as Facebook or Google+ build upon public cloud service provisioning models and create general-purpose services that support communities to a great extent, but also raise issues for communities. Control and ownership of person and community-related data is not in the hands of the communities who actually produced the knowledge as part of their community's shared repertoire.

In the course of this work, this movement was reflected in the development of our LAS server (cf. Section 2.4.3). LAS served as testbed for most prototypic implementations and case study deployments of CIS and MobSOS services and tools discussed in this chapter. In our conceptualization of a CIS success-aware infrastructure, the community repository is under the control of the community. Public cloud models fundamentally violate this assumption with data scattered across a global network of data centers under the control of the service providers. Effectively, communities give ownership and control for their data out of their hands. Furthermore, communities face substantial problems, when individual service providers decide to cancel service provision. Effectively, parts or even the whole

CIS become unusable in such situations. Based on the aforementioned criticism on public cloud service provisioning for community information systems, we currently experience a certain trend towards client-based P2P computing. Such topologies inherently map to real-life community structure and collaboration, hosting a set of services available to network members without the involvement of a third party service provider [BuDa09].

In a bachelor thesis guided by the author of this work, we thus prepared MobSOS for a possible paradigm augmentation or change towards P2P [Lang13]. From a theoretical, conceptual and methodological point of view, the transfer of MobSOS concepts from LAS to las2peer did not rise any serious issues. From a technical point of view, the collection of usage data had to be adapted to a P2P topology. We realized this adaptation with a publish-subscribe pattern (cf. Section 5.2). Only slight technical adaptations were necessary to achieve the transition for the other MobSOS services. The modular design of our conceptual approach allows re-use in both paradigms. As a conclusion, MobSOS methodology, formal CIS success models, and technical infrastructure are conceptually applicable to multiple architectural styles used to realize CIS in practice. In the next chapter, we present several case studies, where MobSOS is applied to different CIS installations in domains such as cultural heritage preservation, health-care and technology-enhanced learning.

Chapter 6

MobSOS Case Studies

Since its inception, we exposed MobSOS to various communities in different mostly professional, but also hedonic domains such as healthcare, multimedia,technology-enhanced learning, Web engineering, and digital entertainment for evaluative purposes. Inline with the DSR methodology pursued in this dissertation, case studies are widely acknowledged as suitable format for the evaluation of design artifacts. Already in the original works of Hevner et al., case studies are prominent part of the build & evaluate cycle (cf. Figure 2.7, p. 22). Further influential works by Peffers et al. [PTRC07] and Sein et al. [SHP*11] integrate case study research with iterative design and development processes. In the same vein, we applied case study research to evaluate different MobSOS components at different stages of their respective iterative development processes.

Our case studies were situated in very different community constellations and concerned with very different types of CIS artifacts, thus resulting in both technical and social scopes from micro to macro. From an epistemological point of view, all case studies more or less make use of the MobSOS methodology (cf. Chapter 3), including the MobSOS CIS success modeling approaches (cf. Chapter 4) and the MobSOS CIS success-aware infrastructure and tool kit (cf. Chapter 5). In our role as design researchers, we developed, deployed, and evaluated several prototypes of CIS artefacts in collaboration with communities. In all studies, we could gain awareness on quality and impact of the community-tailored prototypes under evaluation on the one side and MobSOS on the other.

Tables 6.1 and 6.2 present a comparative summary of all MobSOS case studies conducted in the course of this work. For each case, we list the specific domain, use case, scope, intensity of MobSOS use, and particular outcomes, including publications. For this thesis, we focus our discussion on three case studies (cf. Table 6.1) from the domains of healthcare, multimedia, and TEL for several reasons. First, these studies featured the most intensive use of MobSOS and were thus primarily interesting for the evaluation of MobSOS itself, but also for the evaluation of the involved CIS artifacts. Second, these studies produced valuable empirical evidence and artifacts for the involved communities in the form of elaborate CIS success models, guidelines, and improvements for the tools under evaluation.

Table 6.1: Comparative Summary of Discussed MobSOS Case Studies

Domain	Healthcare	Multimedia	Technology-Enhanced Learning
Use-Case	Aphasics Therapy	Metadata Management	Widget-Based PLE
Communities	one known	few known	many unknown
Artifacts	tool	tool/class of tools	tool ensembles
Analysis Scope [Bron88]	micro +chrono	micro-meso +chrono	micro-meso-macro +chrono
MobSOS Technical Components Used	Monitoring (Surveys) (Query Visualization)	Monitoring Surveys (Query Visualization)	Monitoring Query Visualization
MobSOS Modeling Techniques Used	Exploration, Expert Panel (Regression)	Exploration, Expert Panel Regression	Exploration Expert Panel
Outcomes	Success Model, Tool Improvements	Success Model, Tool Improvements	Success Model, Guidelines
Publications	Grun10, RKJa15b	ReKl09,Schl09	ReKl13,NKR*14a, RKKN15

Third, we achieved several publications on the results of these case studies after rigorous peer reviews. In the case studies listed in Table 6.2, the use of MobSOS still produced valuable insights and outcomes for the communities and us as researchers, but in a less intense manner, i.e. with less users, over shorter time periods, and with less prominent involvement of MobSOS components.

In the following three sections we thus report on the three most important cases of this work that applied MobSOS in professional communities with diverse domain backgrounds over multiple years. All three case studies took place in the context of large-scale national and international research initiatives. In the same vein as in [HMPR04, PTRC07, SHP*11], we align case study activities to the phases of our MobSOS methodology (cf. Chapter 3). We thereby differentiate between findings primarily related to the studied case on the one side and findings directly regarding the usefulness of the MobSOS approach itself on the other. Analysis results on quality and impact of the developed community media prototypes thus do not only stand for themselves, but serve as illustrative examples of applying MobSOS in real-life practice. We thereby deliberately chose an order of presentation that starts with applying MobSOS for one community and one CIS artifact and then successively scales up to whole community ecosystems with thousands of users and a plethora of tools.

In Section 6.1, we discuss a case study on applying MobSOS for the design and evaluation of SOCRATESX, a chat tool serving as therapy supplement in a German aphasia community. In Section 6.2, we present a case study on applying MobSOS for the evalu-

Table 6.2: Comparative Summary of Further MobSOS Case Studies

Domain	Multimedia	Web Engineering			Digital Entertainment
Use-Case	Non-Linear Storytelling	Trust-Aware Real-Time Collaboration	Context-Aware Mobile Recommender	Twitter Microblogging	Computer Games
Communities	few known	one known (developers only)	one known (developers only)	one known (developers only)	one unknown
Artifacts	class of tools	tool ensembles	tool	tool	games in general
Analysis Scope [Bron88]	micro-meso +chrono	micro-meso +chrono	micro +chrono	micro +chrono	meso-macro +chrono
MobSOS Technical Components Used	Monitoring	Monitoring (Survey)	Monitoring Survey Query Visualization	Monitoring Survey Query Visualization	(Survey)
MobSOS Modeling Techniques Used	Exploration Expert Panel	Exploration Expert Panel	Exploration	Exploration	Exploration Expert Panel
Outcomes	Informal Awareness, Tool Improvements	Informal Awareness, Tool Improvements	Basal Success Model	Basal Success Model	Informal Awareness
Publications	CRJ+10, RCLK10	Hock11	Schl11	Schl11	CGK+08,CGKR09

ation of different mobile multimedia application prototypes in the domain of professional multimedia management for digital cultural heritage documentation and preservation. In Section 6.3, we discuss a case study on applying parts of the MobSOS approach for learning analytics in the ROLE Sandbox, a Web platform for informal self-regulated learning in widget-based personal learning environments. In Section 6.4 we conclude this chapter with a final summary, comparison, and critical discussion of case study evaluation outcomes.

6.1 Aphasia Therapy

Since 2004, we participated in a Germany-wide networked aphasia community to develop and research digital media as supplement to regular group therapy sessions and as means to counter the social isolation common among aphasia patients. This participation took place in the context of the collaborative research center SFB-FK 427 *"Medien und kulturelle Kommunikation"* (Media and Cultural Communication), funded by the German National Science Foundation (DFG)[1]. The community consisted of patients and a research team of therapists, linguists and computer scientists across Germany. This particular community constellation had been established and cultivated long before the study. As part of their joint enterprise, the community applied an ATLAS-based user-centered design approach for the creation of SOCRATES, a Web-based chat tool custom tailored to the needs and impairments of aphasia patients. Starting with the involvement of external researchers, the aphasia community began the collaborative and strongly end-user driven development of SOCRATES, a chat tool custom-tailored to the needs of aphasia patients and therapists [SSKJ04]. During year-long use of the tool in therapy practice, the community accumulated a set of central issues for a major update of SOCRATES. In this section, we focus our discussion on the transition from SOCRATES to its next major update SOCRATESX. MobSOS thereby played a major role for both development and evaluation.

6.1.1 Problem Identification

Aphasia [Dama92] results from lesions in the left brain hemisphere responsible for language-related tasks. Lesions are typically caused by strokes, brain injuries, brain tumors or inflammatory brain diseases. Aphasia patients are primarily impaired in speaking, understanding, writing and reading. Brain damage is usually not restricted to the language region, but additionally affects brain regions related to movement, vision and other sensory functions. Since mostly the left brain hemisphere is affected, a right-sided hemiplegia and hemianopsia co-occur quite frequently. Fine motor skills are thus impaired for the right hand and arm. Moreover, reading can be difficult, since parts of the information may not

[1] http://gepris.dfg.de/gepris/projekt/5482830

be processed by the patient. As a consequence, aphasia patients are limited in working memory and attention span. Attention deficit disorder affects the patient's ability to focus attention to one event (e.g. following the conversation with one partner) or the ability to split attention to several simultaneously ongoing events (e.g. simultaneous chat with multiple conversation partners).

Furthermore, patients may suffer from an overall psycho motor slow-down with negative effects on their communication. Serious consequences of aphasia-caused impairments are helplessness, resignation, and social isolation, in turn leading to follow-up problems such as depression. Most aphasia patients are elderly people with typical age-caused impairments such as constrained vision, in addition to their aphasia-caused language impairments. Aphasia strongly varies in specific forms, gravity and related diversity of possible accompanying impairments. Aphasia therapy must start in early stages to efficiently counter the resulting impairments. Therapy should also take place on a regular basis, in particular to avoid social isolation. Due to limited budget coverage by public health insurances, regular, but infrequent therapy sessions must be supplemented, e.g. with ICT.

However, the special conditions of aphasia patients require custom-tailored tools to become useful as a therapy supplement. SOCRATES was designed as custom-tailored chat tool to enable patients to continue training exercises at home, beyond regular group therapy sessions in a central health-care institution. With SOCRATES, aphasia patients received support for training text-based communication and for staying in contact with their fellow patients, families and friends. Therapists received support and data to analyze and control therapy progress. In case of difficulties, patients could switch to a synchronous multi-user chat mode to ask peers or therapists in a chatroom for help in real-time. SOCRATES reportedly helped the community counter the negative effects of their condition. The acceptance of the tool reflected in the fact that it was actively used over several years. However, during this active use the community identified several issues.

The physical or virtual presence of therapists during SOCRATES chat sessions was often necessary to keep conversations going and to avoid frustration among aphasia patients. Patients consistently reported excessive cognitive load regarding UI complexity and fast-paced conversations with more than one partner. Cognitive overload reproducably forced patients into motor lock states while working with SOCRATES. Being confronted with an excessive number of action options on the screen, patients exhibited compulsory behaviour to click arbitrary buttons on the interface. Such lock states could only be evaded with the help of a therapist. Patients also experienced problems with the in-conversation help by peers or therapists. Peers were often unavailable or unable to help. Therapists were only online in very limited time windows. For the major rest of the time, patients effectively remained without help.

Therapists and linguists considered re-deployment and maintenance of the system in other aphasia communities as nearly impossible due to the use of closed-source technologies and a lack of documentation of the system's backend understandable for non-technical audiences. Although all stakeholder groups, in particular the patients, reported SOCRATES as valuable therapy tool, concrete factors establishing its success were largely unknown. Relevant quality and impact factors could thus neither effectively be communicated within the community nor across its boundaries, e.g. to health insurances or funding agencies. These issues in turn served as valuable input for the community to further develop SOCRATES and use MobSOS to make relevant factors and improvements measurable.

6.1.2 Objectives Definition

In a subsequent objectives definition phase, the research team collaboratively revisited goal definitions for SOCRATESX, the successor of SOCRATES, in the light of the challenges identified earlier. As part of social requirements engineering and an initial iteration of expert panel techniques, community experts formulated a prioritized list of objectives in the form of concrete requirements. In particular, we identified the following requirements: *(O1) provision of automated patient help in absence of therapists; (O2) reduced user interface complexity to avoid irritating lock states among patients; (O3) easy redeployment and maintenance for migration and duplication in other aphasia communities;* and *(O4) formal means to assess and evaluate CIS success in terms of impact and quality for improved communication within and across community boundaries*. These requirements were realized and evaluated in a diploma thesis [Grun10] guided by the author of this work.

6.1.3 Design & Development

In the *development& deployment* stage we realized all requirements and pre-evaluated the newly created software artifacts with small test groups from the whole community population. The general technical setup followed our CIS succcess-aware infrastructure (cf. Chapter 5). The backend consisted of a production-ready Openfire XMPP server[2], equipped with a plug-in realizing a MobSOS Pipeline (cf. Section 5.2) for monitoring XMPP protocol activity (cf. Section 4.4.1). SOCRATESX was conceptualized as XMPP chat client, custom tailored for efficient communication among aphasia patients. All further development of central SOCRATESX features was mainly guided by the aforementioned community objectives and requirements.

Word Prediction Support (O1) To realize *O1*, we conceptualized and implemented a word prediction system as an XMPP protocol-compliant chat bot being part of any conversation in SOCRATESX. Whenever a participant typed a word prefix and idled for more than four seconds, the bot would draw upon its built-in language model to recommend possible word completions in a context-sensitive manner. As basis for the prediction system, we generated a dictionary corpus by combining and merging the DeReWo [PBK*09] collection of 100,000 commonly used words in the German language and the OpenOffice

[2]http://igniterealtime.org/projects/openfire

German dictionary [JBH*08] with more than 163,000 words. The resulting dictionary corpus consisted of 167,503 different words. Based on this corpus, we used logs of previous chat conversations among aphasia patients to train a language model based on statistical n-grams [LMHi99, LMHA02]. In particular, we built a database from trigrams (e.g. *"Wo bist Du"*), bigrams (e.g. *"bist Du"*), and unigrams (*"bist"*), along with their frequencies of occurrence in former SOCRATES conversations. The word prediction algorithm based on a fallback model that first attempted to derive word completions from trigrams, if not possible from bigrams, and in turn from unigrams. Word prediction was then integrated into the chat UI .

UI Complexity Reduction (O2) To realize *O2*, we pursued a user-centered rapid prototyping approach in collaboration with therapists and patients. We as computer scientists realized a series of prototypes with inreasingly simplified UIs. Prototypes were repeatedly lab-tested by small groups of patients from the previous SOCRATES user group. The therapist team thoroughly monitored each test and documented particular strengths and weaknesses of the respective prototype. We first trialed standard XMPP chat clients such as Pidgin[3]/Adium[4] or SparkWeb[5]. Patients consistently reported an overly high UI complexity, although the proposed solution already rendered simplifications in comparison to the prior SOCRATES system. Too many UI elements, in particular complex menu structures, again confused the patients and forced them into the known lock states (cf. Section 6.1.1). With a rich selection of libraries supporting basic XMPP protocol communication available, we decided to implement the most simplistic chat client possible from scratch. Figure 6.1 shows the final result of this development process. The SOCRATESX

[3]https://pidgin.im
[4]https://adium.im
[5]http://igniterealtime.org/projects/sparkweb

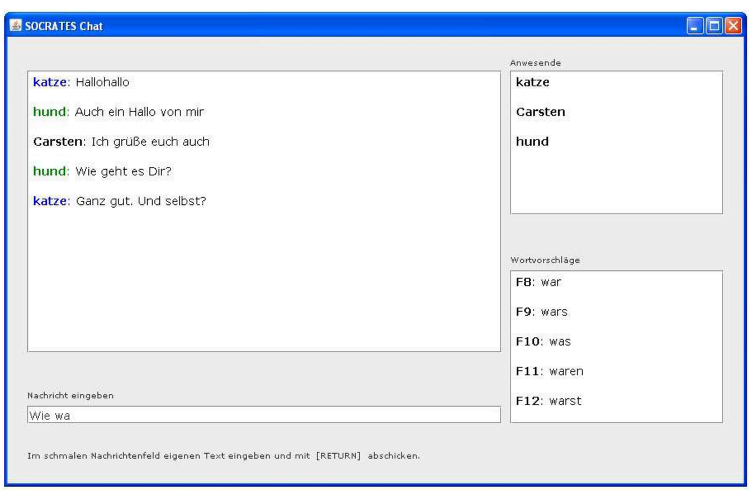

Figure 6.1: SOCRATESX - Aphasia Patient Chat Interface

UI features five interface elements only: a conversation window, a text input field, a list of chat partners, and a word completion list, powered by our word prediction bot. However, in the course of trying out several versions of over-complex user interfaces, many aphasia patients stated their willingness to use the final system, but stayed away from further experiments due to cognitive overload.

Open Source Solution (O3) To realize *O3*, we switched from a closed source protocol implemented on top of the Internet Relay Chat (IRC) protocol [OiRe93] to the open standard XMPP protocol [Sain11a] for federated message exchange in near real-time. XMPP is supported by a rich and well-documented ecosystem of freely available Open Source Software in terms of servers, clients, and programming libraries. Additionally, in collaboration with community experts, community developers produced documentation for server installation and maintenance procedures, suitable for deployment in any organization.

SOCRATESX Success Model (O4) To realize O4, we developed a CIS success model, custom-tailored to our aphasia community, to SOCRATESX as the system under evaluation, and to the particular requirements related to aphasia patients (i.e. O1 & O2). We thereby put an emphasis on patients and their use of SOCRATESX. A separate model could surely have been built for IT administrators concerned with the task of migrating or deploying SOCRATESX in their premises, thus largely addressing O3. We put a clear emphasis on the reduction of survey-based metrics in favor of usage data-driven metrics. This emphasis received strong support from the aphasia community. With the dramatically shortened attention spans of aphasia patients, the completion of a lengthy questionnaire form can become an unnecessarily painful exercise. We constructed an initial a-priori model from a list of factors that was inspired by DeLone & McLean's original work [DeMc92]. Whenever possible, we computed metrics from collected usage data. Only in cases of highly subjective measures, we introduced particular questionnaire items. In an initial metrics exploration initiative, we constructed 58 usage data-based and 14 survey-based metrics for assessing 35 different success factors. Table 6.3 provides an overview of this first a-priori CIS success model. In the course of simplifying the SOCRATESX interface (cf. O2), many usage-data based metrics and factors of the a-priori model became obsolete with the removal of corresponding functionalities. For example, with the removal of chat management functions, metrics derived from operations such as inviting, kicking, banning, joining, and leaving became obsolete. For the sake of parsimony, we removed these constructs from the a-priori model immediately upon obsoletion. After multiple UI simplifications, we further reduced our initial model to an intermediate a-priori model with 15 factors and 24 metrics (11 usage-based, 13 survey-based), as shown in Table 6.4. For the assessment of survey-based success metrics, therapists largely advised questionnaire design by taking into account the specific impairments of aphasia patients. Therapists recommended a simple paper-based design for short questionnaires instead of online questionnaires. We particularly used a large readable font in conjunction with large and easily markable checkboxes. Wide spacing between the different options increased readability

Table 6.3: SOCRATESX A-Priori CIS Success Model Overview

Dimension	#Factors	#Measures	Examples
System Quality	5	3 usage-based, 4 survey-based	• Responsiveness • Ease of Use
Information Quality	9	17 usage-based, 4 survey-based	• Typing Errors • Readability
Use	9	24 usage-based	• Frequency of Use • Duration of Use
User Satisfaction	3	3 survey-based	• Software Satisfaction • Information Satisfaction
Individual Impact	4	2 usage-based, 2 survey-based	• Writing Improvement • Improved Communication
Community Impact	5	12 usage-based, 1 survey-based	• Chat Management • Community Interaction

Table 6.4: SOCRATESX - Reduced Intermediate A-Priori Success Model

Dimension	Factor	Measure/Item	ID
System Quality	Prediction Responsiveness	Avg. Prediction Processing Time	SQ.1.1
		Avg. Keystrokes Until Prediction	SQ.1.2
		Avg. Keystroke Saving Rate	SQ.1.3
		Avg. Hit Rate	SQ.1.4
	Ease of Use	*Is the chat easy to operate?*	SQ.2.1
	Reliability	*Is the system working reliably?*	SQ.3.1
	Feature Completeness	*Does the system posess all relevant features?*	SQ.4.1
	Security	*How important is it to you to only chat with impaired people?*	SQ.5.1
Information Quality	Understandability	Number of Incorrect Words	IQ.1.1
		Avg. Number of Prediction Candidates	IQ.1.2
		How well do you understand other chat participants?	IQ.1.3
	Information Presentation	*How easy is the font readable?*	IQ.2.1
		How easy are different messages to distinguish?	IQ.2.2
Use	Use Frequency	Number of Sessions	U.1.1
	Use Duration	Total Duration of Sessions	U.2.1
User Satisfaction	Overall Satisfaction	*How satisfied are you with the system?*	US.1.1
	Overall Enjoyment	*How much did you enjoy chatting?*	US.2.1
	Prediction Satisfaction	*How satisfied are you with word prediction?*	US.3.1
Individual Impact	Communication Speed Improvement	Increase in #Messages Typed	II.1.1
		Avg. #Words per Message	II.1.2
		Decrease in #Prediction Requests	II.1.3
		How much did your writing improve with word prediction?	II.1.4
	Real-Life Improvement	*How did your communication improve in real-life?*	II.2.1
Community Impact	Real-Life Community Interaction	*How did community interaction improve in real-life?*	CI.1.1

and thus supported easier marking. With maximally three items per page, we assured easy item distinction, which is often problematic for aphasia patients.

6.1.4 Operation & Use

Starting from summer 2010, more than 200 SOCRATES users from our German aphasia community network started to evaluate the new SOCRATESX for a couple of weeks. However, many of these patients later resigned as a result of repeated frustration with the overly high UI complexity of initial client designs. Mediated by an influential therapist, we could engage a small group of patients from the RWTH Aachen University hospital as subjects for more detailed inquiries over a longer time span. In particular, these inquiries included a test-retest design. Over two moderated sessions, we measured both quality and impact of the new word prediction feature. The first session was conducted to establish a baseline by observing and evaluating SOCRATESX use without word prediction. The second session was then conducted with an active and fully functional word prediction system in place to measure impact in terms of differences from the prior baseline.

The second post-test session seemed to be easier for the participating patients. Therapists assigned the same login names to patients as in the first session and provided a brief introduction to using the prediction system. They demonstrated the intended use of the system as means for accelerated text production. Patients then started to use prediction in the intended way. Only few minutes later into the session, usage data recordings proved an unexpected drop in use of the prediction system. It seemed as if the aphasia patients completely ignored prediction features. However, after closer examination, we found that patients were still actively using the prediction system, but in an unexpected way. Patients read the recommended candidates for completion, picked the right candidate, and then finished typing the word on their own. Instead of using the auto-completion function for faster text production, patients appropriated the prediction system as a tool for personal learning and training.

6.1.5 Evaluation

The evaluation of SOCRATESX involved a multi-method approach. In a technical evaluation, we analyzed a set of performance metrics from natural language processing to both measure the technical quality of the word prediction system and optimize its control parameters for most efficient use among aphasia patients. In a user evaluation, we compared baseline and final measurements of usage data-derived performance metrics to judge the impact of SOCRATESX in terms of in/decreased or ac/decelerated text production. In the context of success model validation, the community managed to achieve a model with high content validity with the help of expert panel techniques (cf. Section 4.5.1).

Technical Evaluation

In an aphasia community, personal valuation of a system like SOCRATESX is highly dependent on patient capabilities and impairments. We thus pursued an additional automatic approach to objectively measure the quality of the prediction system with performance and information quality metrics taken from natural language processing research [Fazl02]. The basic idea of this evaluation follows a simulation approach, involving an automated agent as user of the word prediction system. The agent simulates the typing process of a chat participant and queries the predictor with its input on a letter-by-letter basis. After each generated letter of a test message, the predictor is queried with the new context, and the returned result is evaluated. As input for the agent, we divided the corpus of 134,000 lines of patient conversations in SOCRATES into a training and a test set. We thereby used 10% (~13,000 lines) of the corpus as test data, leaving 90% (~121,000 lines) for the training set to prime the predictor. It should be noted that this simulation involves an ideal chat participant under ideal circumstances. In contrast to an aphasia patient, the automatic agent always scans the prediction list after each typed letter and never misses a correct prediction candidate, if presented to him. We thus receive best-case estimates.

Performance Metrics Following recommendations in [Fazl02], we chose the three performance metrics *hit rate (HR)*, *keystrokes until prediction (KUP)* and *keystroke saving rate (KSR)*. HR measures the frequency of generating a correct prediction candidate (i.e. a hit) for a tested word in relation to the total number of words tested (cf. Equation 6.1). KUP measures the number of letters to be typed on average until a prediction with a hit is generated. Obviously, a high value for KUP is a sign for poor prediction performance. KUP is defined as the ratio of the number of letters needed to produce a hit in relation to the number of words with a hit (cf. Equation 6.2). KSR measures how much effort can be saved in the typing process. KSR is defined as number of letters to be typed in relation to the total number of letters in the test text (cf. Equation 6.3).

$$HR = \frac{\#testedWordsWithCandidate}{\#totalWordsTested} \tag{6.1}$$

$$KUP = \frac{\#lettersTypedInWordsWithHit}{\#wordsWithHit} \tag{6.2}$$

$$KSR = 1 - \frac{\#lettersTyped}{\#totalLetters} \tag{6.3}$$

Scenarios To test prediction under different circumstances, we defined three different evaluation scenarios. In the *status quo* scenario, the training text consists of the beginning, the test text of the end of the corpus. In the *random* scenario, the test text is arbitrarily sampled from the corpus. In the *milestone* scenario, the language model is constructed in intervals, with milestones for the test text in between. Each interval consists of an initial training phase, followed by a test phase. The status quo scenario is an estimation of the predictor's current usefulness. The random scenario takes into account that over the years, different patients with different impairments and spelling styles used SOCRATES at different times. Thus, this scenario emulates not only the small group of recent patients, but a more divergent and balanced set of patients. With several iterations of different random samples, we diminish the effects of badly chosen test texts. The milestone scenario emulates prediction behaviour over time and thus allows conclusions for future prediction efficacy.

Results Altogether, we collected data from 21 tests, spanning all three scenarios. In the status quo scenario, we executed eight tests, varying the maximum number of candidates for the candidates list to see effects in our metrics. Measurement results are shown in Figure 6.2. Already with one prediction candidate, hit rate is high at 87.5%. With more than five candidates, hit rate reaches a saturation at 92%. However, a high hit rate is not sufficiently expressive to judge predictor performance alone. If hits are generated only at the end of words, the prediction system cannot be considered useful. Keys until prediction is constantly decreasing with a growing number of candidates presented. Even for one candidate only, a low KUP of 2.23 is already convincing. For five candidates, results are even better with a KUP of 1.51.

Hence, our patients already receive the intended word in their candidate list with only one, maximally two letters typed. Any increase in the number of presented candidates above five would not dramatically improve KUP. However, such an increase would lead to much higher cognitive load on patients and should thus be avoided. KSR and KUP are negatively correlated - as KUP decreases, KSR increases. Comparing KSR for one and five candidates yields a substantial performance improvement by 16.45 percentage points. To exclude possible effects specific to the choice of text lines from the corpus, we executed ten tests with random selections for test and training texts at a fixed number of five candidates. Results are depicted in Figure 6.3. For all ten iterations, metrics stay constant at values comparable to the status-quo test with five candidates. We thus conclude that measurements from status quo tests are representative for the whole corpus. Finally, we executed three milestone tests to evaluate the progression of the prediction system from the beginning to the current status. After each consecutive training interval, we computed HR, KUP, and KSR for the following test interval. We conducted milestone tests for different numbers of intervals from 10 (~1 year), 40 (~3 months), and 120 (~1 month). While coarse-grained intervals did not show clear tendencies, the 120-interval milestone test yielded the results shown in Figure 6.4. Here, we could clearly see a learning curve, yet with high variance in the measured values.

The status quo tests yielded concrete measurement values for word prediction performance. In random tests, we could verify the reliability of these measures. Altogether, these results suggest that presenting five candidates for the prediction list in the SOCRATESX UI is a good choice. A high hit rate combined with a low number of keystrokes until prediction is

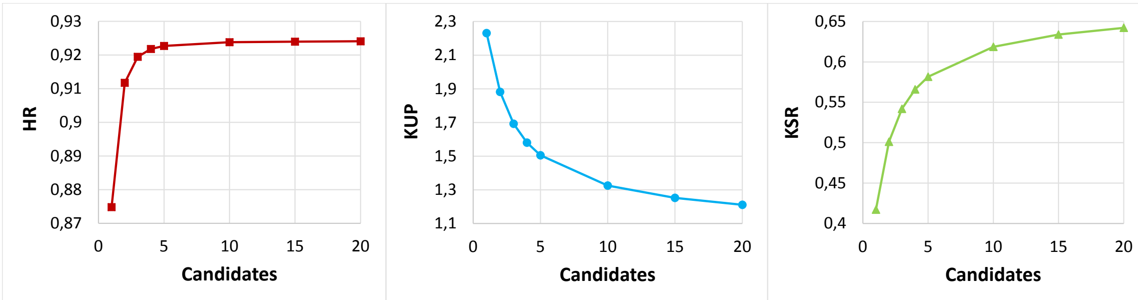

Figure 6.2: Word Prediction Performance - Status-Quo

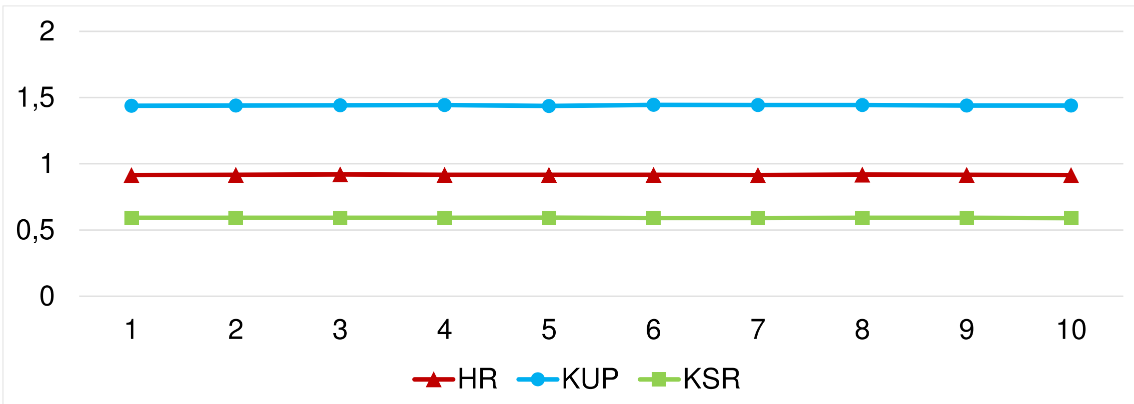

Figure 6.3: Word Prediction Performance - Random Samples

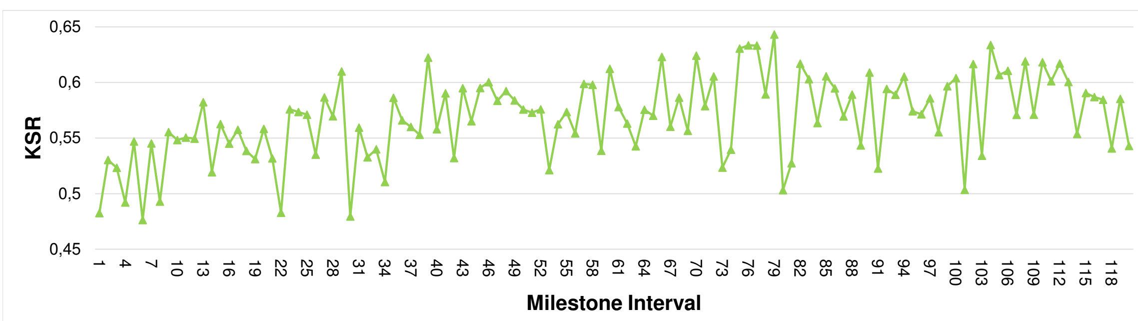

Figure 6.4: Word Prediction Performance - 120-Interval Milestone

an indicator for the good performance of the prediction system. The mild learning curve in keystroke saving rate from our milestone tests shows that our word prediction system already exhibits acceptable performance after short training. Such low training requirements are only possible with a small vocabulary used in chat conversations. Indeed, in their joint sessions, aphasia therapists and patients usually train communication in daily life situations (e.g. introducing oneself, asking simple questions, etc.). These common conversation patterns lead to frequently reoccurring sentence structures with benefits for better prediction quality and less language model training efforts. Given that the German basic vocabulary consists of around 1,000 to 1,200 of the most-used words in its core [Best00], very few training iterations are necessary to cover such limited vocabularies.

End-User Evaluation

In our end-user evaluation, we mainly built upon complete MobSOS data. We therefore collected both usage and survey response data from a small group of aphasia patients before and after the use of the new word prediction feature. An analysis of changes in usage data-derived metrics such as *total number of messages typed*, *total number of words typed* and *average number of words per message* yield the results shown in Figure 6.5. Comparing the average number of words per message, all users achieved an increase. Comparing the total number of messages, we find mixed results. User 3 neither achieved an increase nor suffered a decrease. User 2 achieved an increase of 12.5%. User 1 suffered a considerable decrease of 33%. Comparing the total number of words per session, user 1's performance dropped by 21.6%, while user 2 and user 3 improved by 22.6% and 15.6% respectively. These automatically computed measurements were consistent with self-reported metrics on satisfaction with the overall system and with word prediction in particular. Despite the small number of data samples, these results still allow to derive certain trends. The example furthermore supports community awareness with the direct visibility of improvement or degradation in single patients as well as in the whole community. The raw figures sound rather unspectacular. However, while producing six lines of text merely takes seconds for a normal person, the same task requires about 20 minutes of hard work from an average aphasia patient. Last, but not least, this simple example shows that impact is only observable in changes over consecutive model snapshots (cf. Section 4.2).

Success Model Evaluation

For the evaluation of our a-priori model, the expert panel team had survey responses and measurements for usage data-based metrics at their disposal. Taking into account the initial

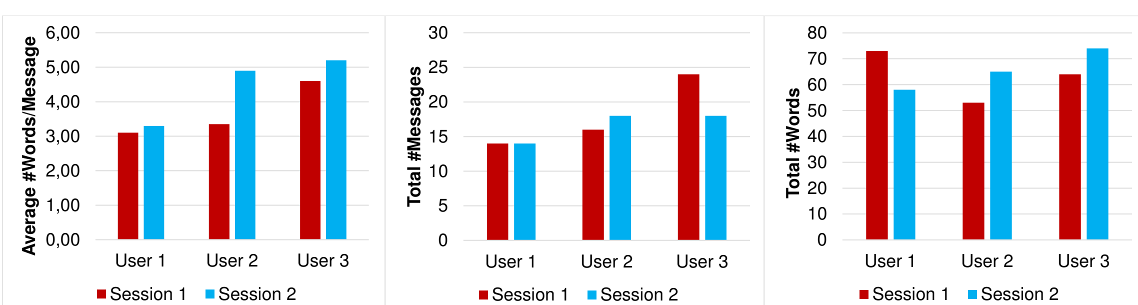

Figure 6.5: Pre-Post Test Results for Aphasia Patient Performance Improvements

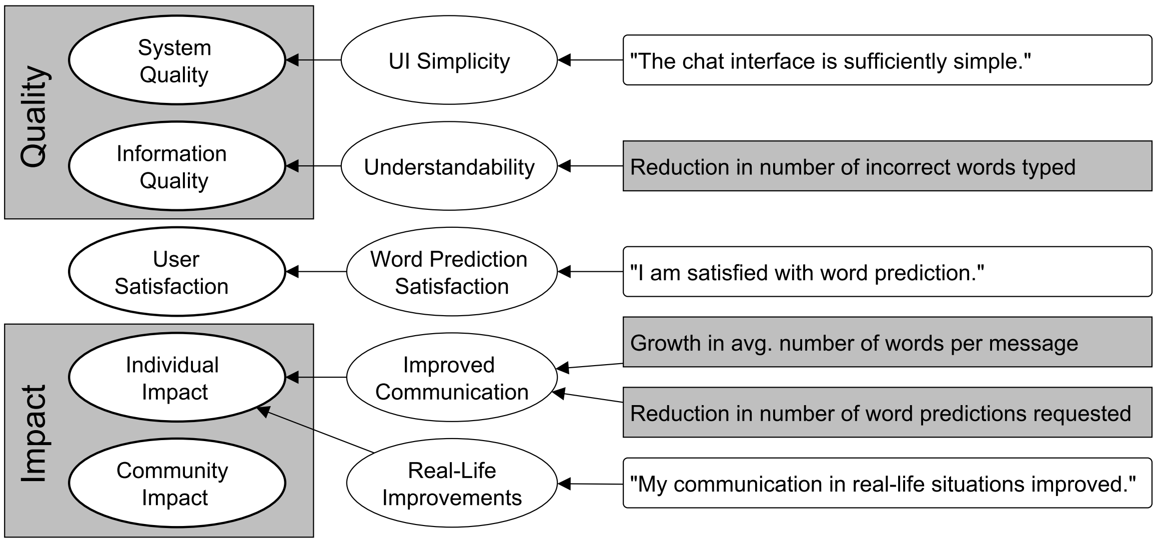

Figure 6.6: SOCRATESX – Final CIS Success Model

objectives with a strong patient perspective and closer scrutinization of available evaluation data, the expert panel negotiated the final success model for SOCRATESX as shown in Figure 6.6. The final model is a result of applying Lawshe's method to estimate an appropriate ranking of success metrics from highest to lowest face and content validity and selecting the first six items from the resulting rank order. As support for or against any ranking decision, we examined each metric regarding its information value for the community. For the final model, the expert panel furthermore improved respective questionnaire items by transformation into Likert-items. We thereby intended a more consistent and uniform use of scales from *totally disagree* to *totally agree*, reducing any further confusions among aphasia patients.

Both quality and impact of word prediction as the first main SOCRATESX objective were mostly reflected in automatically computed measures. Although not contained as explicit metrics in the final model, KSR, KUP, and HR measured per user can be considered as central quality metrics for the word prediction feature. Similarly, the community conceived ease of use in terms of UI simplicity as another major success factor, thus reflecting the respective design objective. A combination of measurably low error rates in user actions and exclusively positive survey response for UI simplicity allows the conclusion that we reached our initial objective O2. UI simplicity furthermore proved its relevance as success factor with being the main cause for the significant loss in patient participation after multiple over-complex UI prototypes. The last metric ultimately assesses real-life improvements in face-to-face conversations among peers.

Interestingly, the final model did not include any factors and measures for the Community Impact dimension. From usage data we infer that aphasia patients indeed conceived SOCRATESX as a personal learning tool rather than its intended role as a tool to accelerate communication and thus reduce waiting time for chat partners. A second explanation confirmed by therapists is that aphasia patients focus their limited attention to own therapy progress rather than the progress of the whole therapy group. A success model tailored to therapists' perceptions of CIS success would probably have included the community impact dimension more prominently.

6.1.6 Conclusions

In this case study, we have demonstrated a very focused case of applying MobSOS-style evaluation, integrated into an overall CIS development process of a community [RKJa15b]. This case study furthermore shows the important role of evaluation with the help of expert panels. Despite the high number of drop-outs caused by overly complex UIs, the community was still able to build a CIS success model with high face validity. We attribute this ability to the rich availability of automatically gathered observation data. The same expert panel techniques used for building a-priori models in combination with automatically captured usage data-based metrics already yield usable information for model building and for further community guidance. Most community experts are already implicitly familiar with such expert techniques from other contexts, but often in a rather qualitative, informal, and poorly documented manner. Only with minimal additional documentation efforts, communities can benefit from a traceability on success factor relevance for future developments. As researchers require quantifiable results for their scientific publications in any case, their documentation brings added value for the community without additional efforts. Undeniably, a wider community participation in evaluation activities, most importantly in providing rich survey response, is still desirable, but often hard or impossible to achieve, as this case has shown. With the additional availability of survey response data, more rigorous statistical validation with regression techniques would probably have provided additional quantified empirical evidence on the success of SOCRATESX.

In the end, the core of aphasia patients remaining in this study was comparably small. However, its unique properties helped explain the importance of establishing a culture of continuously *repeated* evaluation. Qualified statements on improvement resp. deterioration of a CIS artifact are only possible with a principal test-retest design. To that regard, we once more support Gable et al. in that CIS success should be measured as a sequence of largely comparable snapshots [GSCh08]. Such snapshot sequences not only trace changes in relevance and effect strength, but also reflect operations on model structure such as adding relevant or removing irrelevant factors and measures.

Finally, this case study yielded several findings that deserve highlighting. First, by observing only a few very simple, generic, and automatically captured usage-based success metrics, we could prove an emergent, unexpected appropriation of SOCRATESX. Patients had used the word prediction feature as a learning tool, not for accelerating their text production. Second, with the help of few, very specialized, and automatically captured usage-based success metrics from information retrieval (KUP, HR, KSR), we could determine a 5-element candidate list as the ideal configuration for SOCRATESX' word prediction UI. With the same metrics, we could estimate training efforts for the underlying language model. Third, with special regard to a community's central goal of learning how to do better, we could show that MobSOS provides effective support for learning analytics. The impact-related success factors in our model helped to identify learning progress with respect to improved communication speed and resulting real-life improvements. Fourth, we could show that advanced versions of concrete success models are very compact and balanced combinations of a handful of universal generic success factors and metrics on the one side and highly specialized community-tailored factors and metrics on the other – in this model five factors and six metrics. Last, but not least, we could show that a large portion of concrete CIS success models can effectively be computed from objective usage data, thus freeing communities from unnecessary evaluation efforts and related bias.

6.2 Mobile Multimedia Management

Since the early 2000s, we participated in a vibrant community of industrial and academic researchers distributed across Europe with the joint enterprise to design, develop, and research innovative multimedia management technologies. This collaboration took place in the context of the *Ultra High Speed Mobile Information and Communication* (*UMIC*) research cluster, established under the German Federal and State Government Excellence Initiative[6]. The community's main target was to promote and advance multimedia description metadata standards such as MPEG-7 and MPEG-21 [SaSm01, MSSi02]. In an ongoing design-based research endeavour following the ATLAS methodology (cf. Section 3.1), our group made cutting-edge contributions in terms of multimedia management service platforms [SKJR06] and service-powered desktop multimedia management tools, e.g. for non-linear digital storytelling [KSRe06a, KSRe06b] and community-aware multimedia tagging [KSRe07]. With an increasing availability of affordable off-the-shelf mobile devices, our group performed a focus shift from desktop to mobile multimedia applications [CSKR07, KSRe07, KCG*08]. The increasing demand to real-time enabled applications motivated our group to research into the application of real-time protocols such as XMPP for CIS infrastructures [ReKl09]. Within the RWTH cluster of excellence UMIC, we started collaboration with the urban history department at RWTH Aachen University. Their concern with the on-site documentation and preservation of endangered cultural heritage monuments in Afghanistan [KTC*09] was inline with our research interests in modern real-time mobile multimedia management applications for communities [ReKl09, RKCK09, KTC*09, CCD*09].

[6] http://gepris.dfg.de/gepris/projekt/24144303

6.2.1 Problem Identification

A general problem identified throughout multiple prior research efforts was a lack of a general framework for targeted evaluations, reflections and comprehensive awareness of the particular success factors of digital media services and applications. Without success awareness, further developments would lack informed guidance to fulfill the real needs of the communities we collaborated with. This held in particular true for the upcoming class of mobile multimedia applications. We observed that developers of community-tailored digital media applications frequently and repeatedly reinvented the wheel to evaluate their new digital media prototypes. Despite strong conceptual overlapping across different evaluation studies, every developer spent independent efforts to create new proprietary technical setups and questionnaire instruments for each study. The result of this conduct were superfluous efforts in evaluation planning and a general lack of comparability across different evaluation studies due to the heterogeneity of evaluation environments.

6.2.2 Objectives Definition

Our first objective *(O1)* for tackling this problem was to extend the existing LAS [SKJR06] to a CIS testbed with technical means for observing community activity and collecting community feedback to ultimately make mobile multimedia community service success measurable. Based on these means, our second objective *(O2)* was to develop a success measurement model for our mobile multimedia community services. In lack of a mobile multimedia management application to evaluate in the first place, our third objective *(O3)* was to design such an application, powered by our existing LAS MPEG-7 service infrastructure.

6.2.3 Design & Development

Mobile Multimedia Application (O3) Addressing O3, we developed the J2ME-based mobile multimedia application *NMV Mobile* as evaluation target for a first iteration of the MobSOS approach. NMV Mobile made comprehensive use of a mobile device's built-in multimedia and sensor hardware to support users in a wide range of typical multimedia operations such as capturing, viewing, and local storage. Furthermore, NMV Mobile's collaboration features to further annotate, share, and retrieve captured media within communities based on a set of LAS services for MPEG-7 compliant multimedia description, semantic annotation, and retrieval [SKJR06]. On top of plain keyword tagging – the de-facto standard technique in Web 2.0 applications until today – NMV Mobile supported *semantic tagging* with six of the seven semantic entity types defined in the MPEG-7 standard, i.e. agent, object, concept, place, time, and event. With the help of first built-in GPS sensors in mobile devices and respective Java APIs for the programmatic access to live sensor data, NMV Mobile featured semi-automatic semantic tagging for place and time directly upon media capturing. With minimal instrumentation, we prepared NMV Mobile to furthermore transmit additional mobile sensor data and other context information (e.g. device type, current community context, currently used application). This data was transmitted as extended set of header fields along with LAS service requests. Figure 6.7 presents an excerpt from the NMV Mobile user manual, showing the applications's mobile user interface for media viewing and annotation.

CIS Success-Aware Infrastructure (O1) Addressing O1, we augmented LAS and its MPEG-7 services with several of the MobSOS components described in Chapter 5 to create a CIS success-aware infrastructure. We introduced the MobSOS Monitoring Module, an early form of the MobSOS Pipeline (cf. Section 5.2), as means for recording usage data for all LAS services and service-powered applications, among them NMV Mobile. Recorded usage data thereby followed an observation data model for communication over HTTP (cf. Section 4.4.1), being the primary protocol for LAS applications. We furthermore developed the MobSOS Surveys services (cf. Section 5.3) and MobSOS Surveys Mobile as J2ME service frontend. We thus enabled mobile participation in personalized surveys on the success of arbitrary LAS services and applications, directly from within the application.

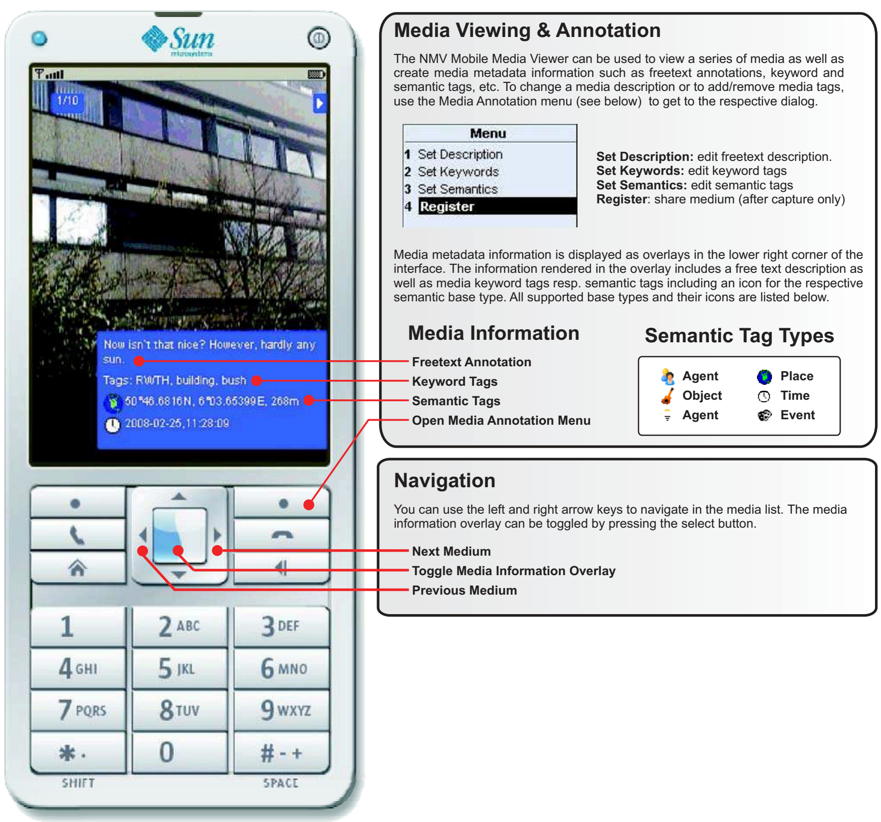

Figure 6.7: NMV Mobile - Multimedia Viewing & Annotation Interface

Table 6.5: Overview of A-Priori CIS Success Model for Multimedia Management Services

Dimension	#Factors	#Measures	Examples
System Quality	12	13 usage-based, 15 survey-based	• Performance • Mobile Context Awareness • Intuitiveness
Information Quality	7	7 survey-based	• Usefulness • Presentation Format • Uniqueness
Use	7	32 usage-based	• Frequency of Use • Duration of Use • Media Usage
User Satisfaction	4	4 survey-based	• Software Satisfaction • Information Satisfaction • Perceived Enjoyment
Individual Impact	4	4 survey-based	• Learning Improvement • Contribution to Personal Goals • Productivity Improvement
Community Impact	6	6 survey-based	• Community Evolution • Motivation for Collaboration • Encouragement for Innovation

Success Model for Mobile Multimedia Management (O2) To address O2, we first developed an a-priori version of a success model for mobile multimedia community services. We therefore compiled a set of 40 different factors and a related set of 81 proxy metrics from both literature and practice and assigned them to the dimensions of DeLone & McLean's I/S Success Model (cf. Section 2.3.2). Table 6.5 provides an overview of our a-priori model. In our compilation, we combined well-established and universally applicable factors and metrics from classic IS success measurement and more recent and community-specific metrics on online community success and multimedia quality of service. With our compilation, we explicitly pursued the principle *"monitor where possible, survey only if inevitable"*. More than half of the included metrics were purely derivable from context-enriched usage data collected with the MobSOS Monitoring Module. For each of these usage-based metrics, we developed formal computation specifications, following the general approach described in Section 4.4.1. An example for *Average Request Processing Time*, a simple, yet universally applicable metric describing the factor *Performance* in the *System Quality* dimension is shown in Figure 6.8.

We furthermore created a pilot questionnaire instrument for our *MobSOS Survey on Mobile Multimedia Community Service Success*. The questionnaire thereby included all survey-based metrics of our a-priori success model and used the personalization and adaptation features described in Section 5.3.2. The questionnaire furthermore included one dedicated

Dimension: System Quality
Factor: Performance
Metric: Average Request Processing Time

```
SELECT uid, AVG(request_endtime - request_starttime) AS apt
FROM MOBSOS.MONITOR
WHERE community = 'mmmc' AND application_code = 'nmvmobile'
GROUP BY uid
```

Figure 6.8: Example Metric: Average Request Processing Time

criterion measure for overall success, thus enabling success model validation by multiple regression (cf. Section 4.5.2). In order to ease later model data analysis, we prepared a convenience database view containing one column per success measure and one row per participant. In later stages of this work, we further automated manual efforts to create such views with the MobSOS Success Modeling service (cf. Section 5.5).

6.2.4 Operation & Use

Over a period of two months, we provided interested community members with evaluation accounts for NMV Mobile and MobSOS Surveys Mobile, including detailed evaluation instructions and manuals for installation and use. Due to limited access to a sufficient number of full-featured mobile devices, we provided an emulation environment supporting participation from regular desktop PCs. In the same manner as installations on real mobile devices, the emulator version contacted our LAS server and thus enabled the collection of context-enriched usage data.

In total, 35 members from two communities, i.e. multimedia developers and urban historians, participated in our evaluation study. We instructed participants to use NMV Mobile at own will and at any time for the next weeks. In a given collaborative mobile multimedia production scenario, we asked participants to collect and annotate multimedia on particular points of interest while they were traveling, commuting, or the like. Participants using the emulation environment could only simulate mobile experience on a stationary PC. However, the emulation environment was feature-complete, including the emulation of changing GPS coordinates and camera use by taking screenshots from a video loop. The most appealing context-enriched usage data was obviously recorded under realistic conditions using a Nokia N95 8GB mobile device.

After their evaluation, we asked participants to complete our a-priori questionnaire using MobSOS Surveys Mobile. We instructed participants to only respond to questionnaire items that seemed relevant and understandable to them. We thus intended to identify a certain ranking among questionnaire items regarding their perceived relevance. At any time, survey participants could revise or retract their questionnaire responses. During the evaluation period, we organized one special evaluation session gathering the majority of participants in a lab setting. Most participants employed the NMV Mobile emulation environment during this session. The intent was rather to analyze performance and stability of both MobSOS components and the evaluated services and applications under more concentrated load.

6.2.5 Evaluation

The evaluation of this case study involves two parts. First, we present evaluation results on technical quality of MobSOS components embedded in our LAS test-bed. Second, we present a detailed discussion of evaluation results regarding CIS success model building and validation with a focus on regression analysis.

Technical Evaluation

For our technical evaluation, we focused on performance, stability and scalability of the MobSOS-specific components developed in this work. The evaluation of the MobSOS Monitoring Module - later extended to the MobSOS Monitoring Pipeline (cf. Section 5.2) - was part of an ongoing adaptation process since the beginning of its implementation. Since the first operational version, we particularly observed usage data logging performance and stability, as well as log data growth with respect to scalability. Usage data logging should guarantee that all requests are logged without excessive blocking of regular CIS service use. Logging over a long community lifetime should furthermore not exceed maximal database table size in near or far future. We thus intended to demonstrate that communities would not have to care about possible table overflows and thus ineffective evaluation data collections over their life cycles.

The average processing time for writing individual log entries was acceptably stable between 4 and 17 ms, even with larger load factors for the database tables storing the data. In combination with the underlying IBM DB2 *Database Management System* (*DBMS*), monitoring provided an acceptable overall performance and stability. However, in its initial implementation, the monitoring module pursued a synchronous writing strategy, thus effectively blocking the underlying connector from serving further requests until the latest log entry was completely written. We effectively solved this issue for all further versions of the MobSOS Monitoring Pipeline by introducing an asynchronous request log buffering strategy. As means for more detailed performance analysis, we later profiled the LAS backend during a 110-minute session with 18 participants evaluating NMVx, a slight extension of NMV by real-time communication and collaboration features using XMPP. As NMV Mobile, NMVx followed the same conceptual CIS success-aware infrastructure, using a MobSOS Monitoring Pipeline for the XMPP protocol. We particularly used the

Table 6.6: MobSOS Monitoring Pipeline Profiling Results

Method name	Time	%
java.lang.Thread.run	01:43:20.806	93.95
i5.las.connectors.XMPP.XMPPConnectionHandler.run	01:43:20.546	93.95
i5.simpleXML.XMLStreamTokenizer.getNextToken	01:42:45.122	93.41
i5.simpleXML.XMLStreamTokenizer.readBufferBlock	01:42:22.577	93.07
i5.simpleXML.XMLStreamParser.getNextElement	01:42:14.835	92.95
java.io.InputStream.read	01:40:04.330	90.97
i5.las.connectors.XMPP.XMPPConnectionHandler.handleTLS	00:01:01.584	0.93
com.sun.net.ssl.internal.ssl.SSLSocketImpl.startHandshake	00:00.32.577	0.49
i5.simpleXML.XMLStreamParser.readHeader	00:00:30.192	0.46
i5.las.connectors.XMPP.XMPPConnectionHandler.resetStream	00:00:29.031	0.44
i5.simpleXML.XMLStreamException.<init>	00:00:03.016	0.05
java.lang.Exception.<init>	00:00:03.016	0.05
i5.simpleXML.EndOfBufferException.<init>	00:00:03.016	0.05
i5.las.components.mobsosx.MobSOSXMonitor.handleEvent	**00:00:02.319**	**0.04**

standard sampling method of yourKit[7] for profiling. With this method, the profiler periodically queried stacks of running threads to measure method execution times. The declared goal was to analyze overall performance and to identify possible performance bottle-necks. Our profiling results listed in Table 6.6 show, that cumulated execution time of usage data collection is acceptably low at 0.4% of overall computing time.

During the evaluation period, we collected all individual MPEG-7 service requests and respective context information from 35 participants of our NMV Mobile evaluation study. The data volume resulting from participants' survey response submission with MobSOS Surveys was negligible in comparison to the mass of usage data. Our estimations regarding the low criticality of data volume growth could be confirmed after a long-term data collection until today. Since its inception in 2008, the system in total recorded 5.7 mio requests from 600 users in more than 20 communities. The involved communities used 30 different services and applications and produced a MobSOS data volume of slightly over 1GB. With such a comparably low data volume, small to medium communities can be estimated to safely stay within acceptable table sizes and overall database performance even for commodity hardware and free software.

With MobSOS Surveys services being integrated into the same CIS infrastructure as the digital media under evaluation, usage data recorded by the MobSOS Monitoring Module was immediately usable for technical evaluation of any CIS service. Besides targeted aggregations for use in our success model, usage data allowed detailed drill-downs revealing technical flaws in service implementations to developers that would otherwise not have

[7] https://www.yourkit.com/java/profiler/

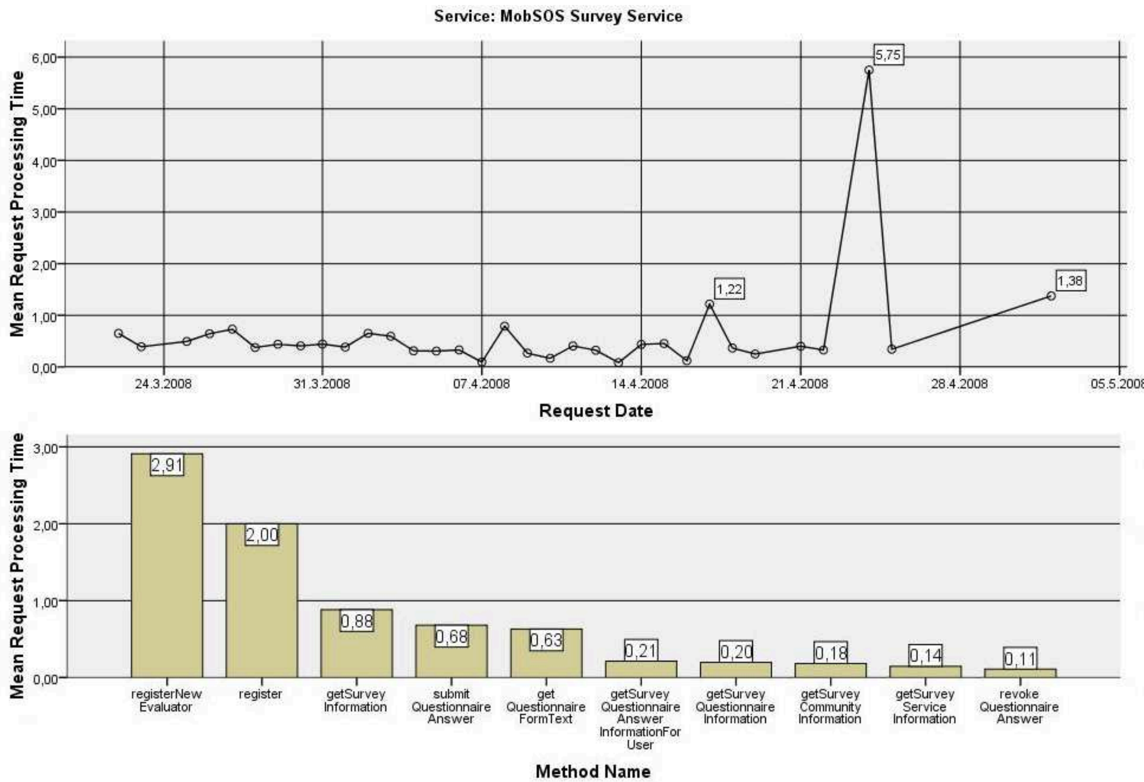

Figure 6.9: Usage Data Drill-Down: MobSOS Surveys Request Processing Time

been discovered. An example for such drill-downs is shown for mean request processing time of MobSOS Surveys services in Figure 6.9. While the top part shows mean request processing times per day on a timeline, the bottom part shows mean processing times per service method. The peaks shown in the upper timeline indicate problems with the underlying database management system. Per-method statistics in the lower bar chart identify the issue as being related with the registration of new evaluation participants. In general, mean request processing time was too high, thus revealing a principal problem. In this case, the underlying experimental XML database used for storing questionnaire forms performed worse than a regular relational database. In a later re-implementation of MobSOS Surveys, we therefore switched to a purely relational DBMS. In the same vein, the underlying CIS and its core services for user management employed another XML database. The high mean processing times in MobSOS Surveys' service methods for evaluator registration resulted from wrapped invocations to user registration methods in the CIS core user management services. We later solved performance issues with user management core services with a completely new user management approach in LAS's P2P-based successor las2peer (cf. Section 2.4.3).

Drill-downs and observations over time essentially help to concretely guide the design and development process. At the same time, they are the predecessors for the development of concrete usage-based success metrics. However, the development of such drill-downs including visualizations was complex and cumbersome, as it required advanced skills to formulate queries to the MobSOS database and generate sophisticated charts using professional statistical software. The reduction of this complexity motivated the development of MobSOS Query Visualization (cf. Section 5.4) as simple browser-based tool for interactive data exploration and success metrics prototyping.

Success Model Evaluation

Apart from this technical evaluation part, the most important target of our evaluation concerned the validation and further refinement of our a-priori success model, based on the collected evaluation data. For this validation, we performed several statistical analysis techniques such as *drop-out* and *correlation analysis* as precursors to applying *multiple regression analysis* as main validation technique (cf. Section 4.5.2). With the results of this validation, the community expert panel completed the construction of a compact and highly valid success model.

Drop-Out Analysis For survey-based metrics, we analyzed drop-outs to the respective questionnaire item among participants. With this analysis, communities can receive first indications of either irrelevant or badly designed items. Since a clear distinction between irrelevance and bad design is not decidable from plain data, we additionally performed informal interviews with involved participants. In Table 6.7 we present all questionnaire items, to which more than 20% of the participants deliberately omitted response.

As an example, we found a high concentration of drop-out rates for survey items on the factor *Multimedia Quality of Service* (*QoS*). In informal interviews, participants reported in unison that they omitted respective items, because they were unsure about the meaning of the term. However, they still assumed its high importance for a dedicated model on mobile multimedia service success. Survey items inquiring about security and privacy were further examples with high drop-out rates. A group of active multimedia application developers relying upon the same MPEG-7 services as in NMV Mobile were familiar with

Table 6.7: Multimedia Management Success Model – Drop-Out Analysis

ID	Description	%
IQ.5.1	Information Timeliness	31.4
SQ.10.2	Multimedia QoS – Perceived Media Quality	25.7
SQ.10.3	Multimedia QoS – Adaptive Media Quality	
US.3.1	Multimedia Content Satisfaction	
SQ.10.1	Multimedia QoS – General	22.9
SQ.12.1	Security – General	
SQ.12.2	Security – Personal Privacy	

yet missing security and privacy preservation measures in LAS service APIs. In informal interviews, they reported their confusion with questionnaire items on quality and impact of security and privacy protection features, because such features were completely absent in the prototype implementation of NMV Mobile.

High drop-out rates usually serve as first indicators to possibly irrelevant success measures. However, voices from our interviews clearly show that high drop-out rates are no necessary conditions for truly irrelevant indicators. Thus, community analysts should not prematurely remove indicators with high drop-out rates from their a-priori CIS success models. They should rather scrutinize the applied data sampling and measurement instruments. In particular, survey instrument design is prone to issues, in particular for indicators on highly subjective, hidden, and underresearched constructs. As a consequence, our informal interviews revealed hidden requirements on API level that also concerned other applications building on the same APIs.

Correlation Analysis We subsequently analyzed correlations between the dependent variable of overall success and individual candidate metrics from our a-priori model. Table 6.8 lists all correlations with high absolute values and being significant at the standard levels of $p < 0.05$ (significant) and $p < 0.01$ (highly significant). Objective metrics for factors in the dimensions *System Quality* and *Use* were mostly deduced from usage data. In contrast, highly subjective metrics for factors in satisfaction and impact-related dimensions were exclusively deduced from survey response data. For example, to assess the factor *genericity* we included a survey item asking community members to rate on a scale, to which degree NMV Mobile features were *rather constrained to specific scenarios (0)* or *widely applicable across usage scenarios (10) (cf. Table 6.8, SQ8.1)*.

Correlation values and significance respectively served as first indicators to effect strength and relevance for a later CIS success model. We identified significant correlations across subjective and objective metrics in all success dimensions, derived from both usage and survey response data. In this work, we only present a small excerpt of a more detailed discussion for this case (cf. [Renz08], pp. 123-124). Several metrics showed that even success metrics with an apparently general universal character could yield highly community-specific results. The respective metric was found highly positively and significantly correlated at the 0.01 level, thus allowing the statement, that the wider participants rate the range of applicability, the higher they rate service success. This finding is typical for a community of multimedia application developers and researchers – more suitable application areas, more dissemination, more overall success. Highly specialized communities in need of special-purpose tools would most likely have provided different assessment results.

Despite previously found high drop-out rates, we found several other metrics with significant correlations to overall CIS success. Against the possible irrelevance due to high drop-out rates, several items on perceived Multimedia Quality of Service were highly correlated to overall success at the $p < 0.01$ level. We thus decided to retain respective survey items in our questionnaire, however only after a careful redesign for better understandability.

Table 6.8: Multimedia Management Success Model – Correlations

ID	Description	Corr.	Sig.
	Usage-Based Metrics		
SQ.4.1	Performance – Avg. Number of Request Bytes Sent per Time Unit	−.350	.020*
SQ.4.2	Performance – Avg. Number of Response Bytes Received per Time Unit	−.289	.046*
SQ.4.3	Performance – Avg. Number of Invocation Bytes Sent per Time Unit	−.353	.019*
SQ.4.4	Performance – Avg. Number of Invocation Bytes Received per Time Unit	−.310	.035*
U.4.6	Performance – Results/Parameters Ratio	−.468	.002**
U.4.7	Performance – Avg. Bytes per Parameter	−.318	.031*
U.5.5	Media Access – Total Number of Media Bytes Transferred	.294	.043*
U.6.3	Duration of Use – Total Invocation Processing Time	.287	.047*
	Survey-Based Metrics		
SQ.1.1	Convenience of Access	.323	.029*
SQ.2.1	Intuitiveness	.458	.003**
SQ.3.1	Responsiveness	.294	.043*
SQ.6.2	Usefulness of Features – General	.539	< .001**
SQ.8.1	Integration - Application Scope	.588	< .001**
SQ.10.1	Multimedia Quality of Service - General	.389	.025*
SQ.10.2	Multimedia Quality of Service – Perceived Media Quality	.466	.008**
SQ.11.1	Mobile Context Awareness	.518	.001**
IQ.1.1	Information Usefulness	.606	< .001**
IQ.4.1	Completeness	−.406	.014*
IQ.7.1	Appropriateness of Format	.429	.05**
US.1.1	System Satisfaction	.543	.001**
US.2.1	Information Satisfaction	.589	< .001**
US.3.1	Multimedia Content Satisfaction	.571	.002**
US.4.1	Perceived Enjoyment	.545	.001**
II.2.1	Improved Personal Productivity	.584	< .001**
II.3.1	Contribution to Personal Goal Achievement	.402	.031*
II.4.1	Individual Influence within Community	.386	.018*
CI.2.1	Improved Community Productivity	.325	.037*
CI.3.1	Contribution to Community Goal Achievement	.334	.033*
CI.6.1	Community Awareness	.310	.045*

**: significant correlation (p < 0.05); **: highly significant correlation (p < 0.01)*

Survey items on *security* and *privacy* with equally high drop-out rates also exhibited low insignificant correlations to overall success. Community members participating in our survey suggested that items unnecessarily inquiring about the quality of absent features should be replaced by more helpful items inquiring about the acceptance of a possible feature realization. Such proposals were insightful, as they emphasize the role of requirements engineering and its relation to success measurement in an overall community development process (cf. Chapter 3). We decided to conceptually separate requirements engineering activities from success measurement of existing community media artifacts. Meanwhile, we see a strong connection between early formulations of requirements and early formulations of success metrics. This connection opens a possible path of further research, discussed in Section 7.2. In a master thesis guided in this work by the author [Behr12], dedicated to the creation of Requirements Bazaar [RBKJ13], we tackled social negotiations of community requirements compliant with our methodology. In the particular case of security and privacy, we found much later that many LAS services lacked sufficient implementations due to the overly complex security API of the underlying CIS testbed LAS (cf. Section 2.4.3). In later diploma and bachelor theses guided by the author of this work [Jans13, Lang13], we simplified the security API and introduced automatically enforced privacy protection features in las2peer (cf. Section 2.4.3). All significant correlations in success dimension *Community Impact* were positive at the 0.05 level, thus allowing the statement, that participants rated overall success higher, if support for community work practices was given and members were aware of each other. Interestingly, measure CI.6.1 was rated high by most participants, although awareness features were obviously not implemented in NMV Mobile. This observation is thus yet another example for a discrepancy between actual and perceived support for community awareness. These discrepancies serve as hint to unfulfilled requirements, in this case for missing community awareness support in NMV Mobile. In later bachelor and diploma theses guided in this work by the author [Schl09, Grun10], we responded to this observation with XMPP-based real-time awareness functions.

Regression Analysis In the next step, we conducted a series of regression analyses with the overall goal to reduce the large a-priori CIS success model to a more compact and statistically validated model. As precursor, we conducted regression analyses for each individual dimension against overall success as the dependent variable. We thus intended to prove that no success dimension on its own would yield a model with sufficient predictive validity to explain overall CIS success. Following DeLone & McLean's original argumentation [DeMc92], a success model should include factors spanning over most, if not all dimensions. For each dimension, we assessed the best fitting regression *technique* along with model *goodness-of-fit* measured by the adjusted coefficient of determination $\overline{R}^2$, the achieved *reduction* as fraction of the number of metrics retained after regression (m_r) and the total number of metrics in the particular dimension of the a-priori model (m). In the next step, we conducted regression analysis over metrics from all dimensions and factors of the a-priori model. We first attempted step-wise regression techniques. Given a certain significance threshold, we shaped several regression models by successively entering different combinations of metrics into the equation, as long as their significance would not drop below the defined threshold. We then chose the best candidate from these several

Table 6.9: Multimedia Management Success – Individual Dimension Regressions

	SQ	IQ	U	US	II	CI
Technique	Stepwise (3 iterations)	Stepwise (3 iterations)	Stepwise (3 iterations)	Stepwise (2 iterations)	Full (1 iteration)	–
Goodness-of-Fit	0.47 (47%)	0.488 (48.8%)	0.35 (35)%	0.411 (41.1%)	0.265 (26.5%)	–
Reduction	3/28 (89.3%)	3/7 (57.1%)	3/32 (90.6%)	3/4 (25%)	6/6 (none)	–

models according to regression statistics as close-to-final form of a CIS success model. In a last step, community experts negotiated the relevance of each success construct and face validity of the respective measures. For prioritization, the expert panel used regression statistics, in particular effect strengths and significance values. Results of our precursor regression analysis are shown in Table 6.9. For most single-dimension models, stepwise regression yielded the highest achievable model fit and reduction. For *Individual Impact*, regression was only possible with all metrics of that dimension and thus achieved no reduction. For the *Community Impact* dimension, regression was not possible at all due to only few metrics and missing data. Although we could achieve model reductions of up to 90.6%, model fit of maximally 48.8% explained variance was unacceptably low for each individual dimension.

In subsequent stepwise regression analyses over the complete a-priori model, we achieved compact candidate models with maximally five measures. However, with an average model fit of 60% of explained variance, none of these models fulfilled our requirements for predictive validity, either. Finally, we generated different combinations and orders for success measures and then entered all selected measures into the regression equation simultaneously without the application of any stepping algorithms. We generated these combinations by successively adding and removing individual success measures from the model in order to observe positive or negative changes in model fit and significance statistics. Table 6.12 shows the selection with best result statistics, serving as our almost-final CIS success model. Half of the constructs in our final model focus on the system quality dimension, which is not surprising for a developer-centric community. The other half is equally distributed across the remaining dimensions. An ANOVA on this best model candidate yielded a small p-value of 0.007, indicating high significance (cf. Table 6.10). The regression model thus bears high explanatory power, i.e. the chosen combination of success metrics helps to predict overall success. For model fit statistics (cf. Table 6.11), the adjusted coefficient of determination $\overline{R}^2 = 0.841$ suggests that an acceptable 84.1% of the variance in overall success is explained by the model's success metrics. The remaining unexplained 15.9% are partially attributable to measurement error, but strongly suggest that the model missed other factors influencing overall success. The evaluation of model coefficients β (cf. Table 6.12) confirms this finding, reflected in regression coefficients. Usually, a higher number of coefficient signs not matching the underlying theory indicates factors yet missing in the model. This is the case for most of the less significant coefficients.

In a final step, our expert panel selected five highly significant measures with reasonable coefficient signs as elements of the final CIS success model. These elements are highlighted in bold in Table 6.12. Ordered by their expected leverage effects, our final model involves a certain rank order given by regression statistics: SQ.10.2,II.2.1,SQ.11.1,CI.6.1,US.2.1. For example, we find that an increase by one unit in perceived media quality (SQ.10.2) is expected to yield a strong leverage with an increase of 1.828 units in overall success. We also find that a one-unit increase in information satisfaction (US.2.1) is expected to only yield a mild leverage with an increase of 0.612 units in overall success.

Table 6.10: Multimedia Management Applications Success Model – ANOVA

	Sum of Squares	df	Mean Square	F	Sig
Regression	95.324	14	6.880	8.568	**0.007****
Residual	4.818	6	0.803		
Total	101.143	20			

Table 6.11: Multimedia Management Applications Success Model – Model Fit

R	R^2	$\overline{R}^2$	Std. Error of Estimate
0.976	0.952	**0.841**	0.896

Table 6.12: Multimedia Management Applications Success Model – Coefficients

Dimension	Factor	Measure/Item	ID	β	Sig.
System Quality	Access Convenience	To what degree is SERVICE convenient to access?	SQ.1.1	-0.124	0.445
	Intuitiveness	To what degree is SERVICE intuitive to use?	SQ.2.1	-0.427	0.056
	Responsiveness	Average Request Processing Time	SQ.3.2	-0.236	0.324
	Usefulness	To what degree are features of SERVICE useful in general?	SQ.6.2	0.160	0.553
	Genericity	To what degree are features of SERVICE constrained to specific usage scenarios?	SQ.8.1	-0.107	0.603
	Perceived Multimedia Quality	**How do you perceive technical quality of multimedia contents served by SERVICE with regard to flaws like jitter, artifacts,etc.?**	**SQ.10.2**	**1.828**	**0.016***
	Mobile Context Awareness	**To what degree is context awareness reasonably realized in SERVICE?**	**SQ.11.1**	**1.028**	**0.010****
Information Quality	Usefulness	How useful is information presented by SERVICE?	IQ.1.1	-1.369	0.106
	Presentation Uniqueness	Have you seen similar forms of the presented information before?	IQ.7.1	-0.823	0.178
User Satisfaction	**Information Satisfaction**	**How satisfied are you with the information presented by SERVICE?**	**US.2.1**	**0.612**	**0.024***
	Perceived Enjoyment	How do you rate your personal enjoyment, when using SERVICE?	US.4.1	-0.112	0.874
Individual Impact	**Improved Personal Productivity**	**To what degree does SERVICE improve your personal productivity?**	**II.2.1**	**1.328**	**0.005****
Community Impact	Improved Community Productivity	To what degree does SERVICE improve the productivity of your community COMMUNITY?	CI.2.1	-0.202	0.503
	Community Awareness	**To what degree does SERVICE make your community COMMUNITY aware of other members' activity?**	**CI.6.1**	**0.836**	**0.013***

The above results confirm that no single-dimension model can fully capture a complex construct like CIS success. Already during the early-phase construction of a-priori models, community evaluators should spread their exploration activities over multiple success dimensions to gain comprehensive awareness. The exact values for regression coefficients suggest the possibility to precisely predict the overall success of an evaluated CIS artifact. However, in the light of our anti-positivist, critical paradigm, quantitative predictions are unlikely to stay exact for a long time. Compliant with [GSCh08], they should rather be understood as snapshots. However, such snapshots contain an explicit rank order, sorted by effect strengths, i.e. regression coefficients. These snapshots provide community analysts with essential information towards a better informed guidance of CIS artifact improvements. A community with strictly limited resources can thus prioritize their decisions for improvements with the highest expected leverage.

6.2.6 Conclusions

In this section, we have discussed the first case study ever applying MobSOS success modeling for the evaluation of mobile applications. We presented the co-development of NMV Mobile among multimedia management application developers and their end-users from a cultural heritage preservation and documentation context.

With a regression model fit of over 84% of variance in overall CIS success explained by model metrics, our final regression model by far outperformed a set of precursor regressions confined to single success dimensions, each of them yielding less than 50% explained variance. By only closely considering the five highly significant success metrics in our final model, we achieved a model reduction in numbers of metrics by 93% from our initial a-priori model featuring 81 candidate metrics. This reduction rate again outperforms all our prior single-dimension regression models. At least for this case, we conclude that no single dimension is sufficiently powerful to explain overall success alone. Instead, we recommend to consider combinations of success factors covering multiple dimensions in order to achieve comprehensive CIS success awareness. In addition to predictive validity, community developers attributed high content and face validity to the final model.

In this case study, the final model included only one success metric derived from usage data (i.e. SQ3.2). In contrast to survey-based metrics, usage data-based metrics were often neither normalized nor normally distributed. Instead, they often followed exponential or power-law distributions. Despite the acceptable quality of our final model, such inherent model properties generally question the applicability of linear regression as technique for CIS success model validation. In Section 4.5.3 we thus discuss ordinal logistic regression as possible alternative. The interpretation of ordinal logistic regression is based on odds and probabilities rather than distinct values as for multiple linear regression. However, both techniques are similarly powerful to produce success metrics rank orders. In other case studies (cf. Section 6.1) we thus focused on usage data-based success metrics.

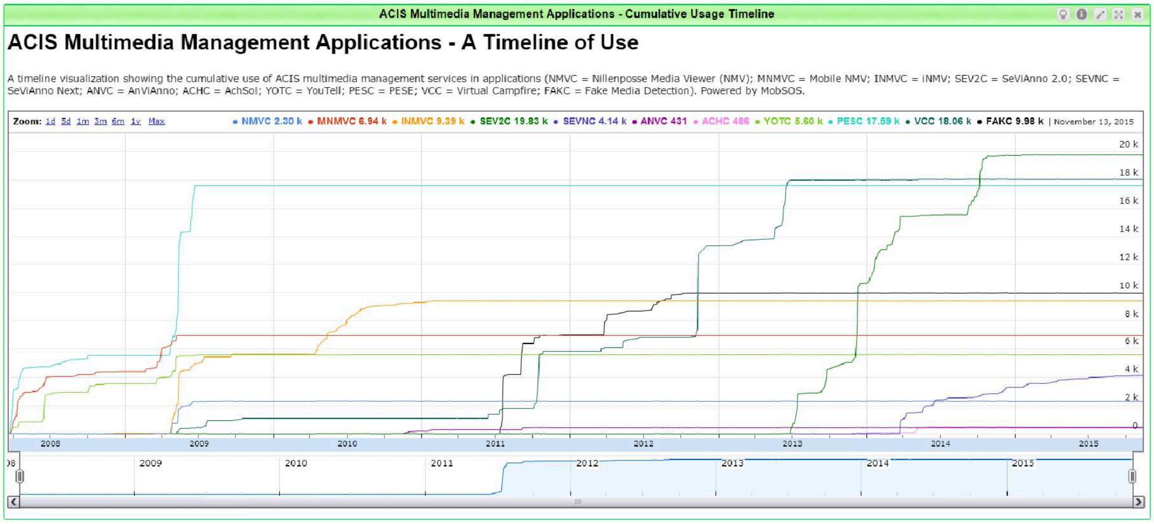

Figure 6.10: Visual Analytics: Cumulative Requests for ACIS Multimedia Applications

Besides their primary purpose of building and validating CIS success models, MobSOS data turned out as applicable to a wide array of different other tasks contributing to community awareness, in particular for visual analytics. An example data visualization widget created with MobSOS QV (cf. Section 5.4) is depicted in Figure 6.10. In this example, we draw upon MobSOS observation data to visualize the cumulative total number of requests to our MPEG-7 services from a number of community applications for multimedia management that evolved from NMV and MNMV until today. On the surface, this timeline chart traces the evolution and superseding of applications developed in our community over time. However, this example also shows the risks of analyzing single pseudo-metrics in isolation and comparing metrics across different contexts. All multimedia applications considered in the chart were powered by the same MPEG-7 services. Static desktop applications such as Virtual Campfire, Fake Media Detection, or PESE with high-bandwidth network access were often lavishly implemented, building upon numerous redundant and overly heavyweight service requests. In contrast, mobile applications such as MNMV or iNMV with low-bandwidth assumptions were optimized for a minimal number of low-data volume requests. Thus, considering the total number of requests as universally applicable success metric is arguable, as it is not robust across the two mentioned desktop and mobile usage contexts and does not include any notion of transferred data volume. In fact, later responsive browser-based multimedia applications designed for both desktop and mobile environments such as SeViAnno strongly benefited from this knowledge.

In general, this example shows that visual analytics are an indispensable tool for exploratory metrics development as part of CIS success model building. Apart from that purpose, visual analytics also allow to trace external influences not under the control of the communities. On the example of this case study, the appearance of new mobile application platforms and respective devices clearly was such an influence. Soon after our study, J2ME-compliant devices practically vanished from the market. They were superseded by the immense commercial success of iPhones, Android smart phones and following new classes of tablet devices until today. Our decision to build NMV Mobile and MobSOS Surveys Mobile as service frontends for an open, yet comparatively proprietary platform technology such as J2ME turned out as dead end. However, since most of the applications' business logic was realized in the service backend infrastructure, we could swiftly realize improved service frontends on newer mobile/Web application development platforms. NMV Mobile [RKCK09] was soon ported to an iPhone version [KTC*09] and later to Android [KAKl12, KNKl14] and Web application [RCLK10, CRJ*10] spin-offs. Developments on MobSOS Surveys continued with a switch to platform-independent open Web standard frontends on the client side in combination with RESTful service APIs in the backend (cf. Section 5.3). Our early decision to build the MobSOS Monitoring Module upon established open Web standards turned out to be the right avenue for further instantiations of the MobSOS CIS success-aware infrastructure in other technical environments.

Finally, this case study yielded several findings that deserve highlighting. First, our technical evaluation showed that the MobSOS approach does not require costly commercial high-performance hardware and software. Even for decade-long data collection in small and medium-sized communities, the amount of collected data stays well within the manageable limits of regular commodity hardware and free libre OSS data management solutions. Second, with only few usage-based system quality metrics, we could accurately localize performance bottlenecks in the evaluated CIS artifact and – based on this information – guide targeted, significant and measurable improvements. Third, we found that especially for early-stage CIS success models, a community's negotiation of success factor relevance reveals hidden requirements to the evaluated CIS artifact. As a result, we find a strong connection between early formulations of requirements and early formulations of success models and metrics. In particular, discrepancies between actual and perceived support for certain CIS features tend to hint to unfulfilled requirements, in this case for missing community awareness support in NMV Mobile. Fourth, we could quantifiably prove that CIS success models spanning over all quality and impact dimensions achieve acceptable model quality in contrast to myopic single-dimension models. We consistently find the same result across all our case studies. Already during the early-phase construction of a-priori models, communities should thus spread their exploration activities over multiple success dimensions to gain comprehensive awareness. Last, but not least, our combination of expert panel and regression techniques proved as effective complementary combination for CIS success model validation. While less formal expert panel techniques even yield acceptable results under the most extreme conditions (small community, low evaluation participation, no usage data), more formal regression techniques are only applicable with sufficient data, but yield quantifiable and operationalizable guidance in terms of overall model fit as well as factor relevance, significance and effect strength.

6.3 Technology-Enhanced Learning

In the context of the European research community on TEL, we collaborated in the development of a Web-based platform for designing and managing a new class of responsive and open PLE [OlLi01]. Such environments empower learners to control and arrange their own learning tool sets, contents, and processes [Down07]. This collaboration with the wider TEL community took place in the context of the large-scale integration project *Responsive Open Learning Environments* (*ROLE*), funded by the European Commission in the 7th Framework Programme (FP7) [8]. For ROLE, we realized a digital approach to PLE with special requirements to openness and responsiveness. We designed the system to be *open* for arbitrary learning communities and *responsive* in terms of personalized recommendations and balanced guidance to respond to the many different learning styles and needs occurring in and across learning communities. The main part of this case study is concerned with the direct evaluation of ROLE project outcomes. We however dedicate a small part of this section to a smaller pilot study in a different project context, as it includes an end-user evaluation of ROLE results and MobSOS QV (cf. Section 5.4). In the following paragraphs, we first provide the reader with a background on ROLE theories, concepts, and technologies.

The ROLE approach builds upon theories of *Self-Regulated Learning* (*SRL*) [Zimm02] actively researched in pedagogy, psychology, neuroscience, and TEL. In particular from a psychological point of view, SRL includes theories on cognition, meta-cognition, motivation, affection, and volition [Kits02]. SRL follows a cyclic process [Zimm02] and includes six key elements, i.e. goal setting, self-monitoring, self-evaluation, task strategies, help seeking, and time management [DaKi04]. Both cognitive and meta-cognitive activities are performed in three phases, i.e. forethought, performance, and self-reflection. Aviram et al. extend the general SRL approach towards a *self-regulated personalised learning (SRPL)* approach by adding learner profiles to indicate personal preferences [ARS*08].

In turn, the ROLE consortium developed a conceptual SRL approach for PLE [NKR*14a, RKKN15], accompanied by a widget-based Web platform infrastructure and a set of compatible SRL-related widgets and Web services [NBD*12]. A *widget* is a packaged, small-scale Web application, clearly focused on small tasks with limited UI form factor. Typical examples for learning widgets are vocabulary trainers, calculators, or digital notepads. Figure 6.11 shows two parts of the ROLE infrastructure and their interplay: a *PLE management platform* and *a widget store*. With the help of the PLE management platform, end-users can autonomously create or join *widget spaces* functioning as contexts for personal or collaborative learning environments. In each widget space, end-users can design and manage PLEs fitting their needs by arranging custom sets of learning widgets on a desktop surface.

As an example for a whole PLE, Figure 6.11 illustrates a widget space for learning quadratic functions. The space consists of a collaboration bar on the left listing widgets members and

[8] http://cordis.europa.eu/project/rcn/89449_en.html

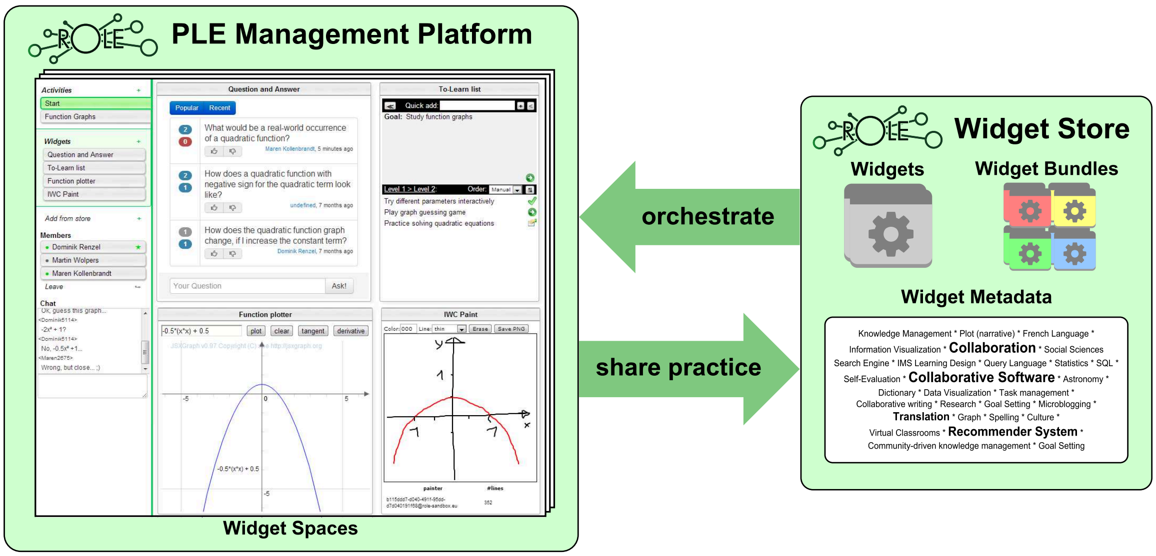

Figure 6.11: Interplay of ROLE PLE Management Platform & Widget Store

chat conversations, and a desktop area with four widgets (Question & Answer, Function Plotter, Paint, and To-Learn List). With the Q&A widget, learners can collect typical questions and answers around the learning topic in the space - in this case quadratic functions. With the Function Plotter widget, learners can receive mathematical function graphs. With the Paint widget, learners can collaboratively draw in real-time. While the first three widgets serve the learning task itself, the ToLearn List widget serves for planning the learning process, e.g. by setting deadlines until an exam. In [RHD*10], we describe a widget-based PLE for language learning as another example.

In analogy to app stores for mobile applications, the *ROLE widget store* [DDFa12] serves as metadata-enhanced repository for widgets and complete widget bundles (cf. Figure 6.11). Learning tool providers can add new widgets and widget bundles, i.e. reasonable combinations of widgets by creating respective metadata. The ROLE PLE management platform realizes a two-way integration with the widget store. In order to *populate* widget spaces, end-users can search and browse an ecosystem of available widgets and bundles and directly integrate widgets into their spaces. As matter of *sharing practice* with other learners, end-users can share individual widgets or well-functioning widget bundles in the store from within their spaces.

In general, the high diversity among learner communities in terms of learning tools, contents, techniques, etc. requires a rich widget ecosystem to choose from. However, as an instance of the general problem tackled in this work, especially niche communities with very specific requirements to learning tools suffered from a lack of tool coverage. In particular, tools for typical meta-cognitive activities in SRL, i.e. planning and reflection, were mostly unavailable. We addressed these shortcomings from conceptual, methodological and technical perspectives with the help of the ROLE *Software Development Kit* (*SDK*).

The ROLE SDK thereby bundles the aforementioned PLE management platform with a development environment for self-regulated learning services and widgets, powered by a set of RESTful APIs, including the project's own APIs for PLE management.

In order to provide a publicly accessible developer sandbox for testing and evaluating new learning widgets, we deployed ROLE Sandbox[9] as an open SaaS installation of the ROLE SDK. We instrumented the installation with a MobSOS Monitoring Pipeline, thus enabling us as platform providers to monitor public activity and to identify potential issues with ROLE SDK during naturalistic operation.

6.3.1 Problem Identification

Soon after its release, log data analysis revealed usage patterns atypical for pure development and testing activities. Usage patterns rather raised the assumption that ROLE Sandbox is used as learning platform by different groups of end-users, i.e. informal learners, teachers, and researchers. These observations raised several interesting research problems, motivating a more extensive application of MobSOS in the direction of learning analytics [BuFe12, Klam13, Pard14] and visual analytics [ThCo05, FWSN08]. Due to the comparably short existence of SRL and widget-based PLEs, only little research had been conducted to observe and analyze SRL processes in small-scale laboratory settings. No research was available on long-term studies of SRL in naturalistic settings.

SRL Learning Analytics With the knowledge of an unknown number of communities actively using ROLE Sandbox, the data set gathered with MobSOS Monitoring Pipeline bears potential for carrying out learning analytics on self-regulated learning on a larger scale. In contrast to small-scale controlled laboratory settings, ROLE Sandbox in conjunction with MobSOS allows for naturalistic studies on self-regulated learning on a much larger-scale. In particular with the original intent to create support for SRL in PLE, a respective learning analytics approach must first target the identification of typical SRL-related activities and their distinction from other activities, e.g. widget development or other forms of learning. In a next step, any learning analytics approach explores for a set of relevant learning indicators, producing actionable insights into the learning process. The awareness achieved with these indicators should guide intervention planning to overcome problems or improve outcomes, not only for learners, but also for the digital learning tools they use. Borrowing from BI&A and *Educational Data Mining* (*EDM*) [BuFe12], this fundamental approach to learning analytics is closely related to the research problem tackled in this work, i.e. creating success awareness with the help of actionable success models.

The ROLE Sandbox case included several other aspects of primary interest for this thesis work. First, social scope and system scope were fundamentally different from the studies presented in Sections 6.1 and 6.2. These studies were clearly focused on one specific CIS

[9] http://role-sandbox.eu

artifact resp. one specific class of artifacts, and we as researchers were closely engaged with its user communities and its development.

Social Scope From a social scope perspective, concrete identities of individuals or communities using ROLE Sandbox largely remained opaque in our log data, thus providing a high level of end-user anonymity. However, observation data gathered from ROLE Sandbox as larger ecosystem of personal or collaborative learning contexts (i.e. widget spaces) appeared as door-opener to multiple inclusive levels of analysis from micro to macro [ReKl13]. These focal lenses range from the individual end-user over communities and networks to societal contexts. As conceptual foundation, we refer to Bronfenbrenner's *Ecological Systems Theory (EST)* [Bron81] and its five nested and interrelated ecosystems around the individual: *microsystem* (direct relation to peer/group), *mesosystem* (entirety of microsystems and relations between them), *exosystem* (network the individual does not belong to, but is indirectly influenced by), *macrosystem* (entirety of all relations in a society incl. norms, rules, traditions, ideologies, etc.), and the orthogonal *chronosystem* (temporal dimension of development). In this case study, such a multi-level scoping serves as conceptual foundation for conducting learning analytics for individuals, for collaboration contexts (i.e. widget spaces with multiple users), and across different learning scenarios. As levels of analysis are nested/inclusive, the availability of micro-level observation data builds the foundation for aggregational analysis on all levels from micro to macro. While many learning analytics initiatives only consider a specific level of analysis [LRC*04, Schr04, BKCV09, DeKl12b], we argued that a comprehensive learning analytics framework should allow analysis on all levels.

System Scope In contrast to previous case studies, CIS artifacts require a much more complex system scope than for a well-delimited single application [DMSe14]. A generic PLE management platform like ROLE Sandbox particularly requires a multi-level perspective of nested system scopes. This perspective is also relevant for the assessment of CIS success. Each widget thereby defines its own success factors, independent from other widgets. In the sense that the whole is more than the sum of its parts, the success of a widget space must be conceived as an aggregate of individual widget qualities and the partial impacts of each widget in this particular constellation.

Interoperability & Capturing Unexpected Learning Behavior Our case study furthermore addresses the generic problem of data interoperability and its particular ramifications in learning analytics. In recent years, the learning analytics research community rather tends to record learning activities and experiences with the help of novel high-level description ontologies and data formats [WNVD07, VRLa15]. In particular in learning service mash-up applications, data on learning experience data from multiple service providers must be available in the same format to allow for an integrated view on one coherent data set. In order to produce such data, learning services and applications must be instrumented individually in a one-time effort. Initial instabilities in specifications introduce further continuous efforts into adaptations in response to specification changes. In typical scenarios, multiple Web-based learning services are combined in learning applications, but monitored separately. The absence of agreed interoperability standards thus complicates cross-service analysis. Taken these additional efforts and complications into account, it is rather surprising that in fact the use of matured standards is often neglected, although cross-service analysis would largely benefit from interoperability [DuVe08]. Furthermore, with an instrumentation approach, learning experience data is only produced for *expected* learning behavior. Unexpected learning behavior as we experienced it in our aphasia case study (cf. Section 6.1) largely remains invisible to any learning analytics framework, that requires extensive upfront instrumentation. As MobSOS follows an approach building on enriched standard protocol log data, such unexpected cases still appear in the data, but must be actively mined for.

6.3.2 Objectives Definition

From the above research problems, we derived a set of three concrete research objectives for our case study. Our primary objective (*O1*) was to trace certain patterns of self-regulated learning solely from context-enriched usage log data. In case such patterns were identifiable, our further objective (*O2*) was then to evaluate the viability of exploring success factors and metrics and combining them to a complete success model for widget-based PLE with respect to self-regulated learning. Our secondary objective (*O3*) was to evaluate MobSOS QV in terms of usability and usefulness as visual learning analytics tool with research experts from the TEL domain.

6.3.3 Design & Development

Although we were deeply involved in development and testing of the PLE management platform as part of our project work, we were not in contact with any particular end-user community using ROLE Sandbox for their particular learning purposes. As such, we were not involved in any learning widget development with end-user community participation. We therefore dedicate this section to the instrumentation of the ROLE Sandbox, providing us as operators with means for automatic usage data collection with MobSOS Monitoring Pipeline (cf. Section 5.2) and with appropriate means for live visual analytics on usage data with MobSOS Query Visualization (cf. Section 5.4).

MobSOS Monitoring Pipeline Figure 6.12 shows the implementation of the ROLE Sandbox MobSOS Monitoring Pipeline following the reverse proxy pattern (cf. Figure 5.3, p. 96) for observing RESTful service interaction (cf. Section 4.4.1) with the ROLE PLE management API. In the pre-processing elements (shown in grey), we filter out irrelevant log information. For later analysis, we are mostly interested in pure API requests and accesses to the ROLE Sandbox main landing pages. In contrast, we are not interested in

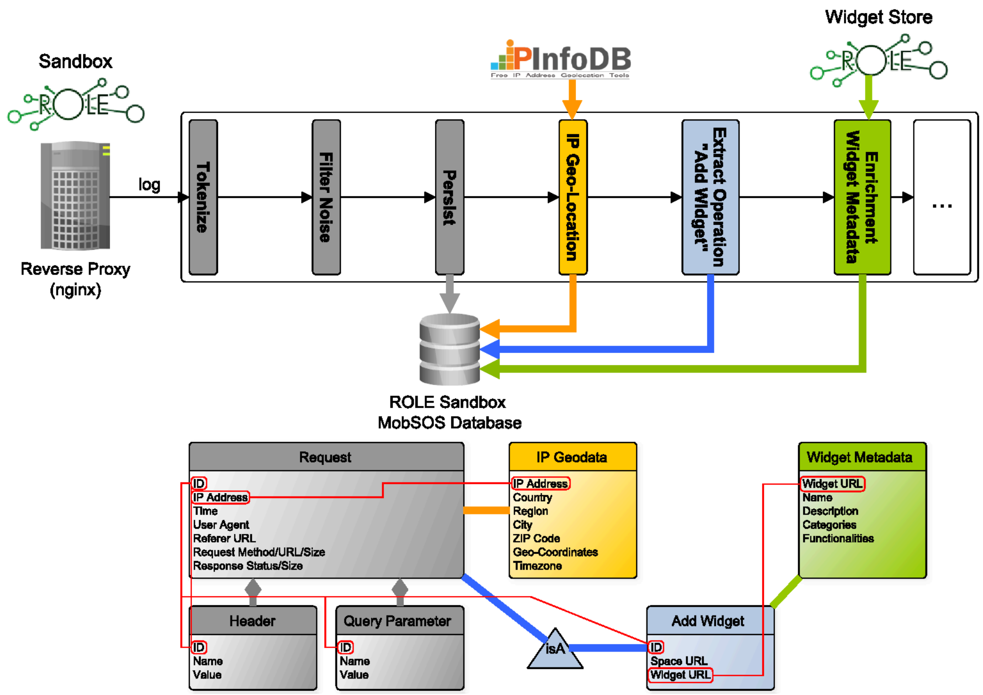

Figure 6.12: ROLE Sandbox – MobSOS Monitoring Pipeline

static content, such as favicons, javascript libraries, stylesheets, etc. Additionally, we introduced a filter for the naturally occurring and ever increasing number of requests from automated software agents such as search engine bots or network security suites. As we are exclusively interested in human agent interaction, we must avoid requests from automated agents, as they introduce considerable bias.

In the enrichment elements (shown in yellow, blue, and green), we augment pure usage data with additional context information. Given a request IP address, an enrichment element for IP geo-location uses the Web service API of IPInfoDB[10] for geo-data retrieval (i.e. country, region, city, ZIP code, geo-coordinates, timezone) and pushes results into the MobSOS data base. Given a request URL, an element for extracting operations of the type *"Add Widget"* filters all requests that semantically describe the action of adding a widget to a space, extracts the relevant information (i.e. widget and space urls), and stores them into a dedicated table in the MobSOS data base. Although the same information in this table is implicitly contained in the request URL, focused analysis of this operation allows more convenient access to the conceptual data fields. In Figure 6.12, we only demonstrate one of multiple different operation extraction elements we created for this case study. For illustrational purposes, Table 6.13 lists four of the 37 distinct RESTful request patterns in interaction with the ROLE PLE management API. The adherence to RESTful principles such as standardized URI syntax and uniform interfaces with well-defined operational semantics [Fiel00]

[10]http://ipinfodb.com

Table 6.13: ROLE Sandbox REST API - URL Template Pattern Syntax & Semantics

URL Template Pattern Syntax	URL Template Pattern Semantics
`GET /spaces/<space-id>`	load space
`PUT /spaces/<space-id>/<data-id>`	change data item in space
`POST /spaces/<space-id>:;tool=<widget_url>`	add widget to space
`DELETE /people/<person-id>/<tool-id>`	remove widget from personal toolbar

eases the definition of automated extraction elements tremendously. Finally, given a widget URL, another enrichment element queries the ROLE Widget Store [NBD*12, DDFa12] for widget metadata (i.e. name, description, categories, functionalities) and pushes results into the MobSOS data base.

MobSOS QV Widget Bundle In response to our visual analytics objective, we decided for a solution seamlessly integrating into an open widget-based PLE management framework. We therefore realized a MobSOS QV widget bundle. This bundle divides the functionality of the original MobSOS QV authoring application into three widgets (cf. Figure 6.13). The bundle thereby supports the export of individual data visualizations as ROLE-compliant widgets. With this mechanism, we created a set of widgets featuring visualizations of ROLE Sandbox MobSOS usage data. We furthermore arranged these widgets in several widget space *activities*. Each activity thereby features a small set of widgets focused to a specific facet of analysis, related to different social and system scopes. Figure 6.14 depicts an overview dashboard used by ROLE Sandbox administrators. A live version of this dashboard is available at `http://role-sandbox.eu/spaces/rsbua`. MobSOS QV's support for creating widget-based visual analytics dashboards also served as technical foundation for the LearningFrontiers portal [DCP*11, DEKl12]. In Section 6.3.5, we discuss this study in more detail, as it includes an end-user evaluation on the usefulness and usability of MobSOS QV. In the course of this study, we extended MobSOS QV's set of supported visualizations by radar charts and data transformation operations such as logarithmization and normalization.

6.3.4 Operation & Use

By the time of writing this manuscript, we have operated the ROLE Sandbox without interruption for four years. Since March 2012, we collected 2.4 million API requests from $>$10000 IP addresses in total. Figure 6.15 provides an overview of spatio-temporal platform usage distribution. The map on top indicates geospatial usage distribution. In total, requests to ROLE Sandbox originated from 1335 cities in 117 countries. Pins on the map thereby encode numbers of distinct IP addresses resolved to the same geo-coordinates with different dot symbols and colors. High numbers of IP addresses with same geo-location hint to usage in larger institutions, while low numbers indicate private use by individuals.

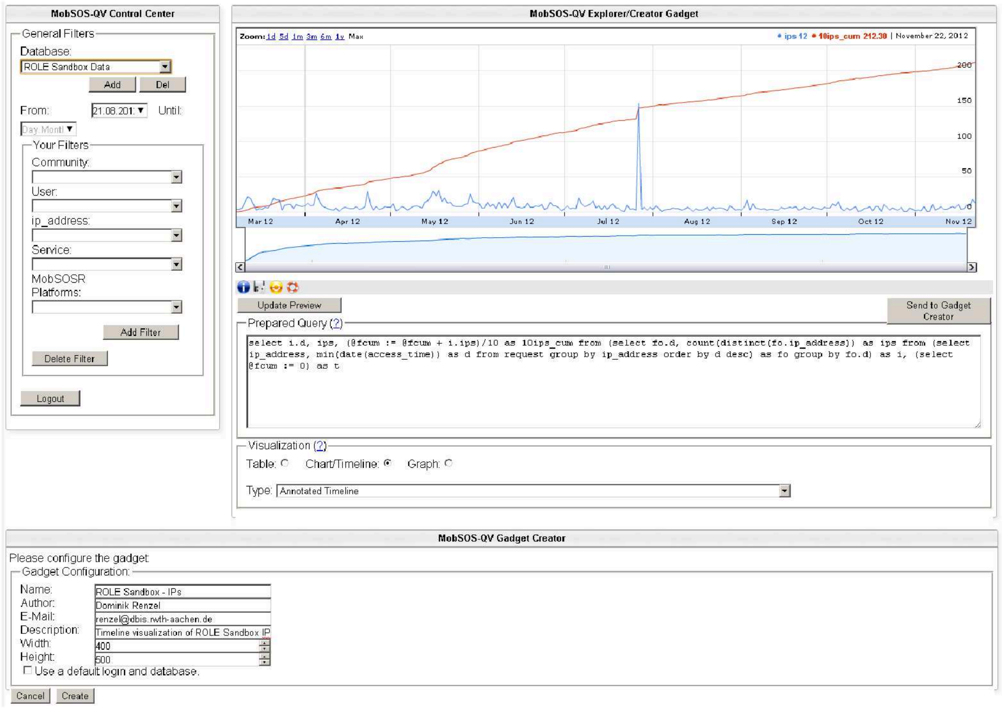

Figure 6.13: ROLE Sandbox – The MobSOS Query Visualization Widget Bundle

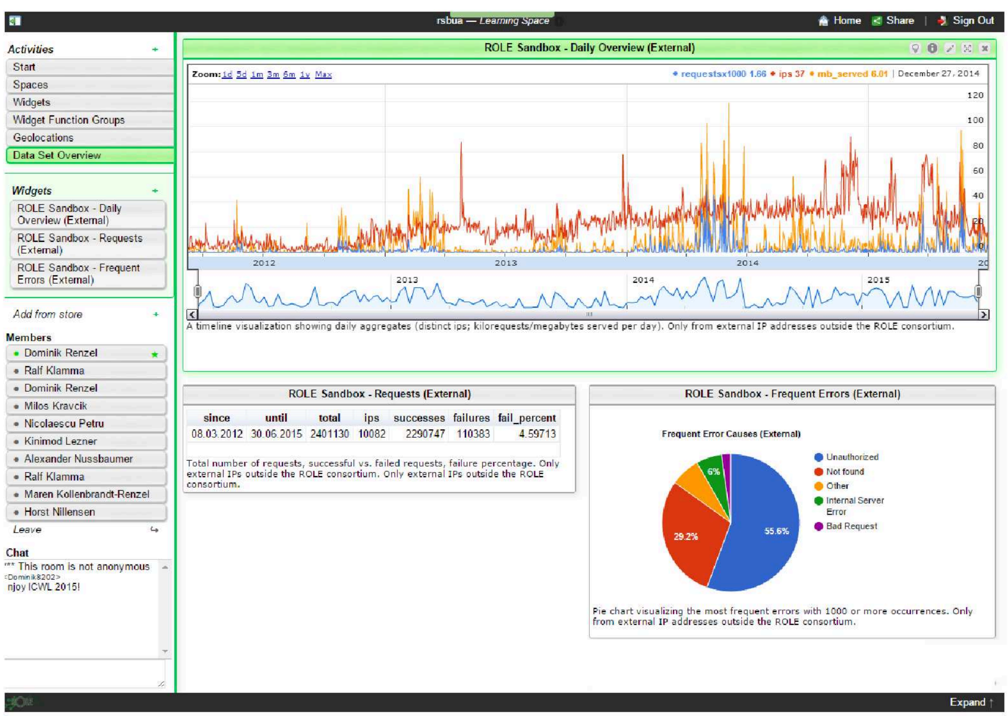

Figure 6.14: ROLE Sandbox – Dashboard of MobSOS Query Visualization Widgets

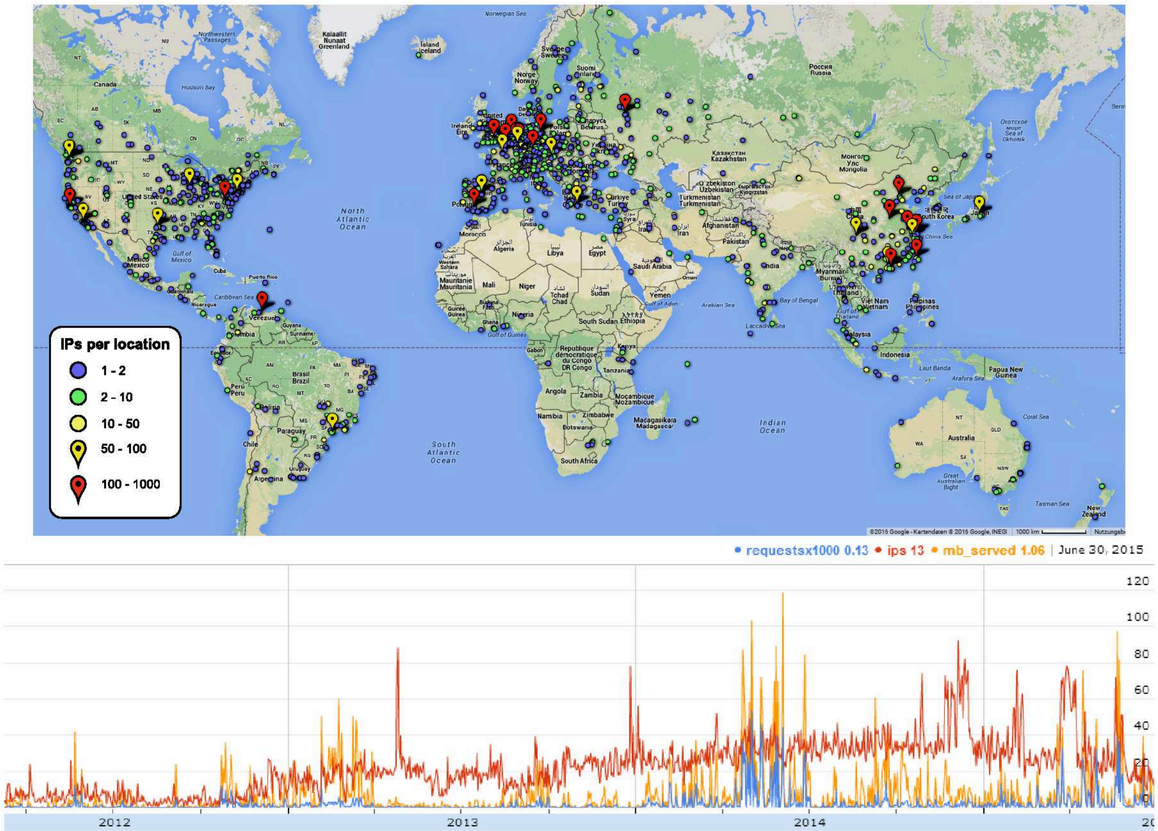

Figure 6.15: ROLE Sandbox – Spatio-Temporal Usage Distribution

Thus, we find that ROLE Sandbox was used by both individuals and institutions with varying size and varying intensity. Usage mainly concentrates on European countries, but also includes less dense international use from individuals to large institutions in China, Russia, South-America, and the USA.

The bottom timeline chart shows temporal usage distribution in terms of daily statistics for request frequency (blue graph indicating 1000s of requests), distinct IP addresses (red graph) and data transfer (yellow graph indicating MBs of data served). On average, ROLE Sandbox processes 2000 requests from 22 different IP addresses per day. Considering the envelope of the red graph, the number of different IP addresses per day has been growing over time. This pattern is an indication for returning end-users, an important group of users in Web-based information systems.

Even with targeted technical measures for filtering out traffic caused by automated agents, we are aware that an unknown fraction of the remaining traffic reported here is still attributable to automated agents in human disguise. Yet, our analysis is mostly focused on client interactions with the ROLE Sandbox API, not on accesses in general. Since these interactions require prior authentication by a human user with a secure authentication method

(OpenID Connect [SBJ*14] in the case of ROLE Sandbox), and ROLE Sandbox API endpoints are not included in search engine indexing, we consider automated agents contacting our API as unlikely. We confirmed this hypothesis in a series of random samplings of failed requests to the ROLE API due to missing authentication.

6.3.5 Evaluation

In response to our initial research objectives (cf. Section 6.3.2), we carried out two strands of evaluation. Referring to objectives O1 and O2 of this study, we analyzed the viability of deriving a success model for SRL in PLE from the ROLE Sandbox log data set. Referring to O3, we present the results of an end-user study assessing usability and usefulness of MobSOS Query Visualization in the context of the Learning Frontiers dashboard.

Success Model Evaluation

Starting point for this evaluation was a usage pattern mining in the observation data collected with MobSOS Monitoring Pipeline. Not surprisingly, most of ROLE Sandbox activity exhibited patterns of our originally intended use - development and testing of widgets and widget bundles by developers. A typical space used for developing widgets or widget bundles shows the following patterns. It carries a development and test-related name (e.g. "iwc-test"). It is usually populated by a single end-user (i.e. a developer). It contains a relatively stable set of widgets (i.e. the widgets under development). It shows bursts of high-frequency reloads or request sequences (i.e. due to frequent manual or automated testing). It contains widgets that were neither added nor used in other spaces (i.e. widgets were not yet released).

However, we also found quite different patterns, raising the assumption that ROLE sandbox was also used for concrete learning activities. Referring to objectives O1 and O2 (cf. Section 6.3.2), we thus focused our exploration to those patterns allowing conclusions on the occurrence of self-regulated learning activities. In particular, we focused on the design and use of personal or collaborative widget spaces as part of the learning planning and preparation phase [NKR*14a, RKKN15]. Addressing the notion of multiple nested system and social scope levels, our evaluation included analyses on different levels from a high-level platform overview to individual widget details. In each of these scopes, we explored for metrics potentially relevant for the success of supporting self-regulated learning activities. With particular respect to O1, we compared SRL-related and non-SRL related entities and activities in order to reveal potential impacts introduced by our SRL tools. Table 6.14 provides our a-priori CIS success model for SRL in PLE with extended information on applicable scope levels for individual metrics (*W: individual widget; S: individual space; an P: whole platform*). In the following paragraphs, we trace the exploration process behind this list of candidate metrics.

Table 6.14: A-Priori Success Model for Self-Regulated Learning in PLE

Dimension	**Factor**	**Measure**	**ID**	**Scope**		
				W	**S**	**P**
System Quality	Reliability	Failure Rate	SQ.1.1	X	X	X
	Focused Functionality	#Assigned Categories	SQ.2.1	X	X	
Information Quality	Guidance & Freedom	Widget Metadata Coverage	IQ.1.1			X
		SRL Tool Proportion	IQ.1.2		X	X
		In-Store Availability	IQ.1.3	X		
Use	Frequency	Widget Add Frequency	U.1.1	X		X
	Users	Space Creator Percentage	U.2.1			X
		Space Joiner Percentage	U.2.2			X
		Widget Adder Percentage	U.2.3		X	X
		Widget Loader Percentage	U.2.4			X
		SRL User Ratio	U.2.5			X
		# Users	U.2.6	X	X	X
Individual Impact	Meta-Cognition & Awareness	Visual Analytics Facilities	II.1.1	X	X	X
Community Impact	Collaboration & Practice Sharing	Collaborative Space Percentage	CI.1.1			X

PLE Management Platform Use Self-regulated learning conceives the continuous design of personal learning environments as important part of planning and preparation of future learning episodes after repeated self-reflection and evaluation of past episodes. Hence, we analyzed the general use of the ROLE PLE management platform for a first overview. From the collected MobSOS data set we find, that users created 1637 spaces in total, where 890 (54.37%) can be considered active, i.e. with more than 100 requests. From 10236 IPs in total, users behind 2610 (33.5%) IP addresses interacted with the ROLE Sandbox in different ways. 178 (1.74%) IPs created new spaces (*U.2.1*), 602 (5.88%) joined spaces (*U.2.2*), 672 (6.57%) added widgets to spaces (*U.2.3*), and 2349 (22.95%) loaded spaces designed by others (*U.2.4*). These statistics confirm the usual participation inequality [Niel06] present in social software systems. Only a small fraction of users become active in terms of designing own learning environments, while most other users benefit from existing learning environments. Based on these overview statistics on PLE design activity, we conclude that only a small fraction of ROLE Sandbox end-users ever was or has become self-regulated learners.

SRL vs. Non-SRL Widgets In a next step, we analyzed the widgets used in the ROLE Sandbox with regard to their relation to SRL. In total, users employed 1177 distinct widgets in personal or collaborative widget spaces. In order to support self-regulated learning, the ROLE consortium designed and implemented a set of 15 SRL widgets for recommendation, self-assessment, self-monitoring, self-evaluation, and other SRL activities. Resulting

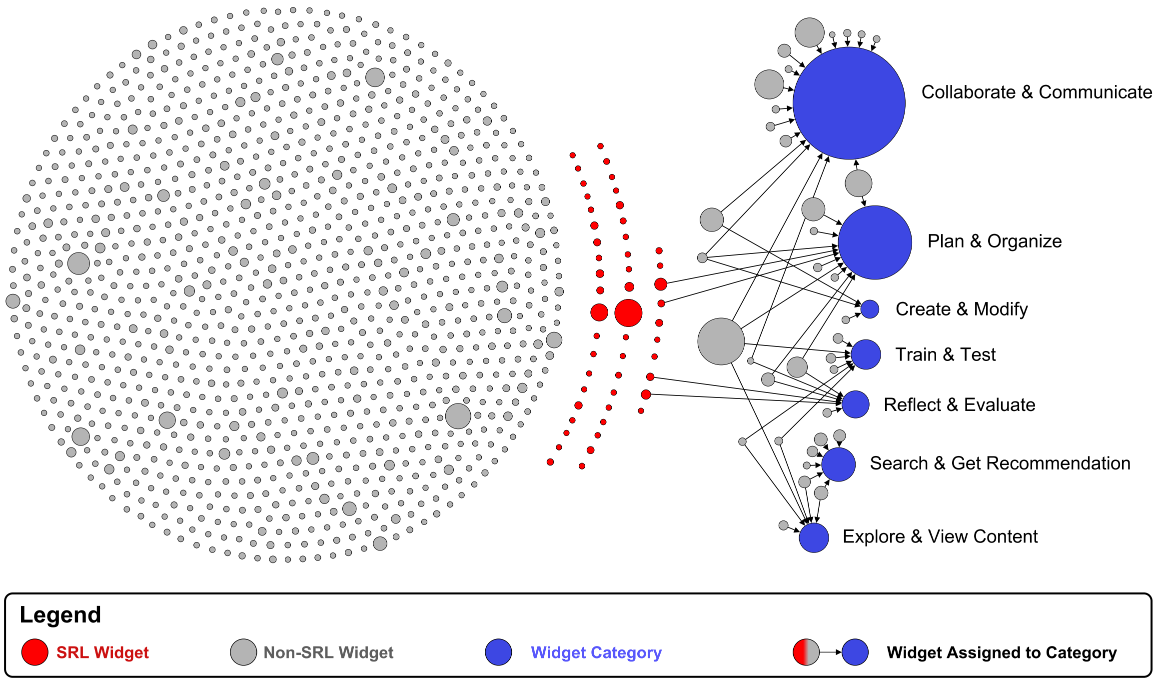

Figure 6.16: SRL and Non-SRL Widget Assigments to Categories

in an overall *SRL Tool Proportion (IQ.1.2)* of 3.99%, we found the use of 47 SRL-related widgets. The additional 32 SRL widgets were adaptations or customizations of the original ROLE SRL widgets, rather than new developments. Resulting in an overall Widget *Metadata Coverage (IQ.1.1)* of 3.39%, 40 widgets were assigned to one or more of the categories *Search & Get Recommendation*, *Plan & Organize*, *Communicate & Collaborate*, *Create & Modify*, *Train & Test*, *Explore & View Content* and *Reflect & Evaluate*, which relate to typical functionality groups assigned to the four phases of the ROLE SRL process model [NKR*14a, RKKN15]. Figure 6.16 provides an overview of *SRL-related* (red dots) vs. *non-SRL-related* widgets (grey dots) assigned to the categories (blue dots). Widget node size encodes *Widget Add Frequency (U.1.1)*, i.e. how often the widget was added to spaces. Category node size encodes the number of widgets assigned.

The number of categories a widget is assigned to serves as quality measure to analyze its *Focused Functionality (SQ.2.1)*. With an undesirable value of zero, the widget developer has not described his widgets functionality at all. Thus, the function of the widget remains unknown to any category-based search or recommendation. Ideally, a widget is focused (and thus assigned) to one or two function categories. An assignment to more than two categories is an indicator for low widget quality in terms of functionality overload. Such a widget should conceptually be divided into multiple widgets with more focused functionality. The vast majority of widgets is neither registered in the widget store nor assigned to any category, including the most influential SRL widgets. This is a clear shortcoming, as the mostly category-based widget recommendation algorithms available in the ROLE ecosystem cannot include these widgets in their results. Most of the assigned widgets are only associated with exactly one category, thus indicating their clear purpose for one of the SRL learning phases. Not surprisingly, widgets assigned to categories are usually added to spaces more frequently, as they appear in recommendation results. Assigning categories to the remaining majority of uncategorized widgets is thus expected to contribute major improvements to search, recommendation, and guidance throughout the widget ecosystem. Maintainers of PLE platforms as well as widget developers should collaborate to guarantee *In-Store Availability (IQ.1.3)* to maximize retrievability, use, and impact of each widget.

In order to examine the relation *widget added by user*, we constructed a bi-partite graph of users and widgets. We thereby distinguished *SRL widgets* vs. *non-SRL widgets* and *SRL widget adders* (i.e. users who added at least one SRL widget to any space) vs. non-SRL widget adders. The resulting graph exhibits 66 connected components with one giant component. Users in the smaller components mostly represent widget developers working on widget prototypes never used by others. Notably, all SRL widgets and SRL widget adders were part of the giant component.

SRL vs. Non-SRL Spaces We furthermore analyzed our data from a space scope perspective. Goal was to investigate significant differences between *SRL spaces*, i.e. spaces in which at least one SRL widget was added or loaded, and *non-SRL spaces*. In total, we found 156 (9.53%) active SRL spaces. We also found differences between SRL and non-SRL spaces in the *Collaborative Space Percentage (CI.1.1)* as depicted in Figure 6.17.

While 53 % of all non-SRL spaces are collaborative, i.e. involve more than one user IP address, 69.1 % of all SRL-spaces are single-user personal learning spaces.

Resulting to a *SRL User Ratio (U.2.5)* of 1.85%, users behind 189 IP addresses actively designed and used spaces including SRL widgets. Users behind 74 (0.72%) IP addresses added SRL widgets to spaces, 39 (0.38%) more than one. 171 (1.67%) users actually used SRL widgets in space contexts, 113 (1.1%) more than one. In general, SRL widget adders are significantly more serendipitous in trying out yet unknown tools.

Regarding widget add frequency per space (*U.1.1*), we clearly observed distribution differences for SRL and non-SRL spaces. Non-SRL spaces span a wider range of widget add frequencies. However, a majority of spaces exhibits very few widget add operations. In contrast, SRL spaces span a closer range, but tend to better distribute widget add frequencies in this range. Regarding the number of distinct categories per space (*SQ.2.1*), we found significant differences, as well. SRL spaces tend to cover more distinct categories to higher extents and less often exhibit widget constellations not assigned to any category. Since categories more or less directly map to the different phases of our SRL model, we can conclude, that SRL spaces tend to cover more learning phases than non-SRL spaces. Again, categories seem to fulfill their role as guidance support. Regarding the number of distinct IP addresses per space (*U.2.6*), we find that SRL spaces involve less learner collaboration than non-SRL spaces (cf. Figure 6.17). The percentage of single-user SRL spaces is significantly higher than for non-SRL spaces. The numbers of distinct IP addresses per space also strongly differ. Regarding the number of distinct widgets, we find that non-SRL spaces concentrate on lower numbers, while SRL spaces exhibit a larger range with a better distribution. We thus conclude that more exploration of potentially valuable widgets for learning happens in SRL spaces than in non-SRL spaces. This advantage is again attributable to the available SRL-related recommendation tools.

Finally, we examined widget add operations from the category perspective to receive an overview which categories showed to be most influential in SRL spaces and in spaces in general. Again, we found significant differences, as depicted in Figure 6.18. A significantly lower percentage of widgets added to spaces belonged to no specific category for SRL spaces (60.45%) in comparison to non-SRL spaces (82.5%).

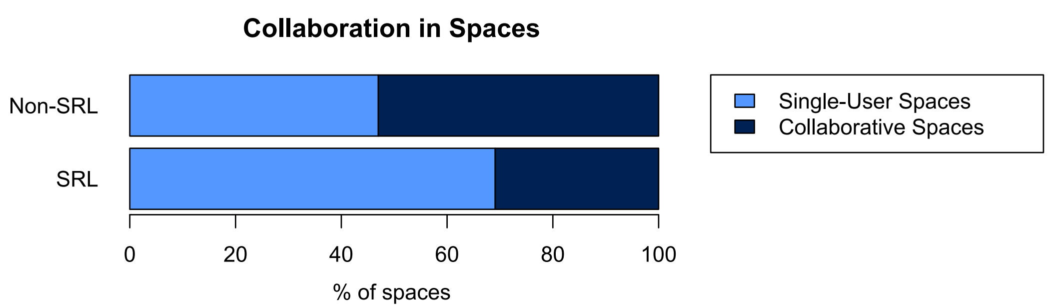

Figure 6.17: Collaboration in SRL and Non-SRL Spaces

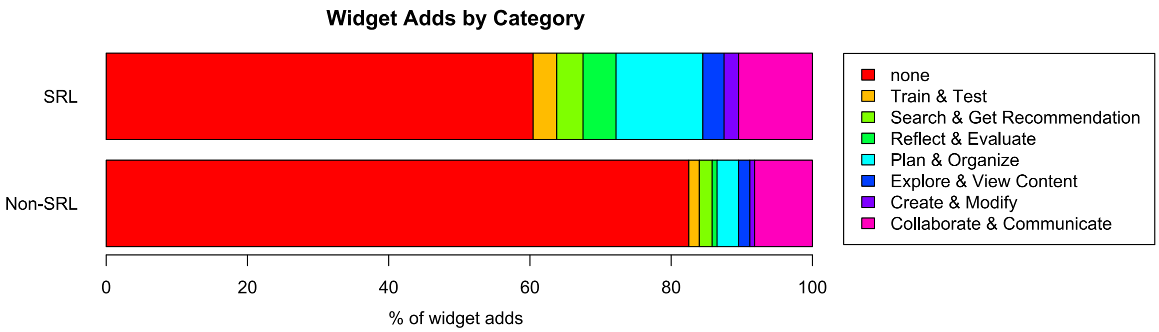

Figure 6.18: ROLE Sandbox – Widget Categories for SRL Spaces vs. All Spaces

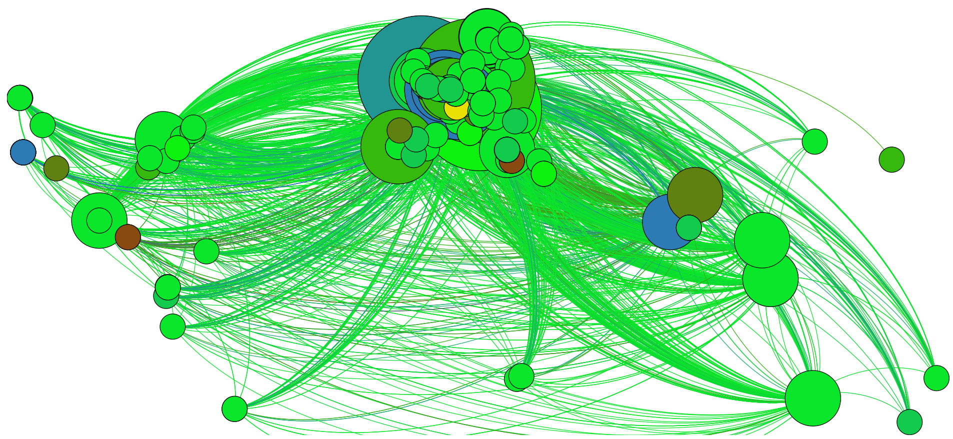

Figure 6.19: ROLE Sandbox – Geo-Layouted Learner Collaboration Network Graph

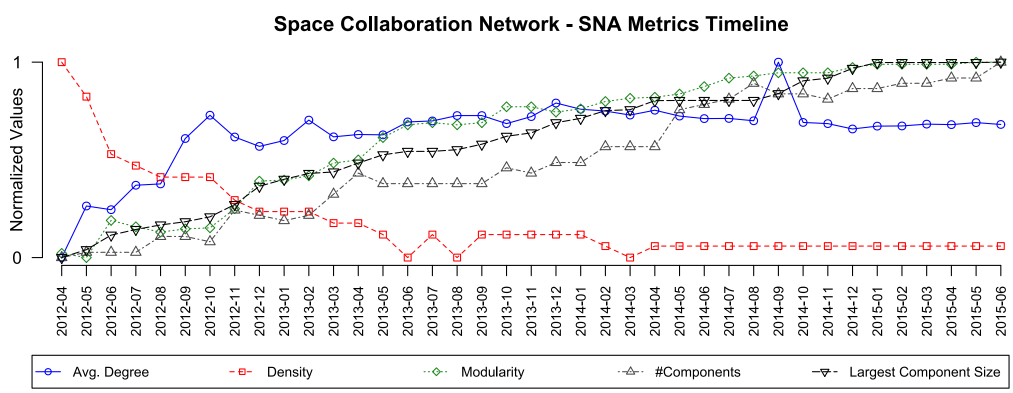

Figure 6.20: ROLE Sandbox – SNA Metrics Timeline Analysis Example

Social Network Analysis As a side objective of this case study, we examined the applicability of social network analysis techniques to ROLE Sandbox usage data. In particular, we studied several social network graphs induced by user interaction with the system. As illustrative example, we demonstrate our analysis for a learner collaboration network graph.

From monitored user collaboration in spaces (two users joined the same space) we first derived the network graph. Nodes in this graph represent users. Edges represent the relation of two users collaborating in one or more spaces. With additional geo-location context data, MobSOS data allowed us to layout the nodes of our learner collaboration network to a planar world map (cf. Figure 6.19). Node size encodes node degree. Node colors encode assignments to communities, based on SNA measures. The dense cluster of nodes in the top center represents users in Europe being the main target audience of ROLE Sandbox. The largest connected component of this graph, indicated with green node color, spans across the whole globe. With most edges leading into this European cluster, we can derive that European users were actively involved in international collaborations, while collaborations between non-European users were rather seldom.

In a timeline analysis, we furthermore examined the development of five key global network metrics over 38 months. In particular, we measured the *number of connected components*, the *size of the largest component*, graph *density* as index for the degree of dyadic connection among ROLE Sandbox users, *modularity* as index for the strength of division into separate graph components, and the global *clustering coefficient* as index for the tendency of users to build clusters. Figure 6.20 shows the results of our timeline analysis with all metrics normalized. Over the years, we find that the largest component has grown stronger, but at the same time a large number of smaller communities has populated the platform.

Guidelines From our explorative analysis of candidate factors and metrics summarized in Table 6.14, we concluded five key success factors of self-regulated learning in PLE: *personalisation*, *guidance & freedom*, *meta-cognition & awareness*, *motivation* and *collaboration & good practice sharing*. Reflecting all these factors, we formulated the following guidelines for self-regulated learning in PLE.

Learners should be empowered to *personalize* and adapt their PLE to preferred learning techniques, content, tools, services, peers, and communities. However, personalization requires an understanding of how to create pedagogically-enabled widget spaces. While novice learners should be guided, proficient learners should be free in their PLE designs.

Guidance and Freedom must be balanced. Therefore, multiple levels and types of guidance should exist for learners with different SRL skills. Guidance should never be prescriptive, but leave the decision to the learners.

Meta-cognition as kind of self-monitoring, self-observation and self-regulation should be stimulated by engaging learners with key SRL activities. To support meta-cognitive processes, we recommend widgets designed for meta-cognitive activities (e.g. reflection or progress visualization). These widgets should provide learners with feedback on their own learning process, thus stimulating *awareness*. Such feedback requires appropriate learning analytics support, as provided with MobSOS QV.

For stimulation of intrinsic *motivation*, PLE must enable learners to develop autonomy, competence, and relatedness. Motivation is a consequence of the right balance between guidance and freedom, thus being an implicit feature of our framework. However, initial extrinsic motivation facilitated by teachers or peers is advisable in any case.

Collaborative activities trigger additional cognitive mechanisms beneficial for learning success. PLE should therefore enable *collaborative learning* as joint interaction among peers in the same learning context [Dill99b].

End-User Evaluation

During the long-term evaluation of ROLE Sandbox, we re-used and further developed the widget-based MobSOS QV dashboard approach [DCP*11] to create the LearningFrontiers portal in the context of the EU Coordination and Support Action TEL-Map[11]. The primary goal of this portal was to explore and visualize the landscape of European TEL research with a visual analytics dashboard approach. MobSOS QV obtained the information presented to dashboard users from our TEL Mediabase [KSCJ06, PeKl08], providing different stakeholder groups such as scientists, policy makers, instructors, and learners with TEL domain-specific information and tools for cross-community and cross-media analysis. This data was further enriched with bibliographic data from DBLP[12], and facts on collaborative EU-funded projects from the European Commission's CORDIS portal[13]. As such, this study once more proved the generic applicability of MobSOS QV for data visualization purposes across different data sets. Implementationwise, we realized the dashboard as ownstanding module for the popular CMS Drupal[14], but built upon MobSOS QV services and frontend elements in major parts. As such, the end-user evaluation of the dashboard [DEKl12] serves as end-user evaluation of MobSOS QV as CIS tool for the TEL community. Figure 6.21 shows the dashboard frontend, divided in two parts. The left part of the interface provides a built-in widget catalogue. Widgets can be searched and added to/removed from the dashboard. The MobSOS QV authoring tool allows further catalogue extensions by the creation of new widgets, visualizing queries to the TEL Mediabase database or other data sets with MobSOS QV. Widgets on the right-side dashboard can be resized and repositioned in an arbitrary number of columns. It should be noted that this dashboard arrangement is conceptually close to a full implementation of the success modeling service and the factor and metric catalogue envisioned in Section 5.5. In contrast to the widget space approach, where all members of a space see the same constellation of widgets on the dashboard, the Learning Frontiers approach allows each authenticated user to configure his own arrangement of widgets on the dashboard.

For our study, we recruited 20 TEL experts from academic, industrial and other organizational backgrounds all over Europe for a remote evaluation of the dashboard. Participants reportedly dedicate two thirds of their total working time to TEL and have more than eight

[11] http://telmap.org
[12] http://dblp.uni-trier.de
[13] http://cordis.europa.eu
[14] http://drupal.org

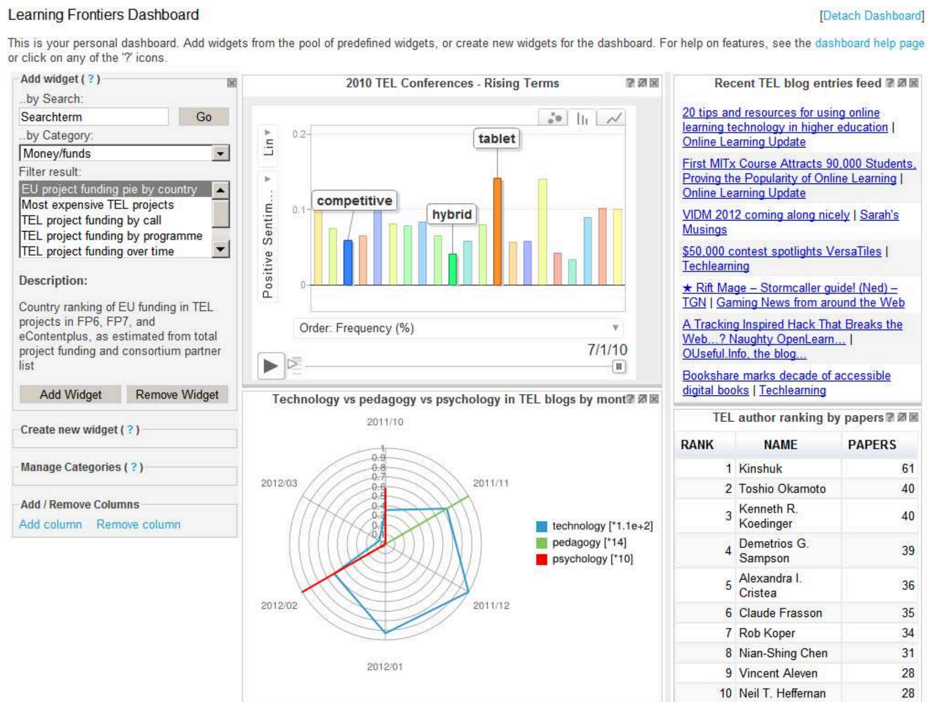

Figure 6.21: Learning Frontiers Portal – Visual Analytics Dashboard [DEKl12]

years of TEL experience on average. We asked participants to test each of the dashboard's supported use cases by following a simple task sequence and then provide feedback by completing a questionnaire. The task sequence included steps such as searching for a particular widget, adding widgets to the dashboard and creating new widgets. The questionnaire included 20 items on usability and usefulness. 18 items involved five-notch Likert scales ranging from *strongly agree (5)* to *strongly disagree (1)*. Two open free-text items asked for additional qualitative feedback. Five additional items collected demographic data such as affiliation and working experience. Figure 6.22 shows the resulting box-plots for our 18 survey items. In general, we received positive feedback, however with noticeable differences between the two dimensions Usability and Usefulness. Participants rated usability ($\overline{U} = 4.21, \sigma = 0.68$) notably higher than usefulness ($\overline{U} = 3.72, \sigma = 0.84$). The high standard deviations in both dimensions are explainable by a positive and highly significant correlation between years of experience and rating scores ($r = 0.623, p < 0.01$). Senior participants rated both usefulness and usability consistently lower than their less experienced peers. This observation is in agreement with our conception of expert roles in communities. Due to their experience and deep involvement in the community, senior experts have much higher expectations to community tools than their less experienced peers. The large range between the worst scoring item (*"This dashboard has all the functions and capabilities I expect it to have"*; $\overline{U} = 3.05, \sigma = 1.08$) and the best scoring item (*"It is easy to remove a widget"*; $\overline{U} = 4.90, \sigma = 0.31$) is also not surprising. Widget removal is a

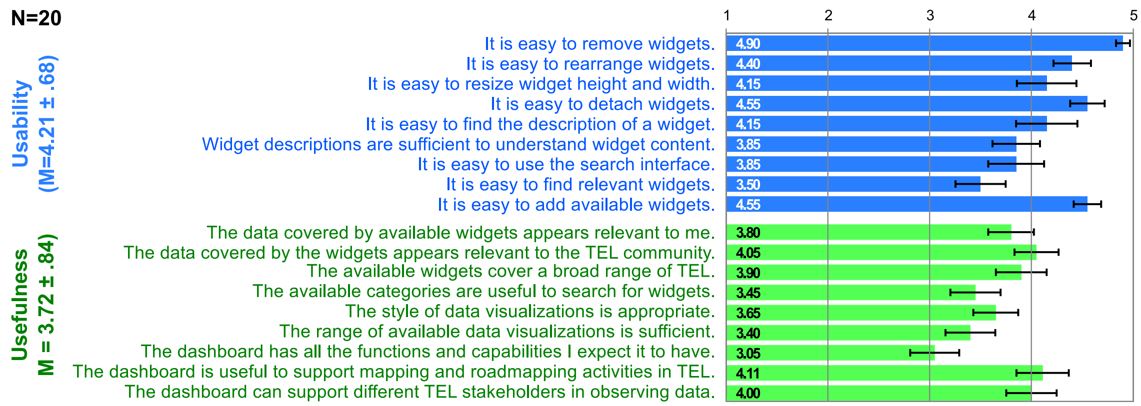

Figure 6.22: Learning Frontiers Portal - User Evaluation Results [DEKl12]

simple standard operation performed with a single mouse click only. In contrast, user expectations regarding a TEL dashboard are multi-faceted and difficult to satisfy, in particular for our TEL research expert audience.

Mostly from senior expert side, qualitative feedback included concrete proposals for improvements. In particular, users proposed more sophisticated data export and visual arrangement facilities. Reportedly with ease, most senior experts managed to finish the most complex evaluation task to create new widgets with MobSOS QV's authoring tool. However, they expressed the need for more intuitive ways to design visualizations for the majority of community members without deep knowledge on data analysis in general and SQL query syntax in particular. Senior experts further commented that visualizations are only one aspect of facilitating analytics. With respect to explorative tasks and for reasoning and decision making, they proposed more interactive and live data visualizations.

6.3.6 Conclusions

Our evaluation of SRL activities towards a success model for self-regulated learning in personal learning environments has demonstrated an extreme case of complexity with regard to the task of exploring success factors and designing respective metrics. Multiple factors contributed to this complexity. First, referring to [DMSe14], the system scope for this evaluation was not clearly delimited to one particular CIS artifact, but rather spanned over widgets, widget spaces, and the whole PLE management platform in conjunction with the related widget store. Second, concrete end-user feedback on overall success was not available. Despite these factors, we could still derive a high-level success model and formulate a set of concrete guidelines for designers of widget-based PLE. Our initial objectives could thus be fulfilled completely. Regarding O1 and O2, we could both trace and formulate a success model for self-regulated learning in PLE. Regarding O3, our end-user evaluation proved both usability and usefulness of visual analytics with MobSOS QV.

We acknowledge that our analysis cannot conclusively prove that SRL took place after all. MobSOS merely captures observation data of PLE management operations, but no formal learning outcomes to which observation data could relate. However, we consider PLE management operations as integral part of SRL, in particular in planning and exploration phases. Several significant differences between SRL-related and non-SRL related contexts suggest that the SRL-related tools used in these contexts have positive impacts on learners. We thus see our results as relevant evidence that SRL took place and created impact by motivating more controlled and serendipitous widget use.

Like all other case studies in this chapter, this study yielded several findings that deserve highlighting. First, our analysis showed that MobSOS serves as a comprehensive CIS success and learning analytics framework, allowing for analysis in different focal scopes from micro (individual) over meso (communities) to macro (societies) and chrono (over time). Second, we find that MobSOS usage data enables communities not only to explore CIS success factors and metrics, but also to explore their members and services in terms of emergent behaviour and structure over time and across communities. Third, we could once more show that MobSOS' expert panel techniques enable communities to even derive a high-level success model and formulate a set of concrete guidelines for designers of widget-based PLE in total absence of concrete end-user feedback.

6.4 Discussion

In this chapter, we presented three case studies focused on the evaluation and analysis of MobSOS outcomes. The diversity of contexts in the presented case studies thereby illustrates and supports the core message of the MobSOS approach: each community has its own conception of CIS success in terms of indicators and factors and their strengths and relevance in complete success models.

Despite the heterogeneity of involved domains, each community in our case studies was able to produce more or less actionable and focused CIS success models. As such, we could independently demonstrate the general validity of the MobSOS approach across cases. Thereby, each case study not only resulted in concrete improvements for the evaluated CIS artifact, but also in concrete improvements for MobSOS components. Hence, not only the CIS artifacts, but also MobSOS as evaluation infrastructure was subject to structuration effects. In all cases, the CIS evaluation infrastructure co-evolved with the community and the CIS infrastructure. We are confident, that MobSOS will continue to emerge along with future applications in other community contexts. This particular emergence can be conceived as yet another special incarnation of structuration theory: the duality between the evaluated CIS and MobSOS as the employed evaluation framework. In the following paragraphs, we summarize a number of patterns we could consistently identify across studies, that show important properties and ultimately prove the validity of the MobSOS approach to achieve and benefit from CIS success awareness (cf. RQ2).

Across our case studies, we found similar recurring properties for the CIS success models we created. Initial versions of CIS success models consisted of large collections of candidate constructs resulting from prior exploration efforts. However, in all cases we could effectively reduce these extensive a-priori versions to advanced versions of negotiated CIS success models being compact and balanced combinations of a handful of universal, generic success constructs on the one side and highly specific, sometimes idiosyncratic, community-tailored success constructs on the other. We could furthermore show, that large portions of our concrete CIS success models are indeed solely computable from automatically captured usage data. In the extreme case of our TEL case study, the complete final CIS success model is based on usage data. This observation is important, as it shows that appropriately designed CIS success models can relieve communities from explicit evaluation efforts (e.g. questionnaire completion) and avoid related forms of bias. Our explicit regression analysis in the context of our multimedia case study shows that only CIS success models spanning over all quality and impact dimensions achieve acceptable model quality, in contrast to myopic single-dimension models. Already during the early-phase construction of a-priori models, community evaluators should thus spread their exploration over multiple success dimensions to gain a comprehensive CIS success awareness.

Across studies, we frequently found connections between early-phase requirements and early-phase success models and metrics during negotiations on factor relevance. Occurrences of these connections often appeared as discrepancies between actual and perceived support for certain CIS features that hint to unfulfilled requirements. For example, the early validation of the CIS success questionnaire in our multimedia case study proved the relevance of survey items on *data security* and *privacy*, although these features were not realized in the evaluated tool. The same discrepancy occurred with the success factor *community awareness*, although the evaluated CIS artifact did not include respective awareness features. We found similar occurrences of this phenomenon in other case studies. This finding suggests to research the explicit combination of requirements engineering and CIS success modeling in early phases of community development processes.

Ultimately, the identification of relevant requirements, connected to highly relevant success factors, is just one part of a particular benefit MobSOS brings to communities: information for guiding improvement on CIS quality. Across case studies, we could show that MobSOS success models foster informed guidance for relevant and significant improvements of CIS artifact quality, e.g. to determine ideal configurations, to estimate further development efforts, to identify and provably eliminate bottlenecks, or to elicit hidden requirements.

Our studies furthermore show that MobSOS brings information on CIS impact as another benefit for communities. With special regard to the central goal of communities of practice, i.e. learning how to do better, we could prove across studies that MobSOS offers effective support for learning analytics. In our aphasia study, we could show improvements in personal writing and reading performance, based on simple usage-based and automatically captured metrics. In our TEL study, we could trace activity patterns hinting to the actual occurrence of self-regulated learning, without any active end-user contribution to evaluation. We could thus show that CIS success models can prove CIS impact, which is essential for a community's decision for or against a certain CIS artifact.

Across our studies, we have shown that MobSOS as a comprehensive CIS success awareness and learning analytics framework allows for analysis in different focal scopes from micro (individuals) over meso (communities) to macro (ecosystems, societies) and chrono (over time). However, we consistently found that usefulness and construction complexity of CIS success models directly depend on the focus of the studied evaluation context in terms of community and system scope. With narrowing focus, CIS success models become more concrete, relevant, and useful as well as less complex to construct. In the aphasia case, we analyzed one clearly defined artifact in one very specific and well-known social context and received a focused success model highly relevant for this particular community. In contrast, in the ROLE Sandbox case, communities were largely unknown, the analysis of CIS success involved several scope levels from individual widgets over widget spaces to the PLE management system as a whole, and the resulting success model only allowed to derive very high-level guidelines. Across case studies, we achieved the best CIS success models for very focused one-community-one-artifact contexts.

Across case studies, we find that MobSOS data enables communities not only to explore CIS success, but also to explore the actual interaction between their members and CIS artifacts in terms of emergent behaviour and structure over time and across communities. By observing the interaction between users and CIS service over time we could reveal emergent, unanticipated usage patterns of exaptation and appropriation. In this context, our aphasia study is particularly noteworthy. With MobSOS, we could clearly demonstrate that our aphasia patients did not use the newly introduced word prediction support in SOCRATESX for accelerated chatting, but *"misused"* it as training tool for spelling – a clear case for proved exaptation. With this knowledge, community developers receive an important sense of awareness fostering improved guidance for future development – a learning tool requires different improvements than a tool for accelerated text production.

Our findings across studies suggest that MobSOS' complementary expert panel and regression techniques proved as effective combination for CIS success model validation. In particular, we have shown the central role of expert panels for the overall evaluation and validation of CIS success models created with our methodology. Expert panels are inherently applicable at the core of every community of practice and foster CIS success model validation even under harsh conditions (e.g. small communities, scarce or no evaluation data, no established evaluation culture). More formal regression techniques are only applicable with sufficient data, but then yield highly valuable quantifiable evidence and guidance in terms of overall model fit as well as factor relevance, significance and effect strength.

From a technical perspective, our case studies have shown that the use of MobSOS only incurs comparably low costs regarding hardware and software requirements. Our technical evaluations proved that MobSOS components stay performant for real-time analytics on CIS in different constellations from one to many communities and CIS artifacts. As indicated in Table 6.15, even years of MobSOS operation in small to medium communities

Table 6.15: Overview of Current MobSOS Data Sets

Data Set	Collection Period		Users	CoPs	Data Volume	
	Begin	End			Size (MB)	Cardinality
SOCRATESX	2010-08-18	2013-05-11	235	1	29.49	17447
LAS	2008-03-19	now	376	24	>1.000	$> 5 * 10^6$
ROLE Sandbox	2012-03-08	now	>5.000	unknown	>10,000	$> 6 * 10^6$
Layers Box	2015-06-27	now	124	2	>300	>200,000

from tens to thousands of users result in such low amounts of data, that the application of costly commercial high-performance data management solutions is not justifiable. Across the different technical setups in our case studies, MobSOS was technically realizable with regular low-cost commodity hardware and no-cost OSS software. MobSOS software components are MIT-licensed free OSS.

Our case studies consistently illustrate that creating CIS success models, in particular factor exploration and metrics development, is and will inherently remain a complex task. A continuous reflection of community practices and objectives is required to produce relevant and valid CIS success models. Despite all the benefits of MobSOS shown in our case studies, communities still decide for themselves if the benefits outweigh the increased necessary efforts. In particular in initial phases of our case studies, communities consistently reported that they usually omit to weigh additional evaluation efforts against the final value of CIS success awareness. To that extent, this work contributes to making communities aware of the concrete efforts, but also to the methodologies and tools that help them achieve and benefit from CIS success-awareness. Without any concrete pressure to prove quality and impact of the CIS artifacts used, it realistically remains highly likely that communities deliberately omit evaluation efforts and instead continue their regular practice. Pressure might still exist in those communities embedded in organizational structures (cf. [Weng98, WDSn02]), as they usually have to justify software development and acquisition costs and prove their return on investment. In contrast, evaluation as means to achieve CIS success awareness is an indispensable task in research and development seriously targeting refereed academic publication - without rigorous evaluation no publicaton. Hence, researcher participation in community development and evaluation is desirable, as researchers bring both skills and obligation to evaluate.

However, given our extensive participation in the respective communities, we identified a long-term shift with regard to which stakeholders would be able to create the strongest leverage in terms of creating beneficial outcomes from CIS success awareness for their communities. While our earlier studies focused on *researchers* (cf. aphasia case study), our later studies identified *developers* as primary target for leveraging CIS success awareness. As developers are the main executive forces of change in terms of CIS improvement and innovation, CIS success awareness should serve as more informed guidance of development efforts for the sake of the whole community.

Chapter 7

Conclusions & Future Work

The overall goal of this dissertation was to enable long tail communities of practice to develop a sense of community information systems success awareness as means for improved self-reflection and guidance of future action. In the past chapters, we outlined our research paradigm, sighted related work and state-of-the-art, and then presented our main contributions as comprehensive response to our three research questions. We summarized all our contributions in the MobSOS framework for CIS success awareness in professional long tail communities of practice. We finally evaluated the components of the MobSOS framework in multiple case studies, of which we presented three particular cases in this work: a chat tool in an aphasia therapy community, multimedia management tools in cultural heritage documentation communities, and personal learning environments in technology-enhanced learning communities. This chapter concludes this dissertation. In Section 7.1, we present a summary of our results and contributions in relation to our research questions. In Section 7.2, we finally conclude with an outlook to future work.

7.1 Summary of Contributions & Results

During this research work, IS success research looked back to a decade-long tradition of a positivist research paradigm. At the same time, BI&A and Web analytics in data-driven enterprise practice just started to recognize the importance of the mass and power of professional long tail communities away from the mainstream, but mostly from a myopic revenue-oriented standpoint and without sufficient consideration of the concrete ontology of self-sustained communities of practice. By acknowledging, that community information systems are always subject to the emergent mutual influence between social and technical as manifestation of structuration theory [Orli92, Orli10], one of the most important findings of this work is that any research on CIS success awareness must inherently follow an anti-positivist approach. We particularly define CIS success awareness as an ongoing, comprehensive, ideally real-time situational awareness for CIS success, serving as informed self-reflection and guidance for community activity. Within communities of practice, we naturally find multiple independent, conflicting perceptions of CIS success among different stakeholders. Across communities and domains, differences in perception are even stronger. Especially within demo/merito/expertocratic governance structures, these different perceptions must not be *abstracted* to a *generic* and *imposed*, but rather *negotiated* to a *community-specific* and *shared* awareness of CIS success. We thus identified a paradigmatic conflict between the mainly positivist tradition in classical mainstream IS research and data-driven enterprise practice and the fundamental anti-positivist ontology and epistemology for researching CIS success in professional long tail communities.

In response to RQ1, our methodological contributions embed CIS success modelling into the *build & evaluation* cycle of a community-oriented adaptation of the IS DSR methodology [HMPR04, PTRC07]. In particular, we find a complementary relation between IS success research and design research with respect to evaluation. We identified evaluation as cross-cutting activity, separate from, but yet with strong mutual influences to design and development. In contrast to typical positivist, one-off research studies on enterprise information systems success, we contribute a different perspective of CIS success modeling as an ongoing collaborative activity to achieve CIS success awareness from a fusion of different individual stakeholder notions throughout the many life cycles in a CIS. Summative and formative evaluation perspectives are appropriate for phases of relative stability within and around a community. For phases of emergent change, progress, or innovation, we emphasize the need for participatory, agile, and data-driven developmental evaluation approaches [Patt11, PrBe12, GPLu13]. However, concrete CIS evaluation processes must first be established in a community-wide culture of embracing CIS success awareness as major benefit for the sake of agency for self-reflection and informed guidance of future developments. DSR provides a suitable research framework, including process models for CIS design and development with an emphasis on evaluation [HMPR04]. As template for CIS success modelling, we adapted influential measurement models from IS success research [DeMc92, GSCh08]. We furthermore conceptualize CIS success modelling as digital adaptation of transcriptivity theory [JJKS08, Klam10]. CIS success models serve as transcripts, able to generate CIS evaluation products such as written reports or interactive dashboards as scripts from pre-scripts such as usage or survey response data. We therefore conceptualize CIS success models as fluid digital media, supporting CIS success negotiation processes with operations such as monitoring, assessing, exploring, modeling, measuring, visualizing, validating, and sharing.

In response to RQ2, our MobSOS formalization framework provides coherent formalisms for CIS success models, including supported operations and data sources powering CIS success measurement, as basis for a concrete implementation. Our CIS success meta-model adapts the structural template of Gable et al.'s IS-Impact model [GSCh08] as influential reconceptualization of DeLone & McLean's seminal I/S Success model [DeMc92]. We particularly formalize CIS success models as multi-dimensional formative indices [JMPo03, GSCh08], following a hierarchical meta-model of dimensions, factors, and measures. In the spirit of our anti-positivist epistemology, our formalization supports the existence of multiple instances of our structural template for different community contexts, different CIS artifacts, different points in time, and different community-dependent constraints. The population of a CIS success model usually consists of a mix of generic, universally applicable constructs on the one side and very community-specific, sometimes idiosyncratic factors and metrics on the other. In the presence of universal or at least reusable CIS success factors and measures, we introduced the concept of CIS success measure catalogues for improved measure reusability. We realized such reuse of success constructs across different CIS success models with formalizations, parameterizable by an extensible set of key entities and contextual constraints. MobSOS acknowledges observation and surveying as two inexpensive, established and complementary pillars for MobSOS basic data collection. Observation is preferable due to its automated collection of quantitative, objective evidence for CIS use. Online surveys complement observation-based metrics with additional assessments on subjective, qualitative success aspects. With this combination, communities can collect sufficiently expressive data to capture both qualitative and quantitative as well as subjective and objective aspects of CIS success.

For observation data collection, we prefer the least invasive approach of context-enriched standard application protocol logging over developer effort-intensive and much more invasive high-level logging API instrumentation. Standard application protocol syntax and semantics usually include the notion of different *modes of interaction* between different actors (e.g. user-to-user, user-to-service, agent-to-agent) as well as different *interaction patterns* (e.g. request-response, push-pull, publish-subscribe). With observation log data models for HTTP, XMPP, and Pastry, we cover the most important protocol families used in contemporary CIS. Before communities can reliably measure CIS success, the respective models must first be validated. We therefore contribute a combination of expert panel techniques with statistical regression techniques in order to assess content and predictive validity. Expert panel techniques are effective means for validation in all stages of the CIS success model building process, as every community includes a core of domain experts. These techniques are even more effective with quantifiable evidence in the form of CIS success models and regression-based validation. Pivotal statistics generated in the context of correlation and regression analysis for a whole model (e.g. $\overline{R^2}$ for model fit) and for its particular constructs (e.g. regression coefficients for effect strength, significance for relevance) serve as basis for reflection of past and decision of future action. Intuitively, improvements on factors with respective high absolute regression coefficient values and high significance values are expected to have stronger effects than insignificant factors with regression coefficient values close to zero. On a higher level, regression statistics enable heuristic strategies towards model *refinements* and *operationalization*. Intuitively, significantly relevant, but low-scoring success metrics for a given factor indicate the urgent need to improve the CIS artifact with respect to this respective factor. Across case studies, we found that formalizations of CIS success models are largely not compliant with the assumptions of multiple regression and thus discussed ordinal logistic regression as better match to the given problem.

In response to RQ3, we contribute an abstract notion of a success-aware CIS infrastructure, including a set of MobSOS components, i.e. monitoring pipelines and services. MobSOS monitoring pipelines realize the collection and further enrichment of observation data in the form of standard application protocol logs, augmented with contextual metadata. The MobSOS tool kit provides a collection of fundamental services necessary to achieve a comprehensive sense of community-wide CIS success awareness. The MobSOS data repository serves as community-controlled backend for all MobSOS-related data, i.e. observation data, survey data, query visualizations, success models, etc. Our implementations of MobSOS components pursue the goal to find a good trade-off between genericity and specificity. On the one hand, MobSOS tools should be sufficiently generic to be applicable to arbitrary CIS and professional long tail communities of practice. On the other hand however, we find that MobSOS tools forefeit usability with exaggerated genericity resp. lack of specificity. Finding a better trade-off is subject to future research.

All contributions of this work have been evaluated in the context of research projects such as SFB-FK 427 and UMIC on the national DFG-funded level, and ROLE, Learning Layers, and TEL-Map on the international EU-funded level. In our case studies, we successfully applied MobSOS in communities with varying scopes in domains such as health care, multimedia management, and technology-enhanced learning. In all cases, we succeeded in exploring and negotiating highly valid and compact CIS success models. After exploration, typical a-priori models consisted of several dozens of candidate success factors and respective proxy metrics. Typical advanced CIS success models include few, yet highly relevant and effective success factors. They are well-balanced combinations of universal vs. community-tailored success factors and metrics, derived from survey response and usage data. In particular, we note that CIS success models with full coverage for both *quality* and *impact* and focused scope are more useful than models with myopic single-dimension focus and a vague scope. Awareness on CIS quality and impact brings communities agency in form of a better informed decision on CIS tool selection, use or active development. We could demonstrate that CIS success models contributed to determine ideal software configurations, to estimate development efforts, to identify and eliminate bottlenecks, to elicit hidden requirements, and to judge concrete impact on the community. MobSOS also proved as effective learning analytics framework to identify learning patterns, to detect usage anomalies, and to measure learning progress. Our technical evaluations finally show, that MobSOS is an effective, performant, and low-cost open-source framework for CIS success awareness.

Contributions and results of this work have been successfully published in both national and international conferences and journals in the major areas of computer science and information systems, but also in community domain-specific outlets. In Table 7.1, we provide a final listing of our major contributions as responses to our research questions. For each contribution, we additionally list relevant refereed publications. Last, but not least, we contribute MobSOS software components as MIT-licensed open-source software, free to use for arbitrary professional communities of practice.

Table 7.1: Research Questions, Contributions & Refereed Publications

Research Question	**Major Contribution**	**Refereed Publications**
RQ1	MobSOS Methodology	[ReKl13,RKJa15b]
RQ2	MobSOS Formal CIS Success Modeling & Validation	[ReKl13, RKJa15b]
RQ3	MobSOS Success Aware CIS Infrastructure	[RKSp08, ReKl09]
	MobSOS Services & Tools	[RKSp08, ReKl09, DEKl12, ReKl13, RBKJ13, ReKl14]
	Case Studies (Aphasia, Cultural Heritage, TEL etc.)	[RKSp08, CGK*08, CGKR09, KTC*09, ReKl09, CRJ*10, RCLK10, ReKl13, NKR*14a, RKJa15b, RKKN15]

7.2 Open Challenges & Future Work

Despite all support for achieving and benefiting from CIS success awareness, its achievement inherently remains a complex and expensive exercise. Only with acceptance, deep engagement, and a lived culture of continuous evaluation, communities can achieve a beneficial sense of success awareness. Motivating a community-wide willingness to commit to the focused and critical analysis of possible success factors is already an important precursor to establishing such a culture. Not only current social media, but also the current rise of the Internet of Things and the connected Industry 4.0 paradigm raise expectations on an ever-growing importance of data as well as metadata and context data, exploitable for the derivation of new success factors and new ways of measuring CIS success. The recent industrial and research interest towards Industry 4.0 show that the data-driven enterprise concept is here to stay. The job position of a data scientist was lately voted the sexiest job on the planet [DaPa12]. With the movie *"Moneyball"*, analytics have found their path into contemporary pop culture. The movie from 2012 tells the story of a baseball trainer guiding his mediocre team to season championship with the help of a data scientist's smart analytics. Time plays into the hands of professional communities, as an increasing number of community members will bring data science competence from their professional backgrounds in near future.

MobSOS thereby lays the foundations to manage complexity in establishing an evaluation culture of CIS success modeling with the help of theory-based methodologies, formalizations, infrastructure patterns, and concrete services and tools. In the true sense of structuration theory, we are perfectly aware that the contributions of this work can only be a start to a never-ending journey, governed by the many intertwined and mutually influencing life cycles of communities and technologies. New modes of collaboration and communication in communities of practice will arise as results of the interplay between new disruptive technologies, their adoption in grassroots movements, and resulting societal changes. To that end, we see a clear trend that ICT will become even more pervasive than it already is today. The current trend towards the IoT will contribute to a densification of context information with the help of advanced sensor and actuator technology, opening new avenues to research CIS success in relation to a wide array of context parameters. The current trend towards real-time communication and collaboration with advanced Web, mobile, and augmented/virtual reality technology will let geographically distributed communities grow together even closer. This trend opens new research avenues towards truly real-time forms of CIS success modeling with respective collaboration environments and real-time CIS success awareness with highly responsive and active evaluation products, e.g. real-time dashboards or active mobile notifications. The ultimate goal of such efforts is the support for ongoing discourses, interwoven in a truly situational awareness of CIS success.

Especially in situations, where communities face hard requirements for custom-tailored CIS artifacts, we repeatedly made the experience that this real-time CIS success awareness should already start during early requirements elicitation phases. Already then, the non-functional requirements stated by communities directly translate to success factors for a future realization. If measured from the very beginning, these success factors not only allow to measure overall success, but also to monitor the satisfactory fulfillment of requirements. As such, a possible concrete avenue of future research lies in the fusion of MobSOS-style CIS success modeling and SRE [LCRK12, RBKJ13, ReKl14, RKJa15a].

Current advances in business intelligence and analytics technology currently build upon the vast computing power and storage facilities of corporate cloud computing models [CCSt12]. At the same time, private and industrial security and privacy concerns and advances in custom-tailored, low-cost commodity hardware pave the way for a more naturalistic community organization in self-organized peer networks. With growing ease-of-use, communities can maintain their own community information systems infrastructures, including more connected and real-time conceptions of quantifiable self-reflection and self-awareness. In this work, we made first contributions to enabling communities to self-maintain, self-sustain, and benefit from information systems success analytics support. We believe that research needs to strengthen efforts towards true community ownership and control over their data, digital media infrastructure, and analytics. As most social media generate profits from data produced by communities, this shift of control is a challenging exercise, less from a technological, but from a political and philosophical perspective.

However, even with a large-scale shift of academic attention for the long tail, most communities will continue to lack access to rich research and development resources. The question is thus, how communities can independently establish a CIS success awareness culture, as discussed in this work. The inherent scarcity of development and analytics expertise and the inherent complexity of this task will remain a bottleneck for the next couple of years. We believe that the results of this work laid the foundations for managing and reducing this complexity. In further steps, we must continuously lower entry barriers and required efforts for communities to achieve CIS success awareness on their own. And yet, CIS success modeling, in particular exploration will remain a complex task.

Recent advances in unsupervised machine learning approaches have proven the general possibility to identify even the most obscure, yet significant and strong correlations from large bodies of data without prior training. With respect to our success modeling approach, machine learning algorithms bear potential to automate time-intensive manual efforts such as success metrics exploration from large data sets. Despite all possible automation in metrics exploration, we continue to argue that human involvement must never be excluded from CIS success modeling. In particular the interpretation of the deeper meanings behind automatically mined correlations should ultimately remain subject to human reasoning and judgement. Without intuitive interpretations, a community cannot make sense of analysis results and thus cannot learn *how to do it better*. We particularly see potential in the exploration of SNA-based CIS success metrics, e.g. for measuring if the success of a social networking application strongly correlates with a growing density in the community's social network. Although we already tried out basal forms of SNA-based metrics in the context of our case studies, a deeper pursuit of this research avenue was out of scope and thus remains future work.

In our case studies, we successfully applied MobSOS to construct valid CIS success models in a few professional long tail communities. Surely, the involved communities profited from the created sense of CIS success awareness and its benefits, induced by us as researchers. The empirical evidence achieved with these few, very community-specific notions of CIS success awareness thus serves as pilot work, preparing for more extensive studies in further long tail communities. The explained long-term goal of our group targets at such a *cross-community analysis* to extract common universal success constructs from an empirical basis, that is larger and thus more representative for the long tail. This research in turn contributes to our long-term vision of societal software as fusion of the many yet disconnected long tail community information systems into a world-wide network. Our long-term goal of finding universal success constructs from a large ecosystem of long tail communities might falsely be identified as positivist research perspective. We once more emphasize this work's anti-positivist ontology, accounting for the inherent diversity and dynamicity of communities, especially in the long tail. We thereby argue that we must first understand the many different notions on CIS success within and across a large number of communities, before we can distill universal findings on CIS success.

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Appendices

Appendix A

Acronyms

ANOVA Analysis of Variance. 81

ANT Actor-Network Theory. 32

API Application Programming Interface. 26

ATLAS Architecture for Transcription, Localization, and Addressing Systems. 5

BI&A Business Intelligence and Analytics. 1

CIS Community Information System. 3

CMS Content Management System. 49

CoP Community of Practice. 1

DBMS Database Management System. 146

DSR Design Science Research. 23

EDM Educational Data Mining. 160

ERD Entity-Relationship Diagram. 73

ETL Extract, Transform, Load. 69

HTTP Hypertext Transfer Protocol. 30

ICT Information & Communication Technology. 1

IoT Internet of Things. 75

IS Information System. 2

IT Information Technology. 21

JID Jabber Identifier. 70

KPI Key Performance Indicator. 29

LAS Lightweight Application Server. 30

LPP Legitimate Peripheral Participation. 9

MIME Multipurpose Internet Mail Extension. 73

MIS Management Information System. 17

MobSOS Mobile Community Information System Oracle for Success. 5

OSN Online Social Network. 16

OSS Open Source Software. 9

P2P Peer-to-Peer. 16

PLE Personal Learning Environment. 30

QoS Quality of Service. 149

RDBMS Relational Database Management System. 67

REST Representational State Transfer. 72

RFC Request for Comments. 63

ROLE Responsive Open Learning Environments. 158

SaaS Software as a Service. 34

SDK Software Development Kit. 159

SEM Structural Equation Modeling. 81

SNA Social Network Analysis. 51

SOA Service-Oriented Architecture. 72

SRE Social Requirements Engineering. 51

SRL Self-Regulated Learning. 158

SSO Single Sign-On. 63

TCD Trust-Confidence-Distrust. 11

TEL Technology-Enhanced Learning. 118

UI User Interface. 34

UMIC Ultra High Speed Mobile Information and Communication. 141

URI Uniform Resource Identifier. 70

UUID Universally Unique IDentifier. 70

XEP XMPP Extension Protocol. 75

XML Extensible Markup Language. 75

XMPP Extensible Messaging and Presence Protocol. 30

Appendix B

Own Publications

Publications Relevant for This Work

[CCD*09] Cao, Yiwei, Chen, Xi, Drobek, Niels, Hahne, Andreas, Hannemann, Anna, Hocken, Christian, Jansen, Michael, Janssen, Holger, Jarke, Matthias, Klamma, Ralf, Kovachev, Dejan, Petrushyna, Zina, Pham, Manh Cuong, Renzel, Dominik, Schlebusch, Patrick, and Toubekis, Georgios. Virtual Campfire - Cross-Platform Services for Mobile Social Software. In *2009 IEEE 10th International Conference on Mobile Data Management: Systems, Services and Middleware*, pp. 363–364. IEEE Computer Society, Los Alamitos, CA, USA, 2009. ISBN 978-0-7695-3650-7. doi:10.1109/MDM.2009.53.

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Appendix C

Curriculum Vitae

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Academic Education:	03/1999 - 04/2009: *Computer Science diploma studies at RWTH Aachen University* (Dipl.-Inform.)
Civil Service:	11/1996 - 11/1997: *Civil servant at St. Christophorus special school for children with learning disabilities, Düren, Germany*
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